Unlocking Circular Potential: Overcoming Barriers to High-Potential Product Group Reuse in the Dutch Building Sector.

A study that identifies Masonry Brickwork as a high-potential building product group and explores the key barriers to its circular implementation, along with strategies to overcome them.

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Summary

The growing impact of human based carbon emissions results in rapid global warming, with temperatures already exceeding the 1.5 °C limit ambition of the Paris Agreement. The Netherlands has responded with ambitious goals: climate neutrality by 2050 and a fully circular economy that halves virgin material use by 2030. This poses a challenge for the construction industry, which consumes roughly 50% of all raw materials, 40% of total energy, and about 35% of national CO_2 emissions. Shifting from a linear to a circular economy is necessary but complex.

Within that transition, two dominant questions arise: how to design today's products and buildings for tomorrow's reuse, and how to reuse building products currently becoming available due to demolition. This thesis focuses on the latter: identifying which product groups from Dutch B&U demolition offer the highest potential for direct reuse and identifying the barriers that hinder large-scale circular implementation of that specific product group.

To identify the product group with the highest potential for circular reuse, a multicriteria analysis (MCA) was performed, comparing product groups using criteria derived from barriers and drivers to circular implementation found in the literature. The study continued with a case study to identify specific implementation barriers and address those barriers.

The process of finding the highest potential product group was executed in three steps. First, an impact study identified ten "high-potential" product groups out of a total list of 139 product groups. Product groups were ranked by impact, defined as yearly demolition mass outflow × MKI. Since the top five of the high-potential list consisted only of stonelike materials (wide slab floors, brick masonry, cast-in-place concrete, screw piles, and hollow-core floor slabs), broader material categories were identified: stone, steel, wood, glass, mixed, and plastics. From each category, the highest-scoring product group was also included. These were heavy structural steel, timber sandwich roof elements, EPS, chipboard, and HR glass. This resulted in a high-potential list of ten product groups that is both high in impact and diverse.

Secondly, the criteria needed to be formed. Literature identified 52 barriers and 21 drivers, which were grouped into four MCA criteria: Costs, Risks, Supply & Demand, and Technical Feasibility. These criteria were combined with a Sustainability criterion reflecting the prior impact score, resulting in five total criteria for the MCA.

Thirdly, the MCA was performed. Ten product groups were compared on the five criteria. The Sustainability, Technical Feasibility, and balance in Supply & Demand criteria were scored quantitatively based on literature, while Cost, Risk and the criteria's weight could not be found in literature and were therefore determined qualitatively by eight semi-structured interviews with circular building industry experts. All quantitative scores were normalised on a 1-5 scale to match the results from the five-point Likert scale retrieved from the interviews. The weighted MCA results in brick masonry as the top performer (score: 4.04 out of 5), followed by heavy structural steel (3.29 out of 5) and hollow-core slabs (2.78 out of 5).

Thus, the case study focused on brick masonry. clay-based bricks have an enormous MKI score. This is due to the firing process at 900 to 1,200 °C in gas powered kilns, approximately 85% of total MKI is in the firing process. Today's linear value chain routes about 99% of demolition bricks into mixed rubble that is crushed for road foundations, which can be seen as recycling at best. The study evaluated four alternative circular routes: (1) demolition-led resale, (2) by reuse specialist firms, (3) manufacturer-led Extended Producer Responsibility (EPR), and (4) crusher-led recovery.

Interviews with five stakeholders, either branch associations or the largest companies active in the sector, showed a consistent message: brick reuse is technically feasible but economically not valuable within current market settings. The reuse specialists emerge as the only viable route for circular brick reuse. Current stakeholders, including demolition companies, rubble crushers, and producers, do not see reuse as a viable option. For them, the business model of brick reuse must not only work but also outperform their current one. All five interviewed experts pointed to reuse-specialist companies as the key drivers of brick reuse.

The market leader in reused bricks, Rebrick, shows promising results. Rebrick's model of on-site mining, certification, and resale already delivers approximately three times lower MKI per brick than new production and has reached around two million bricks per year (only about 0.2% market share). Yet this study finds that four barriers persist for their businesses case: (1) high labour costs of harvesting, (2) long processing time, which includes testing and mining, (3) social frictions regarding their access to demolition sites, and (4) a technical limitation: cement-based mortars (post-1980) that hinder separation.

To overcome these four barriers, two new business models were proposed. Brought Back Bricks (BBB) relocates processing off-site. Instead of pre-testing and on-site selective harvesting of only whole bricks, BBB purchases all brick debris, removes it immediately from the site (reducing friction and delays), and processes it centrally. Usable bricks are cleaned and tested for resale, while scrap is crushed into filler for manufacturers, broadening revenue streams and simplifying logistics for demolition firms.

"BBBBBB" (Brought Back Bricks by Binary Bots) extends BBB by industrialising the processing phase, conceptually through a dedicated machine that separates bricks, removes mortar, and sorts reusable bricks at scale. While such equipment does not yet exist, the analysis shows that automation could shift reuse from a value-driven niche market to a cost-driven mainstream practice.

To conclude, this thesis offers a starting point to accelerate certain circularity in Dutch construction. With the use of a MCA, bricks prove to be the highest potential product group for circular reuse. Reuse of bricks and cutting out the firing process makes reuse of bricks the more attractive path than recycling of bricks. This study explains why the market stalls by identifying the barriers for brick reuse. Two business models are proposed, one showing what could be achieved today, and the other indicating what innovation would be needed to take away all barriers currently in place for the reuse of brick.

Samenvatting

De toenemende impact van Co2 uitstoot leidt tot de snelle opwarming van de aarde, waarbij de 1,5 °C-doelstelling van het Akkoord van Parijs snel zal worden overschreden. Nederland heeft daarom ambitieuze doelstellingen: klimaatneutraliteit in 2050 en een volledig circulaire economie die het gebruik van primaire grondstoffen tegen 2030 halveert. Dit vormt een uitdaging voor de bouwsector, die ongeveer 50% van alle grondstoffen, 40% van de totale energie en circa 35% van de nationale CO_2-uitstoot veroorzaakt. De overgang van een lineaire naar een circulaire economie is noodzakelijk, maar complex.

Binnen die transitie zijn er twee belangrijke vragen: hoe ontwerpen we de producten en gebouwen van vandaag voor hergebruik in de toekomst, en hoe kunnen we bouwproducten hergebruiken die vrijkomen bij sloop? Deze thesis richt zich op het laatste: het identificeren van welke productgroepen uit de Nederlandse B&U-sloopprojecten het grootste potentieel hebben voor direct hergebruik, en het identificeren van de belemmeringen die grootschalige circulaire toepassing van die specifieke productgroep in de weg staan.

Om de productgroep met het hoogste potentieel voor circulair hergebruik te vinden, werd een multicriteria-analyse (MCA) uitgevoerd. Hierbij werden productgroepen vergeleken aan de hand van criteria die zijn afgeleid van drijfveren en barrières voor circulaire toepassing zoals beschreven in literatuur. Vervolgens werd, om specifieke belemmeringen in kaart te brengen, een casestudy uitgevoerd waarin deze verder werden onderzocht en mogelijke oplossingen voorgesteld.

Het proces om de productgroep met het hoogste potentieel te vinden bestond uit drie stappen. Ten eerste identificeerde een impactanalyse tien “hoog-potentiële” productgroepen uit een totale lijst van 139 productgroepen. De productgroepen werden gerangschikt op impact, gedefinieerd als jaarlijkse massa beschikbaarheid door sloop × MKI van dat product. Aangezien de top vijf van de lijst uitsluitend uit steenachtige materialen bestond (kanaalplaatvloeren, metselwerk, in het werk gestort beton, schroefpalen en breedplaatvloeren), werden ook bredere materiaalcategorieën bepaald: steen, staal, hout, glas, gemengd en kunststoffen. Uit elke categorie werd de hoogst scorende productgroep toegevoegd. Dit waren: zwaar constructiestaal, houten dakelementen (sandwichpanelen), EPS, spaanplaat en HR-glas. Dit resulteerde in een top-10-lijst van productgroepen met zowel een hoge impact als een diverse materiaalspreiding.

Ten tweede werden de criteria vastgesteld. Uit de literatuur werden 52 barrières en 21 drijfveren geïdentificeerd, die werden gegroepeerd in vier MCA-criteria: Kosten, Risico’s, Vraag & Aanbod en Technische haalbaarheid. Deze criteria werden gecombineerd met een duurzaamheidscriterium dat het eerdere impactcijfer weerspiegelde, wat resulteerde in vijf totale criteria voor de MCA.

Ten derde werd de MCA uitgevoerd. De tien productgroepen werden vergeleken op de vijf criteria. De criteria Duurzaamheid, Technische haalbaarheid en balans in Vraag & Aanbod werden kwantitatief gescoord op basis van literatuur, terwijl Kosten, Risico’s en de weging van de criteria kwalitatief werden bepaald aan de hand van acht semigestructureerde interviews met experts uit de circulaire bouwsector. Alle kwantitatieve scores werden genormaliseerd op een schaal van 1 tot 5 om te kunnen worden vergeleken met de “five point likert scale” uit de interviews. De gewogen MCA wees baksteenmetselwerk aan als product met het meest potentie (score: 4,04 van 5), gevolgd door zwaar constructiestaal (3,29 van 5) en kanaalplaatvloeren (2,78 van 5).

Daarom richtte de casestudy zich op baksteenmetselwerk. Bakstenen op kleibasis hebben een enorm hoge MKI-score. Dit komt door het bakproces, bij 900-1.200 °C in gasgestookte ovens; ongeveer 85% van de totale MKI is toe te schrijven aan dit proces. In de huidige lineaire keten wordt circa 99% van de sloopbakstenen gebroken tot gemengd granulaat dat wordt gebruikt in wegfunderingen, wat hooguit als recycling kan worden beschouwd. Het onderzoek evalueerde vier alternatieve circulaire routes: (1) sloper gestuurde doorverkoop, (2) hergebruik via gespecialiseerde bedrijven, (3) producent gestuurde uitgebreide producentenverantwoordelijkheid (UPV), en (4) terugwinning door puinbrekers.

Interviews met vijf stakeholders, brancheorganisaties of de grootste bedrijven in de sector, gaven een consistent beeld: hergebruik van bakstenen is technisch haalbaar, maar economisch niet rendabel binnen de huidige marktomstandigheden. Hergebruiksspecialisten blijken de enige levensvatbare route voor circulair baksteenhergebruik. Huidige spelers, zoals sloopbedrijven, puinbrekers en producenten, zien hergebruik niet als een kansrijke optie. Voor hen moet het businessmodel van baksteenhergebruik niet alleen werken, maar ook beter presteren dan hun huidige model. Alle vijf geïnterviewde experts wezen hergebruiksspecialisten aan als de belangrijkste drijvende kracht achter baksteenhergebruik.

De marktleider in hergebruikte bakstenen, Rebrick, laat veelbelovende resultaten zien. Rebrick's model van on-site winning, certificering en doorverkoop levert al ongeveer drie keer lagere MKI per baksteen dan nieuwe productie, met een jaarlijkse afzet van circa twee miljoen bakstenen (ongeveer 0,2% marktaandeel). Toch identificeerde dit onderzoek vier blijvende belemmeringen voor hun businesscase: (1) hoge arbeidskosten voor het oogsten, (2) lange verwerkingstijd (zowel testen als winnen), (3) sociale fricties rondom toegang tot slooplocaties, en (4) een technische beperking: cementgebonden mortels (na 1980) die scheiding bemoeilijken.

Om deze vier barrières te overwinnen, werden twee nieuwe businessmodellen voorgesteld. Brought Back Bricks (BBB) verplaatst de verwerking naar een externe locatie. In plaats van vooraf testen en op de slooplocatie selectief hele bakstenen oogsten, koopt BBB al het baksteenpuin op, verwijdert dit direct van de locatie (waardoor frictie en vertraging worden verminderd) en verwerkt het centraal. Herbruikbare bakstenen worden gereinigd en getest voor wederverkoop, terwijl restmateriaal wordt vermalen tot vulstof voor producenten, wat zorgt voor meerdere inkomstenstromen en eenvoudigere logistiek voor sloopbedrijven.

"BBBBBB" (Brought Back Bricks by Binary Bots) bouwt voort op BBB door de verwerkingsfase te industrialiseren, conceptueel via een speciale machine die bakstenen scheidt, mortel verwijdert en herbruikbare bakstenen op schaal sorteert. Hoewel dergelijke apparatuur nog niet bestaat, laat de analyse zien dat automatisering hergebruik kan verschuiven van een waard gedreven nichemarkt naar een kosten gedreven mainstreampraktijk.

Conclusie: deze thesis biedt een uitgangspunt om circulariteit in de Nederlandse bouwsector te versnellen. Met behulp van een MCA blijken bakstenen de productgroep met het hoogste potentieel voor circulair hergebruik. Hergebruik van bakstenen, waarbij het energie-intensieve bakproces wordt vermeden, is een aantrekkelijker route dan recycling. Dit onderzoek verklaart waarom de markt stagneert door de barrières voor baksteenhergebruik te identificeren. Twee businessmodellen worden voorgesteld: één dat laat zien wat vandaag al mogelijk is, en één dat schetst welke innovaties nodig zijn om alle bestaande belemmeringen voor baksteenhergebruik weg te nemen.

Abstract

The transition towards a more sustainable society is becoming increasingly urgent, with the building sector recognised as a major contributor to both environmental challenges and potential solutions. To meet the Dutch sustainability targets for 2030 and 2050, circularity has been identified as a key strategy for achieving these national goals. Within this strategy, reuse at the product level (R3) provides one of the most direct opportunities by extending the lifespan of building products and reducing environmental impact. This thesis focuses on the reuse potential of products from Dutch building and utility (B&U) demolition projects.

A total of 139 product groups were examined, resulting in the identification of ten high-potential product groups through an impact study that combined mass and environmental cost indicator values. Furthermore, did a literature study reveal five socio-economic criteria influencing circular implementation: costs, risks, technical feasibility, supply-demand balance, and sustainable impact. These criteria were validated by experts and applied in a multi-criteria analysis. The results identified masonry brickwork as the most promising product group for product reuse.

Current brick production remains energy-intensive and dependent on gas-fired kilns, while reuse practices are still constrained by a labour-intensive harvesting process. The stakeholders within the value chain are aware of the circular alternative routes but keep reluctant to derive from their current linear practices. A dive into the business model of reuse specialists highlights both opportunities and limitations for scaling brick reuse. Two alternative business models were developed, illustrating industrialisation pathways and increased incentives for demolition companies.

This thesis concludes that brick reuse has high-potential for circular reuse in the Netherlands, but large-scale implementation requires overcoming economic, technical and organisational barriers such as higher costs, the labour-intensive mining process and stakeholder satisfaction.

Keywords

Building Product, circular building Industry, Netherlands, Barriers, Bricks

Abbreviations/glossary

Circular economy:
An economic system designed to minimise waste and maximise the reuse of resources through closed-loop cycles of production, consumption, reuse, and recycling.

Reuse:
Using products or components again for the same or a function with a similar technical requirement, without major processing or transformation. (R3+R4+R5) 10 R-strategies.

Direct reuse:
The immediate reuse of products after their recovery, without significant processing, modification, or remanufacturing. (R3) 10 R-strategies

Recycling:
Processing waste or discarded materials to produce new materials or products, typically through mechanical or chemical treatment. (R8) 10 R-strategies

Upcycling:
Transforming discarded products or materials into new products of higher quality, greater functionality, or higher value.

Downcycling:
Recycling materials into products of lower quality, functionality, or economic value compared to the original materials.

Environmental impact:
The effects human activities and processes have on ecosystems, biodiversity, resource availability, pollution levels, and climate change.

Climate neutrality:
Achieving net-zero greenhouse gas emissions by balancing emitted gases with equivalent reductions, sequestration, or offsets.

Technical feasibility:
The practicality and viability of implementing a solution or technology based on existing knowledge, methods, and resources.

Socio-economic factors:
Social, cultural, and economic conditions or considerations that affect decision-making, implementation, and effectiveness of a solution or technology.

Product group:
A set of related products categorised based on shared characteristics, usage, or functions.

Material flow:
The movement, transformation, and use of materials throughout their lifecycle, from extraction through production, consumption, recycling, and disposal.

Embodied carbon:
The total amount of greenhouse gas emissions generated throughout the entire lifecycle of a product or material, from raw material extraction to final disposal or reuse.

Carbon emission reduction:
Measures or actions aimed at decreasing the amount of carbon dioxide and other greenhouse gases emitted into the atmosphere.

B&U: Residential and commercial construction
The sector involved in constructing, renovating, and maintaining residential and commercial buildings, including houses, offices, schools, hospitals, and retail spaces.

GWW: Civil engineering works
The branch of engineering and construction related to infrastructure projects such as roads, bridges, tunnels, waterways, railways, and flood defences.

Construction material:
Any material used in the building or infrastructure construction process, such as concrete, steel, wood, brick, and glass.

Building element:
A distinct, functional part or unit of a building, such as walls, floors, roofs, beams, columns, windows, doors, or façades, which can be individually designed, constructed, installed, dismantled, or reused. Materialisation is not included.

Building product:
A manufactured item or element intended for use in the construction, finishing, or furnishing of a building. An element, made from a specific material.

Mass outflow: Former building products, which are retrieved during demolition, either on product or material level.

Demolition waste:
Waste materials produced from the demolition or renovation of buildings or infrastructure, which will not be implemented in a circular manner according to any of the 9-R strategies.

Deconstruction:
The selective dismantling of building components or structures to maximise recovery, reuse, or recycling of materials and components.

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1. Introduction

1.1 Problem Definition

The effects of human-based carbon emission are becoming more evident over time. More carbon is emitted than our planet can absorb, leading to global warming due to the greenhouse effect. The consensus among the majority of the experts, policy makers and the general public is that we as humankind should emit less carbon. Currently, big goals are being set, and steps are being taken to reduce our carbon emissions. In the Paris agreement of 2015, 195 countries signed an agreement stating the intention of: "Holding the increase in the global average temperature to well below 2.0°C above pre-industrial levels and pursuing efforts to limit the temperature increase to 1.5°C above pre-industrial levels." (United Nations 2015) In the year 2024, the Earth was 1.6°C above pre-industrial levels and averaged 1.36 °C over the past 20 years. The last ten years have been the warmest ten years on record. At this rate, the probability of breaching the 1.5°C target of the Paris Agreement within the 2030s is highly likely (Copernicus 2024).

The Dutch government has decided to aim even higher than the Paris agreements, and intends to be carbon neutral in 2050, instead of the agreed 95% reduction (Rijksoverheid 2022). The Dutch government has committed to a circular economy and has set the goals limiting virgin material use to 50% in 2030 and becoming fully circular by 2050. The construction sector is resource intensive. In the Netherlands, construction is estimated to account for 50% of raw material consumption, 40% of total energy consumption, and 30% of total water consumption. Additionally, a significant portion of all waste in the Netherlands (approximately 40%) is related to construction and demolition waste, and the sector is responsible for an estimated 35% of the overall CO_2 emissions (Het ministerie van Infrastructuur en milieu 2016).

The Dutch government stated their intentions in transforming the building industry to a circular economy, however easier said than done. The goals stated in the Paris agreements are ambitious, and therefore lots of research and steps still need to be performed. In circularity, there are two main challenges: how can it be assured, that virgin building products used today, can be reused more efficiently at the end of their use stage? This challenge focuses on what can be done today, to ensure circularity in the future. The other main challenge is; how can the building mass that becomes available due to demolition today, be used in a circular manner for the construction of the future? This challenge focuses on the question what can be done today, to correct linear practices of the past. The latter proves to be particularly challenging, since these building structures were not built with reuse in mind, concepts as demountability or material passports, are not standard practice in structures that are demolished today (De Circulaire bouweconomie 2025).

This second challenge is pursued in this thesis: how can building mass that becomes available due to demolition today, be used in a circular manner for the construction of the future. The amount of mass available in the current building stock has enormous potential, since the environmental impact such as emission and depletion of raw materials has already occurred, but can be limited by unplanned circular use, as it could replace virgin material and products in the future. In this report the 10-R strategy is used, thus since the building mass is already in use, the highest possible form of sustainability is reuse, therefore this thesis focuses specifically on reuse. Reuse is expected to be more challenging to implement than recycling and is currently also performed to a lesser extent than recycling. Only 1.9% of all building material mass is used in a closed cycle, which means recycling or reuse back into a product with the same function (TNO Bletsis et al. 2024a). Even the PBL, an independent government institute stated that "Although various initiatives have been undertaken in the field of circular economy, overall, the transition is not heading in the right direction" (PBL 2025). Action is needed, and needed now, to reach the goal of 50% circular material use by the year 2030.

This report helps to determine what influences the circular use potential of a product group, and thus for which product groups reuse should be prioritised over recycling. Lots of research has already been performed, but the industry has not yet adopted circular reuse practices on a large scale, leading to the question of why implementation remains limited. This study dives into this question, which are the high-potential product groups, what are the existing barriers in place and what is needed for the industry to implement circular products? This could help the industry determine where to start and how to allocate their resources in order for the creation of a new circular product cycle, and get a step closer to reaching the national circularity goals. These questions result in the research question in Chapter 1.2 below.

1.2 Research Questions

Research question

- How can the building product group with the highest circular reuse potential from Dutch B&U demolition be identified, based on technical and socio-economic criteria, and what strategies can help overcome its implementation barriers?

Sub questions

- *(1) What technical and socio-economic factors determine the potential of a product for reuse implementation?*
- *(2) Which building product group retrieved from B&U demolition, has the highest potential for circular reuse, based on the determined technical and socio-economic factors?*
- *(3) What key barriers must be addressed to successfully integrate the chosen high-potential product group into a circular product flow?*
- *(4) How to overcome the product group specific barriers to successfully integrate this high-potential product group into circular product flow?*

1.3 Research Design

Despite Growing attention, the transition from a linear to a circular economy remains hindered by multiple barriers. Many factors play a role in transforming the conservative building industry into this new system. There are many product groups, and starting all at once is simply not feasible for the industry. While some circular cycles exist in the B&U sector, the transition to a circular industry is progressing slower than needed (PBL 2025; TNO Bletsis et al. 2024b).

This study aims to provide advice to the industry on which product reuse cycle should be prioritised next. The study begins broadly, considering as many product groups as possible. These groups will be ranked based on impact. Specifically, the MKI score, multiplied by the mass of the output stream, since this indicates the lost potential when this mass stream is not reused. The results will form the foundation of a high-potential list, with 5 to 15 product groups identified as promising due to their potential for substantial environmental benefit.

Several factors influence the implementation of a new product cycle, including the balance of supply and demand, the technical feasibility of reuse, the labour intensity of the process, cost & risk considerations, and the sustainability of the current end-of-life scenario. However, not all these factors can be assessed with purely quantitative data. Therefore, a Multi-Criteria Analysis (MCA) is proposed to evaluate the high-potential product groups using literature and interviews.

The outcome of the MCA will identify one (or, in the case of a close second, two) product groups that, in theory, are well suited for direct reuse. At this stage, the project will transition into a case study on a specific product group. Again, literature and interviews will be used to determine current bottlenecks and provide recommendations on how to overcome them.

A schematization of the research flow can be found below.

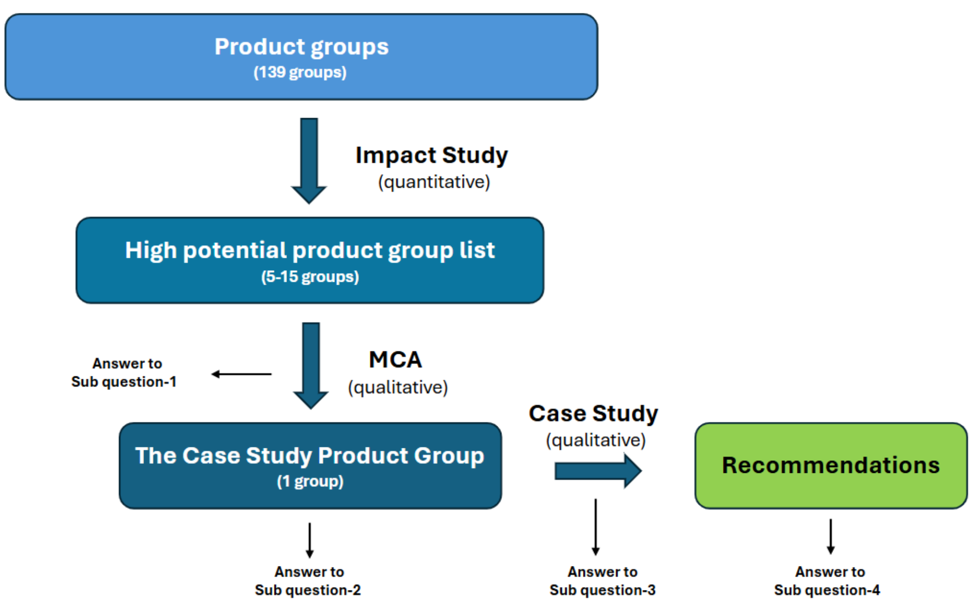


Figure 1. Research design flow.

1.4 The Importance of the Thesis

The goal of this thesis is to identify building product groups with high potential for circular reuse, but which have not yet been successful. The aim is to determine which barriers exist for implementation in the Dutch building industry, and how these barriers can be overcome for the selected product group. The current industry seems stuck: although extensive research has been conducted, the actual transformation to a circular economy is simply not happening. This research focuses on finding a starting point, identifying a product group that could be reused on a regular basis, not just in pilot projects. While broader research has already been performed, this study explores what happens when we focus on and further develop just one specific product group. Results from this research could be used as a starting point for setting up a consortium dedicated to the reuse of that specific product group.

1.5 Reading Guide

This thesis is organised into six Chapters. In Chapter 1, the research problem, objectives, and research questions are introduced. Chapter 2 provides a literature review, presenting the current state of knowledge on circular product use in the Dutch construction sector. Chapters 3 and 4 show the high-potential product group selection. Chapter 3 explains the methodology used for finding the case study product group and will also focus on the data collection and ethics. Chapter 4 presents the results of the high-potential group selection, focusing on the identification of promising product groups for circular use and the barriers to their implementation, resulting in the product group used for the case study. Chapter 5 will build on the findings of Chapter 4 and be about the case study product group. It will discuss current practices, present barriers and alternative circular value chains, resulting in a proposed business model best suited for circular implementation of that specific product group, the case study will be finalised with an own results subchapter. Finally, the thesis is concluded in Chapter 6 by summarising the main findings, providing recommendations, indicating limitations of the performed research approach and suggesting directions for future research. The thesis is structured in such a way as to allow the report to be read seamlessly from beginning to end in chronological order.

2. Literature Review

2.1 The Concept of a Circular Building Sector

Transforming to a more sustainable building sector is no longer optional but essential. The construction industry is one of the largest consumers of raw materials and one of the biggest producers of CO2 emissions in the Netherlands, accounting for about 50% of all raw material use, 35% of carbon emissions, and around 33% of national waste (Cirkelstad 2021). These numbers underline the urgency to transition away from the current linear construction practices and move to circular strategies.

There is no single agreed-upon definition of the circular economy. Kirchherr et al. identified 114 definitions and argued that a clear definition is essential for effective implementation (Kirchherr, 2017). The 3R framework (reduce, reuse, and recycle) is the most used conceptualisation and serves as the basis for circular strategies, while extended models such as the 6-R and 10-R frameworks are also explored in this literature review. The concept of circularity in the building sector involves maintaining the value of materials, products, and even whole buildings over multiple life cycles, while reducing dependency on newly introduced finite resources. This shift is driven by environmental concerns, material scarcity, and therefore, European and national policy commitments that followed, such as the Dutch goal of a fully circular economy by 2050 and the European Green Deal (PBL 2025).

Circular construction is not about eliminating the use of new materials altogether. Rather, it is about minimising the introduction of new resources by keeping current materials in circulation as long as possible. Thus, the idea is not to close off the raw material stream completely but to extend its utility and retain value. Virgin materials are allowed in a circular system, but they must be used responsibly and with foresight (PBL 2021).

A well-known model of strategic circular thinking is the "loop thinking" framework, along with the R-strategies. Numerous variations exist, including my own, presented in Appendix 1, but for the purpose of this thesis, the version of the Planbureau voor de Leefomgeving, is adopted (PBL 2021).

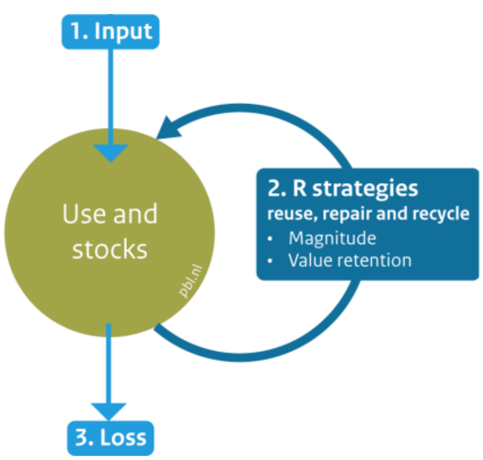


Figure 2. Concept of loop thinking, PBL 2021

The concept of loop thinking is illustrated in Figure 2. It consists of a use phase, with a material input (1) and an output (3), where material is lost. The concept of a circular economy is that materials, once they enter the use phase, should continue to circulate within use cycles (2).

The 6-R strategy expands on this basic concept by introducing six approaches to minimise material use. It addresses the input phase through refusing, rethinking, and reducing materials. It targets the output phase by recovering as much energy as possible when materials must exit the circular system. But primarily, it focuses on the cycles themselves by focusing on reuse, repair, refurbishment, and recycling (Figure 3).

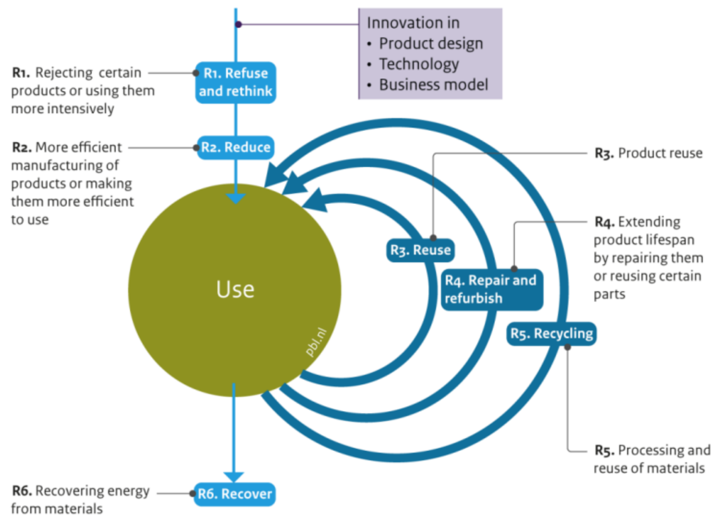


Figure 3. 6-R strategy, PBL 2021

The 10-R strategy, illustrated in Figure 4, represents the most comprehensive variation of circular strategies. It distinguishes refuse (R0) and rethink (R1) as separate approaches. It also differentiates repair (R4) and refurbish (R5), while adding two additional strategies: remanufacture (R6) and repurpose (R7). Moreover, it places greater emphasis on what occurs after the final step recover (R9). It shows that disposal to landfill remains an endpoint, one that lies outside the principles and goals of a circular economy and R strategies.

The lower the number on the 10-R ladder, the greater its potential to retain value and reduce environmental impact. For instance, recycling is typically more effective than recovery. Nonetheless, in a truly functional circular economy, all R-strategies are necessary and should be used simultaneously.

These strategies can also be linked to the loop thinking framework, which includes slowing, narrowing and closing loops. 'Narrowing' focuses on reducing material and energy inputs, corresponding to R0, R1, and R2 in the 10-R model. 'Slowing the loop' refers to extending the lifespan of buildings and materials, which aligns with R3 through R7. 'Closing the loop' involves converting waste back into resources, notably through recycling (R8) and recovery (R9), as shown in Figure 4.

As indicated in the introduction, this thesis will primarily focus on 'slowing the loop', with a specific emphasis on reuse (R3), since this is the highest achievable strategy for retrieved demolition waste already in the use stage according to the 10R-strategy. Nevertheless, strategies R4 through R7, will also be considered, as they are closely related in function and intent.

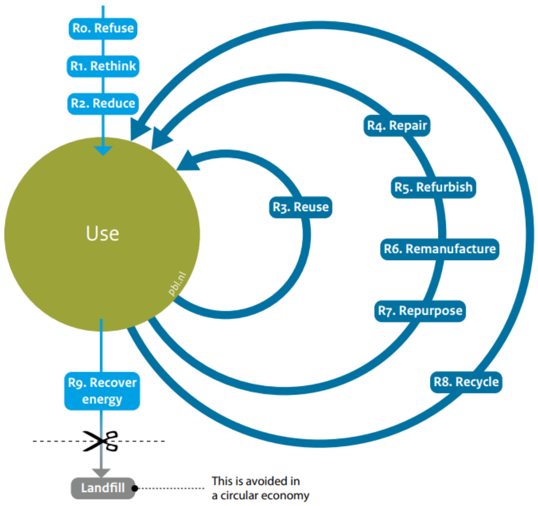


Figure 4. 10-R Strategy, PBL 2021

Emerging techniques such as modular construction, biobased materials, and the design-for-disassembly philosophy have opened new avenues for circularity. Design tools like material passports and Building Information Modelling (BIM) support traceability and smart deconstruction (CB23 2022). These innovations ensure that today's building projects could become tomorrow's material banks.

However, the reality remains that over the next 80 years, millions of tonnes of traditional, non-renewable and non-demountable materials will still be recovered from the existing building stock (CB23 2023b; TNO Bletsis et al. 2024b). This thesis specifically investigates how to facilitate the high-value reuse of those materials; materials not originally designed with multiple use cycles in mind.

The Dutch construction sector is known for its conservative nature and dependency on conventional materials such as concrete. Although the urgency of transformation was already highlighted in reports from as early as 2015, adoption of circular strategies on the ground has been ‘slow’ at best (Copper8 2024; PBL 2025).

2.2 Material Use in the Dutch Building Sector

For a successful transition, a clear understanding of the distinctions between materials, products, and elements is crucial. Products are specific elements made from specific materials. Take, for example, the product *hollow-core concrete floor slab*: the materials used are concrete and steel, and the element type is a floor. Combined, they are a product.

This distinction is essential, since viewing a product either as a collection of materials or as an element determines the difference between recycling (R8) and reuse (R3). Recycling typically involves reprocessing products back into raw materials, from which new products are made. By contrast, reuse involves keeping products intact for direct reapplication, with the general benefit of significantly reducing energy consumption, emissions, and waste compared to recycling. Consequently, reuse usually offers substantial environmental advantages, requiring less energy and producing fewer emissions than recycling (Cirkelstad 2021).

Despite the potential environmental benefits, implementing reuse at large-scale also encounters several challenges, particularly within existing buildings. Buildings demolished today were generally designed without consideration for future reuse, complicating the extraction of building products. This old way of construction significantly restricts large-scale reuse initiatives. A study by TNO highlights that due to these design limitations, substantial reuse of construction elements remains challenging (TNO Bletsis et al. 2024b). Additionally, elements often differ substantially in their life expectancy. Certain structural components may last through multiple lifecycles, whereas others such as installations, often fall short, due to changes in technological standards or durability demands (EIB 2022). This is illustrated in the shearing layers concept (Figure 5).

Reuse is not always an option, for some products recycling is the only circular path. For example, these products may no longer qualify for current building regulations, since regulations have become stricter over the past years, or the products may have passed their life expectancy, and the product is no longer sufficient for a second use cycle. For such products recycling, if possible, is the most appropriate circular route.

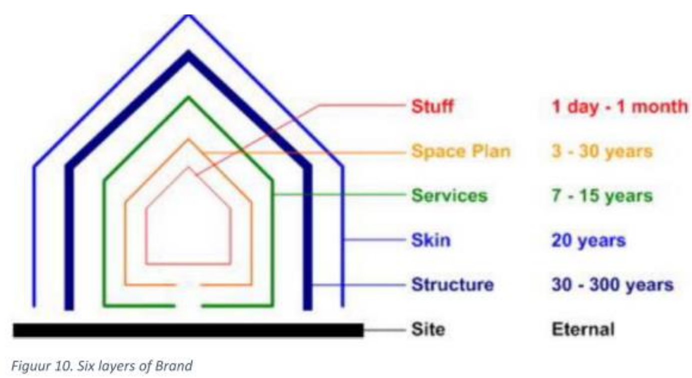


Figure 5. Shearing layers, kanters 2020

Recent data underscores the Netherlands' relatively advanced position within the European Union concerning national industry wide circular material use. The general Circular Material Use Rate (CMUR) reached 27.5% in 2022, considerably higher than the EU average of 11.5% (PBL 2025) indicating that the Netherlands uses a relatively large amount of recycled material. The CMUR is based on all material use in a country, thus not restricted to the building industry alone.

When examining the quantitative mass flow of building materials within the Netherlands, it illustrates the challenges facing circular construction in the Netherlands (Figure 6). In 2019 and 2020, the Dutch construction sector required around 23 million tonnes of materials, dominated by concrete (70%), bricks (5%), steel (4%), and Timber (2%). However, the demolition and renovation processes only reclaimed about 5 million Tonnes in 2019 and 3 million tonnes in 2020. This substantial imbalance indicates a reuse potential of approximately 20%, highlighting a significant in and outflow mass difference in the Dutch building stock (EIB 2020; TNO Bletsis et al. 2024b).

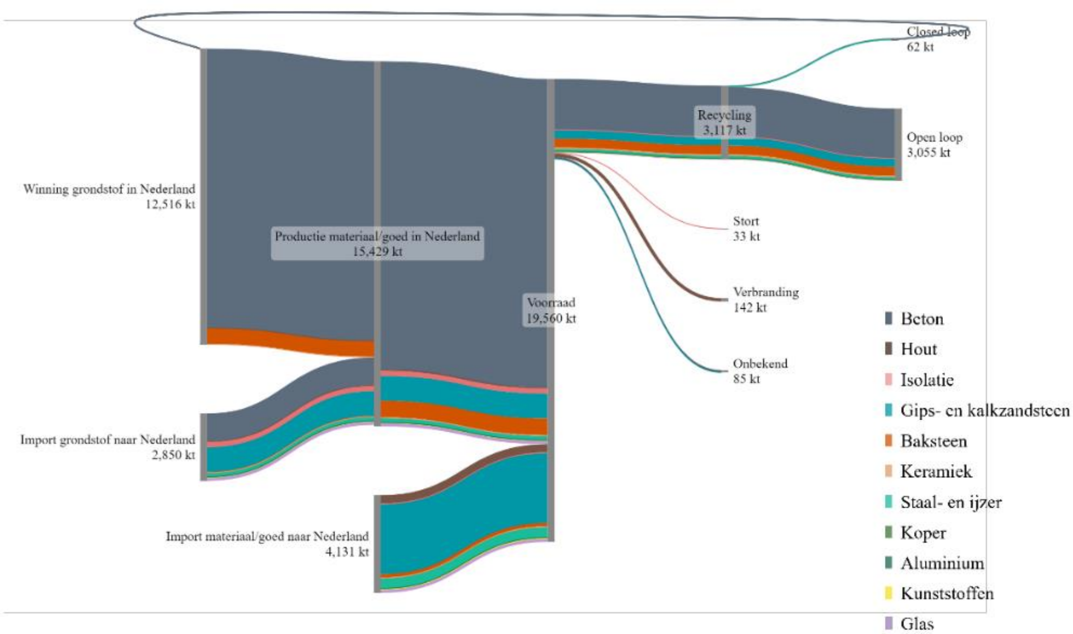


Figure 6. Material flow of Dutch building sector in 2020, TNO bletsis et al 2024b

Moreover, the outflows of materials from the construction sector are predominantly directed towards lower-value applications, typically in road construction as foundation material (PBL 2025). From all building material outflow in 2020, only 1.9% was reused as secondary material inflow, 92,8% was used for road foundation, 1% went to landfills, and 4.3% was burned and used for energy winnings (TNO Bletsis et al. 2024b).

The closed loop of around 1.9% is build op as follows: 82% is concrete, 14% is calcium silicate and gypsum, and 4% is steel. This closed loop materials are 1.9% of the outflow but represent only 0.3% of the overall inflow. Note that these numbers are on material level and therefore indicate reuse and recycling combined. The amount of solitary reuse on product level will therefore be even lower since recycling is still the dominant circular strategy (PBL 2025).

Future trends suggest a slight continued increase in the use of secondary and renewable materials. However, comprehensive changes in construction design, policies, and increased cross-sectoral collaboration are necessary for the transition towards a more circular economy (SGS-Search n.d.). The EIB and Metabolic report on material flow in the building sector, where they anticipate material flows to become more balanced by 2050, driven by increasing renovation activities and a decreasing demand for new construction. This shift could partially address the imbalance between material in- and outflow (EIB 2022).

2.3 Legislation for a Circular Dutch Building Sector

Circularity in the construction sector is embedded within a broader international and national sustainability agenda. At the core lies the Paris Agreement, which requires the 194 involved nations to undertake actions to limit global temperature rise to below 2°C, preferably to 1.5°C above pre-industrial levels (United Nations 2015). The Agreement urges climate neutrality by the second half of the 21st century, leading countries to adopt national circular practices to reduce CO2 emissions. The Netherlands responded through the “Rijksbrede programma Circulaire Economie”, which aims for a fully circular economy by 2050 and sets a 55% reduction target for primary raw materials by 2030. This 55% goal has recently been increased to 60% to build in some room for minor failure and still meet the 55% mark (Rijksoverheid 2022; Rijkswaterstaat 2015).

While these targets are ambitious, it is important to make a clear distinction between goals, which are aspirational and thus non-binding, and regulations, which carry enforceable obligations. The lack of legal consequences for not meeting goals is acknowledged in recent assessments (PBL, 2025), suggesting that implementation and enforcement remain major challenges.

Besides these policies and goals, there are binding regulations in the Netherlands. The main binding legal framework for buildings in the Netherlands is the “Besluit bouwwerken leefomgeving” (Bbl), formerly known as “bouwbesluit”. It outlines minimum standards for safety, health, usability, and, to a lesser extent, sustainability. It refers to calculation methods and standards, such as the Environmental Performance of Buildings (MPG) and sets some regulations on these scores (Het ministerie van Infrastructuur en milieu 2016).

Only documents that are explicitly mentioned in the Bbl are legally binding. Another supplier of widely accepted documentation is written by the “nederlandse normalisatie institute” (NEN). They include; “NEN-normen” (standards), and “Nederlandse Praktijkrichtlijnen” (Practical guidelines) (NPRs), and “Nederlandse Technische Afspraken” (Technical Agreements) (NTAs).

An example of such a technical agreement is NTA 8713:2023, which provides criteria and a testing method for the reuse of structural steel in construction. Though not mandatory, and not cited in the Bbl, this private initiative does give some guidelines and handles for circular use of these specific product groups (NEN 2023).

At the European level, the Construction Products Regulation and harmonised EN standards govern product compliance and CE-marking. These norms are essential for new products but often ill-suited for reused or circular materials, limiting their applicability in a circular economy. This regulatory mismatch highlights the gap between current product legislation and the ambitions of circular construction (EUROPESE UNIE 2024).

In addition to hard law, the Netherlands relies on voluntary agreements and protocols to promote circular construction. These include EPRs (Extended Producer Responsibility / in Dutch: UPVs) and private/industry protocols like those developed by SGS INTRON in collaboration with Rijkswaterstaat for the reuse of structural products like inverted double T Beams (SGS-Intron 2022).

These protocols are not legally binding but can later be transformed into formal standards or certification schemes, such as "Beoordelingsrichtlijnen" (BRLs). These provide a structured method for assessing whether materials meet the technical and environmental criteria needed for certification. Once recognised, they can form the basis for KOMO quality declarations, which confirm compliance with Bbl requirements (Het ministerie van Infrastructuur en milieu 2016).

A similar function is performed by the "CROW-richtlijnen", especially in infrastructure, where they are widely accepted by both public and private contractors. Though not legally mandated, their influence on procurement practices makes them semi standard in the sector. A particular interesting crow-cur document is the "richtlijn 4" for the reuse and quality insurance of precast concrete products (Crow-cur 2023).

Policy instruments in the Netherlands are clustered around knowledge development, market incentives, and voluntary cooperation. The "Programma Klimaat" (2022) frames the circular economy as a key strategy to meet climate goals: 60% CO2 reduction by 2030 and full neutrality by 2050 (Rijksoverheid 2022). However, this too is based on non-binding targets.

The PBL "Integrale Circulaire Economie Rapportage" (ICER 2025) notes that while policies exist, progress is limited. The volume of raw material use increased between 2020 and 2022, and markets for circular products remain underdeveloped. Legislative instruments have mostly addressed waste minimisation and recycling through regulations like the "circular material plan" but lag in supporting high-grade reuse, design for disassembly, or long-term durability (PBL 2025).

A promising development is the expansion of EPR, which obliges manufacturers to consider end-of-life reuse and recycling. While EPR is not yet common in construction, its broader application could stimulate design choices aligned with circular principles (PBL 2025). There is a distinction between obligated EPRs, which in the Netherlands are in place for cars, tyres, plastic packaging and batteries. These EPRs are enforced and regulated by the government. On the other hand, there are voluntary EPRs. For example, cardboard and paper, glass panels (also from construction) and consumer mattresses. These EPRs are set up by the industry itself.

Despite a dense network of standards and policy frameworks, several barriers hinder implementation. First, many existing norms focus on new products and are not designed for reused Products. Second, the fragmented legal landscape means that crucial instruments like the Bbl only partially address circularity, often indirectly.

Third, the status of voluntary instruments creates uncertainty. While these tools offer flexibility, they lack the enforceability needed to guarantee uniform market behaviour. Lastly, market reluctance and insufficient demand for secondary materials persist due to concerns about liability, performance, and availability.

Institutional collaboration is crucial. The "Planbureau voor de Leefomgeving" (PBL), Rijkswaterstaat, TNO, and RVO play leading roles in monitoring and guiding circularity efforts. The "Nationaal Programma Circulaire Economie" (2023-2030) introduces cross-ministerial coordination, involving the Ministries of Infrastructure, Economic Affairs, and the Interior, yet emphasises that most implementation is decentralised and highly dependent on market cooperation (PBL 2025).

The government also collaborates with municipalities, sector organisations, and knowledge institutes. However, ICER (2025) reports that these efforts often remain project-based, lacking the continuity needed for system change.

EU legislation significantly shapes national regulations. The EU Waste Framework Directive and the new Regulation on critical raw materials provide both constraints and opportunities. Dutch circular policy must operate within these constraints while pushing for EU-level regulations, also to accommodate reused materials under CE-marking regimes (Europese Unie, 2024).

The current patchwork of regulations and voluntary initiatives reflects a transitional phase. The direction is clear, but legal certainty and harmonisation are still developing. As highlighted by the 2015 RWS report, a shared vision is essential, but this must be backed by integrated and enforceable legal frameworks (Rijkswaterstaat 2015).

2.4 Current State of Building Material and Product Reuse in the Netherlands

The transition towards a circular economy in the construction sector is crucial but challenging. The ICER report is published every 2 years and discusses the current state of the transformation to a Dutch circular industry. In this report, the PBL stated: "Although various initiatives have been undertaken in the field of circular economy, overall, the transition is not heading in the right direction. The use of raw materials increased between 2020 and 2022, as did the supply risks of most critical raw materials. Additionally, many circular products lack sufficient markets, since current policy focuses more on the outflow than on the stimulation of circular inflow. These negative trends could be reversed through concrete and ambitious national and European policy measures" (PBL 2025).

To stimulate circular practices, various decision-making tools have been developed by and for the Dutch market. The “Beslisboom Hergebruik Gebouwelementen” by SGS-Search, is a flowchart that aims to simplify the complex decision-making processes regarding quality assessments and the suitability of reused building products. The Beslisboom categorizes decisions based on product quality, costs, and sustainability objectives (SGS-Search 2021a, 2021b, 2021c).

Similarly, “de Circulaire bouweconomie” produced comprehensive leaflets designed to guide stakeholders through the circular decision-making process, highlighting the legal possibilities of reuse, such as the equivalence provision rules within Dutch building regulations (Bouweconomie 2023).

Other advisory reports from Platform CB23 focus on circular transition in construction by addressing gaps in existing legislation and standardisation. Publications, such as the 'Leidraad Toekomstig Hergebruik Faciliteren', outline practical barriers to reuse, including unclear regulations and challenges in assessing product quality. The guidelines recommend creating generic standards, such as NEN or NTA norms, explicitly addressing reuse quality assessment to enhance reliability and market acceptance of circular products (CB23 2022).

Additionally, CB23's guidelines on 'Uitgebreide Producenten verantwoordelijkheid' (EPR) and the 'Horizontale Richtlijn Productprestaties' encourage manufacturers to take more responsibility, incorporate circular principles directly into product design. These documents propose product performance documentation for future reuse cycles and thus enabling better informed and more sustainable decisions at every stage of the building lifecycle. Through these frameworks, CB23 aimed to drive circular reuse from an exception to standard practice across the construction sector (CB23 2023c, 2023a).

Current reuse rates within the construction sector remain low. According to the EIB and Metabolic report (2022), a significant gap exists between the potential for reuse and the actual implementation. It indicates that in 2019, only a fraction of potentially reusable building materials was genuinely reused, highlighting practical, economic, and technical barriers still present (EIB 2020, 2022).

“Green Paper Hoogwaardig Hergebruik” (2021) emphasises that high-quality reuse, defined as maintaining or increasing the value of products across multiple life cycles, faces regulatory, technical, and market-based challenges. (Cirkelstad 2021).

Specific product reuse protocols provide examples of targeted circular approaches. For instance, the reuse protocol for inverted T-beams developed by SGS INTRON, outlines detailed steps for processing and final quality checks, demonstrating a structured approach to reuse within infrastructure projects (SGS-Intron 2022). Similarly, the NTA 8713:2023 provides guidance on reusing structural steel, detailing processes for demounting, inspecting, reconditioning, and reusing steel components. This technical agreement ensures reused steel's safety, reliability, and potential helps in market acceptance (NEN 2023). “CROW-CUR Richtlijn 4:2023” further exemplifies structured protocols for the reuse of structural prefabricated concrete elements. This document carefully outlines every phase, from initial inspection through to the reintegration of products into new construction projects, ensuring traceability and quality assurance at each step (Crow-cur 2023). It can be concluded that there are some protocols and “technical industry deals” in place, but even for these products, reuse is limited.

Emerging construction marketplaces and material hubs have gained traction. Yang et al. (2023) highlight circular construction hubs, which function as logistical nodes for managing and distributing secondary products. Their research stresses the environmental and economic benefits of optimally placed hubs, significantly reducing transportation-related emissions and costs (Yang et al. 2023). The DigiC initiative (2024) has further examined the role of digital construction marketplaces, emphasising how these platforms can accelerate high-quality reuse by efficiently matching supply and demand of secondary materials. (DigiC 2024).

Despite numerous guidelines and protocols, actual implementation remains limited. A study by the EIB (2022) shows substantial economic and logistical barriers, with current circular reuse rates remaining disappointingly low compared to the potential. The DigiC report echoes these concerns but adds optimistic recommendations for scaling up digital marketplaces.

Current literature shows a gap between the extensive documentation, guidelines, and actual circular practices. The tools, protocols, and frameworks available are somewhat comprehensive, covering broad guidelines down to highly detailed reuse protocols. Yet, as data from the EIB and Metabolic report illustrate, practical implementation continues to lag significantly behind potential reuse scenarios.

2.5 Barriers for the Transformation to a Circular Building Sector

The transition to a circular economy in the building sector holds considerable promise in tackling resource scarcity, environmental degradation, and carbon emissions. However, despite this potential, the widespread implementation of circular economy principles remains limited due to a complex array of barriers. This Chapter presents these barriers, using academic sources, Dutch government reports and industry reports. Three scientific studies form the academic foundation are: Wuni (2022), who conducted a systematic literature review of Circular economy barriers in the construction sector; Kanters (2020), who interviewed architects and consultants in the Netherlands and Sweden about their experiences with circular design, and Le et al. (2024), who focused on barriers to adoption of circular bio-based building materials in Flanders, Belgium.

In a systematic literature review, Wuni analysed 53 peer-reviewed studies to map and prioritise barriers to circular economy adoption in the construction industry. The study, conducted with a global focus but largely foccused on Europe and Asia, identified 95 individual barriers. These barriers are categorised into eleven taxonomies: financial, knowledge, regulatory, management, supply chain, technical, stakeholder, cultural, technological, market, and organisational. Among the most frequently cited barriers are the high upfront investment costs, lack of technical capabilities and expertise, absence of a supportive regulatory framework, limited awareness of circular strategies among stakeholders, and insufficient financial incentives from governments. These findings reveal how deeply embedded linear practices are in the construction industry, often discouraging systemic change. Wuni also highlighted the interplay of these barriers. For example, financial constraints can limit investments in education and training, thereby reinforcing knowledge barriers. This creates chain reaction mechanisms that stall or reverse progress toward adoption (Wuni 2022).

Jouri Kanters, focused mainly on the Dutch and somewhat broader European context, conducted interviews with architects and consultants to explore practical experiences with circular building design. The study identified several context-specific barriers, such as the disproportionately high cost of labour in Europe relative to materials. This economic imbalance often discourages circular practices like harvesting products from demolition sites (urban mining), which are labour-intensive. (Kanters 2020).

Architects also noted the lack of professionals skilled in reuse and deconstruction techniques, which restrains circular design practices. A consistent finding was that the success of circular projects often depended on the client's commitment and vision, rather than systemic support or market demand. This indicates a market where progress is client-led rather than policy-driven. Kanters also drew attention to broader systemic implications. Circularity could phase out some professions and make certain conventional materials obsolete. However, it also offers room for innovation and new business models, especially when supported by digital tools like BIM and material passports.

Recent research by Lihn Dihn Le, offers a barrier review on circular bio-based building materials, exploring barriers to their adoption in Flanders, Belgium. While many of these obstacles overlap with general Circular economy challenges, such as high initial costs and limited technical knowledge, there are also unique issues specific to bio-based approaches and therefore less useful for this specific thesis.

Through a mixed-methods approach, Le et al. identified 23 barriers, of which 13 were flagged as critical. These barriers were clustered into five categories: cost and risk, technical and cultural, governmental, informational, and market-related barriers. Key challenges include the perception of low material quality, lack of design guidelines, market immaturity, and insufficient supply chains. Notably, the high perceived risk and cost of using unfamiliar products emerged as leading causes.

This study also found that circular bio-based building products often lack formal recognition within building codes and standards, creating regulatory uncertainty. Furthermore, stakeholders expressed concern over the absence of local production, which leads to increased emissions from transport and undermines the environmental rationale for using such products. Despite these challenges, the study identified a growing awareness and intent to use circular biobased materials in the near future, indicating potential for market growth if strategic barriers are addressed (Ie 2024).

This perspective aligns with earlier findings from Kanters regarding the conservatism of the building sector and adds a material-specific layer to Wuni's systemic barrier framework. Together, they illustrate that while many circular economy bottlenecks are universal, targeted strategies will be needed to address collaborations.

In their 2025 report, the Dutch PBL identified persistent barriers that continue to hinder circular economy progress. Central among these is a structural market failure is the "chicken-and-egg" dilemma, where limited demand for circular products discourages supply, and vice versa. Without strong public policy or consumer push, the market for circular products remains underdeveloped.

PBL also points out that environmental side effects are not adequately priced, allowing linear value chains to remain competitive. For instance, Dutch recycling initiatives struggle to remain viable due to low global prices of virgin materials, particularly plastics from China and the United States. The result is an uneven playing field that undermines local circular initiatives (PBL 2025).

Moreover, the report highlights the lack of comprehensive data across the product lifecycle. While data on end-of-life recycling exists, there is limited transparency regarding design and material or product composition early in the value chain. This inhibits producers from taking full lifecycle responsibility. A proposed solution is the development of product passports to improve traceability and accountability.

The report also discusses behavioural barriers: although many consumers are open to circular behaviour, practical barriers like cost and complexity prevent large-scale adoption. Circular products are often more expensive or less accessible than linear alternatives, despite consumer intentions.

These findings complement the 2015 Rijkswaterstaat document exploring institutional and design-based bottlenecks in the Dutch construction sector. And shows that little has changed in the last decade. The report notes that while construction and demolition waste is already extensively recycled, this is mostly low-grade reuse (e.g., as road foundation). The share of secondary materials in new construction remains low, partly because conventional design does not prioritise disassembly or product reuse.

Key challenges include the long lifecycle of buildings, which makes planning for reuse decades in advance difficult, and the fragmentation of responsibilities within government bodies. The report recommends a stronger role for public clients in initiating and supporting Circular economy projects, especially through public procurement and standard-setting (Rijkswaterstaat 2015).

While scholarly and policy-driven insights provide essential theoretical and institutional overviews of circularity in the built environment, equally important is the perspective of industry and independent research organisations. Several recent Dutch reports from engineering firms, consultancies, innovation platforms, and public-private partnerships highlight barriers to circular construction, especially from a business and implementation perspective.

According to Copper8, the construction sector is facing five fundamental structural challenges. These include: the absence of a clear and unified goal across stakeholders regarding what the circular transition entails, misaligned steering mechanisms and performance metrics that fail to support circular processes, inadequate and often obstructive regulation, an aversion to risk and the tendency to delegate it down the value chain, and the challenge of aligning private investment incentives with societal-level benefits. The latter reflects the economic misfit where the costs of innovation (e.g. higher upfront expenses) are carried by developers, while the benefits (e.g. lower environmental impact, resource preservation) are shared more broadly across society (Copper8 2024).

The independent Dutch research institute TNO echoes these findings and highlights further complications in their product group analysis (PGA) for circular housing. First, there is a systemic tension between different societal missions: most notably, the acceleration of affordable housing construction often conflicts with circular goals. Second, stakeholders still prioritise CO_2 reduction over reuse, meaning that circularity is subsumed under energy goals. Third, the strategies and instruments available are dispersed across different maturity levels, leading to fragmented implementation. Furthermore, public clients and procurement practices lack sufficient focus or control on circular performance indicators (TNO Bletsis et al. 2024b).

The DigiC project report reinforces these operational themes by examining the scalability of digital construction marketplaces. While digital reuse platforms are gaining traction, systemic issues like data quality, lack of digital product passports, legal uncertainty about liability for reused components, and poor interoperability of databases limit their potential. The authors stress that without uniform frameworks and trust in the provenance and safety of reused materials, the circular construction market cannot scale effectively (DigiC 2024).

Similarly, the “Beslisboom Hoogwaardig Hergebruik” project, a decision-tree tool for high-quality reuse, identifies institutional uncertainty and fragmented accountability as bottlenecks. Practitioners are unsure how to assess or certify the performance of reused elements. This is especially problematic in projects with multiple reuse cycles or components salvaged from older buildings without adequate records. Legal liability, lack of standardised assessment protocols and compatibility with BBL are identified as critical gaps.(SGS-Search 2021c).

The platform CB'23, emphasises the need for a standardised, legally recognised framework to assess and register materials' performance for reuse. Their guidelines consistently cite the lack of a product passport, harmonised environmental data, and uniform verification methodologies as major obstacles. For example, the "Leidraad Kwaliteitsborging Hergebruik" argues that without clear quality indicators and traceable documentation, stakeholders face too much uncertainty and legal risk to reuse products. Their call for extending EPR to the building sector is rooted in the concern; only through upstream responsibility and traceability can circular flows be ensured (CB23 2022, 2023c, 2023a).

Several reports from Cirkelstad and EIB identify infrastructural and market-side deficiencies. For example, EIB underlines the uneven playing field due to cheap new materials and limited access to high-quality secondary materials. Furthermore, they stress the importance of consistent taxonomy, material classification, and performance data, without which architects and contractors remain hesitant to specify reused products in tenders. (Cirkelstad 2021; EIB 2020)

In this last chapter, numerous barriers are identified by literature study on scholars, government bodies, independent research institutes and the industry to generate an understanding of different perspectives on encountered barriers in the transition process. The Barriers are listed in Appendix-B: Barriers List, and will be used in later product-specific barriers determination.

2.6 Success Criteria in Circular Building Projects

Besides the barriers, certain factors can also stimulate the transition to a circular Dutch building sector. The transition to a circular construction economy is a complicated challenge that depends not only on technological solutions but also on the alignment of stakeholder values, governance involvement, and market incentives. Scientific contributions shed light on the drivers behind successful implementation efforts in the building sector. Below, the findings of Kanters, Giorgi and Tura are discussed (Kanters 2020).

Jouri Kanters identifies the supportive role of clients as a crucial success factor. In his study, the most effective circular projects were those initiated by clients with a strong commitment to sustainability. From the start, this conviction shaped the architectural plans and requirements, empowering designers and contractors to experiment with new materials, creative business models, and novel construction methods.

Similarly, Giorgi et al. highlight the role of proactive ecosystems in five European countries. Success was there, where designers, contractors, and suppliers were embedded in active networks that facilitated trust, information sharing, and joint ventures. Notably, countries that promoted digital traceability tools, common reuse standards, and shared product platforms were better able to realise circular strategies. The availability of such infrastructures meant actors didn’t need to reinvent the wheel; they could rely on existing guidance, tools, and partners (Giorgi et al. 2022).

Nina Tura adds an organisational perspective. Her analysis identifies companies that thrive in circular construction as those with a clear long-term vision, paired with operational flexibility. These organisations often decouple profitability from raw material prices, embracing service-based models or value-retention logic. Internally, they value and invest in new skills and cross-functional collaboration. Externally, they engage in coalitions that reduce perceived risk and allow them to pilot new projects with like-minded partners (Tura et al. 2019).

In addition to scholars, independent institutes like the TNO, EIB, and CB23 also indicated some drivers for a circular sector. TNO's presents that circular success stories are grounded in materials and building products, not abstract concepts. What stands out is how companies, guided by data and regulatory incentives, are beginning to integrate circular products early on in the design process.

One major factor in successful circular systems is standardised reuse-ready building components. TNO reports that elements such as demountable façades, modular wooden frames, and recycled concrete elements are increasingly specified in both new builds and renovations. These choices are driven not only by environmental concern, but also by financial logic: companies found that demountable systems reduce renovation costs in later stages and add value to residual assets. Building demountable isn't an option for buildings under demolition today, however it does indicate that the level of demountability, is a driver in the process (TNO Bletsis et al. 2024b).

In practice, firms that adopted a circular strategy from the design phase benefited from reduced waste costs, increased user satisfaction, and greater project adaptability, particularly important in the face of housing shortages. These examples demonstrate that when circularity is embedded early and supported with robust monitoring, it becomes both feasible and desirable.

The CB'23 guide on quality assurance in reused building elements provides a practical view of how circularity works on site. It documents multiple finished real-world projects where structural components such as steel beams, brickwork, timber, and concrete panels, were successfully reused. The project team reported several key success drivers. Firstly, early collaboration with demolition teams to pre-identify reusable products. This allowed for better preservation and preparation for safe extraction. Furthermore, standardised inspection protocols made it easier to verify the mechanical integrity of structural products. These protocols, developed through CB'23, provided confidence to engineers and insurers. Finally, digital tracking tools, such as material passports and visual tagging, ensured traceability and improved coordination between donor and receiving projects (CB23 2023b).

The EIB and Metabolic report confirm an opportunity: growing renovation and transformation demand. By 2030, reuse will be especially vital in post-war housing being refurbished in enormous amounts (EIB 2020).

Successful cases involved: product mapping prior to demolition, allowing secondary products to be logged, certified, and matched with upcoming developments, and partnerships with housing associations, who were more willing to adopt circular practices due to long-term asset ownership and lifecycle cost focus. This is also shown by the rather successful circular product use cases of Rijkswaterstaat. In these projects, the old function and new application are both organised by the same client, resulting in one client that can push and pull at the same time. These cases illustrate that when owners take a lifecycle view and when reuse logistics are planned proactively, the result is both environmentally and economically sound.

Then there is the 'Beslisboom', a decision-making tool to help the industry with the implementation of the circular product use. It is not just a framework; it's a reflection of what successful reuse looks like in the field. The tool, developed through extensive stakeholder engagement, identifies specific conditions under which reuse delivers value. Success in projects that applied the decision tree came from: Systematic pre-assessment of products during demolition planning, reducing last-minute surprises and preserving material integrity. Secondly, alignment with project timelines: the most effective reuse happened where schedules allowed for the matching of supply and demand between sites. Thirdly, legal clarity: guidance on when reused elements qualify as “products” rather than “waste” helped avoid regulatory grey zones and simplified logistics (SGS-Search 2021a).

The 2025 ICER highlights how public policy can stimulate successful circular construction. The report documents that the most promising outcomes were achieved when: Circular goals were embedded in public procurement, for example, municipal projects that prioritised reused or biobased materials saw significantly higher reuse rates. Also, when local authorities acted as launch customers for innovation, commissioning buildings with explicit reuse targets. And finally, with supportive fiscal instruments, such as tax relief for reused products or innovation subsidies, tipped the business case in favour of circular methods (PBL 2025).

Moreover, ICER identifies a competitive edge: Dutch companies with strong reuse and circular expertise are better positioned for export and innovation funding. When circularity is a policy priority, businesses align, not out of obligation, but opportunity.

2.7 Lessons Drawn From the Literature Study

The Dutch construction sector is a key contributor to environmental degradation, consuming around 50% of all raw materials and generating 35% of national CO_2 emissions. Circular construction, aiming to extend the value and lifespan of materials, presents a necessary response. This thesis focuses on one of the circular strategies; ‘slowing the loop’, that prioritises reuse (R3), supported by adjacent strategies like repair, refurbish, and repurpose (R4-R7).

While innovative design tools and modular construction methods offer hope, the existing building stock consists largely of products not designed for reuse, complicating efforts to keep them in circulation.

Dutch construction is dominated by stonelike materials, particularly concrete and bricks, which are difficult to reuse at high value. Most mineral demolition waste ends up as low-grade material in infrastructure. In 2020, only 1.9% of the total outflow was reused directly in buildings. Although structural components like concrete beams and steel profiles show reuse potential, poor recoverability, high labour costs, and a lack of quality assurance hinder scale-up.

The Netherlands has set ambitious circularity goals, such as becoming fully circular by 2050. However, these ambitions lack legal enforceability. The Bbl offers general sustainability standards, but not mandatory circularity requirements apart from MPG scores. Most circular construction guidelines, like NEN standards or CROW protocols, remain voluntary, contributing to market uncertainty and slow adoption. There is a need for binding rules, especially around certification, procurement, and product traceability. Ultimately, accelerating circularity in construction requires three legal innovations: The adaptation of CE and EN standards for reused products, the formal recognition of private protocols, and stronger national enforcement of existing sustainability criteria (NEN 2023; PBL 2025; Rijksoverheid 2022).

Despite a growing body of knowledge, practical implementation remains rare. Tools like material passports and reuse decision trees exist, but are not widely adopted. The reuse of building products is typically limited to client-driven pilots, rather than standard practice.

Barriers include the gap between policy and implementation, market hesitation due to legal and technical uncertainties, and an absence of economic incentives. High labour costs, limited product documentation, and weak digital infrastructure further undermine progress. Moreover, traditional design practices still ignore future reuse potential, reinforcing the linear model.

Success depends on early client commitment, integration of reuse in design, and strong public procurement. Digital tools and standardised protocols also play a critical role. Projects that prioritise traceability, align timelines between demolition and new builds, and ensure legal clarity tend to achieve better reuse outcomes. Public actors who act as launching customers and enforce reuse targets through tenders are key enablers.

A key lesson is the disconnect between circular ambition and real-world uptake. Voluntary protocols and knowledge platforms have not led to structural change. Without legal certainty and aligned market incentives, circularity remains optional rather than expected.

This literature study also reveals that the current approach is too abstract. Policies and strategies speak broadly of “the sector,” yet materials and products differ widely in performance, reuse potential, and risks. This generalisation prevents targeted implementation.

Thus, a research gap lies in the need for product-specific strategies. Rather than more frameworks, the sector needs detailed reuse strategies and protocols for particular products, which include technical conditions, certification requirements, and digital traceability.

By bridging the gap between high-level policy and operational practice that are grounded in specific products, reuse can move from pilot project to a standard industry practice. The tools are available; the challenge now lays in market implementation.

3. Methodology

This research aims to provide advice to the industry on which circular product group should be prioritised for reuse. The study begins broadly, considering the 139 product groups as determined by the EIB (EIB 2020). These groups will be ranked based on environmental impact. Specifically, the "Milieu Kosten Indicator" (MKI) score, multiplied by the mass of the output stream. This impact score represents the relative potential impact a transformation from linear to circular use can make for each product group. The results will form the foundation of a high-potential list, with 5 to 15 product groups identified as promising due to their potential for substantial environmental benefit.

Next, the most promising product group should be selected from the high-potential product group list. Several socio-economic factors influence the implementation of a new reuse system. Therefore, a Multi-Criteria Analysis (MCA) is performed to evaluate the high-potential products using literature and interviews.

The outcome of the MCA will identify one product group that, theoretically, should be well suited for direct reuse. At this stage, the project will transition into a case study on a specific product group. Again, literature and interviews will be used to determine current bottlenecks and provide recommendations on how to overcome them. A schematization of the research flow can be found in Figure 7.

The Impact study and MCA, are elaborated in the chapters below. The methodology for the case study is mentioned in this chapter, but will be elaborated in Chapter 5, since the case study approach will be partly product group dependent.

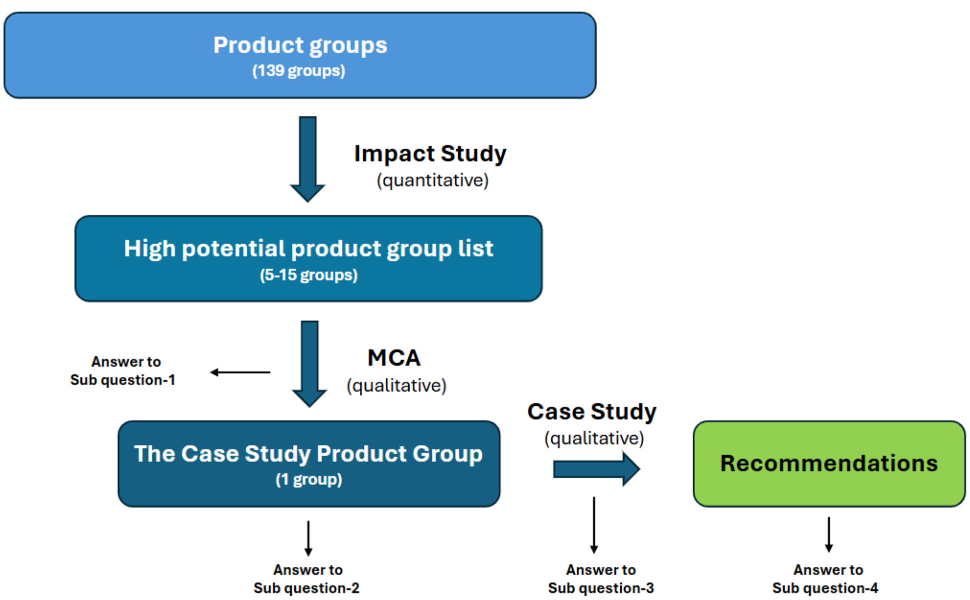


Figure 7. Research flow.

3.1 Impact Study

3.1.1 Defining Product Group

The base documentation for this study is a product group mass flow dataset. This dataset provides information on the inflow and outflow of various product groups within the building sector, over a defined timeframe and geographical area. This research focuses on the Netherlands in the year 2014. The data is based on estimations by EIB and SGS-Search, who extrapolated building models using SYSWOV, BAG, and CBS data. These product groups are defined according to the urban mining model (EIB 2020).

The dataset is opened in Microsoft Excel, translated to English and cleaned by translating non-existent mass stream values from text to the numeric value of 0.

Product groups within the defined product groups list should be merged in some instances. Since the total mass outflow will play a pivotal role in the selection of high-potential product groups, product groups that represent the same purpose and technical specifications should be merged. For the decision-making on product group merging the 9 rules listed below were designed. The rules are necessary because the product group list is based on an estimating computer model, some products are more specific than others. For instance; “PE film” (ID110) and “Polyethylene film” (ID69) are two different product groups in the EIB list, these product groups should be merged. Another example are hollow core slabs, there is “hollow core floor slabs” (ID101), and there is the branded “Dycore hollow core floor slabs 260 mm”. Since brands are not of importance and the thickness of product ID110 is not known, these two product groups are merged for the impact study. It should be noted that this is only done for the impact study. During case studies, the merger could be undone for extensive research. More examples of merges can be found in Appendix-D: Merger of Groups.

Rules for merging of product groups:

1) If a product group, does not explicitly exclude another product group, the two groups must be merged.
2) If concrete products are (partly) cast and can’t be taken apart during or after demolition in such a way that both products stay intact, the products should be merged.
3) Products must not be merged when a product is a subproduct of a larger mixed product group.
4) Products must be merged, when a product is the absolute dominant main product in a mix, based on mass, and efforts to split the product groups can be negligible.
5) Products must be merged when differentiation between original product groups has no technical application for second life use.
6) Groups must be merged when the only differentiation is based on former application in residential or utility construction.
7) Groups must not be merged if either materialisation or dimensions indicate a difference in function.
8) In case of doubt, do not merge.
9) In all other cases, do not merge.

3.1.2 Impact Calculation

The new product group list includes all merged product groups, as well as the original product groups that did not meet the criteria for merging. The product groups are sorted based on mass output, with higher mass outputs ranked higher on the list.

A new column, relative mass, is added. This column represents the ratio of each product group's mass output to the total combined mass output. All product groups with a relative mass output exceeding a specified minimum percentage are included in the impact assessment. This threshold must be set to ensure that the impact study covers at least 15 product groups, three times the length of the shortest high-potential product group list.

In this study, the minimum threshold is determined at 0.5% of the total mass flow. All product groups between 0.5 and 0.1 % should be re-examined, to determine if certain merges will not result in a merged product group that meets the 0.5% boundary value.

In the impact study, each product group's mass output is multiplied by its corresponding MKI value. MKI values are measured in euro per ton, multiplying this by the mass output in tonnes will result in the impact each specific building product has, and thus the potential for minimising this impact reuse could have. The MKI score is better suited than the carbon emissions alone, as it accounts for a broader range of environmental impacts. Depletion of raw materials, toxicity to humans and nature are examples of factors that are also covered by an MKI score, Global Warming Potential (CO2-eq) is generally the largest contributor to the score. MKIs were chosen over individual LCA-scores due to their overall score of the individual LCA-impacts, and that they are publicly available, which is not the case for individual LCA scores. MKI values in this study are obtained from the "National Milieudatabase" using its viewer tool (NMD 2025). It should be noted that the MKI system is only applicable in the Netherlands.

MKI scores in the NMD are categorised into three types; Category 1 (cat-1): Manufacturer-specific values, Category 2 (cat-2): Values submitted by brance associations, Category 3 (cat-3): Values entered by the National Milieu Database itself.

Since the product group list does not distinguish between producers, cat-1 data is not preferred. Therefore, more averaged MKI scores from cat-2 or cat-3 are preferred. However, due to limited availability of cat-2 values for all product groups, cat-3 values are primarily used in this study. Cat-3 data is preferred; when there is no useable cat-3 data, cat-2 data may be used. Only in case of no usable cat-3 or cat-2 data, or when a producer's name is specified in the product name, cat-1 data may be used.

For cat-3 values, a standard penalty of 35% is applied to incentivise the submission of cat-1 and cat-2 data by the industry. In this research, this 35% penalty is not relevant for the analysis and therefore not added to the MKI scores used.

There are two MKI assessment methods available since the NMD is in transition from the old system based on standard EN 15804+A1 (called 'set 1'), to the new system based on the latest standard EN15804+A2 (called 'set 2'). Because not all product groups have scores based on assessment method A2 yet, all MKI values in this study are based on assessment method A1.

MKI values are either in euro per m, euro per m2, euro per m3 or euro per Kg. The MKI Value as euro per ton is calculated according to the formulas given below. The density per m, m^2, m^3 should be retrieved from the NMD viewer site, if given. If not given, substantiated assumptions may be made.

$$MKI_{(€\,/m^1)} \;/\; \rho_{(kg/m^1)} * 1000 \; = MKI_{(€/tonn)}$$

$$MKI_{(€\,/m^2)} \;/\; \rho_{(kg/m^2)} * 1000 \; = MKI_{(€/tonn)}$$

$$MKI_{(€\,/m^3)} \;/\; \rho_{(kg/m^3)} * 1000 \; = MKI_{(€/tonn)}$$

$$MKI_{(€\,/kg)} \; * 1000 \; = MKI_{(€/tonn)}$$

The resulting formula used to determine the impact of a product group's mass outflow is calculation is as follows:

$$inpact_{(€)} = Mass_{(tonn)} * MKI_{(€/tonn)}$$

The formulas above are used to generate a new column in Microsoft Excel, containing the impact per product group.

3.1.3 High-potential List Selection

The next step is the selection of the high-potential product groups. The dataset is sorted on impact, so the highest impact product groups can be retrieved. The top five product groups serve as the initial selection. However, all product groups have also been subdivided into the following categories: Stonelike products, Steel products, Wood products, Glass products, Mixed products and Plastic products. From each category, the highest scoring product group will also be adopted in the high-potential list. Since mass is an important factor for impact scoring, stonelike materials fill the majority of the top 5, the categorisation adds variety to the high-potential list.

The size of the product groups' mass stream, as defined by the EIB, is an extrapolation and thus an estimate. The used MKI values are the closest corresponding values to the product as described by the EIB. This does however, mean that the resulting impact values are subject to some uncertainty due to the input values. In cases where a clear cutoff cannot be established, a broader list of top entries should be considered. The relative impact differences among the top five entries should first be calculated. Following this, the average difference between these top five values is to be determined. If the relative difference between the fifth and following entries is less than this average, this product group will be included in the high-potential list. Conversely, if the relative difference exceeds the average difference within the top five, a cutoff is applied at that point.

The High-potential List, based on impact defined as mass*MKI, is built up as follows:

- The top 5 product groups with the highest impact.
- The highest scoring product group per category (if not already in the top 5).
- Product groups that have a lower relative difference in relation to the fifth product group than the average of the top 5 scoring product groups on impact.

3.2 MCA

3.2.1 Criteria Selection

For the high-potential groups, a more in-depth comparison is required in order to select one promising product group from the list. Multiple socio-economic factors influence the reuse potential of a product group. A multi-criteria analysis will be conducted to compare these high-potential product groups. The criteria are based on Appendix-B: Barriers List and Appendix-C: Drivers List.

The collected list of 52 barriers and 21 drivers found in literature is filtered to form a set of criteria that is neither too limited, thereby lacking sufficient depth, nor too extensive, which could result in inconsistent weighting of the criteria (Dean 2022).

Firstly, a distinction is made regarding whether the driver or barrier is product group-dependent or not. For example, the cost of retrieving a product group can vary considerably: demounting cast-in-place concrete is significantly more costly than dismantling glass panels; therefore, the influence of the financial barrier differs per product group. By contrast, client commitment is identified as a driver; however, it is more challenging to associate client commitment with specific product groups, making it an irrelevant driver for product group comparison. Only drivers and barriers that are product group-dependent are considered for MCA, since the goal is to compare the product groups.

The barriers and drivers should now be consolidated into a set of criteria. All barriers are summarised into their principal issues, and groups are formed for barriers that address similar challenges. The specific barriers and drivers included in each criterion, as well as the reasoning for their inclusion, are detailed in

Appendix-G: MCA Criteria Grouping.

The relevant barriers and drivers are combined into four categories: Costs, Risks, Supply & Demand, and Technical Feasibility. Together with the previously determined environmental impact score, these will constitute the five criteria for the multi-criteria analysis.

3.2.2 Scoring

The multi-criteria analysis consists of the five criteria mentioned above and a high-potential product group list of 5 to 15 product groups. Each product group will be assigned a score ranging from 1 to 5, and each criterion will have an associated weight. Since not all scores and weights can be determined by literature, expert interviews are conducted for the scoring of these criteria. The methods for determining the scores and weights are detailed in the subchapters below. The selection process of the expert on circular implementation can be found in chapter 3.2.3.2 Selection of Interviewees.

The MCA ranges from 1 to 5, based on a 5-point Likert scale. The five-point Likert scale is used during the expert interviews for qualitative rating, and both cost and risk are expressed in these scores. Therefore, all quantitative literature-based scoring, is normalised between 1 and 5. Lower values reflect more persistent barriers within the criteria of a given product group.

3.2.2.1 Sustainability Score

The sustainability scoring is based on findings from a previous impact study, assuming that this impact can be considerably reduced by reuse of the product. Various indicators could be used for the sustainability criterion, including LCA scoring, MKI scoring, Global Warming Potential (CO_2-eq), or environmental impact score. In this study, it was decided to use the previously calculated impact score, as it takes both the MKI score and available mass due to demolition, into account. This is expected to provide a more comprehensive score than just the Global Warming Potential or MKI scoring per tonne.

An alternative approach would involve calculating the current life cycle assessment (LCA) of a product, as well as the LCA of the same product in a second life scenario and subtracting the two to determine the second-life savings potential. This would be more precise than assuming that reuse results in lower environmental impact. However, this approach was not pursued in the present research due to time constraints, although it would be a valuable contribution for future studies.

To translate the impact scores into a scale rating from 1 to 5, the maximum impact of the high-potential list (max_{IHPL}) and the minimum impact of the high-potential list (min_{IHPL}) are identified. Using the following formula, the score can be normalised between 1 and 5.

$$Sustainability\ score = 1 + \frac{\text{Impact} - min_{IHPL}}{max_{IHPL} - min_{IHPL}} \times 4$$

3.2.2.2 Supply and Demand
Balance in supply and demand is an important criterion in determining whether a product group has potential for reuse. In practice, a sound business case is crucial for the successful adoption of a (new) market. Supply and demand should be in balance; a new market will function most effectively for a product group where supply and demand are closely aligned (Firdavs 2023). Excessive supply will result in unsellable products, leading to reluctance and uncertainty among sellers. On the contrary, excessive demand will cause scarcity; new products will continue to enter the market, and when new products are introduced at scale, their pricing and availability will outcompete alternatives such as reused products.

The values for supply and demand were obtained from the study by the EIB and Metabolic (EIB 2020). For demand, the mass inflow of product groups is used, while for supply, the mass outflow, and the mass available due to demolition is used. The balance in supply and demand ranges from 0% to over 300% and can be calculated according to the formula below. Scoring Table 1 is constructed to normalise the balance in supply and demand between 1 and 5, where 5 is a good balance between supply and demand, ranging from 80-150% and a score of 1 is given to product groups where supply and demand lie far apart, resulting in a less effective market penetration (Firdavs 2023).

$$\text{Suply and demand balance} = \frac{\text{Product Demand}}{\text{Product Supply}} \times 100\%$$

Table 1. MCA scoring of Balance in Supply and Demand

Supply and demand score	Demand ≤ Supply	Demand ≥ Supply
5	80 - 150%	
4	60 - 80%	150 - 200%
3	40 - 60%	200 - 250%
2	20 - 40%	250 - 300%
1	0 - 20%	300% <

3.2.2.3 Costs
A (perceived) increase in costs is, after technical feasibility, the second most frequently cited criterion. Barriers such as barrier B17 are rather broad, for example: *"Perception of the extra cost being incurred."* Meanwhile, other barriers are more specific, such as Barrier B6: *"Disproportionately high cost of labour in Europe relative to materials" (*Appendix-B: Barriers List*).* Both barriers highlight the same fundamental issue: the perception that circular, reused building products are more expensive than virgin products from the current linear industry.
Similarly, drivers such as Driver D6: *"Companies that decouple profitability from raw material sales, embracing service-based models or value-retention logic,"* suggest that under current linear

business models, circular practices are not financially viable; business models must evolve to make circular approaches economically feasible.

The influence of costs as a barrier to circular implementation is expected to be product group dependent. Factors such as the amount of labour required for dismantling, the cost of virgin products, and the existing end-of-life scenarios all affect the relevance of the barriers summarised under "costs."

No literature could be found regarding the influence of the cost barrier for the products on the high-potential list within the Dutch industry. Therefore, expert interviews were conducted. Experts were asked to assess the importance of the "costs" barrier on a five-point scale ranging from "absolutely not important" to "very important." Further details on the interview methodology can be found in 3.2.3 Circularity Expert Interviews.

3.2.2.4 Risks

Perceived risks is identified as a significant barrier to the adoption of circular practices, with 8 out of the 52 identified barriers related to concerns about increased risks. These risks span a range of issues, from general uncertainty to rather specific challenges. For instance, some barriers are relatively broad in nature, such as Barrier B16: *"Risks and uncertainties involved in adopting new materials,"* which reflects a widespread concern towards unfamiliar processes and technologies. In contrast, other barriers are more precise and operational, such as Barrier B47: *"Without clear quality indicators and traceable documentation, stakeholders face excessive uncertainty and legal risk in reusing products"* (Appendix-B: Barriers List*).*

These barriers identify that risk perception is a widespread and somewhat vague criteria, since it can have a legal, technical, and reputational meaning for different users. The absence of clear quality assurance measures, insufficient documentation, and lack of experience with reused materials all contribute to stakeholders' hesitance to engage with circular product streams.

As with the assessment of costs, no data were identified regarding the influence of the risk barrier for the selected product groups within the Dutch construction and demolition sector. Therefore, semi structured expert interviews were conducted to gather qualitative insights. During these interviews, experts were asked to rate the importance of the "risks" barrier on a five-point Likert scale, ranging from "absolutely not important" to "very important," based on their professional experience and knowledge of the Dutch market context.

These expert assessments provide valuable input for the multi-criteria analysis, enabling a more nuanced understanding of how risk perception may vary between product groups. A detailed explanation of the interview design, methodology, and participant selection is provided in Chapter 3.2.3.

3.2.2.5 Technical Feasibility

Technical feasibility emerges as the most frequently cited criterion in the literature when evaluating the potential for product group reuse. It was cited 15 times. For example, Barrier B13 highlights this challenge directly: *"Conventional design does not prioritise disassembly or material reuse." (*Appendix-G: MCA Criteria Grouping*).*

Technical feasibility in this context is determined by two key factors: the expected lifespan of the product group and its ease of demountability. Firstly, if the lifespan of a building product group does not extend beyond a single use, reuse becomes an impractical or suboptimal option. Secondly, demountability plays a crucial role in determining technical feasibility. The type of connections used in a product's assembly greatly influences the ease of disassembly: mechanical fasteners such as screws or bolts are generally preferable, as they facilitate straightforward removal, whereas glued or cast connections can significantly hinder reuse, especially when the adhesive is as strong as, or stronger than, the product itself. For instance, glued polyurethane (PUR) elements are extremely difficult to separate without causing damage, while bricks mortared together can often be dismantled more easily because some mortar is weaker than the bricks themselves.

The scores for each sub-criterion (lifespan and demountability) are provided below. Notably, the scoring of demountability was deliberately not based on the "*Meetmethodiek Losmaakbaarheid"* (van Vliet, Grinsven, and Teunizen 2021) , as this methodology does not distinguish between the relative strength of the adhesives and the products, nor did any of the selected high-potential product groups include the top scoring connection "dry connection". Therefore, a derivation was made; this scoring can be found in Table 2 below.

To normalise the overall technical feasibility score, the formula below is constructed. This approach was chosen to avoid the distortions that would arise from a simple average: averaging would inadequately represent cases where a product performs very poorly on one factor. For example, if cast-in-place concrete were scored 1 for demountability and 5 for lifespan, an average score of 3 would misleadingly suggest moderate feasibility, despite the non-realistic option of disassembly, and thus reuse. The multiplication method ensures that poor performance in either criterion is appropriately penalised, thereby better reflecting real-world feasibility barriers.

Table 2. Technical scoring

Sub-Scoring	Lifespan	Demountable
1	Shorter than one lifespan	Cast in place
2	One lifespan	Glued together in place, with glue stronger or equally strong as the product itself.
3	1.5 lifespans	Glued together, with glue less strong than the product itself.
4	2 lifespans	Mechanically connected, demounting results in minor defects (screw holes etc.)
5	More than two lifespans	Demountable without damage

$$Techical\ feasabilety\ = 1 + \frac{Lifespan\ score\ \times Demountabilrty\ score - 1}{6}$$

3.2.2.6 Weighting

In a multi-criteria analysis, each criterion must be appropriately weighted to reflect its relative importance. In this study, the weights were determined through expert interviews using the Best-Worst Method (BWM) (Rezaei 2015).

The Best-Worst Method is particularly suited to small expert groups since it is reliable for a small sample size. Each expert was asked to identify the most important (best) and least important (worst) criterion. The remaining criteria were then evaluated on a nine-point scale in relation to these two anchors. From this, consistent weights were calculated for each criterion.

Full methodological details can be found in the work of Jafar Rezaei (Rezaei 2015). After all individual weightings were obtained, the average was calculated to derive the final weights. To test the robustness of the results, a saturation check must be performed by removing each expert's input individually. If the final ranking remains stable, the results can be considered saturated and not overly influenced by any single expert. In this thesis, the interview questions used to score in the MCA can be found in Appendix-I: Interview Questions.

3.2.3 Circularity Expert Interviews

3.2.3.1 Interview setup

Semi-structured interviews are conducted to obtain the expert input. While standardised questions (Appendix-I: Interview Questions) formed the foundation of the interview protocol, the format allowed for flexibility to explore the specific expertise of each respondent. The interview structure included the following components:

1. Assessment of the interviewee's relevant expertise
2. Scoring of the MCA criteria: Costs and Risks
3. Weighting of the MCA criteria using the Best-Worst Method
4. Validation of the MCA approach and relevance of the selected criteria and products
5. Open-ended questions regarding the circular value chain, to identify additional barriers and drivers and recommendations for further research.

Interviews began with questions about the interviewee's professional background, specifically their experience with product reuse and circular construction. For the criteria scoring, participants were presented with the product list and asked to rate each product on a five-point scale indicating the severity of the criteria, 5 meaning cost or risk are little barriers, one meaning large barriers are in place. The MCA weighting was performed using the Best-Worst Method, as outlined by Rezaei (Rezaei 2015).

Participants were also asked to reflect on the overall value and applicability of the MCA framework and criteria. Final questions addressed the interviewee's position within the value chain to contextualise their insights and guide future research directions. At each stage of the interview, participants were asked whether they felt comfortable answering, whether they considered themselves sufficiently knowledgeable, and whether they wished to add any qualifications to their responses.

3.2.3.2 Selection of Interviewees

Given the complexity and variability across products, it was not feasible to include experts from every segment. Instead, a selection of neutral and independent professionals was made, including sustainability consultants, a PhD candidate, and a municipal official. These individuals were selected based on their credentials and relevance to the topic, and special care was taken to ensure experts had no bias toward specific product groups. It should, however be noted that true objectivity never exists, therefore it was chosen to find “as objective individuals as possible”, with different professions and backgrounds to minimise skewed viewpoints.

The interviewees were asked at the start and at the end how confident they were with their given answers. When the expert indicates uncertainty about specific MCA related questions, their answers will not be used for the results.

Saturation should occur to use the qualitative data as quantitative MCA scores. There is no agreement on the minimal number of interviews needed for saturation (Squire et al. 2024). Research shows that saturation could occur from six interviews onward (Guest, Namey, and Chen 2020). Due to time restraints and this interview round only being a subpart of one subquestion, the goal was set to interview at least six experts. This eventually became eight experts. A saturation analysis is performed in Appendix-J: Saturation Analysis. This analysis shows that saturation for the MCA results was reached with these eight experts.

3.3 Case Study

3.3.1 Case Study Setup

From the MCA, one product group is selected for a case study. The setup of the case study will be product group dependent, the outline of the methodology is described below.

The case study will start with a literature review on the case study product group. Using insights from literature and web-based research, a current value chain will be constructed, and theoretical circular pathways will be added.

Key stakeholders involved in decision-making regarding value chains and potential circular alternatives are identified and interviewed. The current linear value chain is verified, and circular alternatives are proposed. The alternative circular value chains will be compared based on the stakeholder interviews, and the most promising route is selected. The interviews were focus on the stakeholders’ specific decision-making rationales. Why do certain stakeholders, despite having the capacity to shift from a linear to a circular model, choose not to? What motivates them, what concerns them, and what barriers and drivers influence their decisions, and how can their involvement in reuse be improved?

The most promising value chain is tested against the found barriers and drivers list to find which barriers remain intact for the most promising circular reuse value chain of the most promising building product group.

Recommendations based on literature and interviews will be done trying to tackle the remaining barriers. How these recommendations are formed strongly depends on the remaining barriers.

A more detailed product group-specific methodology can be found at the start of Chapter 5.

3.3.2 Case Study Stakeholders Interviews

3.3.2.1 Interview Setup

Semi-structured interviews were conducted to obtain this expert input. While some standardised questions form the foundation of the interview protocol, the format focuses on flexibility to explore the specific expertise and findings of each respondent. The interview structure included the following components:

1. Assessment of the interviewee's relevant expertise
2. Current linear practices of the industry
3. Discussing the completeness of the proposed value chain and possible circular alternative routes
4. Reasoning for their current (linear) practices, and barriers to circular reuse alternatives
5. Future perspective: does the stakeholder plan on circular routes, and what is needed for the change from linear to circular practices.
6. Evaluating the most promising path for circular reuse.

Interviews begin with questions about the interviewee's professional background, specifically their experience with product reuse and circular construction. Their position within the value chain was discussed regarding the case study product group. A clear explanation of current practices is requested, including who are their suppliers, clients, and how does the cooperation work with other stakeholders. Is there any circular reuse in their current practices? After their explanation of current practices, the constructed linear value chain is proposed, for verification. If deemed complete, possible linear circular reuse paths are explained, of which they are the key stakeholder in at least one of the cycles. Their opinion on the circular alternatives is asked, and what barriers they expect for these alternative routes. The additional questions are about the circular value chains they should be involved in. Reasoning and feasibility of their involvement in these loops are key results of this interview.

3.3.2.2 *Selection of Interviewees*

Interviewees selection is based on the constructed value chain and proposed circular paths. Key stakeholders within circular alternative routes are selected for these interviews. Interviewees are expected to be able to make circular decisions by stimulating either a pulling or pushing effect. Therefore, there is no minimal or maximal determined number, but every key stakeholder should be interviewed for a robust result. Due to time limitations, only one interview could be conducted per stakeholder. To rule out biases as much as possible, interviewees were selected to represent the stakeholders as good as possible. When stakeholders had a branch association, an interview should be conducted with the association, since they represent a large part of that industry. When no branch association exist, the leading company should be identified and interviewed. Eventually, five experts were interviewed, three branch associations and two leading companies.

3.4 Data Management and Ethics

A combination of quantitative and qualitative data was used in this research. Where possible, data is retrieved from existing literature and is properly referenced in APA sixth edition throughout the report. However, not all required data is available through secondary sources. To address these gaps, expert opinions are gathered by conducting semi-structured interviews. Two interview rounds were performed; the first round of interviews had the goal of finding MCA scores and was conducted with circular implementation experts. The second interview round are key stakeholders within the value chain of the case study product group (bricks).

Both interview rounds were combined in one data management plan and one ethical review board request, as advised by the data steward.

A data management plan was developed in line with university policy. As the interviews focused exclusively on professional expertise and did not involve the collection of personal or sensitive information (e.g., age, gender). The data management plan (code: DMP-572) was approved on 27-05-2025.

An Ethical Review Board Request was performed where the research was classified as low risk. The request (code: ERB-292) was approved on 11-06-2025. All participants signed the appropriate low-risk ethics form, and anonymity, if requested, was maintained throughout.

All sources used in this research are publicly accessible and were retrieved from reputable online databases. No confidential or proprietary data was supplied by SGS Intron or the university. However, in accordance with existing agreements, SGS Intron will review and approve the final thesis prior to submission.

4. Multi Criteria Analysis Results and Discussion

4.1 Impact Study Result

The original product group list from metabolic, SGS-Search and EIB consists of 139 product groups (EIB 2020). According to the 9 rules, as defined in the methodology, product groups are merged. From the original 139 product groups, 41 groups are merged into 17 new groups. The mergers and applicable rules for merger per product group, can be found in Appendix-D: Merger of Groups.

The new Product group list consists of 115 product groups. The relative mass output is calculated, by summing the mass outputs of all product group streams and dividing each product groups output by this overall output. Multiplication by 100 will give the relative product groups output in percentages.

23 out of 115 product groups have a higher relative mass than 0.5%. And will be used for the impact study. Ranging from 0.5% and 0.1% are 23 other product groups, these product groups are checked once more against merging rules, but no new merges can be made such they make the cutoff of 0.5%. The average relative mass output of the top five product groups is more than 29 times larger than that of the 24th product group, suggesting that the contribution of product groups below the threshold can be neglected. Furthermore, will the highest scoring product group within a category also be used for the impact study. On this basis, the plastic category was not above the 0.5% border but will be taken into account for the impact study. The product group selection for the impact study can be found in Appendix E: General List, Sorted on Mass.

For 24 product groups, the impact study was performed, the MKI score was retrieved from the NMD and multiplied by the outflow mass. The results can be found in Appendix-F: Impact Study.

The high-potential product group list, consists of the following 10 products:

Table 3. High-Potential product group List

ID	selection	Product name English	Impact (€)
ID142	Top5	Wide slab floor, 60mm, icl compression layer; prefab concrete; AB-FAB	23366844.7
ID40	Top5	Brick masonry	17036272.1
ID147	Top5	Concrete, cast in-place, Dominantly C20/25; incl. reinforcement	14804792.4
ID118	Top5	Screw pile; cast-in-place concrete C20/25; incl. reinforcement	12261827.2
ID144	Top5	Hollow core slab, prefab concrete; AB-FAB	12083089.0
ID92	Nr1Cat	Heavy structural steel incl. beams, profiles, girders	11615880.0
ID120	Nr1Cat	Roof elements, timber ribs, stone wool, plywood; sustainable forestry	9005876.0
ID148	Nr1Cat	Expanded Polystyrene (EPS)	5470058.6
ID152	Nr1Cat	Chipboard	1909601.9
ID112	Nr1Cat	High-efficiency glass; dry sealed	1538768.4

Building product group ID142, ID40, ID147, ID118 and ID144 are selected since they are the top 5 scoring groups, on impact defined as mass*MKI, indicated in Table 3 as “Top5”.

Building product groups, ID92, ID120, ID148, ID152 and ID112 are selected since they are the highest scoring product groups in their category, indicated in Table 3 as “Nr1Cat”.

A test was conducted to determine whether any product groups narrowly failed to qualify for inclusion in the high-potential product group list due to sensitivity in the input values. The average relative difference in impact among the top five product groups is 15.5%. The groups ranked sixth (ID92) and seventh (ID120) are already included in the product group list based on the categorisation of building products. The group ranked eighth in terms of impact value is calcium silicate blocks (ID143). Its impact is 34% lower than that of the fifth-ranked group (ID144), approximately twice the average impact of the top five, and was therefore excluded based on sensitivity considerations. A clear cutoff could be made between high-potential product groups. Consequently, the resulting high-potential product group list keeps consisting of ten building products (Table 3).

4.2 Technical and Socio-Economic Factors that Determine Reuse Potential

The high-potential product group will be compared in the multi criteria analysis; however, the criteria still must be selected. 52 barriers and 21 drivers are found in literature (Table 4). 21 barriers and 18 drivers are non-product group dependent and can therefore not be used for product group comparison. The additional 31 barriers and 3 drivers are product group dependent. These barriers and drivers can be brought back to four main criteria, cost, risks technical feasibility and balance in supply and demand. The specific barrier and driver ID labels can be found in the ID column. These four criteria, combined with the impact as determined below, will form the five criteria of the MCA. A more elaborate version of Table 4 can be found in Appendix-G: MCA Criteria Grouping.

Table 4. Criteria collation

	found Barriers	found Drivers	ID
In total	52	21	
Non-product group dependent	21	19	
Product group dependent	31	2	
• Cost	8	1	B1, B15, B5, B6, B10, B48, B12, B17, D8
• Technical	14	1	B2, B4, B7, B18, B22, B11, B13, D9, B24, B27, B36, B38, B43, B49, B26
• Perceived risk	8	0	B16, B31, B37, B41, B19, B39, B44, B47
• Supply and demand	1	0	B9

4.3 MCA Results: the High-Potential Product Group

A total of eight interviews were conducted with relatively independent experts, each with proven expertise in the field of circular construction and building product reuse. All eight participants expressed confidence in their ability to contribute to the weighting of the multi-criteria analysis criteria. As such, the weighting results from all eight experts are included in the final analysis. The weighting results reveal that sustainability, represented here by the previously calculated impact score, is considered the least important of the five criteria, with an average weight of 0.137. Experts explained that, while all product groups have significant environmental impact, the relative differences between them are less critical in determining reuse potential. In contrast, supply and demand balance emerged as the most important criterion, with an average weight of 0.296, more than twice the weight assigned to sustainability. This highlights the central role of market viability in enabling circular reuse.

While all eight experts contributed to the criteria weighting, not all were confident in scoring the perceived cost and risk barriers at the product group level. Several interviewees explicitly stated that they lacked sufficient familiarity with specific materials or products to provide reliable ratings, and that any attempt to do so would involve speculation. As a result, only four experts (ID2, ID5, ID7, and ID8) were deemed sufficiently confident and consistent to be included in the product-level criteria scoring. Their input forms the basis of the MCA scoring of costs and risks presented below. Nevertheless, the weighting applied in the MCA is based on the combined input of all eight experts, reflecting the broader consensus on the importance of each criterion in achieving circularity in the built environment.

The resulting MCA can be found in Table 5. The higher the number, the more suited the product group is for reuse based on that criterion. The impact of wide slabs floor is the largest according to the performed impact study, wide slab floors score the highest on impact, since lots of impact can be made by transfer from linear to circular use. Bricks score high because there is a close balance between supply and demand, and structural steel scores high due to the combination of a long lifespan and is often applied with demountable connections.

Table 5. Potential for Reuse MCA

Criteria / Product group	Sustainable impact		Supply and demand		Costs		Risks		Technical feasibility		**Total**
	literature	weight	literature	weight	expert	weight	expert	weight	literature	weight	
Wide slab floor	**5**	0.137	**2**	0.296	**2.75**	0.172	**3.25**	0.177	**1.67**	0.218	2.69
Brick masonry	**3.83**	0.137	**5**	0.296	**3.00**	0.172	**4.5**	0.177	**3.33**	0.218	4.04
Concrete. cast in-place	**3.43**	0.137	**2**	0.296	**1.50**	0.172	**2.75**	0.177	**1.67**	0.218	2.17
Screw pile; cast-in-place	**2.97**	0.137	**1**	0.296	**2.50**	0.172	**1.75**	0.177	**1.67**	0.218	1.81
Concrete Hollow core slab	**2.93**	0.137	**3**	0.296	**2.75**	0.172	**3.5**	0.177	**1.83**	0.218	2.78
Heavy structural steel	**2.85**	0.137	**2**	0.296	**3.50**	0.172	**3.5**	0.177	**5**	0.218	3.29
Roof elements. timber sandwich	**2.36**	0.137	**1**	0.296	**3.50**	0.172	**3**	0.177	**2.17**	0.218	2.22
Expanded Polystyrene (EPS)	**1.72**	0.137	**3**	0.296	**2.25**	0.172	**3.25**	0.177	**2.17**	0.218	2.56
Chipboard	**1.07**	0.137	**3**	0.296	**3.00**	0.172	**3.75**	0.177	**1.5**	0.218	2.54
High-efficiency glass (HR)	**1**	0.137	**1**	0.296	**3.50**	0.172	**3.5**	0.177	**1.67**	0.218	2.02

Using the criteria scoring provided by the four product-level experts (ID2, ID5, ID7, and ID8), combined with the criterion weightings from all eight experts, masonry emerges as the top-performing product group with a total MCA score of 4.04. Heavy structural steel follows in second place with a score of 3.29, clearly establishing these two as the leading candidates. In third place is the hollow core slab, with a significantly lower score of 2.78. These results indicate a clear distinction between the top two and the remaining product groups.

To test the robustness of the MCA outcome, a saturation analysis was conducted by recalculating the MCA scores with only seven out of the eight expert weightings at a time. This was done to assess whether the results are stable across different combinations of expert input. The findings show that in all eight permutations, masonry remains the top-ranked product, with heavy structural steel consistently in second place. In seven out of eight cases, the hollow core slab retains third place; in only one instance, when expert ID6 is excluded, expanded polystyrene (EPS) replaces it. This suggests that only expert ID6 has a significant effect on the ordering between third and fourth place, while the top two rankings remain stable, and indicate saturation. Full details of this analysis are available in Appendix-J: Saturation Analysis

A second sensitivity check was performed to explore the impact of limiting the weighting input to the same four experts who provided product-level scores (ID2, ID5, ID7, and ID8). Under this scenario, Brick masonry also remains the top-performing product group with a score of 3.81, followed closely by Structural steel, which scores 3.54. Both continue to outperform the third-place product (hollow core slab), which in this case scores 2.48. These results further reinforce the conclusion that steel and masonry are the two clear leaders, regardless of the expert sample used.

Based on both the main MCA results and the sensitivity analyses, masonry and steel consistently rank highest among the high-potential product groups for circular reuse. While minor fluctuations appear in the lower rankings, the top two positions remain stable under different input assumptions.

As all eight experts provided meaningful input on the relative weighting of criteria, and to maximise data richness, the final ranking is based on their combined weightings. Under this condition, masonry holds the top position, though heavy structural steel cannot be ruled out as a viable product group. It is important to emphasise that all product groups within the high-potential shortlist offer opportunities for reuse. However, for the purpose of continuing this research as a case study, a single product group must be selected.

Although masonry brickwork achieves a higher MCA score than heavy structural steel, the difference remains partially dependent on the selection of experts. Still, a final decision must be made to continue the research. Based on the results of the analysis and supporting qualitative insights, masonry brickwork has been selected as the focus for further investigation.

One of the key factors influencing this choice is the current end-of-life scenario for both products. Steel, while ranking slightly lower in the MCA, is already subject to high-value recycling. It retains economic value at end-of-life and is therefore commonly collected, melted, and reused within

industrial supply chains. In contrast, masonry is typically downcycled, most often crushed and used as road base or foundation material, resulting in significant loss of embedded value.
Furthermore, steel has been extensively studied. During the expert interviews, several participants indicated they possessed considerable existing knowledge of steel reuse practices and challenges. While heavy structural steel holds high circular potential, it is already well-recognised in the literature and industry practice, leaving less of a knowledge gap to be addressed through further research.
By comparison, masonry brickwork presents a less explored but highly relevant opportunity, particularly within the Dutch context. It is a common and historically embedded building product in the Netherlands, making it a logical and locally relevant subject for further investigation. Experts acknowledged its potential (Appendix-H: Summary of MCA Interview) for reuse and reported no major barriers. However, they also noted that masonry reuse is not yet applied at scale.

Beyond the MCA scoring, the decision to prioritise masonry brickwork over heavy structural steel can also be justified by examining the potential environmental impact of increased reuse. This comparison can only be performed for the comparison between brick and steel, since not all high-potential exists in the following tool. According to data derived from an unpublished tool developed by the Dutch demolition industry association VERAS, the MKI score is significantly reduced through direct reuse of both bricks and steel profiles.
Specifically, for brickwork, each tonne of direct reuse results in an MKI reduction of approximately €24 per tonne. For steel, the MKI reduction varies depending on the type of reuse: €60 per tonne for general reuse, and €80 per tonne when reused specifically as a structural material.
However, when these per-tonne impact savings are multiplied by the total mass flow of each product group within the Dutch construction and demolition sector, brickwork demonstrates a significantly higher overall potential. Due to its much larger volume in the waste stream, the total environmental benefit of increasing brick reuse is estimated to be two to three times higher than that of heavy structural steel, despite steel's higher MKI savings per tonne.
This broader systemic impact further supports the selection of masonry brickwork as the most promising product group for advancing circularity and environmental benefit within the national context. Fully circular masonry brickwork has a 2-3 times higher impact potential than steel.

Table 6. Potential Impact Saving

Product	MKI per ton (€)	MKI saving per ton (€)	Current impact (€)	Potential impact saving (€)	Relative savings (%)
Heavy structural steel	120	60	11615880.0	-5807940	50
Heavy structural steel Used for building structures	120	80	11615880.0	-7743920	66.6
Brick masonry	26.3	24	17036272.1	-15546408	91.25

Limitations on MCA

During this research, multiple limitations on the research method became apparent. This researcher has a relative broad research scope, and multiple phases are run through to come to the final conclusions, leading to time constraint for finding some sub results. Since this research is partly based on why the industry is not changing, little documentation could be found. The Key limitations for the MCA approach are summarised below.

- The research is on national level, and takes only the product use, legislation and barriers, of the Netherlands into account.
- MKI is a Dutch sustainability scoring, currently only used in the Netherlands.
- This research only takes the 139 product groups, as determined in 2019 by the EIB, into account. This list is extensive, but not complete. It is called a product list, but some products are closer to material than product level. It was confirmed by multiple experts that no better list exists at the moment.
- This research takes into account the reuse of products obtained from the B&U Only. GWW (infra) products are not taken into account.
- Only 23 products groups have a higher mass output than 0,5%. Therefore, only 24 products have been compared on impact.
- The Impact, defined as mass times MKI, is an oversimplification. It does not take into account the amount of available material for reuse, or the MKI of the reuse process.
- An updated MKI Scoring system has been developed, set A2. Because not all product groups have had an A2 score yet, the slightly outdated scoring system A1 is used.
- The MCA scoring is based on four experts. This is a small sample size and makes the scoring on cost and risk vulnerable to bias.

5. Case Study: Brick Masonry

In this chapter, a case study on bricks is presented. The case study starts with a literature review (Chapter 5.1). This review addresses general questions: What are bricks? How are they made? What are the trends in the brick industry in the Netherlands? How sustainable are bricks? What are the sustainability problems, and what further outlook on sustainability exists?

Next, in Chapter 5.2, a linear value chain is constructed, and four circular alternative paths are identified. These four loops are explained, and, where possible, data is provided on mass flow or financial flow to gain a better understanding of the size and margins of the (reuse) market.

Each of the four alternative routes involves key stakeholders who make critical decisions. Interviews are conducted with four of these stakeholders. In these interviews, both the linear value chain and the circular alternatives are discussed. The interviews especially focus on why these stakeholders are not making the transition. The results of these interviews are presented in Chapter 5.3.

Since one of the main underlying conclusions from both rounds of interview rounds was that there is no viable business case, it was decided to design one.

The most promising circular value chain is selected, and the business model of the leading existing company is analysed. This business case is compared against the identified barriers and drivers (Appendix-B: Barriers List ; Appendix-C: Drivers List). Combining the barriers found in literature with those revealed in the interviews results in four key barriers for the best business case in practice.

In Chapter 5.4, two business cases are designed to overcome as many of these barriers as possible. The first business case discusses what is currently feasible and addresses two of the four remaining barriers. The second business case is designed to show what future developments are needed to eliminate all barriers.

5.1 Literature on Brick Masonry

5.1.1 Bricks

Bricks are ceramic products primarily made from clay. In the Netherlands, approximately 85% of the clay used for brick production is sourced locally, with around 75% of this clay extracted along the riverbanks (Appendix-K: Masonry Expert Interviews). The remainder is largely imported from Germany. Bricks are the second most commonly used construction material worldwide based on mass. Between 1900 and 2020, an estimated 92 gigatons of bricks were produced globally (Kuijpers 2024).

The composition of clay is crucial for the quality of the final brick. Variations in mineral content, such as the amount of iron or lime, directly influence colour, durability, and strength of the product (Stenvert 2012). Clay extraction is typically carried out by specialised clay producers, who also determine the precise mixtures required for different brick types. The structure of clay deposits can be compared to layers in a lasagna: selecting the correct layers and proportions is essential to achieve the desired properties in the brick (Appendix-K).

Once the clay has been extracted and prepared, bricks are shaped and fired in kilns. In the Netherlands, firing is still solely carried out in gas-powered kilns. The firing process typically requires temperatures between 900 and 1,200 °C, sustained for a period ranging from 8 to 15 hours (Kuijpers 2024). Combined with the controlled heating and cooling of the bricks, the whole heating period can take up two to three days (KNB 2021).

In the Netherlands, the “waalformaat” is the standard and most used brick size of approximately 210 × 100 × 50 mm. It is estimated that in an average Dutch terraced house, about 4000 of these bricks are used (Appendix-K: Masonry Expert Interviews).

Mortar, the material used for binding bricks, has also evolved over the past century. Until around 1920, lime-based mortars were standard. From 1920 to 1980, so-called “bastaard” freely translated to bastard-mortars (a mixture of lime and cement) became dominant. After 1980, cement-based mortars largely replaced earlier types (FCRBE 2021). These innovations resulted in a lower maintenance product during use but cause trouble for demonstrability at end-of-life scenario.

5.1.2 The Netherlands as a Brick Country

Between 1850 and 1950, brick production in the Netherlands exceeded 100 billion units, underscoring the centrality of this material to the Dutch construction sector (Stenvert 2012).

In the 1850's the number of brick factories peaked at 445 factories. After the First World War the number of factories peaked once more, at 275 factories (Figure 8). Today, there are only 38 brick factories left in the Netherlands. Of which 17 are owned by the largest brick producer in Europe, Wienerberger, and another six are owned by the vandersande groep (dr. Augustin, Prof. dr. Franssen, and prof. dr. Spruit 2023).

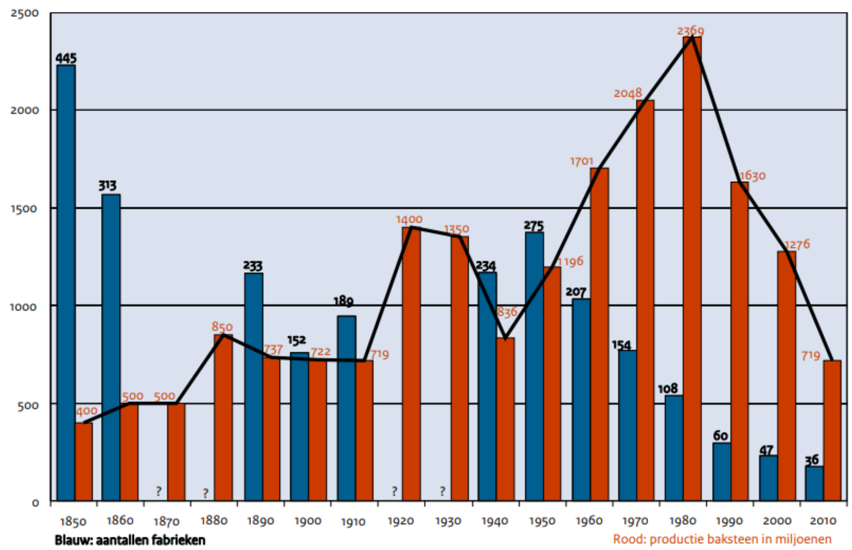


Figure 8. Number of Bricks and brick factories in the Netherlands, Biografie van de baksteen, 2011.

Since the 1980s, overall brick production has been in decline (Figure 8). However, between 2011 and 2023 production appears to have stabilised, with annual output ranging between 700 and 900 million bricks (dr. Augustin et al. 2023). In 2023 still 709.000.000 bricks were produced in the Netherlands. Around 36% is exported, of which the majority to the United Kingdom. We also import 48 million bricks, which Is around 7% relative to the Netherlands own production. These bricks are imported from Germany and Denmark, and are in general the more expensive brick classes (dr. Augustin et al. 2023; Appendix-K: Masonry Expert interviews).

The resilience of the remaining factories is shaped by structural challenges, most notably rising energy costs, but also a decrease in demand (Appendix-K: Masonry Expert Interviews). As a result, production processes are maintained on a continuous, twenty-four-hour basis to optimise efficiency. The majority of former brick workers were unable to sustain operations under these conditions, leading to the current concentration of production within a limited number of industrial sites. To illustrate this in numbers, in 1950 each factory produced an average of 4.3 million bricks, whereas in 2023, each factory produces an average of 18,7 million bricks yearly.

5.1.3 Sustainability of Bricks

Bricks have a relatively poor MKI score. This is not unexpected and, in fact, it was one of the reasons for selecting them as the case study material. The brick industry is well aware of its environmental footprint and is actively seeking to establish a more sustainable profile. Production processes have already been optimised, motivated both by environmental considerations and by cost-efficiency. Many factories are equipped with solar panels in order to meet their electricity demands through self-generated renewable energy. Transportation is carried out predominantly by ship and raw materials are sourced as locally as possible. As is often the case, measures that enhance sustainability also tend to yield financial advantages for producers (Appendix-K: Masonry Expert Interviews). Nevertheless, the industry faces a fundamental challenge, which becomes apparent when examining the environmental impact of a single brick. Life-cycle assessments, expressed in MKI, reveal that the majority of the impact arises from the production process rather than from the extraction of raw materials. "About 85% of the environmental footprint of bricks lies in energy for firing and drying (Appendix-K: Masonry Expert Interviews).

At present, brick production remains heavily dependent on gas. While research is underway to replace gas with hydrogen, successful applications have thus far been limited to pilot projects. Other energy sources currently appear incapable of achieving the extremely high temperatures required for kiln operations (Appendix-K: Masonry Expert Interviews). Hydrogen therefore, represents the most promising pathway towards decarbonization. However, large-scale implementation does not seem imminent: connections to hydrogen infrastructure are expected to become available only after 2030 at the earliest. Furthermore, at current prices, hydrogen remains five to six times more expensive than natural gas. Early adopters would therefore face significant cost disadvantages compared to competitors who continue to rely on gas firing, potentially pricing themselves out of the market.

Efforts to promote reuse and recycling are still limited. A small number of demolition companies resell second-hand bricks, and in the Netherlands only one company, named Rebrick, systematically tests and reintroduces approximately two million bricks annually. The recycling path is pursued more. Large manufacturers such as Wienerberger and Vogelsang market "circular bricks" containing 20-50% filler derived from old ceramics (Vogelensangh 2025; Wienerberger 2025). Yet, the filler route presents its own difficulties: in many cases, the collection, crushing, and transport of reclaimed material result in a higher MKI score than the use of virgin clay, as the product must still undergo energy-intensive kiln firing **(**Appendix-K: Masonry Expert Interviews). Consequently, these circular products are often both more expensive and less sustainable on paper than conventional bricks, raising the question of who wants to pay for the additional costs. At present, circular brick product lines remain more a matter of branding than of genuine environmental improvement.

An alternative approach is "cold baking," in which dry filler material is bound using cementitious compounds. While this method can be more sustainable, when recycled filler and organic glue is used, no kiln is used, and so it results in a non-ceramic product (NXT 2025). Furthermore, is this process on material level, not on product level. Cold baking bricks could however, prove to be the more sustainable route for bricks that do not meet the reuse quality level.

5.2 Brick Value Chain

5.2.1 Current Linear Practises

The linear value chain starts at the clay miners (Figure 9), who are responsible not only for extracting the clay but also for determining the composition of the bricks. As specialists in clay, they prepare mixtures tailored to the requirements of manufacturers. Clay is often sourced in close proximity to the manufacturing site, where clay piles are stored and blended, typically on-site (Appendix-K: Masonry Expert Interviews).

The manufacturer operates a factory, generally running 24/7, where gas-fired bricks are produced. Manufacturers are responsible for the final product, including compliance with CE marking. From the manufacturer, bricks are supplied to contractors, either by resellers or, in the case of larger projects, directly. Since resellers primarily serve as contact and temporary storage between manufacturers and contractors, without changing the composition or adding value to the product itself, they are not considered in the representation of the value chain.

Contractors incorporate the bricks into masonry by binding them with mortar. Once the building is completed, ownership of both the building and thus materials is transferred to the user. After the use phase, the building is demolished. Typically, the owner issues a request for demolition, and demolition contractors submit bids for the project. Once the contract is awarded, the demolition contractor gets ownership of the materials and is thus responsible for their removal.

For bricks, approximately 99% of the material is mixed with other stone-like fractions, such as concrete or calcium silicate elements, and transported as mixed stone debris to a rubble crusher (Appendix-K: Masonry Expert Interviews). The rubble crusher processes the debris into aggregates, ensuring an appropriate brick-to-concrete ratio, and subsequently sells the material. These mixed aggregates are primarily used as foundation layers in road construction. This value chain was verified through interviews with a manufacturer, the demolition branch association, a rubble crusher association, the ceramics branch association and an alternative route stakeholder, and is considered accurate by them (Appendix-K: Masonry Expert Interviews).

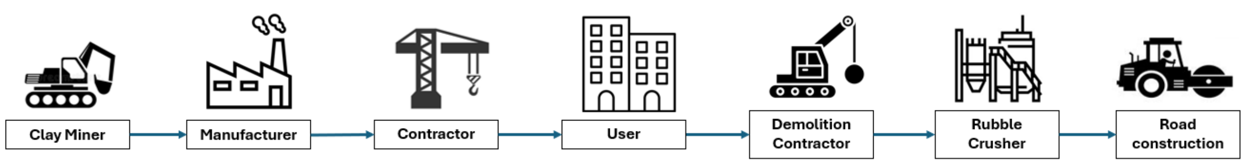


Figure 9. Linear Brick Value Chain.

5.2.2 Potential Circular Value Chains

Competing with the established linear industry presents a significant challenge. As with many low-margin sectors, the current value chain is highly optimised, and stakeholders within it generally appear satisfied with existing practices. For circular pathways to be adopted, they must not only be technically feasible but also demonstrably more attractive than the current linear alternatives. This attractiveness may derive from a stronger value proposition, either through increased financial benefits or enhanced business opportunities resulting from circular practices. Alternatively, regulatory obligations may force the transition. These two drivers, economic incentives and legal requirements, represent the primary mechanisms by which businesses are likely to shift from a linear to a circular economy. The foundation of the brick value chain is relatively straightforward, as illustrated in Figure 10.

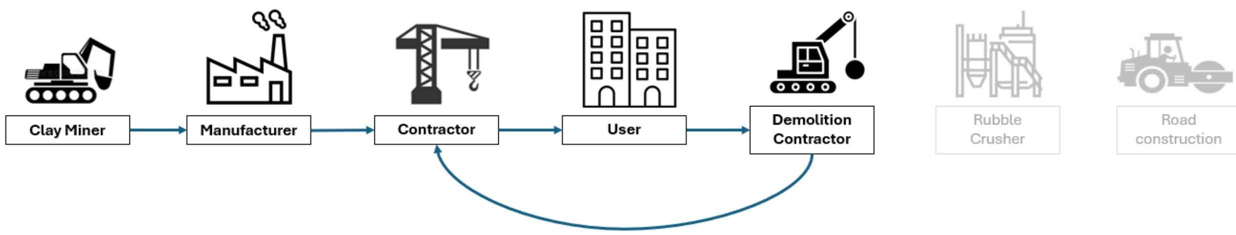


Figure 10. Basis concept of circular bricks.

Within this chain, demolition contractors and rubble crushers appear to be the critical pushing stakeholders to initiate a circular loop. As the owners of building mass at the end of a building's life cycle, they are in a position to separate brick from other material streams and determine its subsequent use. The central concept is that these material streams can be redirected back to contractors or manufacturers who can then reuse building products in new construction projects. Seven circular loops can be created, the four illustrated in Figure 11 below, and in theory loops 1, 2 and 4 could also be directed to the manufacturer instead of the contractor. These three loops however, will pose only one different step, which is the selling of the bricks. When interviews indicated that the main barrier of loop 1, 2, or 4 is finding a resell network, loop 1b, 2b, and 4b can be taken into further consideration. Until then, only the four loops drawn below are taken into consideration for simplicity. The following circular loops are identified and will be explained in the next subchapters.

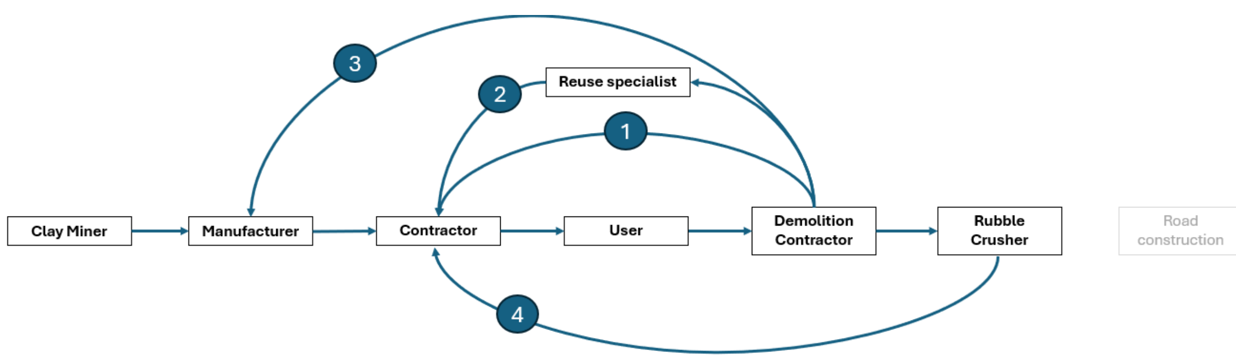


Figure 11. Four identified circular paths.

5.2.2.1 Demolition Company

In this pathway, the demolition company assumes the leading role in implementing circular brick use. The demolition company is responsible for filtering, cleaning, and reselling bricks. Such practices are already occurring on a small scale, as some demolition contractors operate their own marketplaces for second-hand materials. This circular loop is supported by insights from an earlier interview with the Brance association of demolition companies, which emphasised that *"demolition companies are experts in reselling second-hand materials or products, and when there is a financial incentive, contractors will actively pursue this route.* Appendix-H: Summary of MCA Interview" The loop is illustrated in Figure 12.

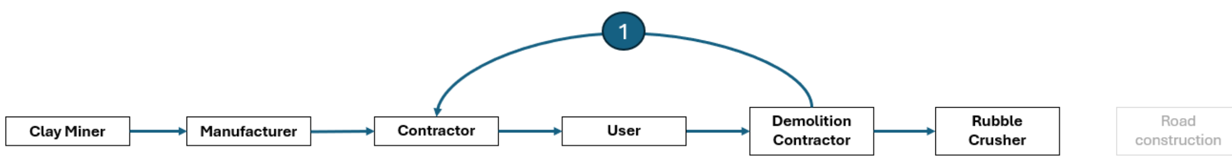


Figure 12. Circular loop 1: Demolition Company

5.2.2.2 Reuse Specialist.

The second circular value chain involves the introduction of a new stakeholder: the reuse specialist. This actor is responsible for identifying suitable products, purchasing them from demolition contractors, processing and testing them, and subsequently reselling the bricks. The structure of this value chain is presented in Figure 13. In the Netherlands, there is currently only one dedicated initiative operating at the reuse level of bricks. This initiative consists of two collaborating companies: the German firm Klinker Historica, which extracts and tests the material, and its exclusive Dutch reseller, Rebrick, which reintroduces the bricks to the Dutch market. Rebrick has been active for only 1.5 years, and the market for reused bricks is still a niche sector.

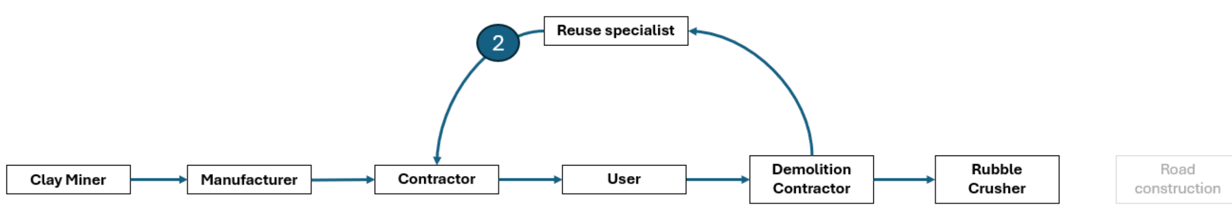


Figure 13. Circular loop 2: Reuse specialist

5.2.2.3 Extended Producer Responsibility

The third potential circular value chain is based on the principle of extended producer responsibility. In this model, the manufacturer assumes the role of leading stakeholder. The manufacturer acquires brick masonry from demolition contractors, processes and tests the material, and resells it under its own brand name (Figure 14). This approach is driven by two main motivations: first, to demonstrate sustainable commitment, and second, to ensure a marketplace in the transition from a linear to a circular economy, purely to survive. Manufacturers are particularly well-positioned to take on this role, as they already possess brand recognition, established sales channels, and testing facilities.

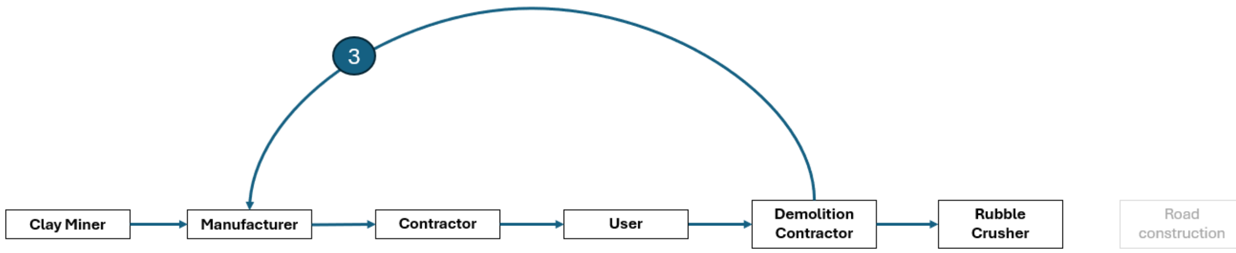


Figure 14. Circular loop 3: EPR.

5.2.2.4 Rubble Crushers

The fourth and final potential circular value chain extends from the rubble crusher back to the contractor (Figure 15). When demolition contractors choose not to separate bricks from other stone-like debris, the rubble crusher becomes the last stakeholder in the chain before the bricks are processed into material level aggregate. In this scenario, bricks arrive mixed with concrete, ceramics, and other stonelike materials. However, rubble crushers often also operate as sorting companies, possessing expertise in identifying valuable products and facilitating their reintroduction into the market.

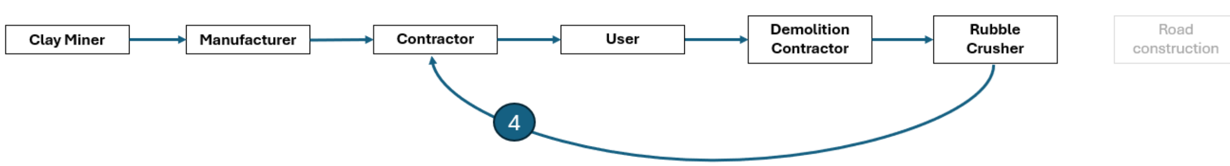


Figure 15. Circular loop 4: Rubble Crushers

5.2.3 The Value Chain in Numbers

To obtain a clearer understanding of the value chain, it is useful to examine the industry in quantitative terms. Since the precise amount of clay transported from clay mines to manufacturers is assumed to equal the total input used, the exact weight in kilograms is of no immediate relevance. Similarly, the volume of aggregates supplied to road construction is considered to be almost entirely utilised, since 83% of demolition waste is stonelike material and 85% of building material is reused as foundation material in infrastructure projects therefore, the specific tonnage is of limited significance (EIB 2020; Rijkswaterstaat 2015). As circular value chains 3 and 4 do not yet exist, they are left out of this analysis. The volume associated with route 1 cannot be estimated. However, because the bricks currently involved in this flow are not certified, they are assumed to be downcycled, due to a decrease in economic value. Consequently, this route is excluded from the value chain representation. The resulting value chain, presented below in Figure 16, depicts the remaining flows within the industry in terms of tonnage.

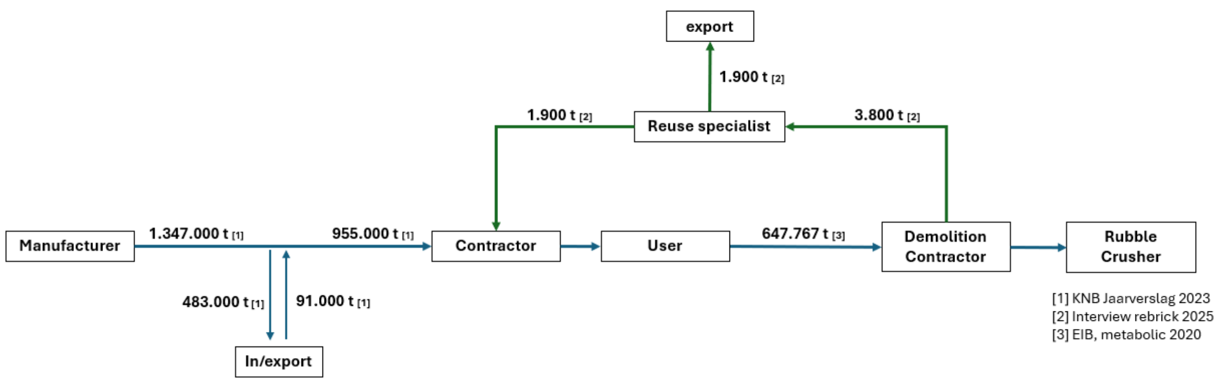


Figure 16. Mass stream within Dutch brick value chain.

Manufacturers produce approximately 1,345,000 tonnes of masonry bricks annually, of which around 483,000 tonnes are exported, and 91,000 tonnes are imported (dr. Augustin et al. 2023). This results in an estimated 955,000 tonnes entering the Dutch construction market each year, according to the Koninklijke Nederlandse Bouwkeramiek (KNB). This figure aligns with the estimation from the EIB, which places the volume at approximately 913,000 tonnes (EIB 2020). The same EIB research further estimated that demolition projects generate approximately 647,000 tonnes of bricks annually. This implies that, currently more bricks are entering the Dutch building stock than are being recovered. According to Rebrick, approximately 3,800 tonnes of bricks will be reclaimed this year. Their own research suggests that the total stock of recoverable bricks amounts to 228,000 tonnes, which would cover only about 25% of the Dutch market demand (Meijs 2024); Appendix-K: Masonry Expert Interviews). Rebrick, currently the sole reseller in the Netherlands, reports annual domestic sales of roughly 1,900 tonnes, while exporting a comparable volume due to stronger international demand. It should be noted that some sources report quantities in numbers of bricks, while others use tonnes. For consistency, conversions were made using the standard "*Waalformaat*" brick, with a weight of 1.9 kilograms per brick.

In addition to the weight, financial metrics provide an equally important quantitative perspective on the value chain. The schematic below offers an indication of the value proposition within the brick industry. It should be emphasised, however, that some of the financial figures are directly derived from interviews with stakeholders and must therefore be interpreted with caution. Brick prices vary considerably depending on factors such as quality, colour, order size, and location. Moreover, many prices are determined on a day-to-day basis and are closely linked to fluctuations in supply and demand. Despite these uncertainties, exploring the financial dimension remains valuable for developing a more comprehensive understanding of the market. The findings are illustrated in Figure 17.

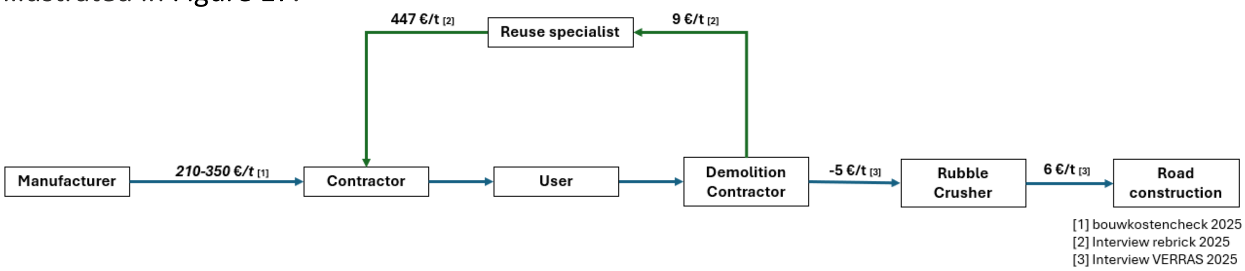


Figure 17. Financial Value Chain of Bricks.

According to Dutch consumer websites, it is common for contractors to charge approximately €400-600 per 1,000 bricks in quotations to clients (WoningkostenCheck 2025). When translated into weight, this corresponds to an average price of €210 to 310 per tonne of new bricks. The same consumer advice indicates that prices can vary widely: high-quality bricks may reach up to €630 per tonne. In the current linear economy, demolition contractors must pay approximately €5 per tonne to dispose of bricks at rubble crushers, meaning that brick disposal represents a cost. Rubble crushers process these stone-like materials into aggregates, which are then sold to road construction companies for roughly €5 to 7 per tonne (Appendix-K: Masonry Expert Interviews). A new market stream is now emerging: Rebrick purchases reusable bricks directly from demolition contractors. This development is particularly relevant to the demolition sector, where profit margins are generally low. Rebrick reports that some contractors are willing to sell them bricks, approximately 50% of the offered bricks can be harvested per project, for approximately €9 per tonne. Rebrick then attempts to resell these bricks at around €850 per 1,000 bricks, which translates to €447 per tonne (Appendix-K: Masonry Expert Interviews).

Based on these figures, Rebrick's reclaimed bricks are between 1.5 and 2 times more expensive than new bricks. The owner of Rebrick, who also owns Bouwcentrum Floris, argues that the price range of €400 to 600 per 1,000 new bricks represents the lower end of the market, and that the quality of Rebrick's products is comparable to new bricks priced at approximately €650 per 1,000. This would imply a price difference of around 30%. These figures, however, could not be independently verified. To contextualise these numbers, an average terraced house in the Netherlands contains roughly 4,000 bricks. Assuming a new brick costs €500 per 1,000 and Rebrick's product costs €850 per 1,000, the use of reclaimed bricks would increase construction costs by approximately €1,400 per dwelling.

5.3 Selection of the Most Promising Circular Value Chain

Having outlined the current linear practices, four alternative circular routes have been distinguished, as illustrated in Figure 11. The next step is to examine these routes and evaluate their potential. The aim is to understand the basis of decision-making: what drives stakeholders, why they have not adopted a circular trajectory, or conversely, why they have chosen to do so.

Five stakeholders were identified as key decision makers in the value chain. These include Wienerberger, the largest manufacturer of new bricks in Europe; Rebrick, the only reuse specialist currently active in the Netherlands; VERAS, the industry association for demolition contractors; BRBS, the association representing rubble crushers; and KNB, the ceramics industry association.

The interviews will begin with an assessment of participants' expertise regarding the product itself, followed by their broader knowledge of the industry context and sustainability objectives. The existing linear value chain will then be presented for validation, allowing the interviewees to assess whether it accurately reflects the current linear economy for the high-potential building product under investigation. A summary of these interviews can be found in Appendix-K: Masonry Expert Interviews.

Subsequently, the proposed circular value chains will be introduced and explained. Participants will be asked to reflect on what might be missing, what developments are already underway, and which value chain they believe holds the greatest potential for success.

Finally, the interviews will address stakeholders' specific decision-making rationales. The focus here will be on why some stakeholders, despite having the capacity to transition from a linear to a circular model, choose not to. The discussion will explore their motivations, concerns, perceived barriers, and drivers.

The findings from these interviews, and thus the barriers and drivers associated with the four proposed circular value chains, are presented in the following section (6.3.1).

5.3.1 Barriers Within the Circular Value Chains.

In reuse route 1, the demolition contractor will separate bricks from other construction debris, process them, potentially arrange testing (either in-house or through a subcontractor), and subsequently reintroduce them to the market. To explore the barriers and drivers associated with this value chain, an interview was conducted with Erik Hoven, secretary of the demolition contractors' association (VERAS).

Hoven explained that demolition contractors are already highly experienced in identifying markets for demolition materials with residual value, and that such sales constitute an important revenue stream. Some of its members are already selling second hand bricks. However, he also emphasised that the demolition sector is characterised by low margins and a strong focus on rapid execution.

The main barriers identified for value chain route 1 are:

- The process is significantly more labour-intensive without being more profitable; the additional effort is not worth the financial return.
- There is often little time between securing a contract and carrying out the demolition, which leaves limited opportunity to identify potential buyers.
- Reselling and storage on large scale present logistical challenges for demolition companies.

According to Hoven, "almost all" bricks are currently mixed in large piles of stone-like material and delivered directly to rubble crushers. The separation of bricks for reuse is considered too time-consuming relative to the financial benefits. He further noted that demolition contractors are unlikely to perform the task of testing bricks against CE regulations. If they do sell reclaimed bricks at all, these are typically offered to smaller, often private buyers rather than the mainstream construction market.

In his view, demolition contractors generally lack the time and manpower required for brick selection and testing. While they may be willing to support reuse initiatives, he believes the second-hand market is best organised by demolition companies at a small scale, while testing and distribution for the larger market should be undertaken by specialised reuse firms. He does advocate for government regulations, forcing all demolition projects to take more time to find potential markets for building products. This way, circular demolition is not outcompeted by the fast demolition.

Reuse route 2 involves an external party specialising in the resale of reclaimed bricks. In this value chain, a dedicated company purchases, processes, tests, stores, and resells the bricks. To investigate the barriers and drivers associated with this route, an interview was conducted with Bob Floris, founder of Rebrick, the only company in the Netherlands fully dedicated to reselling used bricks with a CE Certificate.

Floris explained that Rebrick collaborates with the German company Klinker Historica. While Klinker Historica is responsible for the mining and testing of bricks, Rebrick focuses on storage, rebranding, and sales within the Dutch market. Founded 1.5 years ago, Rebrick was established on the conviction that reselling used bricks carries not only significant sustainability benefits but also strong market potential. The company's business model is fully centred on reuse, and Floris expressed confidence that this specific value chain offers enormous opportunities, both environmentally and financially.

Nonetheless, several barriers were identified:

- The mining process is labour-intensive and therefore costly.
- Bricks must be tested before harvesting, which takes approximately three weeks, a timeline that is often too long for demolition contractors.
- Extraction and processing occur on demolition sites, which can create friction, as demolition companies are generally reluctant to allow external parties to operate there. This barrier was indicated by Erik Hoven in the previous interview.
- Currently, only bricks bonded with bastard or calcium mortar (typically produced before 1980) can be reclaimed.

According to Floris, demand for reclaimed bricks is strong, and the business is steadily growing. The primary challenges are less related to harvesting and more to the sales process. Potential buyers are often housing associations and public housing authorities, which require very large quantities of bricks, posing logistical and scaling challenges for a still-developing company. Nevertheless, Rebrick remains convinced of the viability of this value chain and regards it as the most promising way forward.

Reuse route three is based on the principle of Extended Producer Responsibility, based on manufacturers taking back products from consumers and either reuse or recycle them for reintroduction into the market under their name. To assess the potential of this value chain, an interview was conducted with Dorien van der Weele, Sustainability Manager, and Mees Normann, Project Coordinator for Circular Business at Wienerberger, the largest brick manufacturer in both the Netherlands and Europe.

They acknowledged that brick manufacturers are aware of the sustainability challenges facing the sector and are committed to making progress. A major obstacle, however, remains the reliance on gas-fired kilns for brick production. Regarding the reuse of bricks, they identified several barriers:

- Harvesting and testing reclaimed bricks would require an entirely different business model; manufacturers are producers, not extractors or testers.
- The business case for reuse is less financially viable than current production, primarily due to labour intensity.
- Bricks are not coded or traceable, making it impossible to identify which products are being returned.
- Resources dedicated to sustainability are limited and must be directed towards future-oriented innovations.

Wienerberger representatives emphasised that, while the company is actively pursuing sustainability goals, brick manufacturers are under significant economic pressure due to declining sales and rising gas prices. Their current sustainability efforts, therefore, focus on optimising existing processes, developing hydrogen production, exploring EPR for dry-stacked bricks in the future, and incorporating recycled aggregates into new products. Direct reuse of bricks, however, is not considered a promising option, even within the portfolio of sustainable measures.

They see reuse of bricks as a niche market, unlikely to become mainstream, and point instead to specialised parties such as Rebrick as the most promising actors for developing reuse pathways.

The fourth reuse route considers the possibility of rubble crushers supplying reclaimed bricks back to contractors. This concept is based on the fact that rubble crushers typically receive all construction debris and are highly specialised in separating materials. Moreover, as the final stakeholder in the value chain before products are reduced back to materials, they are well positioned to initiate circular practices.

An interview was conducted with Peter Broere and Arie Mooiman from the industry association BRBS. They explained that member companies currently process all bricks into mixed aggregates for use in road foundations. They emphasised that aggregates in road construction can be considered circular, since aggregates can be reused as aggregates for new road foundation projects after its use stage. The Netherlands, they argued, produces some of the best road foundations in the world. While some critics label crushing as “downcycling,” they questioned whether the material in fact loses significant value through this process.

With regard to the proposed value chain, they identified several barriers:

- If profitability existed in reclaiming bricks, demolition companies, who operate earlier in the chain, would already be exploiting it, as they do for other products. Their absence indicates limited financial viability.
- The current linear business model is profitable, leaving little incentive to develop alternative practices.
- During transport and mixing, bricks deteriorate in quality, reducing their suitability for reuse.
- Once materials are mixed, separating them again is possible, but challenging.
- The process would be extremely labour-intensive.

Although technically feasible, BRBS representatives do not expect this loop within the value chain to be viable. If there was a sound financial case, their members would likely already have adopted such practices. Establishing new segregation lines, involving additional processing and selling of products rather than bulk materials, is not considered realistic for their sector. Instead, when asked, they pointed to Rebrick as the stakeholder with the greatest potential for enabling brick reuse.

A summary of all brick expert interviews can be found in Appendix-K: Masonry Expert Interviews.

5.3.2 Selection of Most Promising Path

The interviews provide a comprehensive picture of both the opportunities and the systemic limitations associated with brick reuse in the construction sector. While sustainability is universally acknowledged as an important and desirable ambition, willingness to engage in circular practices declines when such practices are perceived to undermine profitability, operational stability, or established business models.

First, the current linear value chain remains highly efficient and deeply institutionalised. Firms demonstrate little appetite for fundamental transformation or for building entirely new operational branches, especially in the face of labour scarcity and persistent uncertainties. For many producers and demolition firms, brick reuse is viewed as a “distant prospect”. It is recognised in principle, but does not align with their existing investments, processes, or strategic priorities.

For producers, the priority lies in maintaining and optimising production. Direct reuse of bricks implies reduced demand and, consequently, underutilization of capital-intensive production lines. Since heavy investments have already been made in these lines, producers lack the incentive to embrace reuse. By contrast, recycling options, such as processing brick debris into filler material, are perceived as more compatible because they preserve production volumes while still contributing to circularity.

For demolition companies, brick reuse is technically feasible but economically challenging. Adjusting sorting processes, manually removing mortar, and generating consistent, large-scale flows are all costly and labour-intensive. Furthermore, current markets for reused bricks remain fragmented and small in scale, making upscaling difficult. While some demolition firms already engage in small-scale resale, they are unable to guarantee the quality assurance or the critical mass required for a mature market.

For crushers, the incentive to participate in reuse is even weaker. Their business models are firmly embedded in the established in the current linear economy, particularly in the steady demand for aggregates in road construction. In addition, crushers face significant challenges with mixed rubble streams, which complicate the selective recovery of reusable bricks. As a result, they do not foresee a viable or scalable business case in facilitating direct reuse.

All interviewees consistently highlighted that specialised resellers represent the most credible and effective stakeholder for structuring a viable value chain for brick reuse. Specialised resellers differ in two essential respects:

1. Dedicated focus on solely reuse, unlike producers, demolition companies, or crushers, for whom reuse would only be a second value chain to their core activities and thus should compete internally against the current value chain.
2. Possession of specialised expertise and infrastructure, including quality assurance, sorting technologies, and certification processes. The building sector exists of many specialised experts; these roles are too wide to just take in addition to current practices.

On this basis, the conclusion is clear: the specialised reseller is not simply one possible option, but the only structurally viable configuration for direct brick reuse in the Netherlands. While demolition companies and crushers remain important within the broader materials cycle, their role is primarily supportive or complementary. The central coordination, legitimacy, and scalability of a circular brick value chain has the highest potential with the specialised reseller.

5.3.3 The Case of Rebrick

In the Dutch construction market, a new actor has emerged that focuses on the resale and reuse of bricks. This raises several questions: Who are they? What motivates them? And why are they able to act in ways that established stakeholders do not? The issue is not that existing market players lack the capacity to do so, but rather that they are reluctant to take the necessary risks. Established companies often have more at stake and therefore tend to avoid uncertain ventures.
The biggest new entrant is Rebrick, a company founded 1.5 years ago by Bob Floris. The initiative originated as a continuation of his family's long-standing business in building materials, which included the sale of traditional bricks. Floris sought not only to maintain this legacy but also to address the growing need for a transition from linear practices to circular product use.
The turning point came when Floris came into contact with Klinker Historica, a German company specialising in the mining and testing of bricks. In Germany, these bricks are marketed under the brand name ReviBrick by Wienerberger. When Wienerberger Netherlands declined the opportunity to introduce the product in the Netherlands, Floris seized the chance to become the sole distributor of Klinker Historica's reclaimed bricks in the Netherlands, under his brand Rebrick.

The process operates as follows: In some cases, the demolition contractor is already familiar with Rebrick and has collaborated with them in previous projects. In other cases, either the contractor approaches Klinker Historica or Rebrick when assigned a demolition project, or Rebrick initiates contact with the contractor. The order of engagement is of little importance; what matters is that both parties agree to collaborate.
Once a demolition assignment is in place, approximately 50 sample bricks are collected from the site and sent to a research institute in Germany. There, the bricks undergo testing to determine their suitability for reuse. If approved, they are awarded a CE certification. This procedure generally requires around three weeks, after which, almost always, the bricks are certified.
Following approval, Klinker Historica works in cooperation with the demolition contractor on-site. The contractor provides the company with a designated workspace, which includes both a storage area for the brick piles and sufficient space for stacking pallets of recovered bricks. Once the bricks have been mechanically separated into piles, the subsequent process consists largely of manual labour. Masonry bricks are separated from each other, after which the mortar is manually removed. Cleaned bricks are then placed on pallets, the process is visualised in Figure 18.
When the pallets are complete, the demolition contractor receives payment from Klinker historica and Re-Brick based on the weight of the recovered bricks. Typically, around 50% of the total bricks from a demolition site are suitable for reuse. The remaining bricks, consisting of damaged or broken bricks, remains the responsibility of the demolition contractor.
The value proposition of Rebrick's products lies primarily in their contribution to sustainability. Although the bricks are currently priced significantly higher, approximately 1.5 to 2 times the cost of newly produced alternatives (see Chapter 5.2.3), they deliver substantial environmental benefits. The MKI of Rebrick bricks are approximately three times lower than that of the average newly manufactured competitor (NMD 2025). In addition to this environmental advantage, the aesthetic of reclaimed bricks serve as an added value. For certain clients, these unique visual

characteristics alone justify the premium price and tell the sustainable story. Some examples on the aesthetics of reuse bricks compared to recycled and new bricks can be found in Appendix-M: Aesthetics of Bricks.

Figure 18. Brick Mining process, Rebrick, 2025

Rebrick's business development appears promising. Although the company has only been in operation for 1.5 years, it is projected to resell approximately two million bricks in its second year, which is around 0,2% market share. Profitability is expected to be achieved in the third year of operation. Looking ahead, Rebrick has set an ambitious target of reaching an annual sales volume of 20 million bricks by 2030. This would correspond to an average annual growth rate of approximately 59%. Based on current estimates, profitability can be reached at a sales volume of around three million bricks per year, equivalent to the brick demand for approximately 750 terraced houses.

Rebrick takes an optimistic view of future prospects. The company emphasises that, in comparison to other ceramic-producing countries, the Netherlands lags behind in brick reuse. Germany is estimated to be about ten years ahead, Denmark approximately twenty, while France has already implemented legislation to accelerate the adoption of circular product practices.

The primary customers for Rebrick's products are housing associations and governmental organisations. These actors are motivated less by profit considerations and more by societal objectives, which makes them receptive to circular construction materials. However, demand from these parties frequently exceeds current supply capacity, posing a challenge for the company. Encouragingly, the Dutch government has begun to take more concrete measures, including the integration of circularity as a key evaluation criterion in demolition tenders. Overall, Rebrick regards its future prospects positively, anticipating strong growth as circular construction practices gain further momentum.

Rebrick and Veras have identified three primary barriers when reusing bricks with a reuse specialist. First, the mining process is highly labour-intensive and therefore associated with significant costs. Second, all bricks must undergo testing prior to recovery, a procedure that requires approximately three weeks. This timeline is often considered too long by demolition contractors, who generally have little time between winning a contract and demolition itself. Third, mining and processing activities often take place directly on demolition sites, which can create friction, as demolition contractors are frequently reluctant to allow external parties to operate on their premises.

The reliance on costly and time-consuming manual labour represents a particularly significant barrier, as no existing machinery is currently capable of replacing these manual processes.

Additionally, the requirement for testing and certification could extend the overall project duration, which further discourages some demolition companies from collaboration.
Besides these barriers indicated by Veras and Rebrick, general barriers were previously identified in the literature and discussed in the MCA interviews. In total, 91 barriers were identified and are listed in Appendix-B: Barriers List. Of these, 52 were derived from the literature, while 39 were based on circularity expert interviews. Twelve of the 52 literature-based barriers remain relevant for the business case of a brick reuse specialist, and 13 of the 39 interview-based barriers also apply. This leaves another 25 potential barriers for the reuse specialist case. These barriers are: B1, B4, B5, B6, B12, B13, B15, B23, B32, B49, B51, B52, ID1-3, ID1-5, ID2-2, ID2-5, ID3-3, ID4-2, ID4-3, ID5-5, ID7-1, ID7-2, ID7-3, ID7-4, ID8-1. It would be interesting to see how many of these barriers stay in place for the specific rebrick model.

Five barriers are government related. Many of these concern the legal framework. This issue is addressed in the Rebrick case, since the company is able to test bricks in accordance with CE regulations. The barriers (B5, B23, B52, ID5-5, and ID7-4) involve government involvement, either through financial incentives or enforceable legal mechanisms. The government could apply either a “carrot” (financial support) or a “stick” (regulatory enforcement). However, this has not yet been implemented. The Rebrick case demonstrates that progress is possible without government intervention. While government involvement would be highly beneficial, it is better understood as a driver than as a barrier, since the process can still proceed without it. For this reason, these barriers are acknowledged but not included in the final Rebrick barrier list.

Eleven barriers remain cost-related: B1, B6, B12, B15, B32, B49, ID1-5, ID3-3, ID4-2, ID7-1, and ID7-2. Due to relatively high labour costs and the low price of virgin materials, Rebrick products remain more expensive than competitors who use virgin materials. Buying more expensive rebrick products, for sustainable reasons, thus results in a mismatch between those who bear the costs (the buyer) and those who benefit (society). Rebrick addresses this issue by securing key buyers such as government bodies and housing associations, which are willing to pay a premium. However, the additional costs remain a challenge for large-scale adoption in a price-sensitive, low-margin market. This barrier was also indicated by Rebrick and is added to the Rebrick barrier list.

Stakeholder and client commitment are crucial factors for circular practices. Limited stakeholder awareness (B4), dependency on client demand (B51), and clients’ lack of experience in requesting sustainable options (ID4-3) represent significant challenges. These are better described as challenges rather than absolute barriers. Rebrick is gradually addressing these issues, but this is a time-consuming process. However, their product has the advantage of offering sustainable aesthetic to new buildings (Appendix-M). These challenges are not included in the final barrier list, as they are expected to diminish over time.

A substantial technical barrier remains cement-based mortar, which Rebrick cannot yet process. Although sufficient pre-1980 masonry is currently available, this limitation poses a long-term barrier to mass implementation. Conventional design does not prioritise disassembly or material reuse (B13), which undermines the business case. This barrier is added to the rebricks barrier list.

Finally, several interviewees in the MCA study (ID1-3, ID2-2, ID2-5, ID7-3, and ID8-1) identified time-related barriers. For example, some noted that insufficient time is available to find new buyers. Rebrick addresses this issue by acting as a middleman, storing bricks until a buyer is found. Nevertheless, the preference for speed, simplicity, and low cost often continues to outweigh circular practices. This barrier was also indicated by VERAS and is added to the rebrick barrier list.

Resulting in the following barrier list for the specific rebrick model:

1) **Cost Barrier**: Reused bricks are more costly due to the labour-intensive mining process. Resulting in a mismatch between the client who pays, and society that profits.
2) **Time Barrier**: Testing and harvesting the bricks takes more time than current practices. Resulting in favouritism for linear practices, due to demolition industries tide schedules.
3) **Social Barrier**: Demolition companies are reluctant to let other companies perform activities on their demolition site. Resulting in favouritism for linear practices.
4) **Technical barrier**: Cement based mortar makes separation and processing of brick significantly more difficult. This means that in practice only bricks before 1980 are reused, leaving an increasing number of bricks being used as linear practices.

A driver list was also compiled. This is, however, more difficult to evaluate. Rebrick is already implementing 20 out of the 44 identified drivers. The remaining drivers are either direct opposites of the barriers, outside Rebrick's sphere of influence, or dependent on the actions of other stakeholders.

Only three drivers remain directly within Rebrick's control, primarily those oriented towards the future. Three particularly important ones are:

1) The use of material passports and improved documentation for future reuse.
2) The establishment of consortia in which multiple stakeholders collaborate.
3) Ensure dismantlability in the future by using calcium-based mortar.

For new market entrants specialising in brick reuse, it is advisable to carefully examine the Rebrick case, as Rebrick has already addressed many of the existing barriers. However, it remains important to consider the three drivers mentioned above. For Rebrick itself and new entrants that learn from the Rebrick case, several barriers remain. Chapter 5.4 provides recommendations for overcoming these barriers, with the aim of strengthening the reuse case and enhancing its viability as a large-scale solution for brick reuse.

5.4 The Business Cases

The Rebrick business case already tackles most the barriers in place and therefore seems to function relatively well; however, several barriers remain. Both the cost and technical barriers stem from the labour-intensive harvesting process, whereas the time and social barriers arise from the relationship between reuse specialists and demolition contractors.

5.4.1 Business Case Canvas: BBB

A new business case is proposed. For clarity, the proposed business is named Brought Back Bricks (BBB). The concept of BBB is to eliminate barriers between demolition contractors and brick reuse specialists. The model is straightforward: rather than testing bricks while the building is still standing and waiting three weeks for approval from a testing facility before the labour-intensive harvesting process can begin on site, BBB purchases the brick debris directly. As soon as the bricks are deconstructed and separated from other building debris, they are removed entirely from the demolition site.

In the current Rebrick business model, Rebrick profits more from cooperation with demolition contractors than the other way around. Contractors set aside the bricks and allocate Klinker Historica a dedicated location on the demolition site. They are then compensated for the bricks collected by Klinker Historica. However, approximately 50% of the bricks consist of unusable scraps that remain the responsibility of the demolition contractor. These still have to be transported to a rubble Crusher, requiring additional handling, time, and disposal costs.

By contrast, under BBB, all brick debris is collected as soon as it is removed from the building façade. This offers advantages for demolition contractors: reduced material handling (only a single movement), elimination of time delays from testing, minimal involvement of external companies on site, and still has the ability to demonstrate to clients that the bricks are reused in a circular manner.

Nevertheless, multiple stakeholders are involved, and it might initially seem that if demolition contractors benefit, BBB must lose out. This, however, is not necessarily the case. Approximately 50% of the mass consists of reusable bricks, while the remaining 50% consists of brick scrap. Yet can this material truly be considered “scrap”? In fact, it holds potential value. Filler material, for instance, is expensive. During interviews, VERAS indicated that high-quality filler material could be priced as high as €50-60 per tonne, which is considerable. This number could not be verified. Moreover, Wienerberger noted that filler material is scarce and that they would be interested in purchasing it, but the current supply is too inconsistent for large-scale manufacturers. Additional stakeholders also indicated possible uses, such as concrete aggregates or specialised bricklike products incorporating filler. Thus, brick scrap should not be regarded as mere waste, as there are multiple offset markets for filler materials.

Furthermore, when BBB avoids cherry-picking and accepts all brick material, it is reasonable that the price per tonne would decrease by more than half. Given that demolition contractors would no longer incur costs for handling and disposing of residual scrap, the current average price of approximately €9 per tonne could decrease to €4 per tonne. This leaves additional margin for revenue from filler material.

This approach also represents the most complete form of circularity. Bricks are reused to the greatest possible extent, while those unsuitable for direct reuse enter a lower-level recycling pathway. This ensures that all material follows the most sustainable trajectory available.

BBB also does not need not to be overly concerned with CE marking for reused bricks. Rebrick has indicated that, after the first visual inspection, almost none of the bricks tested in Germany failed to meet CE requirements. The associated risk is therefore minimal.

The BBB business model removes barriers 2 and 3 identified in the Rebrick case, leaving only barriers 1 and 4:

1) Cost Barrier: Reused bricks are more expensive due to the labour-intensive harvesting process, creating a mismatch between the client who pays and society, which benefits.
2) Time Barrier: Testing and harvesting require more time than current practices, favouring linear approaches due to the demolition industry's tight schedules.
3) Social Barrier: Demolition companies are reluctant to allow external companies to operate on their demolition sites, again favouring linear practices.
4) Technical Barrier: Cement-based mortar significantly complicates the separation and processing of bricks. In practice, only pre-1980 bricks are reused, leaving an increasing share of newer bricks subject to linear processing.

A full business model canvas for BBB can be found in Appendix-L: Business Model Canvas BBB and BBBBBB.

Two critical aspects remain unresolved. First, because BBB's processing locations will be stationary, efficiency in brick processing is expected to increase, reducing costs. However, establishing dedicated locations also creates significant fixed costs. Second, transport volumes will rise. Currently, some bricks remain on-site and are reused locally. Under BBB, all material must be transported to central processing facilities. It must therefore be demonstrated that selling filler material is profitable (or at least entails an acceptable loss), and that the efficiencies gained from centralised processing at scale outweigh the additional transport costs.

5.4.2 Business Case Canvas: BBBBBB

Two barriers remain: Barrier 1 (the cost barrier) and Barrier 4 (the technical barrier). To address these, a new business model is proposed. For clarity, this model is named Brought Back Bricks by Binary Bots (BBBBBB). The model is based on industrialising the processing phase through the use of a specialised machine. It should be noted that, at the time of writing, no such machine is commercially available. This business case is therefore illustrative, intended to demonstrate how such a machine could potentially transform the industry.

The premise is that the machine would separate individual bricks, remove mortar residues, and distinguish reusable bricks from broken ones, which could subsequently be used as filler material.

By mechanising the process, the reliance on manual labour would be eliminated, thereby enabling scalability. In general, industrialisation and scaling lower production costs, which could result in reused bricks being sold at a lower price than new alternatives. This would open up new markets. The shift would be from a value-driven product to a cost-driven product, potentially one of even higher value. This represents a win-win scenario. Depending on the machine's design and operating speed, it might even be deployed directly on demolition sites, reducing transport needs while minimising disruption for demolition crews compared to current practices.

Both proposed business models build on the premise that Rebrick has already developed a promising foundation. However, certain barriers persist within the rebrick case. Once these are overcome, large-scale implementation should become achievable. For more information, and a better understanding of the business model, please take a look at Appendix-L: Business Model Canvas BBB and BBBBBB.

The business BBB and BBBBBB were not discussed with experts. New barriers, primarily non-circular related but business or logistics wise, could arise. These business models are designed to solve the existing rebrick barriers, but further research should indicate if these canvases are achievable.

5.5 Case Study: Results and Discussion

The first two sub-questions; *"What technical and socio-economic factors determine the potential of a product for reuse implementation?"* and *"Which building product group retrieved from B&U demolition has the highest potential for circular reuse, based on the determined technical and socio-economic factors?"*, were answered through the development of a multi-criteria analysis which results can be found in Chapter-4.

To answer the two remaining questions; *"What key barriers must be addressed to successfully integrate the chosen high-potential product group into a circular product flow?"* and *"How can the product group–specific barriers be overcome to successfully integrate this high-potential product group into a circular product flow?"*, the case study presented in this chapter was performed.

In Sections 5.5.1 and 5.5.2, the results addressing these sub-questions are presented.

5.5.1 Key Barriers for Circular Implementation of Bricks

To find the current barriers for circular implementation of brick the most promising value chain was selected and discussed. This is the rebrick case, for which only, only four barriers remain:

1) **Cost Barrier**: Reused bricks are more costly due to the labour-intensive mining process. Resulting in a mismatch between the client who pays, and society that profits.
2) **Time Barrier**: Testing and harvesting the bricks takes more time than current practices. Resulting in favouritism for linear practices, due to demolition industries tide schedules.
3) **Social Barrier**: Demolition companies are reluctant to let other companies perform activities on their demolition site. Resulting in favouritism for linear practices.
4) **Technical barrier**: Cement based mortar makes separation and processing of brick significantly more difficult. This means that in practice only bricks before 1980 are reused, leaving an increasing number of bricks being used as linear practices.

These four barriers were identified by the reuse specialist themselves, as well as by the industry association for demolition companies. The cost barrier and technical barrier were independently verified and were also found in the literature review at the beginning of this thesis. The time barrier and social barrier could not be verified, as both relate to the stakeholder interactions between these two parties. However, both parties indicated that these barriers exist, which adds to their credibility. Furthermore, since both parties are committed to this value chain, it would make no sense for them to fabricate nonexistent barriers.

5.5.2 Overcome These Barriers With Novel Business Models

It became evident in the interviews that a viable business case is crucial for market adoption and implementation. Three out of four stakeholders, the manufacturer, demolition company, and rubble crusher, indicated that they do not currently see a viable business case, or at least not one that outperforms their existing business model. The only stakeholder actively engaged in brick reuse is the one that has developed a viable business model for itself. As this is a relatively new company, it does not have to compete with pre-existing internal business models. The business model of Rebrick Still faces the four barriers listed below. To address these barriers while maintaining a viable business model, two new business model canvases were developed.

1) **Cost Barrier**: Reused bricks are more costly due to the labour-intensive mining process. Resulting in a mismatch between the client who pays, and society that profits.
2) **Time Barrier**: Testing and harvesting the bricks takes more time than current practices. Resulting in favouritism for linear practices, due to demolition industries tide schedules.
3) **Social Barrier**: Demolition companies are reluctant to let other companies perform activities on their demolition site. Resulting in favouritism for linear practices.
4) **Technical barrier**: Cement based mortar makes separation and processing of brick significantly more difficult. This means that in practice only bricks before 1980 are reused, leaving an increasing number of bricks being used as linear practices.

The first business model canvas is Brought Back Bricks (BBB), which is based not only on selling reclaimed bricks but also on selling filler material by collecting and processing all brick debris into these two product streams. The proposed business model addresses barriers two and three; however, barriers one and four still persist. Therefore, Brought Back Bricks by Binary Bots was developed, a business model that illustrates the innovation required to overcome the remaining two barriers. These barriers can be resolved through a machine-based mining method, which reduces labour costs and facilitates the separation of mortar from bricks through automated processing.

Both BBB and BBBBBB were developed to address the barriers that remain for the Rebrick case. The new business models, however, have not yet been tested for viability. They appear to be derivations of the Rebrick model, and therefore it is expected that no other barriers currently exist, although new barriers could emerge for these specific business ventures. Processing locations will be required, and additional transport will occur, both factors that may drive up costs. It cannot yet be determined whether the reduction in manual labour costs outweighs the increase in logistics expenses. Nevertheless, the current barriers have been resolved, and since no suitable machine currently exists, this is where the scope of this thesis concludes. Future research recommendations include further investigation into the viability of the proposed business model canvases.

Limitations on Case Study

During this research, multiple limitations on the research method became apparent. This researcher has a relatively broad research scope, and multiple phases are run through to come to the final conclusions, leading to time constraint for finding some sub results. Since this research is partly based on why the industry is not changing, little documentation could be found. The Key limitations of the brick case study are summarised below.

- The research is on a national level, and takes only the product use, legislation and barriers, of the Netherlands into account.
- MKI is a Dutch sustainability scoring, currently only used in the Netherlands.
- Stakeholder interviews were conducted with one interview per stakeholder. Large players and branch associations were found, but results are prone to personal biases of those interviewees.
- The proposed business model canvases were not verified with stakeholders to find new barriers for this specific business model.

Recommendations for Further Research

During the research, multiple new research questions appeared that were not answered in this research question. These questions result in the following recommendations for further research:

- Explore international best practices in brick reuse: During the interviews, Bob Floris highlighted that the Dutch market lags behind other countries in brick reuse. Valuable lessons could be drawn from the experiences of France, Germany, and Denmark. Research into their approaches, policies, and implementation strategies would provide useful insights for the Dutch context.
- Conduct a more detailed impact study: The interviews revealed that an updated mass flow source will soon become available, replacing the current dataset from 2013. Future research should incorporate this newer data for greater accuracy. Moreover, the impact study should focus on the usable fraction of products rather than just the available amounts. For instance, cement-based masonry debris may be widely available but is not currently reusable. Additionally, the study should calculate the difference in environmental impact (MKI) between the current end-of-life scenario and reuse pathways, as reuse is not impact-free.
- Develop a comprehensive business case: A more robust business case is needed, considering logistics such as transport and storage. This should be tested for feasibility in consultation with relevant stakeholders, while also examining pricing structures in greater depth to assess financial viability.
- Expand research beyond bricks: While this thesis identified bricks as the most promising product group, all ten high-potential product groups deserve follow-up research. Their environmental and economic impact could also be significant. In essence, the goal remains to eventually use all products and materials in a circular manner.

6. Conclusion

There is a growing recognition of the need to develop a more sustainable society. The building sector plays a pivotal role in this transition and must take significant steps to meet the Dutch sustainability targets for 2030 and 2050. Within these national objectives, circularity is identified as a central trajectory, and the construction industry is expected to adapt to its principles.

Two key challenges arise: how can we support that every product manufactured today, can be reused after its initial use phase, and how can we maximise the value of products currently becoming available during demolition? This thesis addressed the latter, specifically focusing on demolition waste becoming available in Dutch B&U demolition projects.

For these materials, the strategies of R0 (Refuse), R1 (Rethink), and R2 (Reduce) of the 10-R model have already been surpassed. Consequently, this study concentrates on the next best thing of circularity, R3 (Reuse). Reuse occurs at the product level, while R8 (recycling) refers to the material level.

This study compared 139 product groups. Firstly, a high-potential list was created from this list of products. It is important to assess the theoretical potential of products, but the products should also have sufficient overall impact to justify the required time, effort, and financial investment of circular implementation. Therefore, an impact study was conducted to filter out high-potential product groups. Impact was defined as the amount of mass available per year due Dutch B&U demolition multiplied by the MKI of the product. This filtering process identified 10 product groups. Five product groups were selected due to their overall impact, and an additional five product groups were added to the list for diversification. These five added product groups were the highest-scoring product groups in the predetermined material categories. This resulted in a high-potential list, of not only stone-like materials as, wide slabs floors, brick masonry, cast-in-place concrete, screw piles and hollow core floor slabs, but also adds structural steel, timber sandwich roof elements, EPS, Clipboard and HR glass.

To address the first sub-question; *what technical and socio-economic factors determine the potential of a product for reuse implementation?* A literature study was conducted. In the literature, both barriers and drivers for circular building practices were identified. 52 barriers and 21 drivers were grouped into criteria representing the decision-making factors for circular implementation. The outcome was the identification of four main criteria that influence the potential of a product group for circular implementation: (1) increase in costs, (2) increase in risks, (3) technical feasibility and (4) balance in supply and demand. These four criteria combined with the impact score (5) from the impact study, results in the five criteria used in the MCA. These five criteria were verified by eight experts and were considered a fitting representation of the decision-making process.

To answer the question; *Which building product group retrieved from B&U demolition has the highest potential for circular reuse, based on the determined technical and socio-economic factors?* A multi-criteria analysis was conducted, scored with either literature or expert input. the 10 high-potential product groups were evaluated against the five criteria. This analysis revealed that masonry brickwork is the highest-scoring product group with a score of (4.04 out of 5). Masonry brickwork scored particularly high on the most important criterion, balance in supply and demand, and lower on the criteria cost and technical feasibility. According to this result, brick masonry has 23% more potential than the runner-up, which was structural steel with a score 3.29 of out of 5.

To identify; *What key barriers must be addressed to successfully integrate the chosen high-potential product group into a circular product flow?* the brick industry was investigated. The main challenge of current linear practices lies in the production process, which remains dependent on gas-fired kilns and is responsible for 85% of the MKI score alone. Although the industry is experimenting with hydrogen-powered kilns, the concept is still in the pilot phase. The first hydrogen connections are expected around 2030, but due to supply limitations and significantly higher costs, mass implementation for the brick market is unlikely in the near future.

The current linear value chain was analysed, and four alternative circular routes were proposed. Stakeholders from different parts of the chain were interviewed to capture industry perspectives. While all acknowledged the importance of sustainability and expressed circular ambitions, they all indicated that for them, no viable business case currently existed. The current linear chain is highly optimised, making the transition to circular alternatives less attractive. Current labour-intensive, hand-based mining methods create a business model that is too niche and misaligns with existing stakeholders' strategies.

Nevertheless, there is one dedicated party in the Netherlands focusing on brick reuse: the collaboration of Rebrick and Klinker Historica. Although promising, this single partnership cannot change the industry on its own. Rebrick, despite strong growth ambitions, currently has a market share of only about 0.2%. A dive in this company structure, however, helps address the last sub-question; *How to overcome the product-group-specific barriers to successfully integrate this high-potential product category into a circular product flow? For the rebrick case, only four barriers hinder mass market implementation.* Collaboration with demolition companies, efficient cement-based mortar removal and tackling labour-intensive mining processes remains crucial. These barriers must be removed for large-scale implementation to become feasible.

Two business model canvases were developed. The first named Brough Back Bricks, based on Rebrick's model, increases risk by purchasing all aggregates and selling not only bricks but also filler materials. This approach reduces barriers for collaboration with demolition companies but leaves cost and technical feasibility barriers unresolved. The second business model named brough back bricks by binary bots, demonstrates how industrialisation could transform the brick reuse industry, by machine-based mining processing. With this last model, all identified barriers for a reuse specialist could be solved.

Bricks prove to be a high-potential building product group for reuse in the Dutch construction sector. They represent around 8% of demolition mass and have a high MKI score due to their gas-dependent production process. The risks are minimal since bricks are no longer used as load-bearing elements and can be retested and CE-marked. The MKI score of reused bricks is approximately three times lower than new brick alternatives. Technically, harvesting bricks is highly feasible, though time-consuming and costly. Their standardised sizes facilitate reuse and design integration. Although currently more expensive, the price gap between new and reused bricks is expected to narrow over time, resulting in the potential switch from a value-driven product to a cost-driven product and opening up additional market share.

References

Augustin, Ingrid, Frits Prof. dr. Franssen, and Martijn prof. dr. Spruit. (2023). "Jaarverslag 2023." 25–27.

Bouweconomie, De Circulaire. (2023). "Een Juridische Mogelijkheid Voor Hoogwaardig Hergebruik."

CB23. (2022). "Toekomstig Hergebruik Faciliteren." 1–81.

CB23. (2023a). "Horizontale Richtlijn Productprestaties van Bouwproducten in Volgende Cyclus." 1–27.

CB23. (2023b). "Kwaliteitsbeoordeling En -Borging Bij Hergebruik Uit Bestaande Bouw." 1–56.

CB23. (2023c). "Uitgebreide Producentenverantwoordelijkheid." 1–21.

De Circulaire bouweconomie. (2025). *Folder: Van Koplopers Naar Peleton*.

Cirkelstad, WerkgroepMetSGS. (2021). "Hoogwaardig Hergebruik Bouwproducten En -Materialen."

Copernicus. (2024). "Global Climate Highlights 2024."

Copper8. (2024). "Circulaire Bouweconomie : Regisseren Is Vooruitzien."

Crow-cur, Werkgroep. (2023). "Richtlijn 4:2023 Hergebruik Constructieve Prefab Betonelementen."

Dean, M. (2022). "A Practical Guide to Multi-Criteria Analysis A Practical Guide to Multi-Criteria Analysis Dr Marco Dean Bartlett School of Planning , University College London." *Journal of University College London* (January):1–84. doi:10.13140/RG.2.2.15007.02722.

DigiC, Digital circular building economy. (2024). "BOUWMARKTPLAATSEN, DE HOEKSTENEN VOOR EXPONENTIËLE GROEI VAN HOOGWAARDIG HERGEBRUIK."

EIB. (2022). "Materiaalstromen in de Bouw En Infra. 2019/2030/2050."

EIB, WerkgroepMetSGS. (2020). "Materiaalstromen, Milieu-Impact En Energieverbruik in de Woning- En Utiliteitsbouw. 2030."

EUROPESE UNIE. (2024). “VERORDENING VAN HET EUROPEES PARLEMENT EN DE RAAD Tot Vaststelling van Geharmoniseerde Regels Voor Het Verhandelen van Bouwproducten En Tot Intrekking van Verordening (EU).” 2024.

FCRBE. (2021). “REUSE TOOLKIT: Volle Keramische Baksteen.”

Firdavs, Askarov. (2023). “Supply Demand and Market Balance.”

Giorgi, Serena, Monica Lavagna, Ke Wang, Mohamed Osmani, Gang Liu, and Andrea Campioli. (2022). “Drivers and Barriers towards Circular Economy in the Building Sector: Stakeholder Interviews and Analysis of Five European Countries Policies and Practices.” *Journal of Cleaner Production* 336(December 2021):130395. doi:10.1016/j.jclepro.2022.130395.

Het ministerie van Infrastructuur en milieu. (2016). “Nederland Circulair in 2050; Rijksbreed Programma Circulaire Economie.”

Kanters, Jouri. (2020). “Circular Building Design : An Analysis of Barriers and Drivers for a Circular Building Sector.” (Table 1):1–16. doi:10.3390/buildings10040077.

Kirchherr, J., Reike, D., & Hekkert, M. (2017). Conceptualizing the circular economy: An analysis of 114 definitions. *Resources, Conservation and Recycling, 127*, 221-232. doi:10.1016/j.resconrec.2017.09.005

KNB. (2021). “Van Klei Tot Baksteen.” 1–20.

Kuijpers, Maikel. (2024). “De Baksteen: Een Anker Voor de Toekomst.”

le, Dinh Linh. (2024). “Status and Barriers to Circular Bio-Based Building Material Adoption in Developed Economies : The Case of Flanders , Belgium.” *Journal of Environmental Management* 367(March):121965. doi:10.1016/j.jenvman.2024.121965.

Meijs. (2024). “Onderzoek Naar Marktpotentie Voor Hergebruik Bakstenen.”

NEN, Werkgroep 342086. (2023). “NTA 8713 Hergebruik van Constructiestaal.”

NMD. (2025) “Nationale Millue Database, MKI Viewer Tool.”

NXT. (2025). “NXT Brick.” Retrieved from: nxt-building.nl/producten/nxt-bricks/

PBL. (2021). “NETHERLANDS INTEGRAL CIRCULAR ECONOMY REPORT 2021.”

PBL. (2025). “Integrale Circulaire Economie Rapportage (ICER).”

Rezaei, Jafar. (2015). “Best-Worst Multi-Criteria Decision-Making Method.” *Omega (United Kingdom)* 53:49–57. doi:10.1016/j.omega.2014.11.009.

Rijksoverheid. (2022). “Ontwerp Beleids- Programma Klimaat.”

Rijkswaterstaat. (2015). “Beleidsverkenning Circulaire Economie in de Bouw.”

SGS-Intron. (2022). “Protocol Hergebruik Prefab Betonnen Omgekeerde T-Liggers.”.

SGS-Search. (2021a). “Beslisboom, Eindraport.” 1–55.

SGS-Search. (2021b). “Beslisboom Hergebruik (Ge)Bouwelementen.”

SGS-Search. (2021c). “Beslisboom, Versie-8.” 1–7.

SGS-Search, Metabolic. n.d. “Circulaire Bouwketen in Regio Utrecht.”

Stenvert, Ronald. (2012). “Biografie van de Baksteen 1850-2000.” *W Books* 338.

TNO Bletsis, Auteurs A., J. van Bommel, S. Bours, A. van Hoorn, M. Kamps, and J. van Oorschot Rubricering rapport TNO Publiek Titel. (2024a). “Productgroep Analyse Woningen.” 11278. https://www.pbl.nl/monitoring-circulaire-economie.

TNO Bletsis, Auteurs A., J. van Bommel, S. Bours, A. van Hoorn, M. Kamps, and J. van Oorschot Rubricering rapport TNO Publiek Titel. (2024b). “Productgroep Analyse Woningen.” 11278.

Tura, Nina, Jyri Hanski, Tuomas Ahola, Matias Ståhle, Sini Piiparinen, and Pasi Valkokari. (2019). “Unlocking Circular Business: A Framework of Barriers and Drivers.” *Journal of Cleaner Production* 212:90–98. doi:10.1016/j.jclepro.2018.11.202.

United Nations. (2015). “Paris Agreement.”

van Vliet, Mike, Jip van Grinsven, and Jim Teunizen. (2021). “MEETMETHODIEK LOSMAAKBAARHEID.”

Vogelensangh. (2025). “Vogelensangh FIR.” Retrieved from: https://www.vogelensangh.nl/

Wienerberger. (2025). “Cyclo Brick.” Retrieved from: CicloBrick: de baksteen met een verleden

WoningkostenCheck. (2025). “Metselstenen Kiezen? Vergelijk Formaten En Types Hier.”

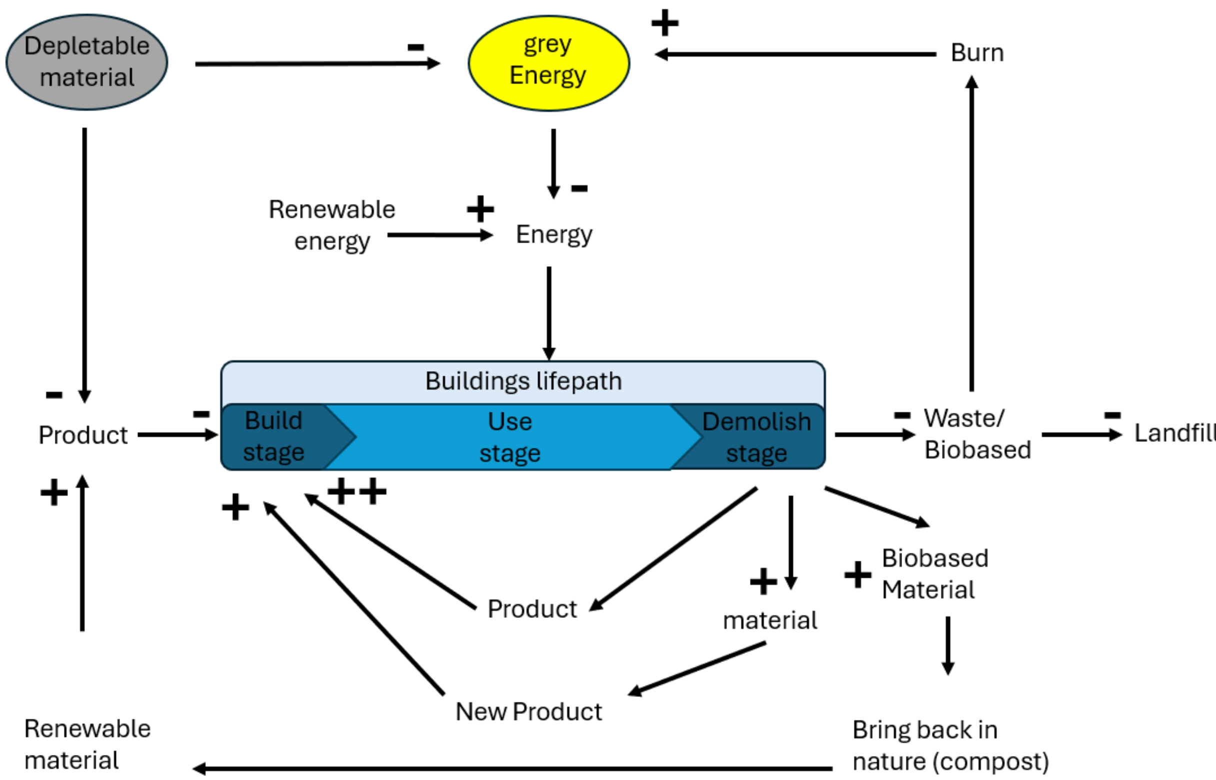
Wuni, Ibrahim Yahaya. (2022). “Mapping the Barriers to Circular Economy Adoption in the Construction Industry: A Systematic Review, Pareto Analysis, and Mitigation Strategy Map.” *Building and Environment*:109453. doi:10.1016/j.buildenv.2022.109453.

Yang, Xining, Mingming Hu, Wenhui Shan, Chunbo Zhang, Tiankun Li, and Yingji Pan. (2023). "Integrating Bottom-up Building Stock Model with Logistics Networks to Support the Site Selection of Circular Construction Hub." *Journal of Cleaner Production* 430(October):139677. doi:10.1016/j.jclepro.2023.139677.

Artificial intelligence–based language models were used to support language editing, including spelling and grammar correction. The author has carefully reviewed all content, and the report fully reflects the author's own work and intellectual contributions.

Appendices

Appendix-A: Own Model on a Sustainable and Circular Future



Appendix-B: Barriers List

(Wuni 2022):
95 barriers identified. Tabel-3 of the paper. Top 5 most cited:

1) high upfront investment costs. (B1)
2) lack of technical capabilities and expertise. (B2)
3) absence of a supportive regulatory framework. (B3)
4) limited awareness of circular strategies among stakeholders. (B4)
5) insufficient financial incentives from governments. (B5)

(Kanters 2020):

1) Disproportionately high cost of labour in Europe relative to materials. (B6)
2) Lack of professionals skilled in reused materials and deconstruction techniques. (B7)
3) Consistent finding was that the success of circular projects often hinged on the client's commitment and vision, rather than systemic support or market demand. (B8)

(PBL 2025):

1) The "chicken-and-egg" dilemma, where limited demand for circular products discourages supply, and vice versa. (B9)
2) Environmental externalities are not adequately priced. Low global prices of virgin materials. Resulting in an unlevel playing field that undermines circular initiatives. (B10)
3) Lack of comprehensive data across the product lifecycle. While data on end-of-life recycling exists, there is limited transparency regarding design and material composition early in the value chain. (B11)
4) practical barriers like cost and complexity prevent large-scale adoption. Circular products are often more expensive or less accessible than linear alternatives. (B12)

(Rijkswaterstaat 2015):

1) Conventional design does not prioritise disassembly or material reuse. (B13)
2) Fragmentation of responsibilities within government bodies. (B14)

(le 2024):

Identified 23 barriers, with 13 being critical.

1) Concern about the high initial cost Survey (B15)
2) Risks and uncertainties involved in adopting new materials (B16)
3) Perception of the extra cost being incurred. (B17)
4) Contractors lack technical knowledge and experience (B18)
5) Clients worrying about profitability (B19)
6) Unwillingness to change from conventional materials to CBBMs (B20)
7) Building code restriction and lack of regulation (B21)
8) Shortage of skilled labourers B08: (B22)
9) Lack of government promotion and incentives (B23)
10) Lack of design knowledge and skills (B24)
11) Perception of low quality in CBBMs (e.g., fire and moisture resistance, low durability, etc.) (B25)
12) Lack of comprehensive tools and data to compare material alternatives (B26)
13) Lack of effective marketing from material producers (B27)

(Copper8 2024):

1) The absence of a clear and unified goal across stakeholders regarding what the circular transition entails. (B28)
2) Misaligned steering mechanisms and performance metrics that fail to support circular processes. (B29)
3) Inadequate and often obstructive regulation. (B30)
4) An aversion to risk and the tendency to delegate it down the value chain. (B31)
5) The challenge of aligning private investment incentives with societal-level benefits. The latter reflects the economic misfit where the costs of innovation (e.g. higher upfront expenses) are borne by developers, while the benefits (e.g. lower environmental impact, resource preservation) accrue more diffusely across society. (B32)

(TNO Bletsis et al. 2024b):

1) Tension between different societal missions:
   EG: affordable housing construction often conflicts with circular goals. (B33)
2) Stakeholders still prioritise CO_2 reduction over material reuse, meaning that circularity is subsumed under energy goals. (B34)
3) The strategies and instruments available are dispersed across different maturity levels, leading to fragmented implementation. (B35)

(DigiC 2024):

1) data quality. (B36)

2) Market reluctance (B37)

3) lack of digital product passports. (B38)

4) legal uncertainty about liability for reused components. (B39)

5) poor interoperability of databases limit their potential. The authors stress that without uniform frameworks and trust in the provenance and safety of reused materials, the circular construction market cannot scale effectively . (B40)

(SGS-Search 2021a, 2021b, 2021c)

1) Institutional uncertainty. (B41)

2) Fragmented accountability as bottlenecks. (B42)

3) Lack of adequate material/product records. (B43)

4) Legal liability. (B44)

5) Lack of standardised assessment protocols, and compatibility with Bouwbesluit remain critical gaps. (B45)

(CB23 2022, 2023c, 2023b, 2023a)

1) Lack of legally recognised framework to assess and register materials' performance for reuse. (B46)

2) without clear quality indicators and traceable documentation, stakeholders face too much uncertainty and legal risk to reuse products. (B47)

(EIB 2020, 2022)

1) Uneven playing field due to cheap virgin materials and limited access to high-quality secondary materials. (B48)

2) Lack of consistent taxonomy, material classification, and performance data, without which architects and contractors remain hesitant to specify reused products in tenders. (B49)

(Cirkelstad 2021)

1) Dependence on integrated design workflows. (B50)

2) Dependence on client demand. (B51)

3) Lack of enforceable legal and financial mechanisms that reward reuse, not just recycling. (B52)

Expert ID_1

1) Strict technical requirements (e.g., insulation value, dimensions) for new building limit the use of reused materials. (ID1-1)
2) Insurance and safety concerns push contractors to over-dimension reused structural elements, eroding sustainability gains. (ID1-2)
3) Current demolition practices favor speed and low costs over careful dismantling because demolition usually starts only after new building permits are granted. This limits circular practises. (ID1-3)
4) Regulations (e.g., Building Decree) and certification systems (e.g., KOMO) restrict high-grade reuse of recycled materials in certain applications like bridges and high-rise structures. (ID1-4)
5) There is often an difference in who benefits, <u>and who pays the price</u>. (ID1-5)

Expert ID_2

1) Short lead times in tenders; effective reuse needs several months for finding buyers, not just weeks. (ID2-1)
2) Lack of alignment between supply (released materials) and demand (new projects). (ID2-2)
3) Strict compliance with the Building Code makes reuse of structural elements with uncertain quality a high-risk proposition, especially for cast-in-place concrete. (ID2-3)
4) Fragmented market dynamics, where conflicting interests between clients and contractors hinder optimal outcomes. (ID2-4)
5) Projects prioritizing speed over careful dismantling due to pressures tied to new construction permits. (ID2-5)

Expert ID_3

1) Lack of a viable business case is the key barrier: even if reuse is technically possible, it won't happen if it's unprofitable. (ID3-1)
2) Regulatory hurdles prohibiting reuse of certain materials (e.g., PU insulation) even when practical solutions exist. (ID3-2)
3) Market volatility: large-scale production of cheap virgin plastics abroad (e.g., US, Asia) suppresses recycled material prices, causing European recyclers to shut down. (ID3-3)
4) Fragmented or inconsistent regulations lead to competitive disadvantages for domestic recyclers. (ID3-4)
5) Overly rigid linear thinking in policy fails to accommodate innovative reuse systems. (ID3-5)

Expert ID_4

1) Lack of standardized and complete material passports; inconsistent documentation leads to missing or unreliable data, particularly problematic for existing buildings without historical records. (ID4-1)
2) Construction industry's tender-driven system: high price sensitivity and low margins discourage experimenting with reuse, as any cost overrun directly threatens profitability. (ID4-2)
3) Clients often lack experience or knowledge to request sustainable options in tenders, resulting in missed reuse opportunities. (ID4-3)
4) Risks of unknown material quality (e.g., hidden asbestos, outdated insulation performance) make reuse unattractive or unsafe. (ID4-4)
5) Organizational skills gaps: even if reuse is technically and economically feasible, a lack of knowledge about extraction, handling, and storage often leads to opting for new materials. (ID4-5)

Expert ID_5

1) Regulatory and certification systems often prevent reusing perfectly functional products (e.g., safety doors) because 100% performance guarantees cannot be re-proven. (ID5-1)
2) Maintenance concerns: reused components might introduce higher or more specialized upkeep requirements, discouraging reuse. (ID5-2)
3) Behavioural factors: project managers prioritize cost, timing, and certainty over sustainability, especially in tenders emphasizing lowest price and risk avoidance. (ID5-3)
4) Many pilots are run without clear goals for learning or scaling; lessons from pilots often fail to translate into standard practice. (ID5-4)

5) Lack of regulation enforcing circularity means widespread adoption remains voluntary, slowing systemic change. (ID5-5)

Expert ID_6

1) Lack of centralized coordination: even with many active networks, fragmentation causes confusion and inefficiency. (ID6-1)

2) Housing corporations often offload innovation responsibility to contractors, who may lack incentives or resources to drive systemic change. (ID6-2)

3) Reuse projects remain isolated pilots without a clear path to scale; repeated reinvention hinders momentum. (ID6-3)

4) Local governments have limited formal power to mandate circularity; national and EU regulations are needed for systemic change. (ID6-4)

5) Differences in market dynamics across regions complicate uniform implementation; e.g., different housing markets in the Netherlands vs. neighbouring countries. (ID6-5)

Expert ID_7

1) Fragmentation of the chain: Current demolition and recycling industries are optimized for downcycling, not reuse; entrenched players may resist change to protect existing business models. (ID7-1)
2) Mismatch of costs and benefits: Parties paying for careful deconstruction (e.g., demolition contractors) often don't capture the value of reused materials, undermining incentives. (ID7-2)
3) Clients' expectations: Building owners or developers frequently prioritize speed and simplicity, which conflicts with the longer timelines and planning needed for reuse. (ID7-3)
4) Lack of mandatory frameworks: Without legal requirements, many industry players will not invest in reuse systems, especially when they are more costly or complex than conventional practices. (ID7-4)

Expert ID_8

1) Lack of early communication: without advance notice of demolition schedules, aligning reclaimed materials with new projects becomes nearly impossible. (ID8-1)
2) Quality assurance: absence of standardized certification for reclaimed materials limits market acceptance, especially in the professional building sector. (ID8-2)
3) Market mismatch: examples like large stockpiles of obsolete toilet bowls illustrate the danger of storing materials without confirmed future use. (ID8-3)
4) Regulatory inertia: outdated codes and lack of circularity-focused updates in national regulations hamper systemic change. (ID8-4)
5) Difference in acceptance: non-profit organizations are more open to reused materials despite lacking warranties, while commercial players often reject uncertified products. (ID8-5)

Appendix-C: Drivers List

(Kanters 2020)

1) Explicitly client requested circular outcomes at the design brief stage. (D1)

(Giorgi et al. 2022)

1) proactive ecosystems; designers, contractors, and suppliers were embedded in active networks that facilitated trust, information sharing, and joint ventures. (D3)

Countries that promoted infrastructure:

2) Digital traceability tools (D4)
3) Common reuse standards (D5)
4) Shared materials platforms (D6)

were better able to realise circular strategies.

(Tura et al. 2019)

1) Companies thrive when they have a clear long-term vision, paired with operational flexibility. (D7)
2) Companies that decouple profitability from raw material sales, embracing service-based models or value-retention logic. (Change in business model) (D8)

(TNO Bletsis et al. 2024b)

1) Demount ability. (D9)
2) firms who adopted a circular strategy from the design phase benefited from reduced waste costs, increased tenant satisfaction, and greater project adaptability. (D10)

(CB23 2023a)

1) Early collaboration with demolition teams to pre-identify reusable elements. (D11)
2) Standardised inspection protocols made it easier to verify the mechanical integrity of reused steel, concrete and wood. (D12)
3) Digital tracking tools, such as material passports and visual tagging, ensured traceability and improved coordination between donor and receiving sites. (D13)

(SGS-Search 2021a)

1) Systematic pre-assessment of materials during demolition planning, reducing last-minute surprises and preserving material integrity. (D14)
2) Alignment with project timelines: the most effective reuse happened where schedules allowed for matching of supply and demand between sites. (D15)
3) Legal clarity: guidance on when reused elements qualify as “products” rather than “waste” helped avoid regulatory grey zones and simplified logistics. (D16)

(PBL 2025)

1) Circular goals were embedded in public procurement, for example, municipal projects that prioritised reused or biobased materials saw significantly higher reuse rates. (D17)
2) Local authorities acted as launch customers for innovation, commissioning buildings with explicit reuse targets. (D18)

3) Supportive fiscal instruments, such as tax relief for reused materials or innovation subsidies, tipped the business case in favour of circular methods. (D19)

(EIB 2020)

1) Material mapping prior to demolition, allowing secondary products to be logged, certified, and matched with upcoming developments. (D20)

2) Partnerships with housing associations, who were more willing to adopt circular practices due to long-term asset ownership and lifecycle cost focus. (D21)

Expert ID_1

1) Regulatory incentives, such as lowering taxes on labor and increasing taxes on primary raw materials. (ID1-D1)
2) Direct reuse at the same location (short reuse cycles), which is currently hindered by the timing of demolition and new construction permits. (ID1-D2)
3) Proven demand in informal markets (ID1-D3)

Expert ID_2

1) Projects with clients willing to "stick their necks out," taking shared responsibility instead of pushing all risks onto contractors, resulting in better prices and higher chances of reuse. (ID2-D1)

2) Clear contractual requirements mandating high-value reuse unless proven impossible due to safety, technical, or economic reasons, placing the burden of proof on contractors. (ID2-D2)

3) Legislative changes (e.g., upcoming Circular Materials Plan) could further push circular practices. (ID2-D3)

Expert ID_3

1) Balanced supply-demand relationships enable stable prices and viable business cases. (ID3-D2)
2) Equal regulatory frameworks across countries to maintain a level playing field; differences in national requirements (e.g., recycled content quotas) risk undermining domestic recyclers. (ID3-D2)
3) Initiatives like the "Bouwmaterialenakkoord" (Construction Materials Accord) bring industry and government together to develop feasible roadmaps for improving circularity, aligning technical possibilities with policy measures. (ID3-D3)

Expert ID_4

1) Companies specializing in reclaiming and marketing second-hand building materials demonstrate reuse is possible. (ID4-D1)
2) Emerging digital tools (material passports, digital building logbooks) could enable better reuse by making information about existing materials accessible, but only if standardized across the industry. (ID4-D2)

Expert ID_5

1) Viewing reused materials as standardized products with verified quality could reduce perceived risks and costs, making reuse more attractive and scalable. (ID5-D1)
2) Recognizing reuse as a mixed-material strategy: optimal solutions likely combine reused concrete, steel, wood, etc., rather than relying solely on one material type. (ID5-D2)
3) Emphasizing the small successes and existing positive examples can inspire wider adoption. (ID5-D3)

Expert ID_6

1) Strong local initiatives (e.g., housing corporations managing 37% of Eindhoven's housing stock) offer opportunities to build volume and momentum for reuse. (ID6-D1)
2) Cross-sector collaboration can generate strategic alliances between contractors, housing corporations, product developers, and manufacturers. (ID6-D2)
3) Efforts to coordinate fragmented networks and platforms (e.g., Cirkelstad Eindhoven, Brabantse aanpak) can reduce duplication and confusion. (ID6-D3)
4) Aesthetic appeal of reused elements can inspire acceptance and even generate marketing value for circular projects. (ID6-D4)

Expert ID_7

1) Extended Producer Responsibility by making producers responsible for their products' entire lifecycle, it encourages better planning for reuse and helps avoid market competition that can undermine reuse efforts. (ID7-D1)
2) European regulations: Mandatory design-for-reuse requirements at EU level would create a level playing field and drive systemic change across national markets. (ID7-D2)
3) Market demand for unique, aged materials (e.g., old bricks) can support reuse if buyers value aesthetic or historical qualities. (ID7-D3)

Expert ID_8

1) Niche players specializing in specific materials (e.g., reclaimed windows, bitumen, kitchen components) show strong market readiness; bringing them together can streamline reuse efforts. (ID8-D1)
2) Early involvement of architects to design with available reclaimed materials instead of specifying new products first. (ID8-D2)
3) Platforms like Duspot or Stichting Insert enable early matching of supply and demand, giving projects enough lead time to plan reuse. (ID8-D3)

Appendix-D: Merger of Groups

Red product groups from the original EIB list are merged into the “new” product group in green that is listed below the product groups.

Example given: product group 63 and 27 are merged into the new product group 140.

Nr	Productname english	Merge Rules applicable
114	Drainage fixtures; residential	9
63	Fixed and/or operable coated aluminium	
27	Coated aluminium	
140	Coated aluminium	1
68	Aluminium; powder coated	9
22	Aluminium grilles	9
34	Fixtures & TL-5 lamps, 28 W	9
40	Brick masonry	9
127	BB&S concrete façade brick + masonry + joint mortar	9
121	Concrete	8
78	Prefab concrete, utility buildings	
75	Prefab concrete, residential construction; AB-FAB	
76	Prefab concrete; AB-FAB	
113	Prefab concrete; reinforcement: 120kg/m3	
141	prefab concrete	1
100	Concrete, cast in-situ, C20/25; incl. reinforcement	
105	Concrete, cast in-situ, C20/25; incl. reinforcement + EPS	
138	concrete, cast in place c30/37	
147	Concrete, cast in-situ, C20/25; incl. reinforcement (100+105+138)	2,4
128	Concrete; Prefab, slim shaft, 400x400 mm	7
93	Concrete blocks (bonded)	9
73	Concrete roof tile	9
108	Hollow core slab excl. top layer, 60mm; prefab concrete; AB-FAB_23.01.024	
80	Hollow core slab excl. top layer, 60mm; prefab concrete; AB-FAB_27.01.012	
109	Top layer hollow core floor; concrete C30/37; incl. reinforcement	
79	Top layer hollow core floor; concrete C20/25; incl. reinforcement	
142	breedplaat floor	2,5
103	Aerated concrete blocks (Xella-Ytong)	9
72	PVC/lead combination	9
46	Windowsill	9
61	Compression chiller	9
120	Roof elements, timber ribs, stone wool, plywood; sustainable forestry	3
29	ROOF and ENVIRONMENT Modified bitumen, two-layer fully bonded (torch-on method)	9
96	Solid overhead door; sectional; aluminium + polycarbonate, insulated	9
102	EPDM, SBS foil; mechanically fixed	9
90	EPDM, SBS foil; glued	9
41	Expanded Polystyrene (EPS)	
133	EPS, 50% recycled	
148	Expanded Polystyrene (EPS) (41+133)	5
62	European hardwood components; untreated; sustainable forestry	9
129	European softwood; sustainable forestry	9
10	European softwood; painted with acrylic; sustainable forestry	
12	European softwood; painted; sustainable forestry	
14	Wood; painted with alkyd paint	
154	Wood; painted	5
37	European softwood; slats; sustainable forestry	7
60	European softwood beams with plywood; sustainable forestry	3,7
20	European softwood components	7
52	European softwood elements on batten system, insulated; sustainable forestry	7
126	Coated steel with Meranti steps; sustainable forestry	7
56	Insulated electrical wiring with PVC conduit	9
57	Gypsum blocks, normal density (NBVG)	9
47	Plasterboard system wall 100mm, double layer with insulation (NBVG)	9
112	High-efficiency glass; dry sealed	7
115	Double glazing; dry sealed	7
98	Single glazing; dry sealed	7
48	Triple glazing; dry sealed	7
30	Glass; 4mm; with 4mm plywood and PUR core	7
117	Glass wool MWA 2012; panels	7
50	Glass wool ceiling tiles	7
139	gravel	9
16	Bluestone	8
26	Honeycomb panel; painted with alkyd paint	9
19	Non-durable wood; painted	9
2	Non-load-bearing wooden interior wall, HSB prefab; sustainable forestry; NBvT	3
1	Wood, including concrete pilehead	3
31	Wood; painted with alkyd; window opening: 0.85m2	7
8	Stone wool, wood wool cement board	
36	Wood wool cement boards	
149	Wood wool cement boards (36+8)	1
86	HSB element; European softwood plywood and plasterboard; sustainable forestry	3
53	Individual central heating boiler 24 kW (solo)	9
3	Calcium silicate elements	
131	Calcium silicate adhesive blocks	
143	Calcium silicate elements	1
101	Hollow core slab, prefab concrete; AB-FAB_23.01.023	
55	Hollow core slab, prefab concrete; AB-FAB_27.01.011	
91	Dycore hollow core floor 260 mm (insulated)	
144	Hollow core slab, prefab concrete; AB-FAB	5
89	Ducts and grille for top cooling (light cooling)	
25	Ceramic sink	
4	Ceramic roof tile - unglazed	

33	Ceramic tiles; glazed/glued	
11	Ceramic tiles (11+33)	
150	Ceramic tiles	1
17	Climate ceiling with combined heating and cooling; steel ceiling with piping	9
66	Copper	8
58	Copper (pipe + conduit)	8
107	Artificial stone	
106	Artificial stone; element	
145	Artificial stone	1
24	Skylight (commercial buildings)	
70	Skylight (residential)	
146	Skylight	6
38	Glass skylight (commercial buildings)	9
44	skylight polycarbonate	9
65	Air handling unit; mechanical ventilation	9
59	Mechanical supply and exhaust; galvanized steel incl. grilles	9
77	Meranti; sustainable forestry	8
15	Meranti; painted with acrylic; standard forestry	7
125	Natural stone; cement-bonded	9
49	Natural stone; bonded	9
5	Natural stone	
13	Natural stone; slab	
151	Natural stone (5+13)	1
39	Polybutene; heating pipes	9
51	Polyethylene/polybutene heating pipes incl. fittings and distribution	9
69	Polyethylene foil	
110	PE film	
156	Polyethylene foil (69+110)	1
28	Wall-mounted toilet + basin, porcelain; including plastic reservoir	9
135	prefab concrete	7
132	PUR (air-based)	9
23	PVC; recycled PVC; steel box profiles	9
45	PVC, recycled pypes	9
94	PVC; recycled; diameter: 80mm; thickness: 1.8mm	9
54	Radiator, 50-70°C	9
119	Ribbed slab / rib cassette floor; incl. insulation	9
123	Reed, screw roof	9
35	Stainless steel, round 60 mm	9
95	Trapezoidal sandwich panel, steel + stone wool; powder-coated (55µ)	9
118	Screw pile; cast-in-place concrete C20/25; incl. reinforcement	9
18	Chipboard; 30mm thick with plastic layer	
85	Chipboard; plastic layer	
152	Chipboard (18+85)	1
6	Chipboard; sheet	7
83	Spray plaster	9
7	Coated steel, round 60 mm	9
32	Steel with Meranti steps; sustainable forestry	9
92	Heavy structural steel incl. beams, profiles, girders	9
124	Garage tilt door (residential), steel, galvanized	9
42	Powder-coated steel; filled with glass panel	9
9	Powder-coated steel; bars	9
81	Steel lifting structure + counterweight; 1 floor	9
88	Steel; passenger lift; coated	9
84	Steel; galvanized + coated	9
97	Galvanized steel roof panel	9
21	Stone wool MWA 2012, compressed; 20mm; with steel profiles	
134	Stonewool	
155	Stonewool	1
116	Inlet and outlet fixtures	9
64	Air intake and exhaust grilles	9
122	Ventilation ducts, exhaust and return	
99	Ventilation ducts, exhaust; residential	
153	Ventilation ducts, exhaust and return (122+99)	6
82	Fans; residential	9
71	Underfloor heating; polybutene pipes + accessories	9
43	Solid core panel on batten system, insulated	9
74	Spruce / zinc; standard forestry	9
111	Spruce plywood; 18 mm, incl. spruce frame; sustainable forestry	9
130	Wall heating; polybutene pipes + accessories	9
137	Third-party heat supply, delivery set ITW (individual domestic hot water)	9
136	Ground source heat pump 5 kW; incl. polyethylene probes	9
67	Heat recovery ventilation unit (HRV)	9
104	Sand	9
87	Sand-cement screed	9

Appendix E: General List, Sorted on Mass

The green product groups are selected for the impact study.

Nr	Group	Productnaam nederlands	Productname english	Input (ton)	Output (ton)	% of Total	Balance
142	Stone	Breedplaat vloer, (80+108+109+79)	Hollow core slab excl. top layer, 60mm; prefab concrete; AB-FAB	5216403	1792387	22.77	2.91
147	Stone	Beton,in het werk gestort, C20/25; incl.wapening (100+105+138)	Concrete, cast in-situ, C20/25; incl. reinforcement	3243620	1162636	14.77	2.79
144	Stone	Kanaalplaatvloer (101 + 55 + 91)	Hollow core slab, prefab concrete; AB-FAB	2410814	971466	12.34	2.48
143	Stone	Kalkzandsteen elementen (3+131)	Calcium silicate elements	3134563	871282	11.07	3.60
40	Stone	Baksteenmetselwerk	Brick masonry	912548	647767	8.23	1.41
87	Stone	Zandcement	Sand-cement screed	750695	309442	3.93	2.43
118	Stone	Schroefpaal; beton,in het werk gestort, C20/25; incl.wapening	Screw pile; cast-in-place concrete C20/25; incl. reinforcement	861628	229300	2.91	3.76
141	Stone	Beton prefab element, (75+76+78+113)	prefab concrete	515981	200945	2.55	2.57
1	Wood	Hout, inclusief oplanger	Wood, including concrete pilehead	0	152124	1.93	0.00
92	Steel	Staal zwaar constructiestaal o.a. balken, profielen en liggers	Heavy structural steel incl. beams, profiles, girders	248395	96799	1.23	2.57
128	Stone	Beton; Prefab, met slanke schacht, 400x400 mm	Concrete; Prefab, slim shaft, 400x400 mm	378522	90583	1.15	4.18
152	Wood	spaanplaat (18+85)	Chipboard (18+85)	198505	83256	1.06	2.38
120	Mix	Dak elementen, houten ribben, steenwol, multiplex; duurzame bosbouw	Roof elements, timber ribs, stone wool, plywood; sustainable forestry	320342	82278	1.05	3.89
119	Mix	Ribbenvloer / ribcassette vloer; incl. isolatie	Ribbed slab / rib cassette floor; incl. insulation	310982	81261	1.03	3.83
104	Stone	Zand	Sand	222727	76322	0.97	2.92
73	Stone	Betonpan	Concrete roof tile	160479	76225	0.97	2.11
103	Stone	Cellenbeton blokken (Xella-Ytong)	Aerated concrete blocks (Xella-Ytong)	207124	71144	0.90	2.91
150	Stone	Keramische tegels (11+33)	Ceramic tiles	92235	69142	0.88	1.33
112	Glass	glas (HR); droog beglaasd	High-efficiency glass; dry sealed	224420	66393	0.84	3.38
57	Stone	Gipsblokken, normale dichtheid (NBVG)	Gypsum blocks, normal density (NBVG)	104436	57045	0.72	1.83
115	Glass	glas, dubbel, droog beglaasd	Double glazing; dry sealed	194578	54854	0.70	3.55
155	Stone	Steenwol	Stonewool	184336	48735	0.62	3.78
149	Mix	Houtwolcementplaten (36+8)	Wood wool cement boards (36+8)	7098	40827	0.52	0.17
83	Stone	Spuitpleister	Spray plaster	88849	37286	0.47	2.38
154	Wood	Hout, beschilerd (10+12+14)	Wood; painted	30220	31706	0.40	0.95
96	Steel	Dichte overheaddeur; segmentendeur; aluminium+polycarbonaat, geisoleerd	Solid overhead door; sectional; aluminium + polycarbonate, insulated	74830	27851	0.35	2.69
15	Wood	Meranti; geschilderd, acryl; standaard bosbouw	Meranti; painted with acrylic; standard forestry	27141	27485	0.35	0.99
47	Mix	Gipskartonplaat systeemwand 100mm, dubbel beplaat met isolatie (NBVG)	Plasterboard system wall 100mm, double layer with insulation (NBVG)	37386	23090	0.29	1.62
30	Glass	Glas; 4mm; +4mm multiplex+pur-vulling	Glass; 4mm; with 4mm plywood and PUR core	27585	22480	0.29	1.23
148	plastic	EPS (41+133)	Expanded Polystyrene (EPS) (41+133)	45796	21633	0.27	2.12
81	Steel	Staal; hefconstructie+contragewicht; 1 bouwlaag	Steel lifting structure + counterweight; 1 floor	49617	21169	0.27	2.34
23	Mix	Pvc; gerecyceld pvc; stalen kokerprofielen	PVC; recycled PVC; steel box profiles	20329	19170	0.24	1.06
97	Steel	Stalen dakplaat verzinkt	Galvanized steel roof panel	48571	18072	0.23	2.69
29	Rest	DAK en MILIEU Bitumen gemod. tweelaags volledig gekleefd (brandmethode)	ROOF and ENVIRONMENT Modified bitumen, two-layer fully bonded (torch-on method)	21803	17862	0.23	1.22
60	Wood	Europees naaldhouten balken met europees naaldhouten multiplex; duurzame bosbouw	European softwood beams with plywood; sustainable forestry	26587	14348	0.18	1.85
95	Mix	Sandwich paneel trapeziumvormige, staal + steenwol; gepoedercoat (55mu)	Trapezoidal sandwich panel, steel + stone wool; powder-coated (55μ)	36537	13622	0.17	2.68
111	Wood	Vuren multiplex; 18 mm, incl vuren regelwerk; 56 mm; duurzame bosbouw	Spruce plywood; 18 mm, incl. spruce frame; sustainable forestry	41914	12846	0.16	3.26
94	plastic	Pvc; grecycled; diameter:80mm; d:1.8mm	PVC; recycled; diameter: 80mm; thickness: 1.8mm	31087	11894	0.15	2.61
17	Mix	Klimaatplafond gecombineerd warmte en koude; staalplafond+leidingen	Climate ceiling with combined heating and cooling; steel ceiling with piping	10788	10783	0.14	1.00
135	Stone	Prefab beton; h:2.7.b:1.1m; incl. bordes	prefab concrete	93558	10454	0.13	8.95
86	Wood	HSB element; Europees naaldhouten multiplex en gipsplaat; duurzame bosbouw	HSB element; European softwood plywood and plasterboard; sustainable forestry	23170	9580	0.12	2.42
140	Steel	Aluminium, gecoat(27+63)	Coated aluminium	15740	9502	0.12	1.66
62	Wood	Europees loofhouten delen; onbehandeld; duurzame bosbouw	European hardwood components; untreated; sustainable forestry	17070	8953	0.11	1.91
34	Mix	Armatuur & lampen, TL-5, 28 W	Fixtures & TL-5 lamps, 28 W	11456	8463	0.11	1.35
88	Steel	Staal; personenlift; gemoffeld	Steel; passenger lift; coated	20208	8157	0.10	2.48
4	Stone	Keramische pan - ongeglazuurd	Ceramic roof tile - unglazed	0	7773	0.10	0.00
74	Wood	Vuren / Zink; standaard bosbouw	Spruce / zinc; standard forestry	16062	7390	0.09	2.17
125	Stone	Natuursteen; cement	Natural stone; cement-bonded	28743	6950	0.09	4.14
121	Stone	Beton	Concrete	24965	6299	0.08	3.96
9	Steel	Staal; gepoedercoat; spijlen	Powder-coated steel; bars	2297	5987	0.08	0.38
56	Rest	Geïsoleerde installatiedraad + mantelbuis:pvc	Insulated electrical wiring with PVC conduit	10854	5973	0.08	1.82
61	Mix	Compressiekoelmachine	Compression chiller	9340	4992	0.06	1.87
43	Rest	Volkern; op regelwerk, geisoleerd	Solid core panel on batten system, insulated	7246	4907	0.06	1.48
102	Rest	EPDM, sbs cachering; mechanisch bevestigd	EPDM, SBS foil; mechanically fixed	13357	4835	0.06	2.76
93	Stone	Betonblokken (gelijmd)	Concrete blocks (bonded)	12572	4810	0.06	2.61
117	Glass	Glaswol MWA 2012; platen;	Glass wool MWA 2012; panels	17724	4742	0.06	3.74
28	Stone	porselein Wandcloset + fontein, porselein; incl. kunststof reservoir	Wall-mounted toilet + basin, porcelain; including plastic reservoir	5621	4620	0.06	1.22
127	Stone	BB&S betongevelsteen + metselmortel + voegmortel	BB&S concrete façade brick + masonry + joint mortar	19153	4585	0.06	4.18
126	Steel	Gecoat staal met Meranti treden; duurzame bosbouw	Coated steel with Meranti steps; sustainable forestry	19059	4575	0.06	4.17
26	Wood	Honingraat; geschilderd:alkyd	Honeycomb panel; painted with alkyd paint	5047	4332	0.06	1.17
37	Wood	Europees naaldhout; spijlen; duurzame bosbouw	European softwood; slats; sustainable forestry	5782	4163	0.05	1.39
145	Stone	Kunststeen (106+107)	Artificial stone	12037	3977	0.05	3.03
65	Mix	Luchtbehandelingskast; mechanische ventilatie	Air handling unit; mechanical ventilation	7444	3867	0.05	1.92
35	Steel	RVS, rond 60 mm	Stainless steel, round 60 mm	5208	3812	0.05	1.37
25	Stone	Keramiek; wastafel	Ceramic sink	3965	3483	0.04	1.14
98	Glass	glas, enkel droog beglaasd	Single glazing; dry sealed	8831	3272	0.04	2.70
90	Rest	EPDM, sbs cachering; verkleefd	EPDM, SBS foil; glued	7032	2795	0.04	2.52
132	Mix	PUR (lucht)	PUR (air-based)	13604	2589	0.03	5.25
72	Mix	Combinatie PVC/Lood	PVC/lead combination	5256	2543	0.03	2.07
7	Steel	Staal gecoat, rond 60 mm	Coated steel, round 60 mm	0	2407	0.03	0.00
45	plastic	Pvc; gerecycled; leiding	PVC, recycled pypes	3448	2256	0.03	1.53
54	Steel	Radiator, 50-70 C	Radiator, 50-70°C	3861	2210	0.03	1.75
84	Steel	Staal; verzinkt+gemoffeld	Steel; galvanized + coated	3983	1667	0.02	2.39
151	Stone	Natuursteen (5+13)	Natural stone (5+13)	1551	1601	0.02	0.97
44	plastic	Lichtstraat polycarbonaat (utiliteitsbouw)	skylight polycarbonate	2375	1576	0.02	1.51
52	Wood	Europees naaldhouten delen; op regelwerk, geisoleerd; duurzame bosbouw	European softwood elements on batten system, insulated; sustainable forestry	2669	1567	0.02	1.70
31	Wood	Hout; geschilderd:alkyd; glasopening:0.85m2	Wood; painted with alkyd; window opening: 0.85m2	1904	1517	0.02	1.26
77	Wood	Meranti; duurzame bosbouw	Meranti; sustainable forestry	3405	1517	0.02	2.25

129	Wood	Europees naaldhout; duurzame bosbouw	European softwood; sustainable forestry	6607	1512	0.02	4.37
16	Stone	Hardsteen	Bluestone	1443	1443	0.02	1.00
48	Glass	Glas: Drievoudig glas; droog beglaasd	Triple glazing; dry sealed	2336	1423	0.02	1.64
46	Stone	Composietsteen, Vensterbank - gegoten composietsteen	Windowsill	2173	1419	0.02	1.53
51	plastic	Polyetheen/polybuteen; cv-leidingen; incl. koppelingen + verdeling	Polyethylene/polybutene heating pipes incl. fittings and distribution	2158	1271	0.02	1.70
71	Mix	Vloerverwarming; leidingen:polybuteen+toebehoren	Underfloor heating; polybutene pipes + accessories	2599	1263	0.02	2.06
123	Rest	Riet, schroefdak	Reed, screw roof	5084	1255	0.02	4.05
59	Mix	Mechanische aan- en afvoer; verzinkt staal, incl. roosters	Mechanical supply and exhaust; galvanized steel incl. grilles	2171	1181	0.02	1.84
156	plastic	Polyetheen, folie (69+110)	Polyethylene foil (69+110)	2729	1084	0.01	2.52
22	Steel	Aluminiumroosters	Aluminium grilles	1094	1042	0.01	1.05
19	Wood	hout Onverduurzaamd ; geverfd	Non-durable wood; painted	1014	1001	0.01	1.01
42	Steel	Staal; gepoedercoat; glasplaat vulling	Powder-coated steel; filled with glass panel	1416	961	0.01	1.47
32	Steel	Staal met Meranti treden; duurzame bosbouw	Steel with Meranti steps; sustainable forestry	1225	958	0.01	1.28
58	Steel	Koper (leiding +mantelbuis)	Copper (pipe + conduit)	1654	902	0.01	1.83
53	Steel	Individuele cv-ketel 24 kW (solo)	Individual central heating boiler 24 kW (solo)	1215	704	0.01	1.73
153	Steel	Ventilatiekanalen, aan en afvoer (122+99)	Ventilation ducts, exhaust and return (122+99)	2004	652	0.01	3.07
67	Steel	WTW-unit	Heat recovery ventilation unit (HRV)	1147	589	0.01	1.95
2	Wood	Hout, Houten niet dragende binnenwand, HSB prefab; duurzaam bosbeheer; NBvT	Non-load-bearing wooden interior wall, HSB prefab; sustainable forestry; NBvT	0	585	0.01	0.00
89	Steel	Kanalen en rooster tbv Topkoeling (koeling licht)	Ducts and grille for top cooling (light cooling)	1155	460	0.01	2.51
50	Glass	Glaswoltegels	Glass wool ceiling tiles	769	458	0.01	1.68
68	Steel	Aluminium; gemoffeld	Aluminium; powder coated	885	454	0.01	1.95
49	Stone	Natuursteen; gelijmd	Natural stone; bonded	604	363	0.00	1.66
6	Wood	Spaanplaat; plaat	Chipboard; sheet	0	283	0.00	0.00
20	Wood	Europees naaldhouten delen	European softwood components	290	282	0.00	1.03
66	Steel	Koper	Copper	272	140	0.00	1.95
130	Mix	Wandverwarming; leidingen: polybutene+toebehoren	Wall heating; polybutene pipes + accessories	606	132	0.00	4.57
38	Glass	Lichtstraat glas (utiliteitsbouw)	Glass skylight (commercial buildings)	164	118	0.00	1.39
124	Steel	Staal, Garagekanteldeur (woningbouw), staal, verzinkt	Garage tilt door (residential), steel, galvanized	472	114	0.00	4.14
64	Steel	Toe- en afvoerroosters	Air intake and exhaust grilles	139	72	0.00	1.92
82	Steel	Ventilatoren; woningbouw	Fans; residential	172	72	0.00	2.37
39	plastic	Polybuteen; cv-leidingen	Polybutene; heating pipes	93	67	0.00	1.39
146	Glass	Lichtkoepel (24+70)	Skylight	104	52	0.00	2.00
114	Stone	Afvoerornamenten; woningbouw	Drainage fixtures; residential	17	5	0.00	3.40
137	Mix	Warmtelevering derden, afleverset ITW (individueel warmtapwater)	Third-party heat supply, delivery set ITW (individual domestic hot water)	43	4	0.00	11.85
116	Stone	Toe- en afvoerornamenten	Inlet and outlet fixtures	3	1	0.00	3.57
136	Mix	Warmtepomp bodem 5 kW; incl. aardsondes:polyetheen	Ground source heat pump 5 kW; incl. polyethylene probes	5	1	0.00	9.20
139	Stone	Grind	gravel	191732	0	0.00	nvt

Appendix-F: Impact Study

Nr	Group	Productnaam nederlands	Productname English	Input (ton)	Output (ton)	MKI kg	MKI m	MKI m2	MKI m3	bron MKI	cat	kg/m2	kg/m3	soarce	MKI/TON	Inpact
142	Stone	Breedplaat vloer, (80+108+109+79)	Hollow core slab excl. top layer, 60mm; prefab concrete; AB-FAB	5216403	1792387			7.882		#nmd_29055 + #nmd_10814	2	604.6		#nmd_29055 + #nmd_10814	13.0367185	23366844.7
147	Stone	Beton,in het werk gestort, C20/25; incl.wapening (100+105+138)	Concrete, cast in-situ, C20/25; incl. reinforcement	3243620	1162636				31.07051	#nmd_29494 + #nmd_45791	3		2440	#nmd_201630	12.7338156	14804792.4
144	Stone	Kanaalplaatvloer (101 + 55 + 91)	Hollow core slab, prefab concrete; AB-FAB	2410814	971466			4.714		#nmd_94094	1	379		#nmd_94094	12.4379947	12083089.0
143	Stone	Kalkzandsteen elementen (3+131)	Calcium silicate elements	3134563	871282			1.932		#nmd_201457	1	219		1*	8.82191781	7686378.2
40	Stone	Baksteenmetselwerk	Brick masonry	912548	647767			4.734		#nmd_28186	3	180		#nmd_28186	26.3	17036272.1
87	stone	Zandcement	Sand-cement screed	750695	309442			1.369		#nmd_28628	3	105		2*	13.0380952	4034534.3
118	stone	Schroefpaal; beton,in het werk gestort, C20/25; incl.wapening	Screw pile; cast-in-place concrete C20/25; incl. reinforcement	861628	229300		10.49		130.5235	#nmd_27459	3		2440.83	#nmd_201630	53.4750422	12261827.2
141	Stone	Beton prefab element, (75+76+78+113)	prefab concrete	515981	200945				57.1625	#nmd_106854	3		2462	#nmd_10837	23.2179123	4665523.4
1	wood	Hout, inclusief oplanger	Wood, including concrete pilehead	0	152124		0.24		2.081973	#nmd_27502	3		942.8571	1meter beton, 6 meter hardhout 3*	2.20815349	335913.1
92	Steel	Staal zwaar constructiestaal o.a. balken, profielen en liggers	Heavy structural steel incl. beams, profiles, girders	248395	96799	0.12				#nmd_91193	3				120	11615880.0
128	Stone	Beton; Prefab, met slanke schacht, 400x400 mm	Concrete; Prefab, slim shaft, 400x400 mm	378522	90583		7.24		45.25	#nmd_37855	3		2462	141	18.3793664	1664858.1
152	wood	spaanplaat (18+85)	Chipboard (18+85)	198505	83256			0.289		#nmd_91381	1	12.6		4*	22.9365079	1909601.9
120	mix	Dak elementen, houten ribben, steenwol, multiplex; duurzame bosbouw	Roof elements, timber ribs, stone wool, plywood; sustainable forestry	320342	82278			3.183		#nmd_29337	3	29.08		#nmd_29337	109.456671	9005876.0
119	mix	Ribbenvloer / ribcassette vloer; incl. isolatie	Ribbed slab / rib cassette floor; incl. insulation	310982	81261			7.969		#nmd_29032	3	219		#nmd_29032	36.3881279	2956935.7
104	stone	Zand	Sand	222727	76322				2.989	#nmd_36251	3		1500	#nmd_36251	1.99266667	152084.3
73	Stone	Betonpan	Concrete roof tile	160479	76225			1.009		#nmd_32290	3	42		5*	24.0238095	1831214.9
103	stone	Cellenbeton blokken (Xella-Ytong)	Aerated concrete blocks (Xella-Ytong)	207124	71144			3.294		#nmd_28124	3	107.26		#nmd_28124	30.7104233	2184862.4
150	stone	Keramische tegels (11+33)	Ceramic tiles	92235	69142			2.166		#nmd_37815	3	24		8*	90.25	6240065.5
112	Glass	glas (HR); droog beglaasd	High-efficiency glass; dry sealed	224420	66393			6.953		#nmd_31140	3	300		#nmd_31140	23.1766667	1538768.4
57	stone	Gipsblokken, normale dichtheid (NBVG)	Gypsum blocks, normal density (NBVG)	104436	57045			2.045		#nmd_36704	2	51.1		6*	40.0195695	2282916.3
115	Glass	glas, dubbel, droog beglaasd	Double glazing; dry sealed	194578	54854			4.121		#nmd_29896	3	275		#nmd_29896	14.9854545	822012.1
155	Stone	Steenwol (21+134)	Stonewool	184336	48735			1.338		#nmd_31990	3	18.2		#nmd_31990	73.5164835	3582825.8
149	Mix	Houtwolcementplaten (36+8)	Wood wool cement boards (36+8)	7098	40827			0.468		#nmd_32216	3	13.1		#nmd_32216	35.7251908	1458552.4
148	Plastic	EPS (41+133)	Expanded Polystyrene (EPS) (41+133)	45796	21633			0.531		#nmd_201461	2	2.1		7*	252.857143	5470058.6

1* : https://www.xella.nl/product/silka-lijmblokken/20002271
2* : https://www.joostdevree.nl/shtmls/zandcement.shtml#:~:text=Zandcement%20wordt%20meestal%20gelegd%20in,kunnen%20zijn%20(hechtende%20dekvloer). En https://schuimbetonvloer.nl/lichtgewicht-zandcement/#:~:text=Zandcement%20heeft%20gemiddeld%20een%20dichtheid,effici%C3%ABnter%20en%20bouw%20je%20zorgeloos.
3: https://www.kcaf.nl/richtlijn-onderzoek-naar-houten-paalfundering/
4: https://www.baars-bloemhoff.nl/product/unilin-evola-spaanplaat-00551-cst-zid347815
5: https://www.bmigroup.com/nl/hellend-dak/betondakpannen/sneldek/sneldek-aerlox/#:~:text=Een%20betonnen%20dakpan%20weegt%20gemiddeld%2042%20kg%20per%20m2.
6: https://www.bmn.nl/media/akeneo_connector/asset_files/K/n/Knauf_Gipsblokken_KOMO_2022pdf_8ce3.pdf
7* https://www.joostdevree.nl/shtmls/eps.shtml
8* https://www.environdec.com/library/epd6762

Appendix-G: MCA Criteria Grouping

	B = Barrier D = Driver	Relevant categories for MCA (Product Dependent)	other found categories (Not product related)	Reasoning
	ID			
1) high upfront investment costs.	B1	**Costs**		suggest that for at least someone in the process, costs will increase
1) Concern about the high initial cost Survey	B15	**Costs / perceived Risk**		suggest that for at least someone in the process, costs will increase
5) insufficient financial incentives from governments.	B5	**Costs**	**Lack of government initiative / regulations**	Suggest that without subsidies, no changes will occur since it is not profitable
1) Disproportionately high cost of labour in Europe relative to materials.	B6	**Costs**		Circular design is more labour intensive, suggest costs will increase
2) Environmental externalities are not adequately priced. Low global prices of virgin materials. Resulting in an unlevel playing field that undermines circular initiatives.	B10	**Costs**		Uneven playing field, with circular materials as the more expensive option
1) Uneven playing field due to cheap virgin materials and limited access to high-quality secondary materials.	B48	**Costs**		Uneven playing field, with circular materials as the more expensive option
4) practical barriers like cost and complexity prevent large-scale adoption. Circular products are often more expensive or less accessible than linear alternatives.	B12	**Costs**		"Circular products are often more expensive"
3) Perception of the extra cost being incurred	B17	**Costs**		Higher costs, or higher perceived cost are a slippery slope. However costs are based on expert "opinion"
2) Companies that decouple profitability from raw material sales, embracing service-based models or value-retention logic. (Change in business model)	D8	**Costs**		suggest that without change in business model, circularity is more expensive
				all above suggest, circularity is more expensive. Resulting in a question about relevance of cost, and difference between product groups.
2) lack of technical capabilities and expertise.	B2	**Technical expertise/capabilities**		suggest lack of capability and expertise
4) limited awareness of circular strategies among stakeholders.	B4	**Technical expertise/capabilities**		suggest lack of expertise
2) Lack of professionals skilled in reused materials and deconstruction techniques.	B7	**Technical expertise/capabilities**		suggest lack of expertise
4) Contractors lack technical knowledge and experience	B18	**Technical expertise/capabilities**		suggest lack of expertise
8) Shortage of skilled labourers	B22	**Technical expertise/capabilities**		suggest lack of expertise
3) Lack of comprehensive data across the product lifecycle. While data on end-of-life recycling exists, there is limited transparency regarding design and material composition early in the value chain.	B11	**Technical expertise/capabilities**		Lack of capability due to lack of knowledge
1) Conventional design does not prioritise disassembly or material reuse.	B13	**Technical expertise/capabilities**		lack of capability , because not demountable
1) Demount ability.	D9	**Technical expertise/capabilities**		lack of capability , because not demountable
10) Lack of design knowledge and skills	B24	**Technical expertise/capabilities**		Lack of capability
13) Lack of effective marketing from material producers	B27	**Technical expertise/capabilities**		Lack of capability
1) data quality.	B36	**Technical expertise/capabilities**		Lack of capability, due to lack of data
3) lack of digital product passports.	B38	**Technical expertise/capabilities**		Lack of capability, due to lack of data
3) Lack of adequate material/product records.	B43	**Technical expertise/capabilities**		Lack of capability, due to lack of data
2) Lack of consistent taxonomy, material classification, and performance data, without which architects and contractors remain hesitant to specify reused products in tenders .	B49	**Technical expertise/capabilities**		Lack of capability, due to lack of data
12) Lack of comprehensive tools and data to compare material alternatives	B26	**Technical expertise/capabilities**	**Lack of uniform framework**	lack of capability, due to lack of tool and data
				all above suggest, there is either a lack of knowledge about the products/material, within stakeholders, or it is simply technical not feasible. This will not be a question on the interview, since anwsers can be found in literature, and lack of knowledge is not product dependent.
2) Risks and uncertainties involved in adopting new materials	B16	**Perceived Risks / uncertainty**		suggest, higher "perceived' risks
4) An aversion to risk and the tendency to delegate it down the value chain.	B31	**Perceived Risks / uncertainty**		suggest, higher "perceived' risks
2) Market reluctance	B37	**Perceived Risks / uncertainty**		suggest, higher "perceived' risks
1) Institutional uncertainty.	B41	**Perceived Risks / uncertainty**		suggest, higher "perceived' risks
5) Clients worrying about profitability	B19	**Perceived Risks / uncertainty**		suggest, higher "perceived' financial risks
4) legal uncertainty about liability for reused components.	B39	**Perceived Risks / uncertainty**		suggest, higher "perceived' legal risks
4) Legal liability.	B44	**Perceived Risks / uncertainty**		suggest, higher "perceived' legal risks
2) without clear quality indicators and traceable documentation, stakeholders face too much uncertainty and legal risk to reuse products.	B47	**Perceived Risks / uncertainty**		suggest, higher "perceived' legal risks
				All above suggest, that circular product/material usage, results in a "perceived' higher risk, either legal or financial. This will be a interview question, since the risk can be perceived to be higher for loadbearing structures then for plywood.
1) The "chicken-and-egg" dilemma, where limited demand for circular products discourages supply, and vice versa.	B9	**Supply and Demand**		Suggest that it is important for supply and demand to be somewhat in balance, or demand to be higher then supply.
				This can be found in literature
2) Fragmentation of responsibilities within government bodies.	B14	-	**Lack of government initiative / regulations**	not product group dependent
7) Building code restriction and lack of regulation	B21	-	**Lack of government initiative / regulations**	not product group dependent
9) Lack of government promotion and incentives	B23	-	**Lack of government initiative / regulations**	not product group dependent
3) Inadequate and often obstructive regulation.	B30	-	**Lack of government initiative / regulations**	not product group dependent
5) Lack of standardised assessment protocols, and compatibility with Bouwbesluit remain critical gaps.	B45	-	**Lack of government initiative / regulations**	not product group dependent
3) Lack of enforceable legal and financial mechanisms that reward reuse, not just recycling.	B52	-	**Lack of government initiative / regulations**	not product group dependent
3) absence of a supportive regulatory framework.	B3	-	**Lack of government initiative / regulations**	not product group dependent
3) Legal clarity: guidance on when reused elements qualify as "products" rather than "waste" helped avoid regulatory grey zones and simplified logistics.	D16	-	**Government initiative / regulations**	not product group dependent
3) Supportive fiscal instruments, such as tax relief for reused materials or innovation subsidies, tipped the business case in favour of circular methods.	D19	-	**Government initiative / regulations**	not product group dependent

1) The absence of a clear and unified goal across stakeholders regarding what the circular transition entails.	B28	-	**Lack of uniform framework**	not product group dependent
2) Misaligned steering mechanisms and performance metrics that fail to support circular processes.	B29	-	**Lack of uniform framework**	not product group dependent
3) The strategies and instruments available are dispersed across different maturity levels, leading to fragmented implementation.	B35	-	**Lack of uniform framework**	not product group dependent
5) poor interoperability of databases limit their potential. The authors stress that without uniform frameworks and trust in the provenance and safety of reused materials, the circular construction market cannot scale effectively .	B40	-	**Lack of uniform framework**	not product group dependent
1) Lack of legally recognised framework to assess and register materials' performance for reuse.	B46	-	**Lack of uniform framework**	not product group dependent
1) Dependence on integrated design workflows.	B50	-	**Lack of uniform framework**	not product group dependent
1) proactive ecosystems; designers, contractors, and suppliers were embedded in active networks that facilitated trust, information sharing, and joint ventures.	D3	-	**uniform framework**	not product group dependent
2) Digital traceability tools	D4	-	**uniform framework**	not product group dependent
3) Common reuse standards	D5	-	**uniform framework**	not product group dependent
4) Shared materials platforms	D6	-	**uniform framework**	not product group dependent
2) Standardised inspection protocols made it easier to verify the mechanical integrity of reused steel, concrete and wood.	D12	-	**uniform framework**	not product group dependent
3) Digital tracking tools, such as material passports and visual tagging, ensured traceability and improved coordination between donor and receiving sites.	D13	-	**uniform framework**	not product group dependent
2) Fragmented accountability as bottlenecks.	B42	-	**Fragmented accountability**	not product group dependent
2) Dependence on client demand.	B51	-	**Client commitment**	not product group dependent
3) Consistent finding was that the success of circular projects often hinged on the client's commitment and vision, rather than systemic support or market demand.	B8	-	**Client commitment**	not product group dependent
1) Explicitly client requested circular outcomes at the design brief stage.	D1	-	**Client commitment**	not product group dependent
1) Circular goals were embedded in public procurement, for example, municipal projects that prioritised reused or biobased materials saw significantly higher reuse rates.	D17	-	**Client commitment**	not product group dependent
2) Local authorities acted as launch customers for innovation, commissioning buildings with explicit reuse targets.	D18	-	**Client commitment**	not product group dependent
2) Partnerships with housing associations, who were more willing to adopt circular practices due to long-term asset ownership and lifecycle cost focus.	D21	-	**Client commitment**	not product group dependent
2) firms who adopted a circular strategy from the design phase benefited from reduced waste costs, increased tenant satisfaction, and greater project adaptability.	D10	-	**Early incorporation of circularity**	not product group dependent
1) Early collaboration with demolition teams to pre-identify reusable elements.	D11	-	**Early incorporation of circularity**	not product group dependent
1) Systematic pre-assessment of materials during demolition planning, reducing last-minute surprises and preserving material integrity.	D14	-	**Early incorporation of circularity**	not product group dependent
1) Material mapping prior to demolition, allowing secondary products to be logged, certified, and matched with upcoming developments.	D20	-	**Early incorporation of circularity**	not product group dependent
2) Alignment with project timelines: the most effective reuse happened where schedules allowed for matching of supply and demand between sites.	D15	-	**Planning accounted for matchmaking**	not product group dependent
1) Companies thrive when they have a clear long-term vision, paired with operational flexibility.	D7	-	**?**	not product group dependent
6) Unwillingness to change from conventional materials to CBBMs	B20	-	-	not product group dependent
11) Perception of low quality in CBBMs (e.g., fire and moisture resistance, low durability, etc.)	B25	-	-	not product group dependent
5) The challenge of aligning private investment incentives with societal-level benefits. The latter reflects the economic misfit where the costs of innovation (e.g. higher upfront expenses) are borne by developers, while the benefits (e.g. lower environmental impact, resource preservation) accrue more diffusely across society.	B32	-	-	not product group dependent
1) Tension between different societal missions: EG: affordable housing construction often conflicts with circular goals.	B33	-	-	not product group dependent
2) Stakeholders still prioritise CO_2 reduction over material reuse, meaning that circularity is subsumed under energy goals.	B34	-	-	not product group dependent

Appendix-H: Summary of MCA Interviews

Eight interviews were conducted. During the eight interviews some trends could be found in topics indicated by the interviewees. In the list below, these topics and the number of interviews it was indicated in can be seen.

Topic	Times cited
Time is Crucial	**6**
It will depends on who you ask	**3**
Housing associations are key	**2**
Technical limits do not exist	**5**
The criteria influence each other	**3**
Structural elements are riskier and more complex	**4**
Mismatch: Who pays, who will profit	**2**
Steel Is the most promising product group	**3**
Timber Is the most promising product group	**4**

Expert Interview 1:

Expertise: Position in the Chain
The expert has extensive experience with BRL 2506 and quality management of recycled rubble aggregates, having worked with these materials throughout his career. He manages the foundation that oversees the BRL, facilitates expert committees, and works at MISA Advies, an agency supporting various industry associations, including demolition contractors representing 80-90% of the Dutch professional demolition market.

Confidence in Providing Answers
He spoke with confidence about his knowledge of concrete and brickwork recycling but expressed reservations about assessing reuse potential in other materials. He acknowledged limitations when asked for examples beyond his core expertise.

Highlighted materials

- **Steel:** Highest potential: High value per ton makes both recycling and reuse attractive, but quality assurance leads to overengineering for safety, significantly reducing CO_2 savings. Key barrier: risk perception and insurance.
- **Wood:** High-potential: Especially structural timber has a thriving informal reuse market; no significant barriers beyond logistics.
- **Brickwork:** Complete walls are almost never reused; disassembling individual bricks is technically possible but expensive, limiting feasibility. The demolition company can easily peal of the outer layer. But doesn't since it is not financially interesting.

Relevant and Irrelevant Criteria

- **Important criteria:**
  - Balance between supply and demand.
  - Marginal effort for selective dismantling versus potential revenue.

- Risk and insurability of reused structural elements.

- **Less relevant criteria:**
  - Costs alone are not decisive if there's demand for the material.
  - Environmental LCA scores are not yet a primary driver for demolition contractors.

Drivers and Barriers in the Chain

- **Drivers:**
  1) Regulatory incentives, such as lowering taxes on labor and increasing taxes on primary raw materials.
  2) Direct reuse at the same location (short reuse cycles), which is currently hindered by the timing of demolition and new construction permits.
  3) Proven demand in informal markets.

- **Barriers:**
  1) Strict technical requirements (e.g., insulation value, dimensions) for new builds limit the use of reused materials.
  2) Insurance and safety concerns push contractors to over-dimension reused structural elements, eroding sustainability gains.
  3) Current demolition practices favor speed and low costs over careful dismantling because demolition usually starts only after new building permits are granted. This limits circular practises.
  4) Regulations (e.g., Building Decree) and certification systems (e.g., KOMO) restrict high-grade reuse of recycled materials in certain applications like bridges and high-rise structures.
  5) There is often an difference in who benefits, and who pays the price. Eg: steel lighting, free to hand in for circular reuse, but as steel some money is paid.

Additional comments:

- The informal market (selling to private individuals), is booming.
- Risks for structural elements are higher

Expert Interview 2:

Expertise: Position in the Chain

This expert works at SGS, focusing on existing buildings, supervising or preparing demolition projects, and mapping opportunities for high-value reuse and recycling of released materials. Their role bridges technical knowledge and process management, helping clients (often municipalities) integrate circularity into procurement documents, specifications, and selection guidelines, and sometimes acting as an evaluator in tenders.

Confidence in Providing Answers

He was confident discussing both the technical and process-related aspects of reuse, sharing concrete examples from recent projects and expressing a nuanced understanding of the practicalities and economic dynamics in demolition and reuse.

Steel, Wood, and Especially Brickwork

- **Brickwork:** Reuse by cleaning individual bricks is increasingly common, especially when clients accept slightly higher costs due to significant environmental benefits. Risks are considered low if bricks are cleaned properly.

- **Wood:** Structural beams (especially untreated) are highly suitable for one-to-one reuse. Detailed knowledge of dimensions and condition (e.g., beams from 1941 still in excellent state) supports confident reuse if designs can adapt to available materials.

- **Steel:** Preferred material for reuse due to its monolithic nature, consistent specifications, significant environmental benefits, and well-established norms (e.g., NTR) to verify quality.

Relevant and Irrelevant Criteria

- **Important criteria:**
    - **Balance of supply and demand:** The most decisive factor; without a buyer, products will be conventionally demolished.
    - **Technical feasibility:** Especially for structural elements that must comply with the Building Code.
    - **Verification of quality:** Key to ensuring safety, particularly for load-bearing components.
    - **Sufficient time for arranging reuse:** Without time, even reusable products end up in waste streams.
- **Less relevant criteria:**
    - Costs and risks are secondary but still significant; their importance grows if clients are commercial developers rather than public bodies.
    - LCA scores alone are not decisive; direct reuse does not automatically guarantee a better environmental score, as the National Environmental Database formula shows.

Drivers and Barriers in the Chain

- **Drivers:**

1) Projects with clients willing to "stick their necks out," taking shared responsibility instead of pushing all risks onto contractors, resulting in better prices and higher chances of reuse.
2) Clear contractual requirements mandating high-value reuse unless proven impossible due to safety, technical, or economic reasons, placing the burden of proof on contractors.
3) Legislative changes (e.g., upcoming Circular Materials Plan) could further push circular practices.

- **Barriers:**

1) Short lead times in tenders; effective reuse needs several months for finding buyers, not just weeks.
2) Lack of alignment between supply (released materials) and demand (new projects).
3) Strict compliance with the Building Code makes reuse of structural elements with uncertain quality a high-risk proposition, especially for cast-in-place concrete.
4) Fragmented market dynamics, where conflicting interests between clients and contractors hinder optimal outcomes.
5) Projects prioritizing speed over careful dismantling due to pressures tied to new construction permits.

Expert Interview 3:

Expertise: Position in the Chain

This expert works for the Federation of Dutch Rubber and Plastics Industry (NRK), representing ~400 companies in the plastics and rubber manufacturing and recycling sector, estimated to cover 80% of the Dutch market by turnover. The expert has focused on extended producer responsibility in the construction sector, contributing as lead author on CB23's guidelines. Although its experience spans only a few years, it is concentrated on plastics and recycling policy.

Confidence in Providing Answers

He confidently discussed the economic and regulatory dimensions of recycling and reuse, particularly regarding plastics and insulation materials. He acknowledged limited knowledge outside plastics (e.g., metals, concrete) but provided detailed insights on market dynamics, regulation, and business models for plastics.

Product groups of interest.

- **EPS (Expanded Polystyrene):** Reuse is technically feasible and effective if handled correctly; it remains a promising material when regulations allow.
- **PU (Polyurethane) insulation:** New projects show high reuse potential for PU panels if proper cleaning and de-gassing are applied. However, current regulations restrict reuse, which the expert considers outdated.
- **Other materials (steel, concrete, brick):** Outside his specialization; he refrained from concrete statements, but emphasized similar financial drivers across product types.

Relevant and Irrelevant Criteria

- **Most important criteria:**
  - **Balance of supply and demand:** Crucial for establishing a profitable business case; without demand, products cannot be reused profitably.
  - **LCA score (environmental performance):** Relevant, but only after the market potential is assessed.
  - **Technical feasibility:** Companies will solve technical challenges if there's a strong enough business incentive.
- **Less important criteria:**
  - **Costs:** Secondary to demand; high costs can be justified if resale prices are correspondingly high.
  - **Risks:** Intertwined with technical feasibility and costs, but harder to separate as an independent factor.

Drivers and Barriers in the Chain

- **Drivers:**

1) Balanced supply-demand relationships enable stable prices and viable business cases.
2) Equal regulatory frameworks across countries to maintain a level playing field; differences in national requirements (e.g., recycled content quotas) risk undermining domestic recyclers.
3) Initiatives like the "Bouwmaterialenakkoord" (Construction Materials Accord) bring industry and government together to develop feasible roadmaps for improving circularity, aligning technical possibilities with policy measures.

- **Barriers:**

1) Lack of a viable business case is the key barrier: even if reuse is technically possible, it won't happen if it's unprofitable.
2) Regulatory hurdles prohibiting reuse of certain materials (e.g., PU insulation) even when practical solutions exist.
3) Market volatility: large-scale production of cheap virgin plastics abroad (e.g., US, Asia) suppresses recycled material prices, causing European recyclers to shut down.

4) Fragmented or inconsistent regulations lead to competitive disadvantages for domestic recyclers.

5) Overly rigid linear thinking in policy fails to accommodate innovative reuse systems.

Expert Interview 4:

Expertise: Position in the Chain

This expert is a PhD candidate researching reuse of construction and demolition waste. The PhD project, a collaboration between TU Eindhoven, TU Delft, and Utrecht University, investigates technical, economic, and behavioral aspects: Eindhoven develops digital infrastructure, Delft examines business models, and Utrecht studies behavioral change.

Confidence in Providing Answers

The expert was candid about its limited hands-on experience in the industry but confident in sharing insights from interviews with practitioners. They provided clear, nuanced views on information challenges and industry perceptions of costs and risks. But kept reminding me of its limited experience and knowledge.

Steel, Wood, and Especially Brickwork

- **Brickwork:** No direct examples encountered of brick reuse; safety and certification concerns often lead to defaulting to new materials, especially for load-bearing walls.
- **Glass:** Reuse potential exists but hampered by difficulties in extraction, transport, and storage, combined with organizational challenges rather than purely costs.
- **Wood and other materials:** If components (like beams) can be dismantled and resized, reuse makes sense, but practical barriers (e.g., weight, embedded fasteners) often discourage reuse.
- **Steel:** Reuse is technically possible but complicated by certification requirements demanding testing of each reused piece, which increases complexity.

Relevant and Irrelevant Criteria

- **Most important criteria:**
    - **Costs:** Repeatedly cited as the primary driver; without a profitable case, stakeholders are unlikely to pursue reuse.
    - **Technical feasibility:** Especially relevant when safety and certification requirements must be met.
    - **Balance of supply and demand:** Fundamental for determining whether reuse is economically viable.

- **Less important criteria:**
    - **LCA score (environmental performance):** Seen as less decisive; while companies may consider sustainability, decisions are driven primarily by economic factors.
    - **Risks:** Intertwined with costs and technical feasibility but not always the explicit reason for rejecting reuse.

Drivers and Barriers in the Chain

- **Drivers:**

1) Companies specializing in reclaiming and marketing second-hand building materials demonstrate reuse is possible.

2) Emerging digital tools (material passports, digital building logbooks) could enable better reuse by making information about existing materials accessible, but only if standardized across the industry.

- **Barriers:**

1) Lack of standardized and complete material passports; inconsistent documentation leads to missing or unreliable data, particularly problematic for existing buildings without historical records.
2) Construction industry's tender-driven system: high price sensitivity and low margins discourage experimenting with reuse, as any cost overrun directly threatens profitability.
3) Clients often lack experience or knowledge to request sustainable options in tenders, resulting in missed reuse opportunities.
4) Risks of unknown material quality (e.g., hidden asbestos, outdated insulation performance) make reuse unattractive or unsafe.
5) Organizational skills gaps: even if reuse is technically and economically feasible, a lack of knowledge about extraction, handling, and storage often leads to opting for new materials.

Expert Interview 5:

Expertise: Position in the Chain

This expert has been working on circular economy in the civil engineering sector since 2016, focusing on practical implementation of reuse principles in projects. They led a project for the municipality of Rotterdam aiming for 100% reuse in public spaces and infrastructure, guiding it from conceptual design through realization. Their experience includes dealing with the complexities of organizing reuse: verifying material quality, managing storage and processing, and connecting supply and demand.

Confidence in Providing Answers

They spoke with practical experience and clear examples, especially regarding the challenges of certifying reused materials, project execution, and behavioural barriers. Their insights were confident and grounded in real-world projects.

Steel, Wood, and Especially Brickwork

- **Steel and precast floor slabs:** Seen as having low inherent risks; if the elements are intact and unaltered, they can continue to serve their structural purpose.
- **Brickwork:** Considered low-risk for reuse; expert sees no major barriers aside from general certification challenges.
- **Concrete (in-situ):** Viewed sceptically; reusing in-situ concrete is complex and generally impractical.
- **Foundations (e.g., screw piles):** Identified as high-risk due to their critical role in structural stability.

Relevant and Irrelevant Criteria

- **Most important criteria (in practical sequence):**
    1. **Technical feasibility:** Determines if reuse is realistically possible without compromising quality.
    2. **Balance of supply and demand:** Essential for scaling reuse; focusing on markets where large volumes can be reused helps lower costs and risks.
    3. **Potential gains (e.g., cost savings or value creation).**
    4. **Risks:** Legal, technical, or organizational uncertainties that could derail reuse plans.

5. **Costs:** Contrary to common perception, expert suggests costs often follow other factors and shouldn't be the primary criterion.

- **Missing criterion: Impact on maintenance (Impact for Management):** Reused materials might lead to increased maintenance needs or require specialized knowledge, making them less attractive despite technical feasibility.

Drivers and Barriers in the Chain

- **Drivers:**

1) Viewing reused materials as standardized products with verified quality could reduce perceived risks and costs, making reuse more attractive and scalable.
2) Recognizing reuse as a mixed-material strategy: optimal solutions likely combine reused concrete, steel, wood, etc., rather than relying solely on one material type.
3) Emphasizing the small successes and existing positive examples can inspire wider adoption.

- **Barriers:**

1) Regulatory and certification systems often prevent reusing perfectly functional products (e.g., safety doors) because 100% performance guarantees cannot be re-proven.
2) Maintenance concerns: reused components might introduce higher or more specialized upkeep requirements, discouraging reuse.
3) Behavioural factors: project managers prioritize cost, timing, and certainty over sustainability, especially in tenders emphasizing lowest price and risk avoidance.
4) Many pilots are run without clear goals for learning or scaling; lessons from pilots often fail to translate into standard practice.
5) Lack of regulation enforcing circularity means widespread adoption remains voluntary, slowing systemic change.

Expert Interview 6:

Expertise: Position in the Chain

This expert is a municipal policy advisor on circular construction with a background in architecture, urban planning, and design research. They have worked both as a designer and researcher, and now advise various municipal departments, housing corporations, and urban development projects on integrating circularity into policy and practice. Their experience includes applying system thinking to urban metabolism and working directly with stakeholders like housing associations to implement circular strategies (e.g., reusing roof tiles, glass).

Confidence in Providing Answers

The expert provided clear, context-rich perspectives grounded in experience advising projects and developing municipal policy. They demonstrated a nuanced understanding of how circularity intersects with design, policy, and market realities. However, risk assessment of product groups was not performed. The expert indicated that it was not comfortable with giving these numbers.

Interesting materials

- **Glass:** Currently exploring circular glass reuse at scale, though availability of reclaimed glass limits feasibility; large panes (>1 m^2) are viable, but smaller sizes are not yet economically competitive.
- **Roof tiles:** Focus area with housing corporations due to high volumes and potential environmental gains.
- **Wood products and composite boards (e.g., particleboard):** Deemed impractical for reuse because of inconsistent sizes, fastening methods (e.g., nails), and degradation during removal.
- **Concrete:** Acknowledged as a significant challenge due to its scale, environmental impact, and lack of clear strategies for large-scale reuse; highlighted the national Betonakkoord as an initiative to accelerate progress.

Relevant and Irrelevant Criteria

- **Most important criteria:**
  - **Balance of supply and demand:** Key to prioritizing which materials and processes to focus on; housing corporations' large stock can enable impactful reuse if markets are aligned.
  - **Technical feasibility:** Fundamental for determining whether reuse can deliver reliable quality.
  - **Aesthetic/experiential value:** Proposed as an additional criterion, reused elements can provide unique character and communicate circularity to end-users, offering non-financial value.
- **Less important criteria:**
  - **Costs:** Although often raised first in discussions, expert suggested costs should not dominate decisions if broader system benefits are clear.
  - **Risks:** Practical and regulatory risks exist but were not emphasized as the biggest barrier; rather, organizational coordination was highlighted.

Drivers and Barriers in the Chain

- **Drivers:**

1) Strong local initiatives (e.g., housing corporations managing 37% of Eindhoven's housing stock) offer opportunities to build volume and momentum for reuse.
2) Cross-sector collaboration can generate strategic alliances between contractors, housing corporations, product developers, and manufacturers.
3) Efforts to coordinate fragmented networks and platforms (e.g., Cirkelstad Eindhoven, Brabantse aanpak) can reduce duplication and confusion.
4) Aesthetic appeal of reused elements can inspire acceptance and even generate marketing value for circular projects.

- **Barriers:**

1) Lack of centralized coordination: even with many active networks, fragmentation causes confusion and inefficiency.
2) Housing corporations often offload innovation responsibility to contractors, who may lack incentives or resources to drive systemic change.
3) Reuse projects remain isolated pilots without a clear path to scale; repeated reinvention hinders momentum.
4) Local governments have limited formal power to mandate circularity; national and EU regulations are needed for systemic change.
5) Differences in market dynamics across regions complicate uniform implementation; e.g., different housing markets in the Netherlands vs. neighboring countries.

Expert Interview 7:

Expertise: Position in the Chain

This expert is a seasoned specialist in the environmental and sustainability assessment of construction products. Their primary focus is on evaluating products' environmental performance and leaching behavior, with decades of experience spanning both practical projects and standardization work. They actively participate in national initiatives like CB'23 and European committees, specifically working on circularity and reuse standards. Their expertise gives them insight into both the technical feasibility and systemic challenges of scaling reuse.

Confidence in Providing Answers

The expert demonstrated a clear understanding of the technical, logistical, and economic realities of reuse, especially for key materials like steel and masonry. The answers were informed by extensive experience with real-world projects, including advising on reuse schemes (e.g., reusing steel girders) and working in committees setting circular construction standards.

Steel, Masonry, and Other Key Products

- Structural steel: Seen as a strong candidate for reuse, technically straightforward, inspection and testing are feasible, and existing projects prove its viability. Risks are low, and reuse happens already in practice.
- Brick masonry: Recognized for its aesthetic value, which can offset higher reuse costs. There is stable demand for reclaimed bricks in both renovations and new construction seeking authentic finishes.
- Concrete: Highlighted as difficult due to logistics, costs of removal, testing, and lack of clear scalable strategies; temporary storage and multiple transport steps make it especially expensive.
- Other products: Noted that many products' reuse potential depends heavily on whether producers or demolition contractors take ownership of reuse logistics. Emphasized the advantage of Extended Producer Responsibility (EPR) models where manufacturers reclaim and redeploy their own products.

Relevant and Irrelevant Criteria

Most important criteria:

- Business model viability: Central to whether reuse can happen; includes alignment of costs, benefits, and responsibilities across stakeholders.
- Technical feasibility: Many materials are technically reusable, but practical constraints (e.g., lifespan, testing requirements) can still limit feasibility.
- Cost-risk interplay: Costs alone do not determine success; how risks are distributed among stakeholders can enable or block reuse.

Less important criteria:

- Balance of supply and demand: Seen as temporary and context-dependent; imbalance is typical at the start of new reuse schemes and should not derail efforts.
- LCA scores: Relevant, but their practical importance depends on the national scale and impact of the product , some products with low overall usage in the Netherlands may not warrant large efforts despite high per-unit impact.

Drivers and Barriers in the Chain

Drivers:

- Extended Producer Responsibility By making producers responsible for their products' entire lifecycle, it encourages better planning for reuse and helps avoid market competition that can undermine reuse efforts.
- European regulations: Mandatory design-for-reuse requirements at EU level would create a level playing field and drive systemic change across national markets.
- Market demand for unique, aged materials (e.g., old bricks) can support reuse if buyers value aesthetic or historical qualities.

Barriers:

- Fragmentation of the chain: Current demolition and recycling industries are optimized for downcycling, not reuse; entrenched players may resist change to protect existing business models.
- Mismatch of costs and benefits: Parties paying for careful deconstruction (e.g., demolition contractors) often don't capture the value of reused materials, undermining incentives.
- Clients' expectations: Building owners or developers frequently prioritize speed and simplicity, which conflicts with the longer timelines and planning needed for reuse.
- Lack of mandatory frameworks: Without legal requirements, many industry players will not invest in reuse systems, especially when they are more costly or complex than conventional practices.

Expert Interview 8:

Expertise: Position in the Chain
This expert works as an advisor and project supervisor in demolition and circular material reuse. With hands-on experience in demolition work, including material recovery on-site, they now lead projects for housing corporations, municipalities, developers, and contractors. Their role focuses on drafting tender documents, supervising demolition projects, and actively promoting circularity through clear contractual requirements. They bring deep practical knowledge from over two decades in the demolition and consultancy sectors.

Confidence in Providing Answers
The expert offered confident, detailed perspectives based on personal fieldwork and years of project management. Their insights are grounded in practical realities of sourcing, processing, and reusing construction materials.

Material-Specific Insights

- **Brickwork**: High-potential, especially as initiatives like Klinker Historica (Germany) already prove scalable models; historical bricks can command a premium price and meet market demand.
- **Timber**: Top priority for reuse; highly circular, widely available from demolished houses, and currently often cheaper than new lumber; seasoned reclaimed timber also offers superior quality.
- **Concrete**: Predicted to become "the new gold" due to high circular potential; believes circular concrete will gain significant market value.
- **Precast elements (e.g., hollow core slabs)**: Strong potential if available in large quantities; these elements are already reused in practice for new utilitarian buildings.
- **Roof tiles**: High volumes and straightforward reuse potential; considered one of the top candidates for direct reuse.

Relevant and Irrelevant Criteria
Most important criteria:

- **Technical feasibility and ease of disassembly**: Assessed by whether materials can be practically and economically dismantled and processed.
- **Project risks**: Factors like contamination (e.g., lead paint) can render reused materials unviable.
- **Balance of supply and demand**: Essential but relevant only to certain high-potential materials; storing materials unlikely to match future demand (e.g., outdated toilet bowls) leads to waste of effort and storage costs.

Less important criteria:

- **Current costs**: Acknowledged as a major decision factor but expected to shift as circular markets mature; sees price parity coming only in the longer term.
- **Regulatory risks**: Points out that current building codes are outdated (e.g., Dutch Building Decree from 2012) and don't yet align with circular materials, posing a barrier.

Drivers and Barriers in the Chain
Drivers:

4) Niche players specializing in specific materials (e.g., reclaimed windows, bitumen, kitchen components) show strong market readiness; bringing them together can streamline reuse efforts.
5) Early involvement of architects to design with available reclaimed materials instead of specifying new products first.
6) Platforms like Duspot or Stichting Insert enable early matching of supply and demand, giving projects enough lead time to plan reuse.

Barriers:

- Lack of early communication: without advance notice of demolition schedules, aligning reclaimed materials with new projects becomes nearly impossible.
- Quality assurance: absence of standardized certification for reclaimed materials limits market acceptance, especially in the professional building sector.
- Market mismatch: examples like large stockpiles of obsolete toilet bowls illustrate the danger of storing materials without confirmed future use.
- Regulatory inertia: outdated codes and lack of circularity-focused updates in national regulations hamper systemic change.

- Difference in acceptance: non-profit organizations are more open to reused materials despite lacking warranties, while commercial players often reject uncertified products.

Additional Highlights

- Emphasized time as a crucial enabler: longer planning horizons give better opportunities to reuse materials.
- Advocated for involving local communities in redevelopment, both to source materials and build support.
- Stressed the need for updated regulations, standardized certifications, and market facilitation to unlock the full potential of circular materials.

Summary on brickwork:

Expert ID1

- Saw brick reuse as technically possible but practically challenging: “You see that if you want to reuse bricks, you almost always have to manually chisel them out to keep them intact, that is incredibly labor-intensive.”
- Believes the costs of labor make it uncompetitive: “If it costs too much manpower to get it out whole, it’s simply cheaper to buy new bricks.”
- Mentioned that symbolic reuse happens: “Sometimes they’ll reuse a few bricks as a showpiece or for historical value, but it’s not mainstream.”
- “You increasingly see that bricks are being automatically cleaned, and that those bricks are actually being reused.”
- When it comes to separating concrete and brickwork, for example: if you have a house with an inner layer of concrete and an outer layer of brickwork, during demolition, a contractor might simply push the wall over, resulting in mixed rubble. Selective demolition is technically possible, removing the outer brick layer first, then the concrete, but it requires more effort. For concrete, contractors generally don’t pay much or anything to deliver it to a recycling facility. For brickwork, they actually pay around €5 per ton. That’s not a significant difference. As a result, most contractors choose to demolish everything together, because the cost savings from separating materials don’t justify the extra time and effort. By mixing everything, they can demolish faster and handle everything in one go. This logic applies to many materials, technically you could send someone in with a screwdriver to remove sockets individually, but it’s just not practical.

Expert ID2

- Clearly stated: “Brick reuse is very difficult because you just damage a lot when dismantling.”
- Observed that in some special projects it’s done, but “generally speaking, brick reuse is not widely applied.”
- Considered brick reuse a niche due to complexity in removal and cleaning.
- I think at some point, with enough ambition, people might accept that if a brick can be cleaned of cement, it will still be a bit more expensive than new material or a new system. But clients might accept that extra cost because it comes with significant environmental benefits.
- It’s increasingly common for bricks to be cleaned of cement so they can be reused.
- Regarding risks with reused brickwork: I don’t think it’s significant. It depends a bit on the application, whether it’s a load-bearing wall or not, but a brick is a brick. If cleaned of cement, it can be used like a new brick without major risks. Increased risk would only come from cracks or defects you can’t see. So I don’t consider the risk a significant barrier.

Expert ID3

- Said reuse is “not really happening structurally” because bricks are “hard to get out undamaged,” and if there’s damage, they lose their aesthetic or structural value.
- Argued that the market doesn’t demand reused bricks enough to drive change: “People usually just opt for new bricks because it’s easier and they can get certification and guarantees.”

Expert ID4

- Admitted limited knowledge but suggested: “I don’t think there are many cases of brickwork being reused, it just doesn’t happen much.”

- Highlighted certification and safety as barriers: “If it’s a load-bearing application, there’s risk and certification becomes a hurdle.”

Expert ID5

- Viewed technical risks as low: “If the brick did its job in the wall and hasn’t crumbled, it’ll keep functioning, one stone doesn’t suddenly fail.”
- However, pointed to certification: “Legally you’d need proof the reused brick meets the same standards as new, which is hard.”
- Emphasized regulatory issues: “Even if everyone can see the brick is fine, the permit process requires new certification.”
- Costs will be inportant, since it encounters a lot of labour.

Expert ID6

- Saw potential but stressed aesthetics: “Brick can add value if reused visibly , it tells a story that can make a project stand out.”
- Argued that marketing circularity is underutilized: “We miss chances by hiding reused elements. why not make them part of the building’s narrative?”
- Rebrick is a company that does this. It is kind of a niche, but could look cool.

Expert ID7

- Observed that “there’s always demand for old bricks in renovations and new projects because people find them beautiful.”
- But costs can be high: “Recovering, cleaning, and storing them costs a lot; you can only make it work if the market pays extra for the look of old bricks.”
- Suggested: “It’s essential to have a business model where the party bearing the cost can also capture the added value.”
- Old bricks may be more expensive than new bricks.

Expert ID8

- Extremely optimistic: “Brick reuse will only get cheaper over time, especially with CO_2 reductions becoming more important.”
- Cited specific examples: “Klinker Historica from Germany tests, certifies, and repalletizes reclaimed bricks right on-site.” But also NXT and recomended contact with Robin clement
- Predicted: “Bricks will become ‘certified circular’ products with proper quality marks, and then they’ll really take off.”

Appendix-I: Interview Questions

Expert Interview:

Heeft u het document wat ik je heb doorgestuurd, het "informed consent formulier" gelezen, en geeft u toestemming om mee te werken aan dit onderzoek volgens de afspraken dat formulier?

Was de voorafgaande presentatie voor jou duidelijk.
Heeft u een goed beeld van de strekking van dit onderzoek, en de functie van dit interview in dat onderzoek?

Voordat we beginnen met de specifieke vragen, kan je me wat vertellen over jouw rol, en ervaring met circulair producthergebruik?

Hoeveel jaar ervaring heb je daarmee?

De verwachting is, dat de toename in de kosten voor hergebruik per productgroep kunnen verschillen.

Bezien over de hele keten; In hoeverre is de (mogelijke) <u>toenamen in kosten</u>, een barrière voor direct producthergebruik van onderstaande productgroepen?

	Heel erg belangrijk	belangrijk	neutraal	Niet belangrijk	Helemaal niet belangrijk
Staal zwaar constructiestaal o.a. balken, profielen en liggers					
Breedplaat vloer					
Baksteenmetselwerk					
Beton,in het werk gestort, C20/25; incl.wapening					
Schroefpaal; beton,in het werk gestort, C20/25; incl.wapening					
Kanaalplaatvloer					
Dak elementen, houten ribben, steenwol, multiplex; duurzame bosbouw					
EPS					
Spaanplaat					
glas (HR); droog beglaasd					

Welke dingen wil je nog kwijt over bovenstaande antwoorden?

De verwachting is, dat de toename in de ervaren risico's voor hergebruik per productgroep kunnen verschillen.

Bezien over de hele keten; In hoeverre is de (mogelijke) toenamen in Risico's, een barrière voor direct producthergebruik van onderstaande productgroepen?

Risico's is een breedte begrip, In literatuur wordt er gesproken over: onzekerheid/risicomijdend, en juridische risico's.

	Heel erg belangrijk	belangrijk	neutraal	Niet belangrijk	Helemaal niet belangrijk
Staal zwaar constructiestaal o.a. balken, profielen en liggers					
Breedplaat vloer					
Baksteenmetselwerk					
Beton, in het werk gestort, C20/25; incl. wapening					
Schroefpaal; beton, in het werk gestort, C20/25; incl. wapening					
Kanaalplaatvloer					
Dak elementen, houten ribben, steenwol, multiplex; duurzame bosbouw					
EPS					
Spaanplaat					
glas (HR); droog beglaasd					

Welke dingen wil je nog kwijt over bovenstaande antwoorden?

Van de volgende 5 Criteria: welke weegt volgens jou het zwaarste mee, in de potentie van een productgroep voor direct hergebruik? En welke is het minst relevant?

- LCA Score (duurzaamheid)
- Balans in vraag en aanbod
- kosten
- risico's
- Technische haalbaarheid (levensduur & losmaakbaarheid)

Als je de overgebleven 4 criteria, zou moeten vergelijken met de belangrijkste [……….….]. Hoe zou je de relatieve belangen dan met elkaar omschrijven:

- [……………..] TOV LCA Score
- [……………..] TOV Balans in vraag en aanbod
- [……………..] TOV kosten
- [……………..] TOV risico's
- [……………..] TOV Technische haalbaarheid

The meaning of the numbers 1-9:
1: **Equal** importance
2: Somewhat between Equal and Moderate
3: **Moderately** more important than
4: Somewhat between Moderate and Strong
5: **Strongly** more important than
6: Somewhat between Strong and Very strong
7: **Very strongly** important than
8: Somewhat between Very strong and Absolute
9: **Absulutly** more important than

Als je de overgebleven 4 criteria, zou moeten vergelijken met de minst belangrijke [……].
Hoe zou je de relatieve belangen dan met elkaar omschrijven:

- LCA Score TOV […………
- Balans in vraag en aanbod TOV […………
- kosten TOV […………
- risico's TOV […………
- Technische haalbaarheid TOV […………

Criteria Number = 5	Criterion 1	Criterion 2	Criterion 3	Criterion 4	Criterion 5
Names of Criteria					

Select the Best	

Select the Worst	

Best to Others	Criterion 1	Criterion 2	Criterion 3	Criterion 4	Criterion 5
0					

Others to the Worst	0
Criterion 1	
Criterion 2	
Criterion 3	
Criterion 4	
Criterion 5	

Zijn er Criteria waarvan jij voelt dat ik ze over het hoofd zie met bovenstaande onderzoek?

Voortbouwend; Heb jij het gevoel dat deze ook relevant zijn in het onderscheid maken tussen deze productgroepen?

Van de 10 voorgestelde productgroepen: Welke productgroep heeft volgens jou het meest potentie voor direct hergebruik.

Welke productgroepen denk jij dat ik over het hoofd zie met bovenstaande onderzoek?

Heb je verder nog toevoegingen of nuances die je wilt toevoegen?

Kijkend naar de gehele keten, productgroep onafhankelijk, wat en wie zie jij als de "remmers" en bezwaren die momenteel plaatsvinden in een transitie naar hoogwaardig hergebruik.

Kijkend naar de gehele keten, productgroep onafhankelijk, wat en wie zie jij als de drivers en kansen die momenteel plaatsvinden in een transitie naar hoogwaardig hergebruik.

Bedankt voor deelname aan dit interview!

Appendix-J: Saturation Analysis

In the tables below, each MCA result (column) is color-formatted, making it easy to distinguish between product groups and identify partners. For example, bricks are green (high-potential) in all permutations, indicating consistency and saturation. The variation column illustrates how much the maximal and minimal permutations differ, where low scores (green) indicate consensus along the expert over a specific product group.

All interviews without:	ID1	ID2	ID3	ID4	ID5	ID6	ID7	ID8	LOW	HIGH	Var
Heavy structural steel	3.253	3.100	3.171	3.217	3.004	3.149	3.142	3.075	3.004	3.253	0.249
Wide slab floor	2.618	2.676	2.574	2.671	2.486	2.565	2.649	2.634	2.486	2.676	0.190
Brick masonry	3.821	4.007	3.982	3.998	4.030	3.999	3.967	4.045	3.821	4.045	0.224
Concrete, cast in-place	2.278	2.378	2.235	2.241	2.220	2.268	2.312	2.315	2.220	2.378	0.158
Screw pile; cast-in-place	1.938	2.006	1.890	1.834	1.822	1.916	1.932	1.962	1.822	2.006	0.183
Hollow core slab, prefab concrete	2.748	2.806	2.766	2.767	2.903	2.775	2.791	2.782	2.748	2.903	0.155
Roof elements, timber sandwich	2.301	2.261	2.340	2.145	2.308	2.319	2.322	2.225	2.145	2.340	0.195
Expanded Polystyrene (EPS)	2.535	2.608	2.553	2.575	2.601	2.812	2.526	2.595	2.526	2.812	0.286
Chipboard	2.464	2.514	2.551	2.477	2.567	2.562	2.463	2.646	2.463	2.646	0.183
High-efficiency glass; dry sealed	2.105	2.032	2.114	1.833	2.033	2.114	2.004	2.107	1.833	2.114	0.281

The table above shows, that all 8 permutations of 7, result in the same top 3, except for the number three when the scoring if id6 was not used. The expert opinion seems to be saturated.

Only the four complete without:	ID2	ID5	ID7	ID8	LOW	HIGH	Var	AVG
Heavy structural steel	3.605	3.381	3.682	3.503	3.381	3.682	0.301	3.543
Wide slab floor	2.754	2.337	2.684	2.629	2.337	2.754	0.417	2.601
Brick masonry	3.876	4.001	3.786	3.993	3.786	4.001	0.214	3.914
Concrete, cast in-place	2.218	1.914	2.117	2.206	1.914	2.218	0.305	2.114
Screw pile; cast-in-place	1.985	1.616	1.909	1.848	1.616	1.985	0.369	1.840
Hollow core slab, prefab concrete	2.675	2.727	2.640	2.658	2.640	2.727	0.087	2.675
Roof elements, timber sandwich	2.285	2.374	2.388	2.151	2.151	2.388	0.237	2.300
Expanded Polystyrene (EPS)	2.541	2.546	2.376	2.556	2.376	2.556	0.180	2.505
Chipboard	2.356	2.516	2.241	2.601	2.241	2.601	0.360	2.429
High-efficiency glass; dry sealed	2.040	2.060	1.999	2.112	1.999	2.112	0.113	2.053

When we make permutations of just the four experts that showed expertise on product level, we see a bit more differentiation in scoring. However, steel and masonry are still the top 2.

just:	ID2	ID5	ID7	ID8	LOW	HIGH	Var	AVG
Heavy structural steel	3.361	3.956	3.164	3.705	3.164	3.956	0.792	3.547
Wide slab floor	2.182	3.217	2.353	2.604	2.182	3.217	1.035	2.589
Brick masonry	4.016	3.792	4.215	3.826	3.792	4.215	0.423	3.962
Concrete, cast in-place	1.819	2.638	2.131	2.010	1.819	2.638	0.819	2.149
Screw pile; cast-in-place	1.431	2.091	1.915	2.089	1.431	2.091	0.660	1.882
Hollow core slab, prefab concrete	2.653	2.615	2.721	2.926	2.615	2.926	0.311	2.729
Roof elements, timber sandwich	2.286	2.294	1.891	2.842	1.891	2.842	0.952	2.328
Expanded Polystyrene (EPS)	2.405	2.399	2.952	2.514	2.399	2.952	0.553	2.568
Chipboard	2.621	2.168	3.001	2.074	2.074	3.001	0.926	2.466
High-efficiency glass; dry sealed	2.079	1.982	2.276	1.715	1.715	2.276	0.561	2.013

When we look at the results for the MCA when we would only have conducted one expert opinion interview we see that the results lay further apart, still steel and masonry are the top2.

Appendix-K: Masonry Expert Interviews

Summary - Erik Hoven, Dutch Demolition Association VERAS (July 9, 2025)

Technical Feasibility

- Separating brick masonry during demolition is technically possible, but requires extra time, effort, and advanced techniques.
- Example: Dusseldorp is developing a laser-guided method to remove mortar between bricks.

Current Practice

- Currently, about 99% of brickwork ends up crushed into mixed aggregate, used as base material in road construction.
- Only a few initiatives (e.g., Klinker Historica and REBRICK) focus on on-site brick reuse.
- Demolition contractors typically become the legal owners of the recovered materials, giving them control over what happens with them.

Barriers

Technical & Logistical

- Separating inner and outer wall layers (e.g., concrete and masonry) is difficult and labor-intensive.
- Tight timelines and space constraints on demolition sites make it challenging to accommodate third parties for cleaning and collecting bricks.
- Demolition companies prefer to control their own material streams and site operations.

Financial

- Current market prices provide little incentive:
  - Concrete can often be dumped for free.
  - Mixed debris costs approx. €5/ton to dispose of.
  - The potential savings don't outweigh the added effort of separation.
- The demolition industry is driven by low margins and high efficiency, making it difficult for circular alternatives to compete without financial incentives.

Structural

- Buildings are not designed with brick reuse in mind.
- There is little market demand for reused bricks, and demolition contractors do not control that downstream demand.

Opportunities & Circular Alternatives

- Several innovative recycling technologies exist:
  - Circulair Mineraal, URBAN Mine, CtoC, NXT Building.
  - These can process masonry into high-quality filler or aggregate for concrete.
- Filler material can be worth €50-€60 per ton.
- Reuse can contribute to better MKI/LCA scores.

Financial Considerations

- Hoven provides a case example:
    - For a demolition project with 1000 tons of debris (500t concrete, 500t brick):
        - Mixed: €5000 disposal cost.
        - If concrete is separated: €2500.
    - Even with this potential saving, the extra labor and logistics make it unfeasible under current conditions.

Market & Systemic Constraints

- Mobile crushers dominate the market:
    - Efficient and cost-effective.
    - Crush material into mixed aggregate directly on-site.
    - Hard to compete with the established models.
- Demolition contractors already have well-developed logistics and sales channels.
- Market pull for reused materials must come from the construction sector itself.
    - Only then does reuse become commercially viable for demolition companies.

Role of Brick Manufacturers

- Some manufacturers (e.g., in the Betuwe region) are experimenting with circular bricks using crushed brick as material level.
- Hoven is not deeply familiar with their involvement in the reuse supply chain.

Conclusion

- Reuse of brick masonry is technically feasible and environmentally beneficial, but faces financial and logistical challenges.
- Key success factors:
    - Stimulating demand from the construction industry.
    - Providing financial incentives or regulatory support.
    - Designing buildings with end-of-life reuse in mind.
    - Take away the time and cost barrier.

Summary - Bob Floris, Rebrick (July 28, 2025)

Introduction: Heritage Meets Innovation

Bob Floris represents the fourth generation in the Floris Group, a century-old family business with strong roots in building materials supply. With an eye on long-term sustainability and the need for CO_2 reduction in the built environment, they launched Rebrick, a circular initiative company focused on the reuse of traditional brick masonry.

This initiative emerged from both corporate responsibility and strategic foresight, recognising that any future-proof business in construction must adapt to the climate goals of 2050.

From Pilot to Practice: Building a Scalable Model

Rebrick has a partnership with the German company Klinker Historica, which specializes in harvesting bricks.

Floris took initiative by establishing a dedicated sales brand and supply chain for reused bricks, creating a robust commercial channel in the Netherlands. "We've built Rebrick in just 1.5 years, complete with nationwide supply and demand coordination."

Division of Roles in the Circular Supply Chain
Rebrick operates as the sales and logistics arm, while Klinker Historica handles demolition and material testing. Upon demolition, 50 representative bricks are tested in collaboration with a German lab, assessing brick specifications as compressive strength and moisture absorption, such the bricks can be CE marked.

“We are contacted once circular demolition is included in the tender documents. Then we assess whether the bricks are recoverable.” We pay the demolition company approximately €9 per ton of usable material, however keep in mind that these prices can differ per project.

Certification, Quality, and Aesthetic Standards
One of Rebrick's core differentiators is certification. Unlike the informal second-hand market, Rebrick ensures its products meet strict performance criteria through external validation and documented standards (a BRL or CE mark).

“Nobody certifies second-hand bricks. That’s what sets us apart.”

Only six standard colors in Waal format are stocked, allowing Rebrick to guarantee design uniformity and minimize logistical complexity. Rebrick deliberately excludes unique, small-scale demolition materials (e.g., from farms or castles) due to insufficient volume and lack of standardization.

"I’m not interested in one-off demolitions. We need volume, not variety."

Technical Limitations and Innovations
Brick reuse is primarily viable for buildings constructed before 1980, as post-1980 bricks often contain higher cement content, making deconstruction and cleaning more difficult.

The innovation of a machine would reduce reliance on manual labor, a current barrier both in cost and speed, and help Rebrick approach price parity with new bricks.

Economic and Environmental Impact
Rebrick’s pricing strategy ranges from €850-990 per 1,000 bricks, depending on volume and project size. While this is still above the €530-€700 range of conventional bricks, their MKI score (environmental performance) is three times better.

“We aim to dive below the 850 per 1,000 bricks on larger projects. At that point, the sustainability case becomes economically viable too.”

Rebrick processed ~2 million bricks in 2025, 1 million sold in the netherlands, the other million is exported abroad. Long-term ambition is to reach 20 million bricks per year by 2030, with national potential estimated at 120 million bricks annually.

"Inventory is not a goal in itself. Ideally, you go straight from demolition to new construction."

Institutional Context and Systemic Change

Rebrick is involved in "circulair deals", regional agreements initiated by the Province of North Holland to align public bodies, housing associations, demolition firms, and suppliers around circular construction goals. Floris views such public-private initiatives as a blueprint for nationwide adoption.

“We are a thorn in the side of the linear economy, but also the answer to national climate goals.”

“Every demolition company I speak to agrees: circular demolition is no longer nonsense.”

Demand and Market Positioning

Rebrick's primary clients are government bodies, housing associations, and sustainability-driven developers. The company does not cater to the consumer market, focusing instead on projects with predictable demand and specifications. “We prefer housing associations. They have volume and long-term vision.”

They also export to countries with stronger circular mandates, such as France, Denmark, Germany, and Belgium. "A whole residential district in France was built with bricks from Rotterdam, nobody wanted them here."

Structural and Policy Barriers

Rebrick identifies time, cost, and labor intensity as main barriers. Especially problematic are short demolition timelines and the limited window to conduct pre-demolition testing. “There’s serious CO_2 reduction potential. “You need to design for deconstruction, plan longer ahead, and align stakeholders early on.

Outlook and Reflections

While currently not yet profitable, Floris considers Rebrick’s trajectory to be sound and consistent with the typical startup lifecycle.

“Most businesses aren’t profitable in the first three years. We’re right on track.”

His vision is not just technical or financial, t’s cultural: “The brick is part of our national identity. You get a building with soul when you reuse bricks. That’s what excites architects too.”

Summary - Mees Normann & Dorien van der Weele, Wienerberger (July 31, 2025)

1. Position in the chain and role of intermediaries
Contractors usually do not buy directly from the producer but through traders or building centers. These intermediaries make the supply chain more complex and affect both the price and availability of secondary raw materials. A fully integrated chain, from owner, demolisher, crusher to producer, is rare.

2. Reuse and recycling of bricks

- Direct reuse is often limited. Not every brick can be reapplied, which always results in residual streams that need to be processed elsewhere. Therefore, multiple streams, like reuse and recycle should run simultaneously.
- Producers see opportunities in using brick granulate as a secondary raw material, but point out that this will remain a niche as long as volumes stay small and costs high.
- Products such as paving stones and roof tiles are easier to reuse, as they are detachable and more uniform. For masonry bricks and façade bricks this is more complex due to variation, mortar residues, and quality requirements.

3. Limitations and feasibility of circular applications

- A reuse rate above 20% is considered technically and economically difficult. At higher percentages, risks increase regarding product quality.
- In many cases, recycling (e.g., crushed bricks as aggregates) is legally more complicated and expensive than directly reusing whole building products.
- Transport, storage, and certification are key cost and environmental factors. The effect of recycled aggregates on the Environmental Cost Indicator (MKI) is often limited or even negative, since the environmental impact of secondary raw materials can be higher than that of primary clay.

4. Roof tiles: case study and conclusions

- Roof tiles appear more promising than bricks, as they can be detached and recovered individually.
- However, major drawbacks remain:
    - Multiple tile types on a single roof complicate sorting.
    - Inspection and certification are costly.
    - Products must be delivered under warranty, which imposes additional requirements.
- Ultimately, a reused roof tile ends up being up to twice as expensive as a new one, without the advantages of uniformity and warranty. For now, this makes reuse economically unviable.

5. Market, business case, and niches

- Large players primarily focus on mass production and large clients. Circular initiatives are seen as niche markets.
- A business case must compete with alternative investments. Reused bricks or roof tiles currently do not make the priority list.
- Secondary raw materials become attractive only if they are equal in cost or cheaper and comply with quality and certification requirements.

6. Limitations of secondary raw materials

- Secondary raw materials such as mortar or mixed rubble often have more disadvantages than benefits: higher crushing and processing costs, poorer product properties, and higher environmental impact.
- Replacing small percentages of aggregates is relatively easy, but larger substitutions quickly lead to significant cost increases and technical constraints.

7. Policy context and regulation

- European and Dutch regulations (such as the Taxonomy Act) steer towards limiting primary material use. Targets like a maximum of 70% primary materials in buildings put pressure on producers.
- For concrete, steel, and ceramics, binding targets are set. For ceramics, even if all released streams were reused, the required volumes could barely be met according to them.

8. Environmental impact and CO_2 challenges

- Despite the circular potential of secondary flows, the environmental impact can turn out higher due to transport, processing, and emissions.
- The expected rise in CO_2 allowance prices (possibly €80-100 per ton) is a risk factor. Producers want to avoid situations where secondary raw materials lead to higher emissions.
- In many cases, Dutch river clay remains the more sustainable option, due to its low impact and local availability.

9. Regional differences and market demand

- In the Randstad region, especially Amsterdam and Utrecht, circularity has already become an explicit award criterion in tenders.
- Large contractors such as Heijmans, BAM, Van Wijnen, and VolkerWessels increasingly demand circular solutions.

- Outside these core regions, however, demand remains limited and price is often valued higher than sustainability.

10. Innovation and future perspective

- Alternative products such as cold-baked bricks or biobased solutions are considered interesting but are technically and aesthetically fundamentally different. They cannot simply replace ceramic bricks.
- Since 2011, the sector has made clear progress in sustainability and circularity. Without these developments.
- At the same time, companies that fail to adapt in time may fall behind. For producers, it is therefore crucial to remain visible and adaptive.

Summary - Peter Broere & Otto Friebel, BRBS (sep 1, 2025)

BRBS is the Dutch trade association for recycling companies and rubble Crushers.

- Peter Broere , 30+ years in the sector; leads the “minerals” portfolio: rubble collection, crushing, quality control, standards and legislation.
- Otto Friebel , ~6 years at BRBS (25 years prior in commercial recycling); also active in the Breaking and Circular Economy working groups and national transition fora.

1) How the sector works today

What “circular” means to BRBS

- Mechanical recycling of construction & demolition (C&D) minerals into secondary aggregates is circular and far better than landfilling.
- The Netherlands already recycles ~99% of mineral rubble; output is predominantly road base/foundation layers (high performance even if sometimes labeled “downcycling”).

Main mineral streams & specs

- Plants typically run two depots: mixed rubble and concrete rubble.
- Standard Dutch aggregate families (simplified):
    - Betongranulaat (>80% concrete)
    - Menggranulaat (At least 50% concrete)
    - Metselwerkgranulaat (≥80% fired-clay masonry;).
- Road specs are written with minimum concrete content and maximum masonry content. Masonry is functionally an allowable filler as long as strength/durability stay on-spec.

Where bricks end up

- Almost all brickwork entering recycling is crushed into mixed aggregate for road construction.
- Direct reuse of whole bricks is rare and niche (heritage formats, special sizes). It is very labor-intensive and only feasible for high-value selections (“cherry-picking”).

Market balance

- Recent years show a balance between inflow and outlet; regional spikes around mega-projects can tighten supply.
- No structural shortage of brick rubble; operators tune blends to meet specs. If brick share decreases, specs still allow compliance because concrete minima drive design.

2) Technical feasibility & process realities

Separation at source vs. plant

- If demolition doesn't deliver a distinct brick stream (e.g., intact walls or largely brick-rich rubble), crushers won't re-separate later: once mixed, it goes on the mixed pile.
- Plant-side sorting technologies used today target other aims (e.g., color sorters to increase concrete share, not to harvest clean brick). Economic rationale for brick extraction is absent.

Mortar matters

- Post-1980 cementitious mortars bond much tighter than historical lime mortars. That makes deconstruction/cleaning the main barrier for reuse.
- Brick furnaces are sensitive to cementitious contamination (both residual mortar and concrete fragments) a constraint for closed-loop brickmaking.

Contaminants & innovation caution

- Concern: under the banner of "innovation," new additives (e.g., geopolymer binders, biogenic Fibers like miscanthus) get introduced without end-of-life testing, risking future recyclability.

3) Economics, prices & incentives

Order-of-magnitude gate fees (non-binding, day-price dependent)

- Concrete rubble: roughly €0-2/ton (most attractive).
- Mixed rubble: ~€5/ton to dispose (can be higher if quality is poor).
- Clean brick/masonry delivered separately would be treated similar to mixed from an economic standpoint.

Note: BRBS cannot provide or coordinate pricing due to competition law; values are indicative only.

Why whole-brick reuse struggles

- Manual deconstruction/cleaning is labor-intensive and costly; only works for high-value, aesthetic selections or where clients pay a premium.
- Demolition is a low-margin, high-efficiency business: without time and money in the tender, crews revert to mobile crushing → mixed aggregate.

Business case for brick recovery at crushers

- Not viable today: no existing cost-effective machinery to extract reusable bricks from mixed streams; operators won't post-sort with excavators either.

4) Supply chain options discussed (feasibility view)

"Four pathways" to circular bricks (as presented by the interviewer)

Crushers harvest bricks from mixed input: not realistic today (no tech + weak economics).

Who is best placed to run it?

- If anyone, specialist operators (dedicated harvest/QA/logistics) have the best chance, provided there is stable demand and premiums to cover costs.

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5) Policy, regulation & system change

What would actually move the needle?

- Mandated recycled content (hard “recycled-content” requirements for projects/products) or strong procurement levers.
- Earlier tender planning and longer demolition windows to allow testing and harvesting.
- Coherent policy: today, circularity is fragmented across ministries/agencies (waste, materials, spatial planning), creating mixed signals (e.g., concessions for primary extraction while subsidizing circular pilots).

Without push, niche persists

- Startups and pilots (often subsidy or crowdfunding backed) are valuable for learning but struggle to scale profitably against entrenched linear economics.
- Absent mandates or clear price signals, the market reverts to high-performing roadbase recycling.

What will make or break it

- Economics first: any solution must beat (or be subsidized/mandated against) the low-cost, high-throughput baseline of mobile crushing + roadbase.
- Consistent demand: architects/clients willing to specify and pay for reused bricks at scale, backed by certification and predictable formats.
- Governance coherence: align waste, materials, and spatial policies to avoid contradictory incentives.

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Summary - Arie Mooiman, KNB (sep 2, 2025)

Background & Role
Arie Mooiman: Chairs the Dutch norm committee on sustainable construction, and contributes to the technical committee of the National Environmental Database. Within KNB he is secretary of the Sustainability Working Group.

1. Current State of the Dutch Brick Industry

Production & Markets

- Annual production has dropped from ~800 million to ~550 million bricks (2024-2025).
- ~95% of bricks used in NL are produced domestically; ~5% are imported (Denmark, Germany) mainly used for higher-end projects.
- The industry consumes 1.2 million m^3 of clay annually, of which ~85% is Dutch. ~75% of the Dutch clay comes from river floodplains (uiterwaarden), considered a renewable source.

Clay Supply Chain

- Clay extraction is outsourced to two main companies: K3 Delgromij and Van de Wetering.
- They build clay stockpiles ("clay lasagna") blending layers to achieve the right composition for color, processing, and firing quality.
- Clay is typically stored on manufacturer's sites; transport often occurs by barge.

2. Sustainability Challenges & Innovations

Energy & CO_2

- About 85% of the environmental footprint of bricks lies in energy for firing and drying.
- Since the 1970s, energy use has been cut by ~60% through efficiency and scale (continuous 24/7 production).
- Next steps focus on fossil-free fuels: hydrogen, biogas, CCS/CCU.
- Hydrogen: technically feasible (bricks already fired successfully), but not expected at scale before 2030 due to price (currently 5-6x gas) and availability.
- Electric kilns exist (e.g., Wienerberger Belgium making brick slips with on-site wind power).

Collective Initiatives

- Brick Valley (Gelders Eiland): collaboration between four producers to explore joint energy transition strategies.
- Some producers experiment and make bricks with CO_2-hardening products (e.g., Vandersanden using steel slag with captured CO_2). That are no clay bricks.

3. Reuse & Recycling of Bricks

Hergebruik (direct reuse)

- Bricks are technically highly durable (facades last >75 years, outliving buildings), making them suitable for reuse.
- The main barrier is mortar: lime and “bastard” mortars (pre-1980) can often be removed; post-1980 cement mortars make separation very hard.
- Direct reuse is viewed as an opportunity, not a threat by KNB, but volumes from demolition remain small compared to new demand.
- Companies like Rebrick and Klinker Historica are seen as niche but interesting; not eligible as KNB members since they are not producers.

Recycling (into new products)

- Several members (Wienerberger, Vogelensangh, DC Bricks) already mix ceramic recyclate into new bricks, typically up to 20-50% depending on process and quality.
- Visual quality is key: recycled content must not compromise color or texture.

UPV (Extended Producer Responsibility)

- Seen as unrealistic for bricks: life span (~100 years) makes take-back impractical.
- Tracking origins of demolished bricks is nearly impossible.
- KNB focuses instead on designing future bricks and mortars for easier dismantling (dry-stack systems, new mortars).

4. Barriers to Circularity

Technical & Aesthetic

- Mortar residues, irregular sizes, and color variation hinder reuse.
- Builders and masons demand dimensional accuracy; reused bricks with tolerances can reduce worksite efficiency.
- Architectural demand for reused brick aesthetics is limited to specific styles; Rebrick’s product portfolio is restricted by appearance.

Economic

- Reused bricks are often more expensive than new ones.
- Given the huge gap between annual new production and relatively small demolition volumes, reused bricks will remain niche.

5. Drivers & Opportunities

Environmental

- Reuse sharply reduces environmental impact (MKI values). Rebrick's products are already listed in the Nationale Milieu Database (NMD).
- Substituting virgin clay with recyclate reduces raw material demand and can improve sustainability scores.

Image & Market Pull

- Reuse offers strong branding. Companies gain reputational benefits from circular practices.
- Some large contractors and public clients increasingly demand circular materials.

Future Focus

- Dry-stack systems and innovative mortars enabling dismantling.
- Increasing recycled content in new bricks, possibly with specialty "eco-lines."
- Continuing the transition to fossil-free production energy.

6. Outlook

- Direct reuse will remain a niche opportunity, valuable for image, Circularity improvement and MKI improvement, but limited in scale due to demolition volumes, mortar constraints, and economics.
- Recycling into new ceramic products is more scalable.
- The main sustainability challenge for the sector remains the energy transition: switching from natural gas to hydrogen, electricity, or alternative low-carbon processes.
- Circularity in bricks will grow primarily through designing for future reuse, integrating secondary materials, and policy frameworks like the Bouwmaterialenakkoord.

Appendix-L: Business Model Canvas BBB and BBBBBB

Business Model Canvas

Designed for: Brought Back Bricks

Designed by: Van Tongeren, T.

Date: 11-09-2025

Version: 1

Key Partners

Demolition companies:
Supply the bricks Mansory debris. Separating bricks should be financially more attractive then current linear end of live. Receive a certificate for circular demolition to win tenders.

Brick Buyers:
MKI 3 times lower, and 95% CO2 relative reduction. Should be willing to pay a bit more for sustainability.

Filler Buyers:
Brick manufactures, concrete manufactures or debris crushers. Filler material, could be worth substantial money to manufacturers for usage in their circular product line.

Testing company:
Service based partner, should be able to provide a CE mark within a short timeframe.

Key Activities

Buying all brick debris from demolition sites. Filtering out as much as possible whole unbroken bricks to sell as on product level. Crushing the additional scrap bricks into filler material for concrete, bricks or concrete bricks.

Key Resources

Balance in supply and demand.
Enough stock to fill any order, either from government or manufactures.

Testing procedure
A certified CE marking process.

Manual Labour personnel
The bricks are cleaned by hand.

Value Propositions

Reused bricks will reduce the MPG of a building, and have a 95% lower carbon emission then new products.

Aesthetically different, and for some more pleasing then alternatives.

using recycled aggregates, as concrete filler. Could be seen as upscaling.

Just as convenient as new bricks: CE marked and Waal size.

Customer Relationships

Selling bricks:
The business should be able to provide the demand of large building projects, it should be just as easy as new bricks.

Selling Filler:
A Constant stream of filler material of constant quality should be delivered to manufactures

Channels

The architect is a key stakeholder to be convinced and should know the product.
they can be reached by: Hardware stores, Construction fairs, pilot projects and industry magazines.
There should be no doubt, when a building is designed in bricks, and sets sustainability goals, this is the way to go.

Customer Segments

There are three types of customers segments that should be targeted.
In general the market that is willing to pay more, for more sustainable products, but also the market that likes the aesthetics.

Government bodies:
Should and are willing to lead by example. Has an enormous portfolio of public buildings.

Housing associates:
Have a social mission. and no profit goals, making them more inclined to pay for sustainability. 28% of housing is owned by these associations.

High end market:
Niche market. Only 4% of dwellings are 1 million euro's or more expensive.

Cost Structure

Buying the material is relatively cheap.
Transport and storage is semi expensive, but when organises correctly not more expensive than the current competition.
The manual labour is the most expensive part. It is an labour intensive process.

BroughBackBricks is an Value driven business. Bricks will, remain more expensive then new alternatives. But scaling up could limit the gap.
The value is in the sustainability of the product. For some, the value is in the aesthetics and history of the product itself.

Revenue Streams

Two types of revenue streams will exist, the selling of the bricks, and of the filler.

Bricks:
Dynamic pricing: Sales are project based and thus depending on size of the order. Also dependent on stock of product and balance in supply and demand of that moment.

Filler/aggregate:
Fixed Prising: Selling to Manufactures. Constant pricing, volume and material quality are of key importance for this revenue stream.

Business Model Canvas

Designed for:	Designed by:	Date:	Version:
BBB-ByBinaryBots	Van Tongeren, T.	11-09-2025	1

Key Partners

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Brick Buyers:
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Filler Buyers:
Brick manufactures, concrete manufactures or debris crushers. Filler material, could be worth substantial money to manufacturers for usage in their circular product line.

Testing company:
Service based partner, should be able to provide a CE mark within a short timeframe.

Key Activities

Buying all brick debris from demolition sites. Filtering out as much whole unbroken bricks as possible to sell as on product level. Crushing the additional scrap bricks into filler material for concrete, bricks or concrete bricks.

Key Resources

Balance in supply and demand.
Enough stock to fill any order, either from government or manufactures.

Testing procedure
A certified CE marking process.

Automated Mortar removal machine
A machine that operates below manual labour cost. Does not yet exist.

Value Propositions

Reused bricks will reduce the MPG of a building, and have a 95% lower carbon emission then new products.

Aesthetically different, and for some more pleasing then alternatives.

using recycled aggregates, as concrete filler. Could be seen as upscaling.

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Selling Filler:
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they can be reached by:
Hardware stores, Construction fairs, pilot projects and industry magazines.
There should be no doubt, when a building is designed in bricks, and sets sustainability goals, this is the way to go.

Customer Segments

All new building projects could be reached. The product is more sustainable and cheaper.
The aesthetics should be accepted.

Government bodies:
Should and are willing to lead by example. Has an enormous portfolio of public buildings.

Housing associates:
Have a social mission and generally aims for sustainability. 28% of housing is owned by these associations.

Private housing market:
Both budget housing as the high end market can be reached. Eather by the aesthetics or by costs arguments.

Cost Structure

Buying the material is relatively cheap.
Transport and storage is semi expensive, but when organises correctly not more expensive than the current competition.
Machine mass production is in general less expensive then manual labour.

BroughBackBricksByBinaryBots is both an Value driven business, as an cost driven business.
More sustainable bricks will be available for less money. Both bricks have the same CE mark. For some, the value is in the aesthetics and history of the product itself.

Revenue Streams

Two types of revenue streams will exist, the selling of the bricks, and of the filler.

Bricks:
Dynamic pricing: Sales are project based and thus depending on size of the order. Also dependent on stock of product and balance in supply and demand of that moment.

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Business Model Canvas

Designed for: BBB-ByBinaryBots

Designed by: Van Tongeren, T.

Date: 11-09-2025

Version: 1

Key Partners

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Filler/aggregate:
Fixed Prising: Selling to Manufactures. Constant pricing, volume and material quality are of key importance for this revenue stream.

Appendix-M: Aesthetics of Bricks

Factory new	**85% recycled filler material**	**Reused**
A Typical Dutch brick	NXT brick	Rebrick / Terca brick
Gas fired	Cold baked	Mined
		
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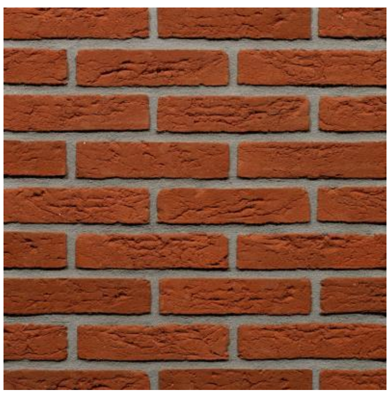		
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		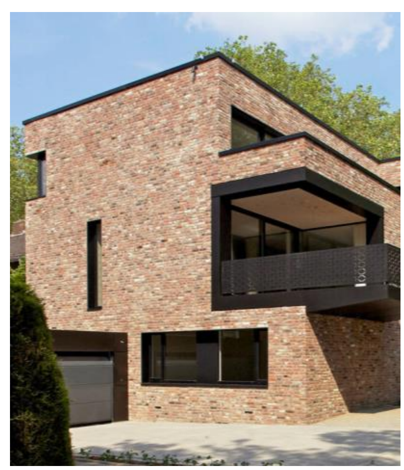
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