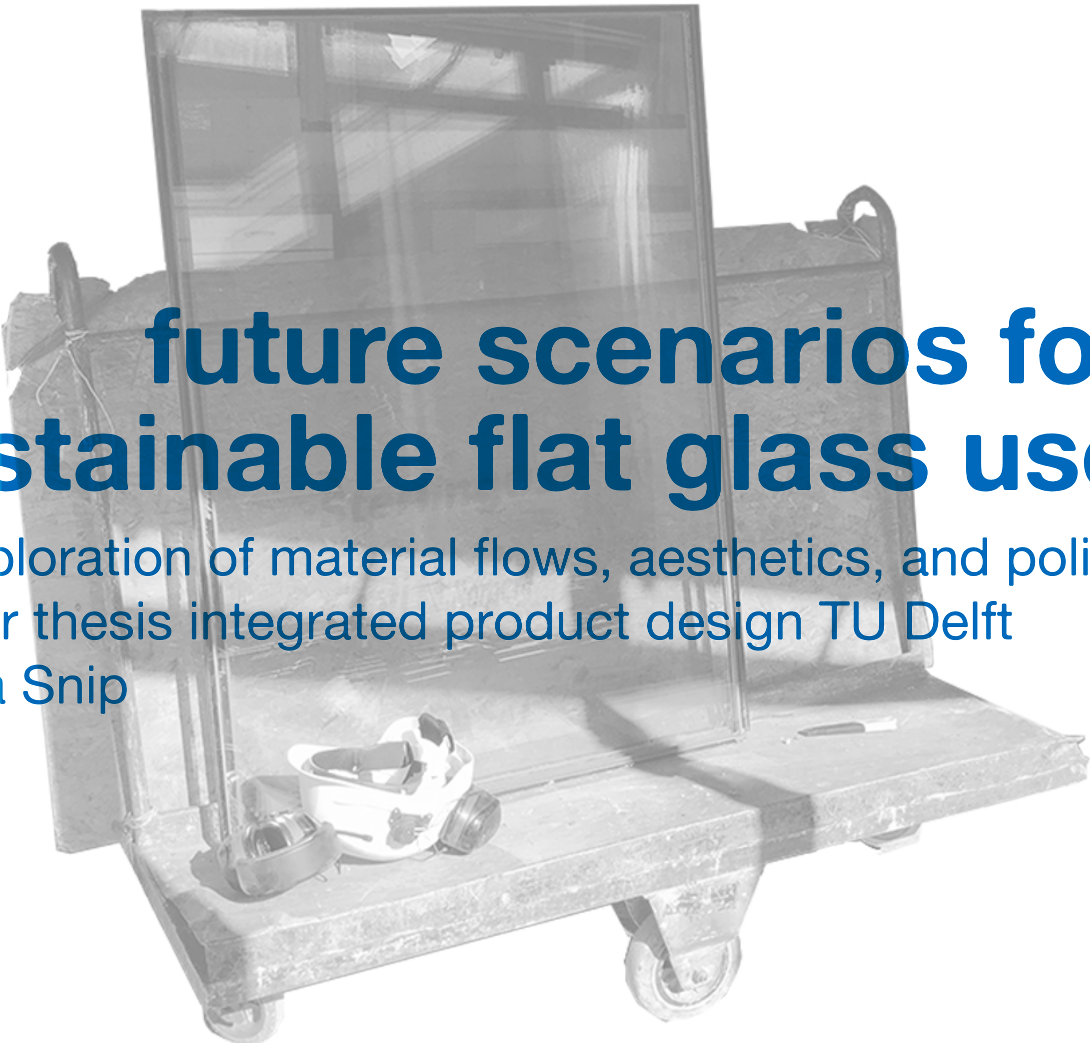

future scenarios for sustainable flat glass use

an exploration of material flows, aesthetics, and policy

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Delft, November 2023

abstract

Float glass is a largely unexplored material flow in the context of circularity. As the Dutch government wants construction to be fully circular by 2050, new ways have to be found to deal with float glass. Five scenarios for sustainable glass handling are discussed: what would happen if all available secondary windows would be recycled, remanufactured, reused, repaired, or if glass use would be reduced? The effects on material demand, energy use, value chain processes, and product are explored and compared. Finally, policy options are proposed to stimulate these sustainable strategies.

contents

introduction

In the light of resource depletion and the climate crisis, more sustainable production and consumption are urgently needed. The Netherlands, along with many other countries, have set up ambitious plans for a circular, more sustainable economy: in 2030, the Netherlands should use 50% less abiotic resources (minerals, metals and fossil) and by 2050 the economy should be fully circular[1]. Construction is using most resources and causing most waste of all sectors[2]. An interesting material stream in this context is float glass. In theory, glass can be infinitely recycled, and does not age. In reality however, it is mostly downcycled, losing value and energy. How could float glass be handled more sustainably?

project aim & scope
Various strategies exist to enhance the sustainability of material flows. The aim of this project is to explore these strategies in five scenarios, and to analyse how they would impact both the glass value chain and the user experience. Most of the research is qualitative, but rough quantitative estimates are made of impacts on material use and energy demand. Furthermore, policy options are proposed to support the sustainable strategies discussed. Finally, the scenarios are visualised to communicate their desirability and inspire designers and policymakers alike.

project approach
This project started without a concrete research question or design assignment. A substantial part of the time was spent on desktop research and getting to know the field through company visits, interviews and attending project meetings. The initial idea was to design something to help demolition workers remove windows. However, it soon turned out that the current method could hardly be simplified, except perhaps by a large autonomous window remover robot, which was beyond the scope of this project. As it became clear that window removal was but one of many challenges in the field of sustainable glass, and that a little financial incentive or extra time would perhaps be more effective than a complicated engineering solution, the idea emerged to analyse the system on a larger scale. From that point onward, the project diverged from the typical IPD scope; from designing and testing a tangible product to imagining and analysing a set of possible futures. This made the process more challenging, but also more interesting and rewarding to me.

research questions

1. In what ways could architectural float glass be handled more sustainably?

   a) Which scenario, or combination of strategies, would be most effective in terms of material saved?

   b) Which scenario, or combination of strategies would be most effective in terms of energy saved?

   c) What would be the influence of different strategies on processes in the float glass value chain?

   d) What would be the influence of different strategies on the product: the aesthetics of architecture, and the user's relationship with it?

2. What policy would be most effective to improve sustainable handling of architectural float glass?

float glass, now

Since the visionary architects of 'het Nieuwe Bouwen' promised light and air to everyone in the first half of the 20th century, freeing the masses from the suffocating pettiness of the previous centuries, we have liked our windows big and flawless. Large amounts of glass also have their drawbacks. Despite gradualy improving U-values (overall heat transfer coefficient) and recent inventions like vacuum glass, windows stay some of the least insulating surfaces of a building. Big windows mean high heating bills in winter and a sauna effect in summer, which will only get stronger as global temperatures rise.

Large windows are omnipresent. The global glass market is growing, driven by industrialisation, population growth and urbanisation. From 2021 to 2030, a growth rate of 4,1% per year is expected[3]. The demand for the sand necessary for glass and cement rises faster than natural sources can sustain. According to the UN, roughly 40 billion tonnes of sand are extracted per year for concrete, asphalt and glass[4]. This comes down to 18 kg of sand per day for every person on Earth. Sand scarcity is expected to result in a price surge of up to 30% in the upcoming 20 years. This will likely hinder construction plans and make glass less accessible for poorer groups.

In the Netherlands, 192.000 tonnes of flat glass are brought to the market annually[5]. Over 100.000 tonnes of secondary flat glass could be collected by recycling organisation VRN per year. The difference can partially be attributed to construction of homes because of the growing population and the decreasing size of households. Furthermore, people upgrade to more effective insulation glass units (IGUs) to improve the thermal performance of their houses, for environmental and financial reasons.

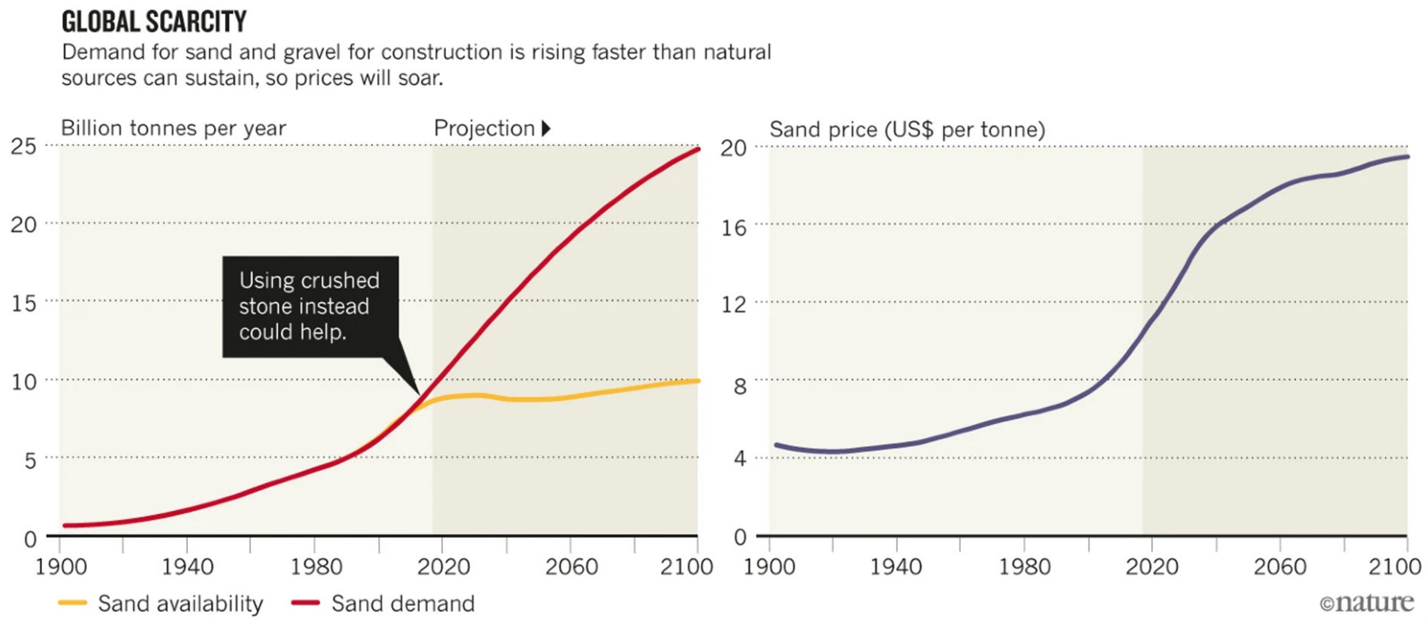


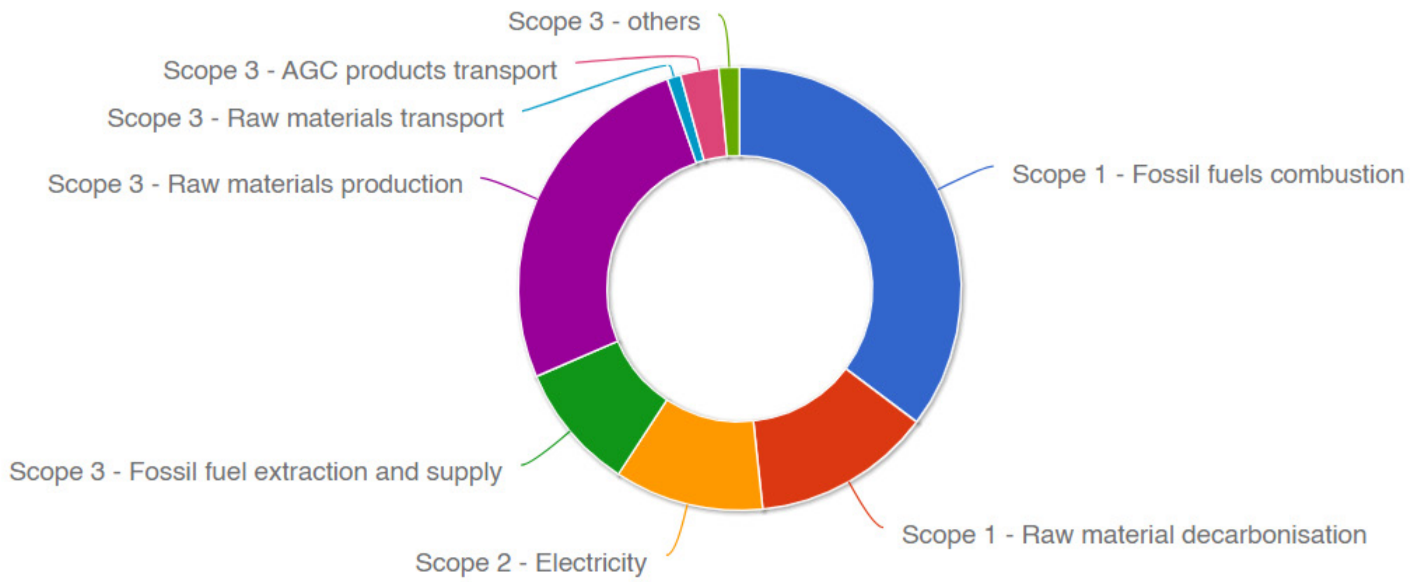
Figure 1 – global sand scarcity is on the rise[3]

In theory, glass is infinitely recyclable without value loss[6]. In practice however, virtually all flat glass is downcycled into products like food containers and insulation. This linear process is costly in terms of materials and of energy. The European glass production uses approximately 81 PJ of energy per year, which corresponds to 0,4% of the EU's gross inland energy consumption. 70-80% of the energy comes from gas, the rest is electricity. According to Glass Alliance Europe, the share of electricity use is steadily increasing due to improvements in electric firing technology and sustainability considerations[7].

European float glass company Saint-Gobain is increasing the amount of recycled glass, cullet, in their process[8], although the percentage of post-consumer cullet does not yet reach 1%. There are also remanufacturing initiatives: Dutch glass company GSF offers IGUs with 50% reused glass. Reuse also happens, both by individuals on a small scale, like the squatters in De Achtertuin in Wageningen who built their own homes from secondary materials, and by pioneering architecture firms like Superuse studios, who harvest materials around the country. What would happen if these initiatives would become the new normal for material use? Are there perhaps even more radical options, and what would their impact be?

Below, figure 2 gives an indication of the carbon footprint breakdown of the glass production process, in this case self-reported by AGC. Over a third is strictly related to the production, transport and decarbonisation of raw materials. This indicates that the footrpint could be decreased by using cullet, which decreases the need for raw material production, decarbonisation, and most likely transport.

Figure 2 - carbon footprint breakdown of AGC's float glass production[81]



significance

impact of construction materials

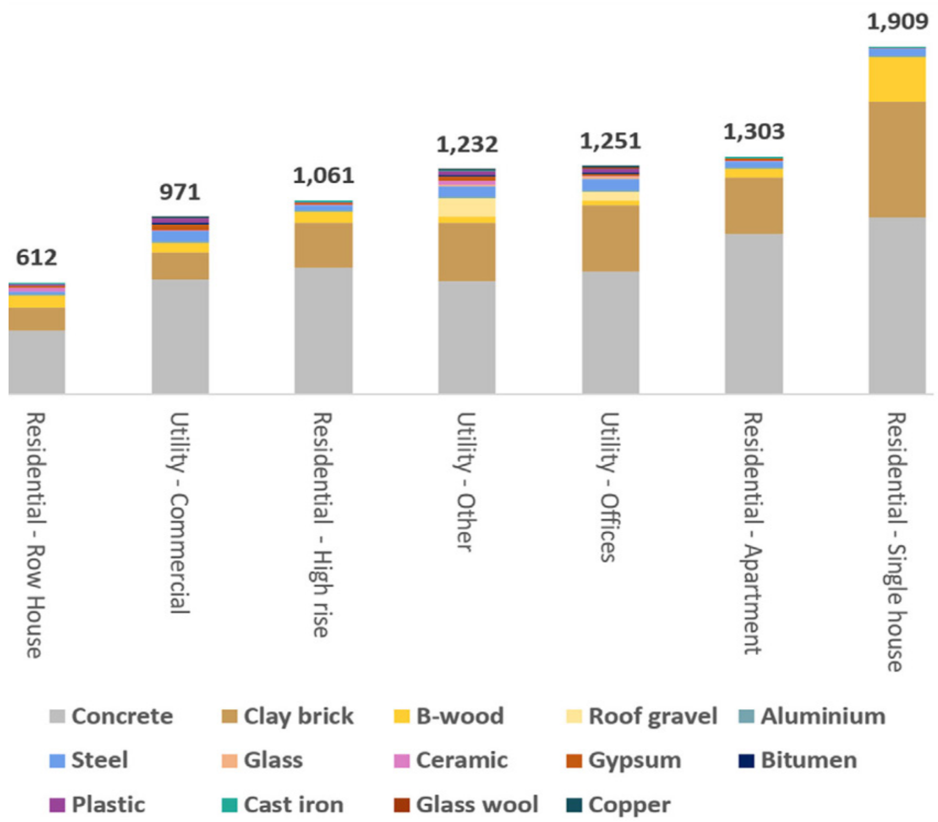
About half of the extracted resources in Europe are used by the construction sector. Over a third of Europe's waste is generated at construction and demolition sites[2]. Moreover, as of 2018, the buildings and construction sector together account for 36% of global final energy use, and for 39% of energy and process related CO2, 11% of which came from production of steel, cement, glass and the like[9]. Between 1995 and 2015, greenhouse gas emissions from the production of materials has risen from 15% to 23% of the total global emissions. In the construction sector, material production contributes 70% of the carbon footprint[10].

Construction material flows vary in their environmental impact. There are different ways to measure impact too; comparing emissions per kg of building material, per m^2 living space or as a fraction of the total global emissions. All give different, relevant, results. In absolute numbers concrete is the greatest polluter, mostly because of its widespread use: the cement industry alone is responsible for about 7% of global GHG emissions[11].

When comparing emissions per kg, aluminium sheets are by far the worst emitters (10.46 kg CO2 eq /kg). Triple (1,86 kg CO2 eq /kg) and double glazed glass panes (1,76 kg CO2 eq /kg) are the 16th and 17th most emitting out of the 64 most used building materials[12]. It should be noted that weight is not always the most relevant unit for comparison, as the amount of material used in a building varies greatly per material, as illustrated by fig. 3 below. Glass is a relatively small material flow, but the fact that the material itself basically doesn't age makes it interesting for high-value circularity.

Figure 3 average material intensity per building type in the Netherlands. Sprecher et al, 2021[13]

Figure 4 Byggeriets Material pyramid, ranking building materials in kg CO2 eq / g[12]



the insulation glass unit

An insulation glass unit (IGU), also known as HR+ or HR++ in the Netherlands, is the most used type of glazing. It consists of a number of layers, typically the following, from inside out:

1. Float glass pane, usually 4,5, or 6 mm thick
2. Low-e coating, directly applied on the pane, improving the thermal performance of the IGU. Contains silver or other low emissivity material, reflecting infrared energy. Nearly invisible, but it is said that coated glass from different factories can have subtle colour differences.
3. Butyl rubber primary seal, connecting the spacer to the panes and keeping the gas in Spacer, typically aluminium, determining the distance between the glass panes
4. Desiccants, small balls of a drying agent removing humidity and moisture. Usually silica and zeolites[11]
5. Cavity filled with a gas slowing the heat transfer, usually argon, sometimes krypton or others.
6. Secondary sealant, closing off the system. Polysulphide, silicone or polyurethane

The thermal transmittance of a building material is represented by its U-value, W/(m2K). The lower the U-value, the better the insulation. The U-value of IGUs is usually around 1,6, but can be as low as 1,1[14].

The difference between HR+ and HR++ is that ++ has an improved coating. Other types of glazing are single glass (U=5,6), double glass or Thermopane (U≈2,9), triple glazing HR+++ (U≈0,9), and vacuum glass (U≈0,4)[15]. For roof windows and glass lower than 80 cm one of the glass panes is layered for strength, meaning it consists of two panes stuck to each other with a foil in between.

Glass itself does not age. The idea that glass is an extremely viscous liquid that slowly flows down and thickens at the bottom is a myth[16]. However, there are other reasons why old IGUs do not fulfil their function anymore. First of all, argon gas can slowly leak out through manufacturing defects such as sealant voids and contamination. For IGUs qualified for the European standard EN 1279 no more than 1% of the gas should leak out per year. A new IGU, typically filled with 90% argon, only has a 16% better insulation value compared to one filled with air[17]. Hence, this leaking has a relatively small effect: after 100 years, when all argon has disappeared, the IGU still has 86% of its original insulation value. As more gas leaks out, moisture can also get in, causing condensation, an aesthetic incentive for users to replace their IGU. IGU manufacturers provide a 10-year guarantee on the tightness of their products[18]. Furthermore, low-e coatings deteriorate unevenly over time, as condensation causes it to oxidise.

Even if they would remain in perfect state, many older windows do not meet the new Dutch building standard. From 2012, any window, door or frame cannot exceed U=2,2, and the average of these elements in a building should not exceed U=1,65[19]. Hence, single glazing and Thermopane are not sufficient anymore, and IGUs without gas can only be used when compensated by other elements with a lower U-value.

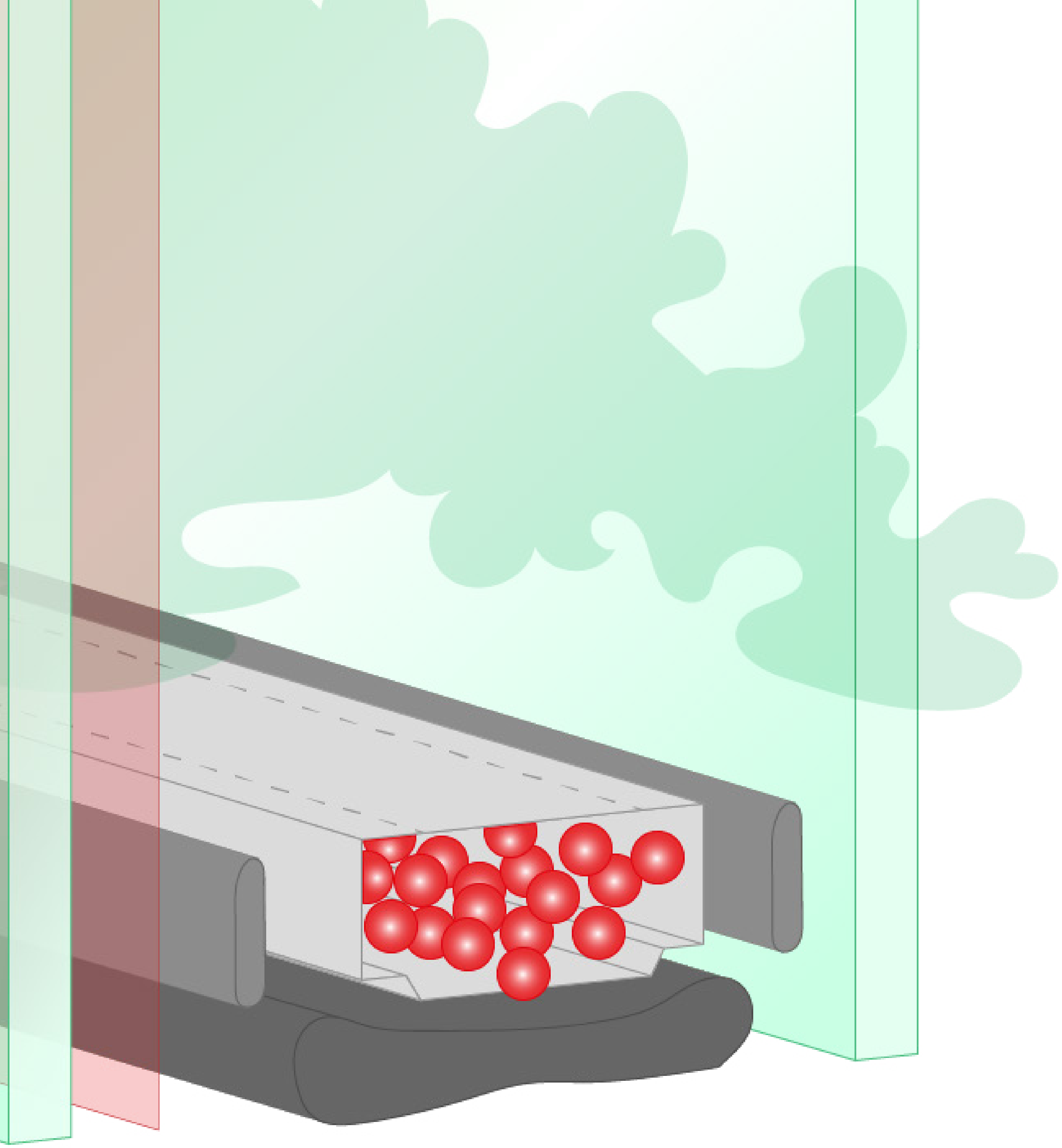


Figure 5 exploded view of an IGU

Figure 6 different types of insulation glass, Dutch nomenclature[14]

methodology

The project started with desktop research, site visits, and interviews. The initial goal was to generate an understanding of circular initiatives in the construction sector in general, and find an interesting material flow to focus on. After settling on glass as a topic, research was focused towards the float glass value chain, its stakeholders, challenges, and existing sustainability initiatives.

Throughout the project, regular discussions took place with Dick van Veelen, general director Meijs Ingenieurs, and with a researcher connected to the Hogeschool van Amsterdam project Hergebruikt Isolatieglas ('reused insulation glass').

Multiple sites relevant to circular building and glass reuse were visited:

- The demolition site at Strandwal 38, Heiloo, where a GGZ building was taken down by C.A. de Groot. Asbestos sanitation and winodow removal were observed, and conversations took place with multiple managers and demolition workers
- Cirkelstad meeting and co-creation session in Alkmaar. Representatives of the building and demolition sector and sustainable entrepreneurs came together to present their projects and discuss circular plans for the redevelopment of a heritage site.
- GSF circular insulated glass unit (IGU) production line
- HvA IGU reuse workshop for architecture and building construction/management students
- Material inventory by Meijs Ingenieurs at TU Delft's CiTG faculty

The following people were interviewed:

- Cor Wittekoek, director Vlakglas Recycling Nederland (VRN)
- An architect at Superuse Studios
- A managing director at a construction company
- A transition circularity developer at Insert
- An event manager at New Horizon
- A site manager of the GSF circular production line
- A public affairs manager at another glazing company

The following people were consulted for feedback on the scenarios:

- A transition manager circular construction at a Dutch province
- A senior policy officer on climate and circular economy at the Ministry of Infrastructure and Water Management
- A project leader circular construction economy at the ministry of interior and kingdom relations

research questions

RQ 1 In what ways could architectural float glass be handled more sustainably?

Desktop research was conducted into sustainable design and business strategies and scenario writing. The Dutch float glass material flow was mapped. The structure was based on mappings of other countries, notably by Hartwell et al[30]. Most of the data came from VRN year reports and a 'Notification on the flat glass waste management of declaring the agreement on waste management fee for flat glass generally binding' by the Ministry of Infrastructure and Water Management.

Based on this mapping, opportunities for narrowing, prolonging, and closing loops were identified. Then, in a first round of ideation, various design techniques were used: brainstorming, analogies, how-to's and storyboards[59]. Ideas were clustered and the five scenarios were outlined.

The remanufacturing and reusing scenarios have been coupled to opposite architectural design approaches: standardisation and flexibilisation, respectively. These design approaches help reaching the full potential of each sustainable strategy. They also increase the difference between the scenarios, which allows an exploration of a wider range of possible futures and makes the comparison more interesting.

1a. Which scenario, or combination of strategies, would be most effective in terms of material saved?

Estimates of the available amounts of secondary glass and their suitability for different circular practices were based on VRN publications. Estimates by GSF about their current and potential processing capacities were used for the remanufacturing scenario. Assumptions were made as to the influence of standardisation, reuse, and decreased demolition. The resulting amounts were compared to the Dutch annual glass demand.

1b. Which scenario, or combination of strategies, would be most effective in terms of energy saved?

To answer this question, an overview was needed of the energy use of the different processes in the glass value chain. Self-reported carbon footprint data from glass producers AGC and Euroglas was used, next to scientific reports on the influence of cullet on energy requirements. As a full LCA of float glass was out of scope, the answer to this question remained coarse.

1c. What would be the influence of different strategies on processes in the float glass value chain?

Alternative value chains were imagined using creative techniques like brainstorming, story boards, and analogies. Real-life circular initiatives were used as references. The resulting ideas were discussed with policy makers and industry insiders.

1d. What would be the influence of different strategies on the product: the aesthetics of architecture, and the user's relationship with it?

The unique aspects of each scenario were enlarged and linked to existing aesthetic frameworks. Pinterest, Google Images, and various architecture websites were used as inspiration. Mood boards were created as a basis for collages and illustrations.

2. What policy would be most effective to improve sustainable handling of architectural float glass?

Literature on policies related to recycling, remanufacturing and conscious energy use was consulted, as well as existing policy from various countries, and related initiatives. Unrelated examples were translated to the context of float glass. After brainstorming, clustering, and filtering, the ideas were discussed with policy makers and industry insiders, and detailed further.

float glass life cycle

production

Float glass, the glass used for windows, is made from sand, soda ash (sodium carbonate), dolomite, limestone, and salt cake (sodium sulphate). Often, waste glass (cullet) is added as well. The materials are mixed and heated to 1500-1650°C, to melt, and the mixture is kept at that temperature for some hours to clear out gas bubbles[20]. Then, the temperature is lowered to 1100-1200°C and fed into a bath of liquid tin, in a chamber with a protective atmosphere to prevent oxidation. The glass floats on top of the tin to form a layer with a perfectly smooth surface. The temperature is then gradually reduced to 600°C and the sheet is lifted onto rollers. A coating of metal oxides is applied, and the glass is cooled down. Finally, the quality of the glass is inspected by an optic laser and automatically cut in 6x3,21m panes.

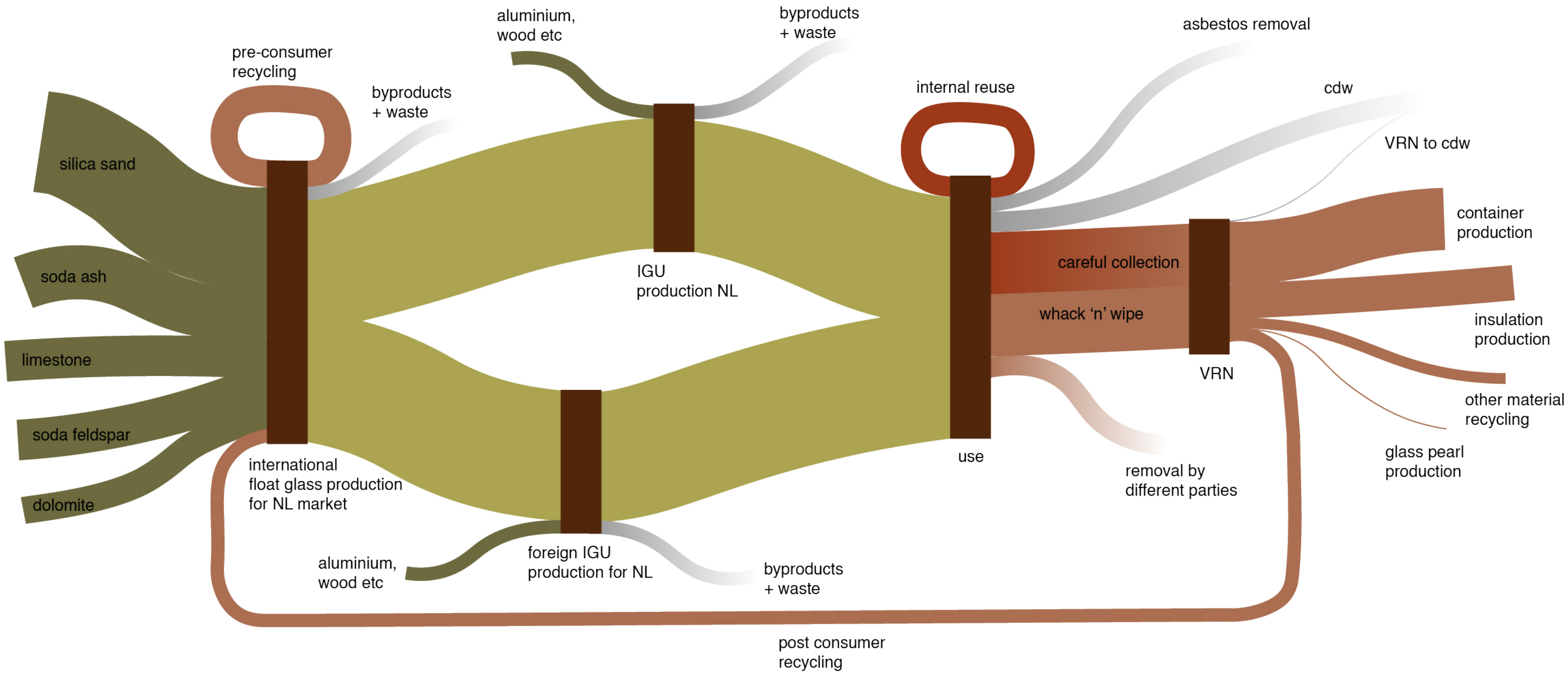
Float glass plants are located all over the world, notably in China (around 200 producti on lines[21, 22]), the US (around 30 lines)[21], and Europe (around 50[23, 24]). The last Dutch float glass factory closed in 2013[23]. Float glass plants operate in a continuous production process, meaning the furnaces stay at 1500-1650°C for the full length of the plant's lifetime, around 15-20 years[25]. Continuous energy supply is vital for the flat glass industry. 75% of the energy for European float glass production comes from natural gas, the rest from electricity. In total, European production uses approximately 61.000 TJ of gas annually[26], roughly 0,4% of the EU's gross inland consumption. On average, European glass production requires around 7,8GJ per tonne of saleable product[27]. For comparison, at least 20GJ/t is needed for crude steel [28]. Global glass production emits roughly 86 Mt of CO_2 annually[29].

Less energy is needed in the production process when more cullet is used. At Saint Gobain, ~30% cullet is currently being used: 19% internal cullet from their own production process, 11% pre-consumer cullet from coating lines and transformation sites and <1% post-consumer cullet[8]. Similar numbers apply for the UK glass production[30]. The company aims to use 50% cullet by 2025. Theoretically, making glass using 90% cullet would be possible[31].

Not just any type of sand can be used to produce glass. Approximately 32-50 billion tonnes of suitable sand are consumed each year, mostly to produce concrete, glass, and electronics, and this demand could outstrip the supply as early as 2050[32].

All circular practices (excluding energy recovering) contribute to closing the loop and decreasing the amount of resources needed by the glass industry. Practices from repurposing upwards on the R-ladder, so above recycling, have the added benefits of maintaining more value and decreasing the amount of energy needed for glass production.

Figure 7 Sankey diagram giving an overview of the flat glass material flow in the Netherlands



end of life: glass downcycling

Most of the time when a building is demolished, asbestos has to be removed first. At that stage, an unknown amount of glass gets taken away. According to a survey sent out for this project, this could be between 20-50% of the glass in a building. Once asbestos is cleared and demolition starts, workers remove the rest of the glass. Different methods exist for removing glass.

In an interview with a demolition company[37], Van der Meij describes their current demolition practices: 'The quickest method is to tap the window from the inside out as this is the cheapest. The 'neat' method of smashing a window is to tap the glass inwards after which it is swept up and put in the glass container, after which the glass can be recycled. This decision depends on the client, about 80% is not recovered but considered debris because this is also the cheapest demolition.' This suggests that a significant amount of secondary glass is not even separately collected, despite it being legally required since 2012. Interestingly, in the aforementioned survey, demolition companies reported that only 10% of the glass ends up in CDW.

Dutch float glass recycling organisation VRN collects the glass and brings it to recycling plants, from where it gets downcycled.

Compared to other countries, flat glass recycling is rather advanced in the Netherlands[30, 33]. Improvements, for example upgrading from recycling to reusing, in the Dutch system could potentially also be an example for other countries. About 192.000 tonnes of new float glass are brought to the Dutch market annually[5] for construction, renovation, etc. There is no exact overview of the amounts of secondary float glass available from demolition, renovation, and other projects in total. In 2018, it was estimated 100.000 tonnes of secondary float glass were available[5]. Current amounts are estimated as high as 130.000 tonnes[34]. In this report, 100.000 tonnes is used, as most data is available related to that estimation.

VRN annually collects a majority of the secondary glass: 90.861 tonnes in 2021[35]. VRN documents what they collect and has estimations of the total amounts available, but the data is incomplete. It is estimated that 15.000 tonnes are internally reused, for example in greenhouses (Cor Wittekoek, VRN director, in person conversation), and up to 15.000 tonnes disappear in CDW annually[36], even though separating glass during demolition is obligatory since 2012. Table 1 shows the source of the collected flat glass.

When assuming that the amount of glass from demolition, renovation, and municipalities added up approximates the amount of potentially intact glass panes that can be reused, that would be 76% of the available secondary glass. This is a rough estimation, but not necessarily too positive: it is very well possible that a large part of the glass from damage repairs, production and 'other' is suitable for reuse as well. That means in 2018 about 76.000 tonnes of glass could have been reused, corresponding with ~39,6% of the new glass market. As material will get lost in the process, this number will likely get smaller, but the order of magnitude stays correct.

	Glas wat vrijkomt	Glas wat door VRN ingezameld	Percentage ingezameld tov vrijkomend	Percentage ingezameld tov op de markt gebracht
	Tonnage	Tonnage		
Renovatie	60.000	48.000	48%	25%
Sloop	8.000	5.000	5%	3%
Gemeentes	8.000	8.000	8%	4%
Glasherstel	6.000	5.000	8%	4%
Productie	18.000	8.000	8%	4%
totaal	**100.000**	**74.000**	**74%**	**40%**

Table 1 origins of secondary glass collected by VRN, 2018

sustainable beginnings

demolition: supplying secondary glass

C. A. de Groot is one of the demolition companies with a circular focus. Most materials and products ‘harvested’ from their demolition sites are recycled or traded to be reused. I was invited to take a look at their demolition process at a site in Heiloo to observe the glass being removed. Because of the financial value of hardwood, the wooden window frames of the building are taken apart carefully, leaving the IGUs intact until they are dropped in the glass container. The process takes at least two people. First, the ‘glazing strip’ is removed with hammer and chisel. Then, the IGU is secured with suction cups on one side, and the sealant is cut through with a multi tool from the other side. The glass is carefully lifted out of the frame and moved to a stillage (bok). The stillage is then driven to the container and the glass is thrown in. This process takes longer than the whack & wipe method, depending on the location and accessibility of the glass. Disregarding these factors the extra time is estimated to be between 5 minutes per window to 15 minutes per m2, according to the director of the company.

Demolition, and especially circularity in demolition, seems to have a lower priority than construction, and available time and money are usually limited as a result. This is likely connected to the notion that part of the value of sustainability for clients is its visibility, communicating a sustainable narrative: ‘look at this interesting floor, the wood came from such-and-such old building, very sustainable’. In demolition, the results are not visible, so a sustainable narrative is not automatically communicated. Moreover, a new building is generally something positive, an exciting achievement to look forward to, while an old building is something negative, a chore that takes up precious time and money. Late planning of demolition closes off circular opportunities.

Figure 8, 9, 10, 11, 12, 13: removing an IGU

processing

GSF, originally a glass distribution and repair company, is a frontrunner in circular IGUs. In their Hilversum based production plant they manufacture IGUs with 50% reused glass. The secondary glass is collected at their own repair projects and placed at stillages, with little cork spacers in between them. An external company arranges the glass transport. At the factory, the IGUs are separated with a specially designed tool: a horizontal circular saw moving past the cutting table on rails. Because the sealant is so hard to remove, 5 cm of each side of the glass is cut off. A new machine is being developed by an external company that promises to speed up the dismantling process and clean the edges. This machine should arrive within a year.

Of the secondary IGUs, only the uncoated panes are reused. As the quality of the coating has most probably unevenly deteriorated, the coated pane cannot be reused as such, and is disposed of. In theory, coated panes could be reused as uncoated ones, but this does not happen because of subtle colour differences. Removing coatings is not possible as of now because of the small scale of the production plant. Coating reclaimed panes is not viable either, as of now, as the scale of the project is too small scale for coating companies to consider.

The reclaimed uncoated pane and a new coated pane are cut in the desired dimensions and inspected on visual quality. An aluminium spacer is made to size, filled with desiccant, and a butyl seal is applied on its sides. The panes and spacer are put in place and pressed together, then filled with argon, and finally a secondary seal is applied.

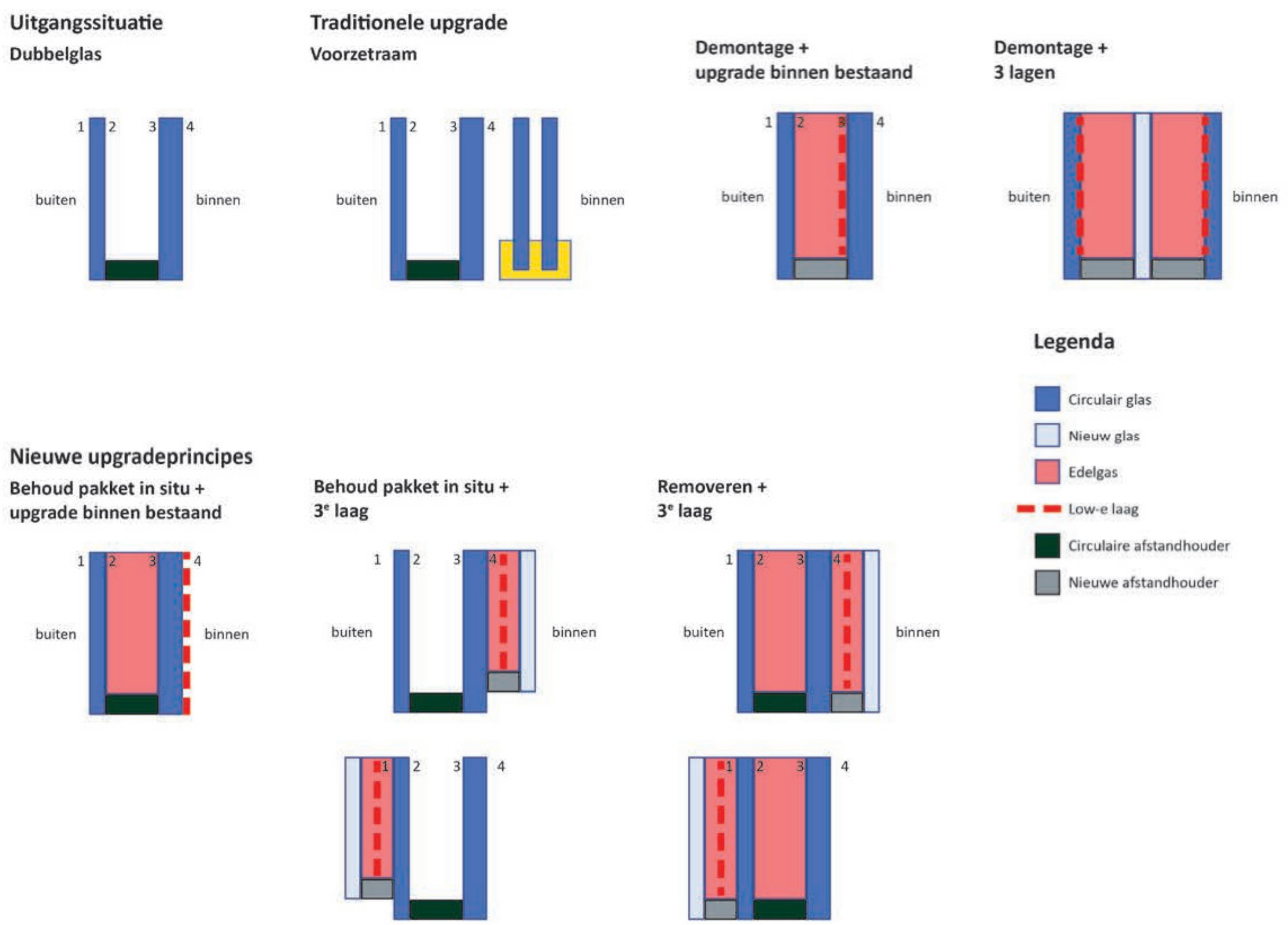
GSF is ‘not losing money’ on their process. They sell their IGUs, depending on size, for about 5-10% above the market price. The minimum price is that for 1m2 IGUs. Their IGUs have a 10 year warranty, conform the industry norm, and the company is in the process of getting a CE warranty.

FIgure 14: GSF’s IGU remanufacturing plant

reuse innovation

In collaboration with GSF and a range of other companies, Hogeschool van Amsterdam researchers Melet and Van Nieuwenhuijzen have set up a project ‘Hergebruikt Isolatieglas (2021-2023) investigating IGU reuse. In the project, nine principles to upgrade old IGUs are tested[37]. Some methods improve IGUs in their existing context, for others they need to be removed or dismantled. Glass, foil, and gas can be added in different positions. The results of the project will be out later this year.

Figure 15: remanufacturing principles as presented by the HvA project



stakeholders

Demolition companies are in charge of demolishing buildings, and hence the ones responsible for the part of the process where glass usually has the steepest drop in value: from functioning architectural element to risky shards, waste. According to VERAS, the demolition trade association, ‘the transition [to a circular construction economy] is in full swing and VERAS and its members are aware of the important contribution they can make to it: Demolition contractors are the raw material suppliers for construction’.[38] VERAS is involved in circular projects like Betonakkoord, SUPERLOCAL and CB’23, next to setting up initiatives of their own. ‘Many members’ are certified for the CO2 Performance Ladder. Various demolition companies are involved in harvesting materials from the buildings they demolish. In urban mining surveys, the materials in a building are mapped. The high market value of some materials, like copper, has established a trade in secondary material; for other materials no application has been found yet. A part of the materials and construction products is offered on circular trading platforms or traded via circular wholesalers. Demolition companies meet and collaborate with construction companies in initiatives like Cirkelstad (‘geen afval, geen uitval’) and Platform CB’23. Despite the green initiatives, two of the interviewees working in construction material recovery described the demolition industry as ‘a conservative sector.’

According to a researcher involved in the HvA project, integral removal of IGUs currently is not a viable practice, as it is too complex to be done quickly. Interviewees working at demolition companies mention that clients usually don’t want to spend more time and money on demolition projects, limiting the harvesting options for demolition companies. The demolition of buildings is often planned only after the construction of something new has been planned, leaving little flexibility.

C. A. de Groot removed IGUs in one piece for an unexpected reason: the hardwood window frames are collected and traded. After careful removal, the IGUs were disposed of in a glass container. VRN collects the container and takes care of its processing. According to employees, the chosen removal methods and their success rates greatly depend on the type of window frame and glass at hand. Double glazing stays intact more often than single glazing, and reinforced glass is ‘a different story altogether’. It also matters whether the glazing strip, keeping the window in its frame, is nailed, stapled, or kitted. It is easier to remove glazing from aluminium and plastic frames than from soft wooden ones, and hard wood is even more difficult. Plastic frames are not very common. Kit from before 1993 often contains asbestos, in which case the glass has to be disposed. Finally, the skill level of the individual worker handling the IGU matters. Expertise and craftmanship are ‘extremely valuable’.

For more circular handling of IGUs, a viable and feasible process for demolition companies should be developed. They either need more time, or the IGU removal process needs to be sped up drastically. Individual demolition workers need to get instructions and tools needed to remove and transport the glass safely and without damage. Moreover, space is needed to store secondary glass and other materials. Shared ‘hubs’, where material from multiple demolishers is stored and sold, is suggested as a solution.

49,9% of IGUs in the Netherlands are made by *Dutch IGU manufacturers*. They import float glass from abroad and create custom windows for their clients. Their work can vary from glazing big projects, like new apartment buildings, to replacing individual defective IGUs. Sustainability is rarely mentioned on the websites of IGU manufacturers[39]. If it is, it typically relates to added insulation value or durability of the product. Five glazing companies are involved in the reused IGU project by HvA. A representative of one of these said that after two tryouts, they decided not to offer remanufactured IGUs. ‘Processes are so lean that each deviation will rather cost money than make money’.

As far as known, GSF the only company in the Netherlands offering IGUs (partially) made from secondary glass panes. As of now, their process is a bit slower and about 5-10% more costly than average, mostly due to the complexity of disassembling and cleaning secondary glass, but this is expected to improve within this year.

In case of a different IGU value chain, the role of the manufacturers would change. They would be required to work with different materials, or have less business altogether. To upscale remanufacturing, the capacity for collecting, disassembling, cleaning, and inspecting secondary glass will have to be increased. Uncoating and (re-) coating installations would allow more secondary material to be remanufactured. Economies of scale would help make these functions viable. Upscaling could happen through elaborating the work of existing companies, or setting up independent projects. Independent projects can be inefficient in terms of experience and capital, but are free to fully commit to sustainability straight from the beginning, with no existing structures and vested interests slowing down change. Existing companies have the advantage of experience, organised logistics, capital, and network, but potentially find it harder to radically change due to their existing, less sustainable business. Changing the industry would be easier with their collaboration.

Architects and construction companies are the ones designing and constructing buildings for clients. The degree to which they are involved with sustainability varies from merely following the requirements in Bouwbesluit, to fully specialising in sustainable construction, for example through striving for energy neutrality and using renewable or reused materials. Construction companies deal with logistically complex projects. Switching to more sustainable building practices can require more tailoring and new supply chains, which can be a threshold: if constructors need to collect secondary building products at multiple different locations, as would be the case with secondary doors right now, their process wouldn't work. According to a director of one construction company, 'clients, often housing companies, usually don't want to spend more time or money than strictly necessary. They might opt for a cheaper, less sustainable company. It appears they often say they care about sustainability, while in practice they do very little to make it happen'. This director expects that, just like with nitrogen limitations, the government might impose CO2 emission limitations in the future. The province of Utrecht already started putting a price on CO2. Because the director 'prefer[s] to pioneer before the pressure gets too high', they already started innovating. According to them, there is already some demand for circular materials on the private market, but not yet on the commercial market, and altogether the supply is too small for large projects. In their company, five categories of circular building material are used in renovation and real estate maintenance. These are the products that can be implemented without disturbing the project planning too much; other categories require more time. The director and Dick van Veelen agree that 'there is a problematic all-encompassing short-sightedness' and that 'greenwashing is an issue'. 'There is no continuity yet', sustainable initiatives only happen because some individuals happen to care about their part of the process.

According to the transition circularity developer at Insert, the construction sector is working more on circularity than the infrastructure sector, 'probably because the government is more on top of it', despite the large material impact of infrastructure. Construction companies need clarity around warranties as well: since 2019, the quality assurance law (wet kwaliteitsborging) implies that constructors need to prove the quality of their materials and constructions. Secondary products can pose a risk here, as it is not always clear who is responsible for their quality.

To architects, aesthetic freedom can be an issue, meaning they don't like to be limited in the appearance and most importantly the size of the windows in their designs. The government's Bouwbesluit ('buidling code') is a bottleneck in the transition to circular construction, according to the Insert employee. 'This legislation is not built for circularity'. They mention labour as another bottleneck making circularity expensive. The Ex'Tax project 'might help'. Other issues mentioned around construction with secondary material are quality, ignorance, transportation, aligning the logistics of supply and demand. 'If supply grows, the demand will grow, and the other way around. It's complicated'. The government demands for 2030 ('all tenders circular') are expected to give a boost.

Over the last years, construction in the Netherlands has been hindered by nitrogen, inflation and material shortages, negatively impacting architects and construction companies[40,41].

According to an architect working for at Superuse studios, circular construction does not cost more than the linear process. 'It will become even more attractive when more provinces will follow Utrecht's example and start taxing CO2'. Regarding demolition, according to the architect, history has shown that society often only starts appreciating certain styles of architecture once it is too late and half of it has been torn down already. The architect suggests invloving welfare committees (welstandscommissies) in the demolition process as well, to prevent this from happening. Not demolishing is 'usually the most sustainable option'. The architect knows someone who tried to reuse IGUs, but they gave up, disillusioned.

The different perspectives on sustainability within the sector were illustrated in a Cirkelstad meeting where the development of a 'hub' was discussed. Where one architect envisioned the hub as a space where local residents could find materials and inspiration for personal projects, the present people from demolition companies were looking for a large scale storage space for the tonnes of materials they harvested in their demolition projects.

In line with the Paris agreement, _the Dutch government_ has presented its own plans in the Klimaatakkoord, and worked out programs like the Uitvoeringsprogramma Circulaire Economie. The goals are ambitious: in 2030, the Netherlands should use 50% less abiotic resources (minerals, metals and fossil) and by 2050 the economy should be fully circular[1]. There are many definitions of the 'circular economy'. The Dutch government defines it as an economy where (1) sustainable, renewable resources are used as much as possible, (2) products and resources are being reused, and (3) waste almost doesn't exist. Furthermore, in terms of CO2, the aim is to halve the emissions of the construction sector by 2030, and to reach 0 in 2050[42]. This comes down to a reduction of ~107 megaton CO2-eq. Initiatives like Platform CB23 have been set up to generate knowledge and determine a strategy to reach these goals.

The government can influence the transition to a circular economy in three ways: pricing (carbon taxes, waste disposal fees), standardising (setting rules) and incentivising (subsidies). As they are not a player in the glass value chain themselves, they are in a position to see and press for changes that could benefit the whole chain, that individual companies perhaps would not think of.

Unlike engineering, politics can be capricious. Interest in and commitment to sustainability vary per political party, and with each new cabinet, the priorities of the government can shift. Hence, while a political decision can have more impact than a design intervention, it might be harder to reach.

International float glass industry Float glass companies AGC, Saint-Gobain, Guardian Glass, NSG, Euroglas, Sisecam, and Vetropack operate in Europe. They all boast some commitment to sustainability, like low-carbon glass products, net-zero carbon emissions by 2050, some degree of glass recycling, or 'increased efficiency'. They also point out the contribution of their products to a decreasing energy demand. The steps to net-zero are typically undefined. Energy prices have been an issue for the glass industry in recent years. According to the HvA researchers, the float glass industry was not interested in joining the IGU reuse project.

Other glass industries, producing containers, insulation and glass pearls, use secondary float glass as a resource. If the float glass industry would shift to a more circular business model, the material inflow for other glass industries could be impacted, forcing them to look for other resources or to implement more circular practices themselves.

The European Union aims to be 'climate-neutral by 2050[43]. With their strong internal market, they can force multinationals to meet their standards. A recent example is the Apple iPhone 15, which is equipped with an USB-C charging port, contrary to its predecessors. This was enforced by the EU through a new law requiring phone manufacturers to adopt a shared charger connection, to decrease waste[44]. However, just like the Dutch government, the EU has to deal with contradictory voices. Their strict rules are not always appreciated by member states.

Like most people living in northern latitudes, *Dutch building users* appreciate natural light in their buildings[45]. The large windows in Dutch 'doorzonwoningen' (typical row houses) are considered a legacy of Calvinism, associated with honesty and having nothing to hide[46]. They also allow for cherished cultural expressions like a pair of identical Xenos candlesticks. Simultaneously, Dutch dwellers have a need for privacy, indicated by the amount of urban windows covered by curtains, blinds, and foil. They are increasingly environmentally conscious[47]. Recently, the energy crisis has increased energy awareness, but this effect might fade as the prices have dropped again[48].

sustainable frameworks

There are different ways to get from business as usual, take-make-waste, towards a more sustainable system. Bocken, Bakker and de Pauw (2015)[49] identified three approaches for resource use reduction, applicable in (product) design as well as in business models: narrowing, slowing, and closing resource loops. Narrowing means decreasing the amount of resources needed per product, or on a larger scale, the amount of products needed. Slowing aims at extending the useful life time of a product, through good design, maintenance, and repair. Closing loops prevents from leaving the system.

In a circular economy, products and materials should be circulated at their highest value[50]. The 9R framework distinguishes 10 different levels of circularity. Disposal is not included[51]. The framework can be used as a tool to determine the current circularity of a system and identify ways to improve it. The three overarching categories overlap with the narrowing, slowing and closing terminology.

The value hill is a 'circular business strategy tool[52]. The model describes the increase and decrease of value throughout the life of a product in the linear economy. Pre-use, the value of a product is increased through extraction, manufacturing, assembly, and retail. Post-use, the value drops down to waste. In a circular economy, loops can be closed by 'intercepting' the post-use product and re-introducing it on various value levels.

Sustainable strategies currently applied in the float glass value chain

In the context of float glass, closing loops on a small level is common: most float factories add small amounts of pre-consumer cullet to the raw materials they process. Only a fraction of post-consumer glass returns to float glass lines. Most of the glass ends up being downcycled, so recycled in a lower value material chain. Remanufacturing and reuse happen on a small scale by GSF and Superuse architects.

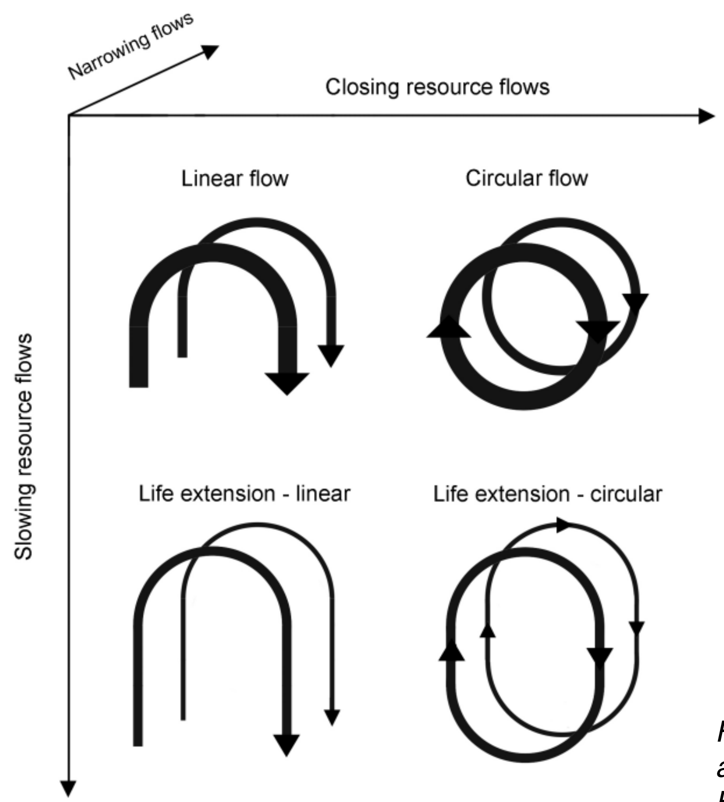
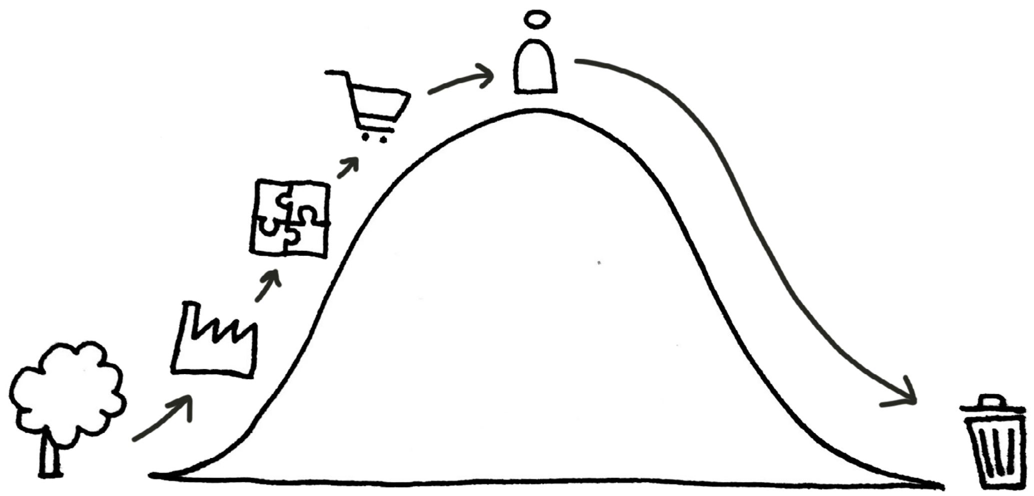


Fig. 16: categorisation of linear and circular approaches for reducing resource use. Bocken, Bakker, and de Pauw (2015)

Figure 17: the value hill

Table 2: the R-ladder



Smarter product use & manufacturing	R0	Refuse	Make products redundant: abandon its function or offer the same function with a radically different product
	R1	Rethink	Make product use more intensive (e.g. by sharing product)
	R2	Reduce	Increase efficiency in product manufacture or use by consuming fewer natural resources and materials
Extend lifespan of product and its parts	R3	Reuse	Reuse by another consumer of discarded product which is still in good condition and fulfils its original function
	R4	Repair	Repair and maintenance of defective product so it can be used with its original function
	R5	Refurbish	Restore old product and bring up to date
	R6	Remanufacture	Use parts of discarded product in a new product with the same function
	R7	Repurpose	Use (parts of) discarded product with a different function
Useful application of materials	R8	Recycle	Process materials to obtain the same or lower quality
	R9	Recover	Incineration of material with energy recovery

chosen scenarios

The following scenarios were explored:

1. Business as usual (BAU): nothing is changed
2. Recycling: closing the loop on material level: feeding all secondary IGUs back into the float lines as cullet
3. Remanufacturing: closing the loop on component level; using panes from secondary IGUs to craft new IGUs
4. Reuse: closing the loop on product level: using entire secondary IGUs in a new context, with some repair if necessary
5. Repair: prolonging the IGU life by repairing it in its context, and maintaining that context
6. Reduce: narrowing the glass flow by shifting to different materials

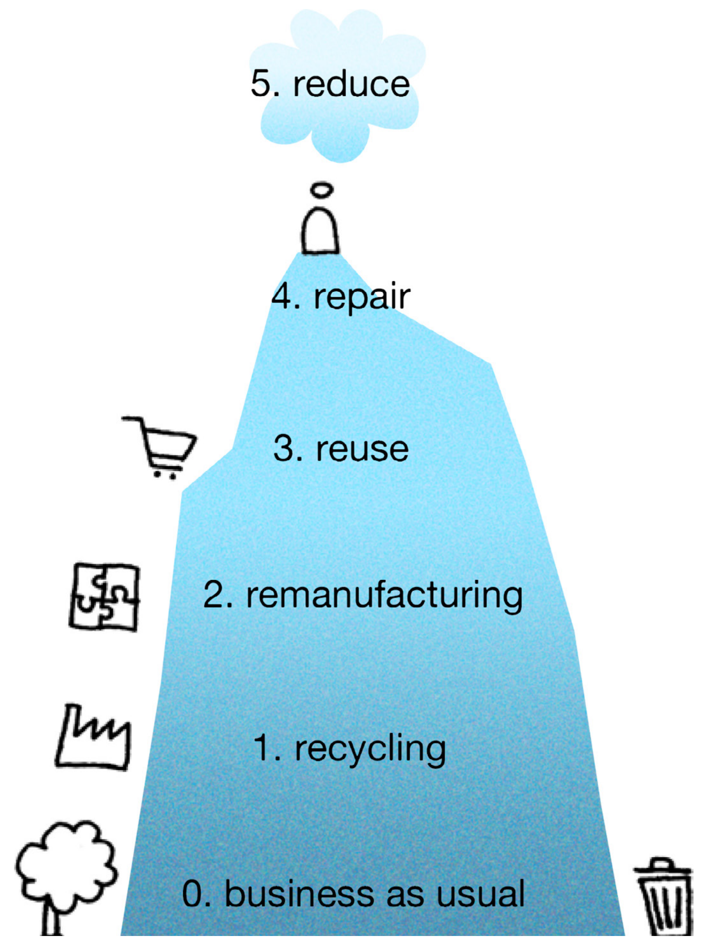
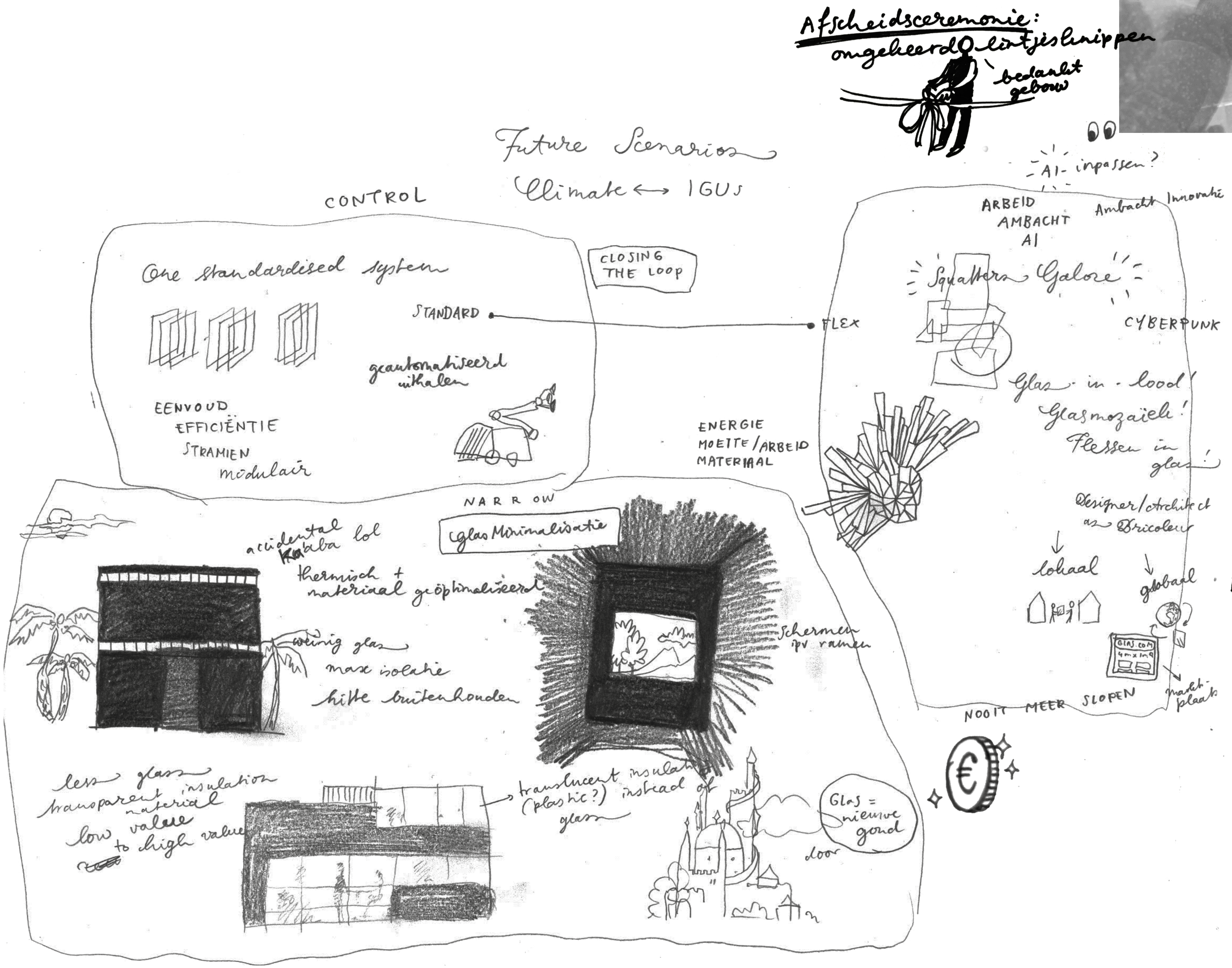
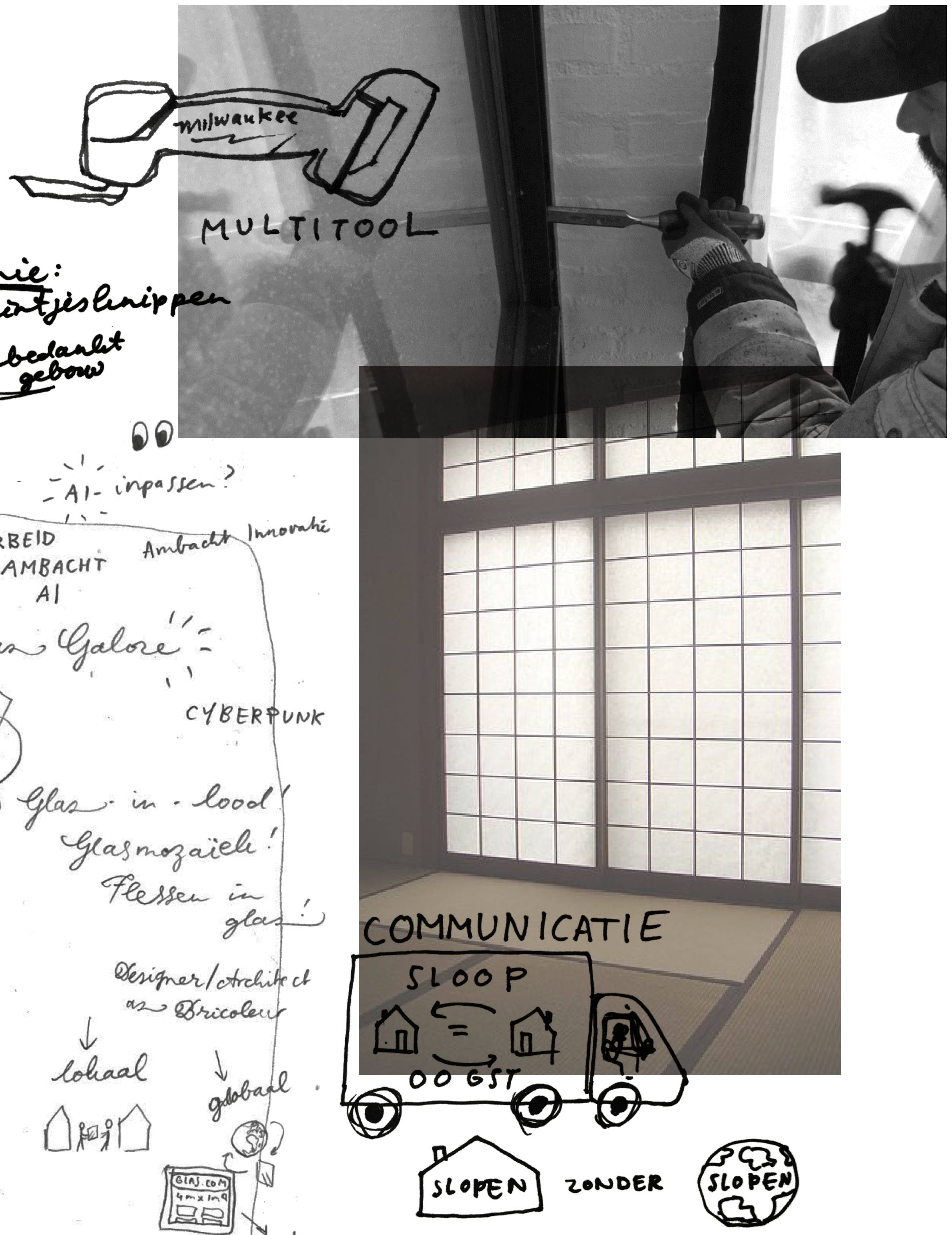
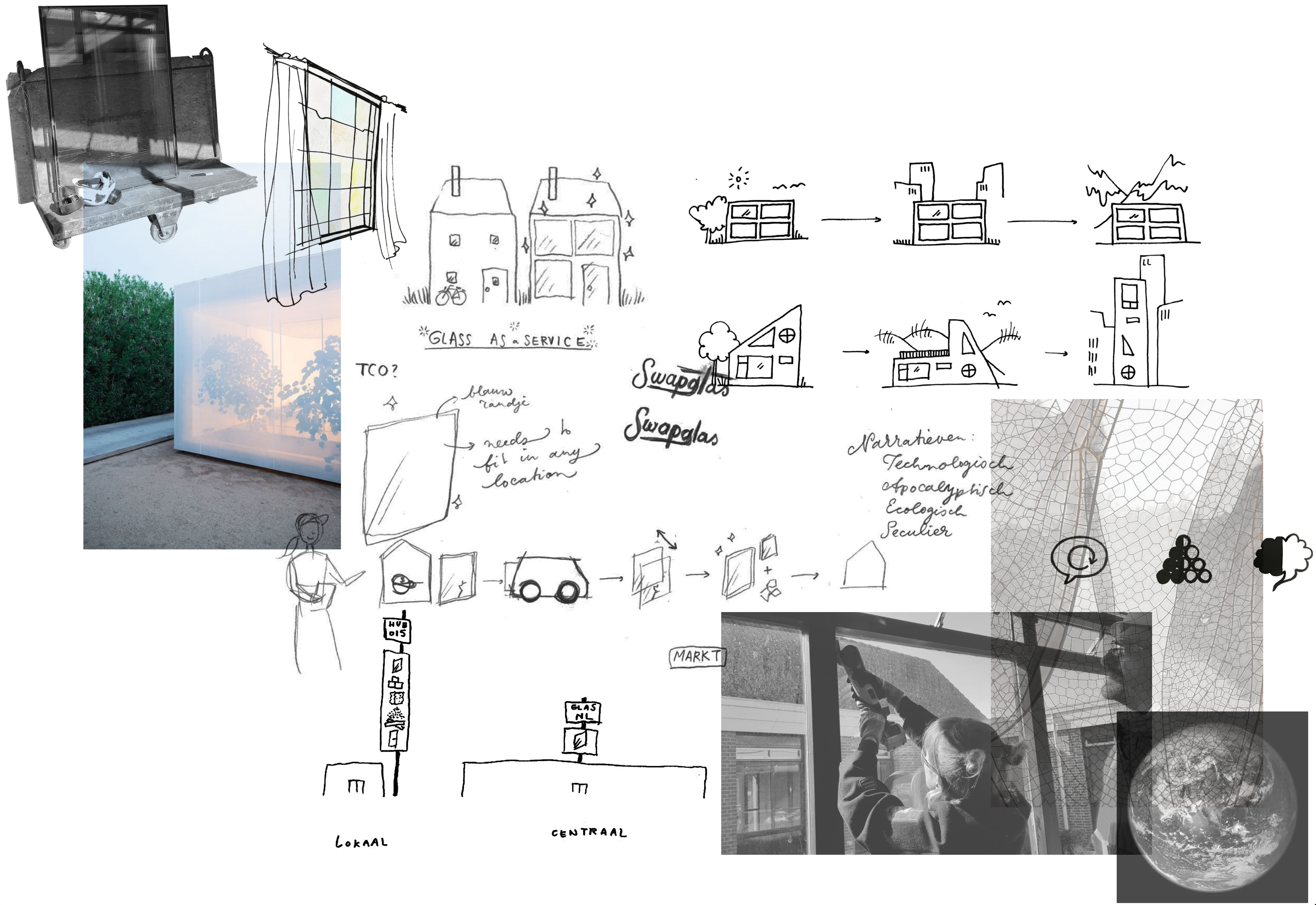


Figure 18: the chosen scenarios in the value hill

intermezzo: ideation






GLASS AS a SERVICE
TCO?
blauw randje
needs to fit in any location
Swapglas
Swapglas
Narratieven:
Technologisch
Apocalyptisch
Ecologisch
Seculier
MARKT
GLAS NL
LOKAAL
CENTRAAL

~~NARROW~~ PROLONG

NOOIT MEER SLOPEN

minimale verandering

MAINTAIN

nooit meer slopen

WEINIG ARBEID

alles door robots

niks veranderen

te weinig mensen om levensstandaard te onderhouden

alles oplappen

materiaalbewust

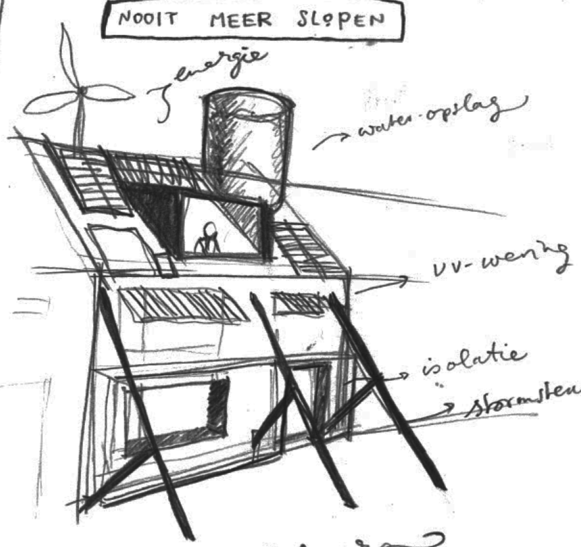
meer mensen wonen alleen

dijken

NOx :

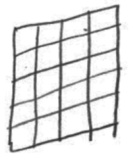
niet meer gebouwd

huizen kleiner



+ local repair

KIT

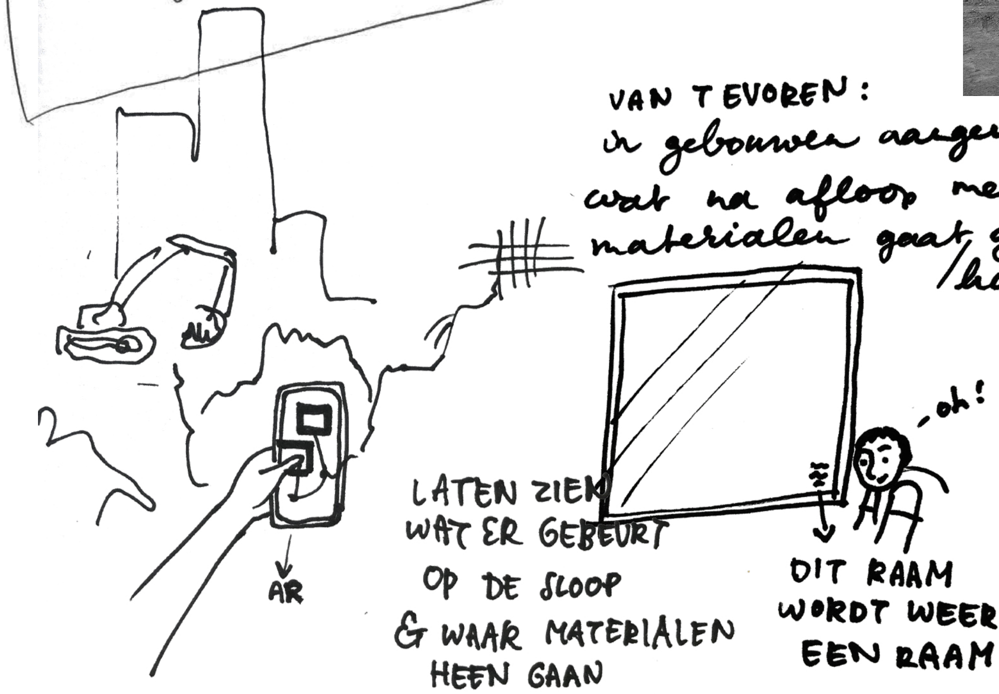


terug naar kleine ruitjes

Glashandelaars diversiferen: allround onderhoud

VAN TEVOREN:

in gebouwen aangeven wat na afloop met de materialen gaat gebeuren /kan



LATEN ZIEN WAT ER GEBEURT OP DE SLOOP & WAAR MATERIALEN HEEN GAAN

DIT RAAM WORDT WEER EEN RAAM

NATIONALISED GLASS INDUSTRY

Gov't — centralised — Market — profitable

Slow, large-scale, long-term

quick reaction, desirable, viable

decentral

People

Squatters, local reuse

nicer than the neighbours

local hubs, low-tech

reageren, meebewegen, aanpassen — beleersen, voorkomen

temp draagbaar hergebruiken

Performance

Labour

Energy

Material

Time

Money

Global — Tech Local

Policy — Tech — Social

Bottom-up — Top-down

Gov't — Market — People

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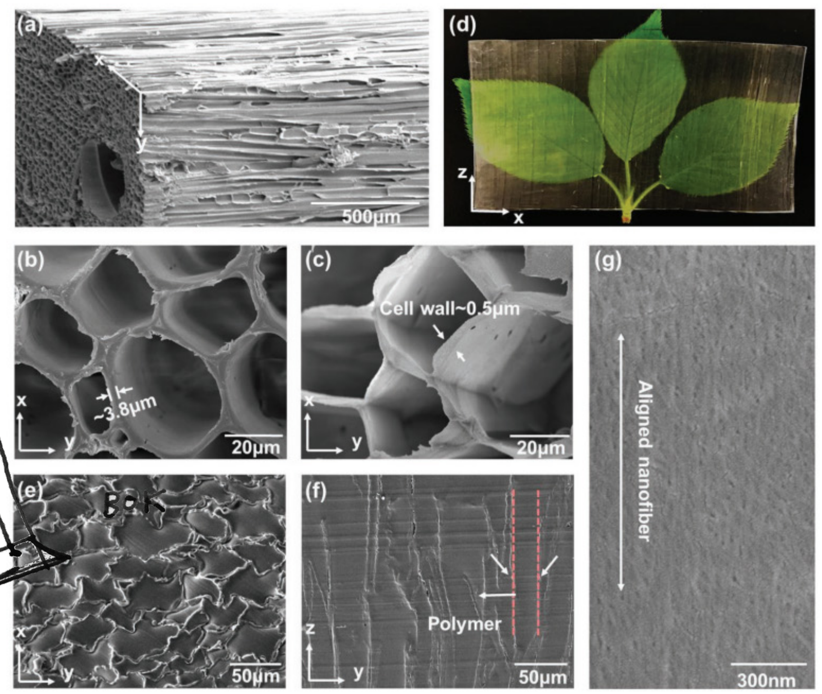
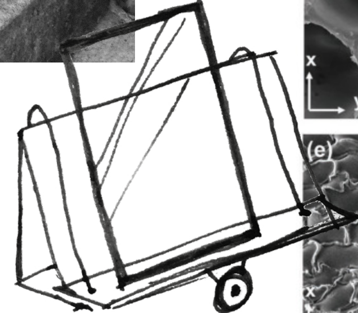
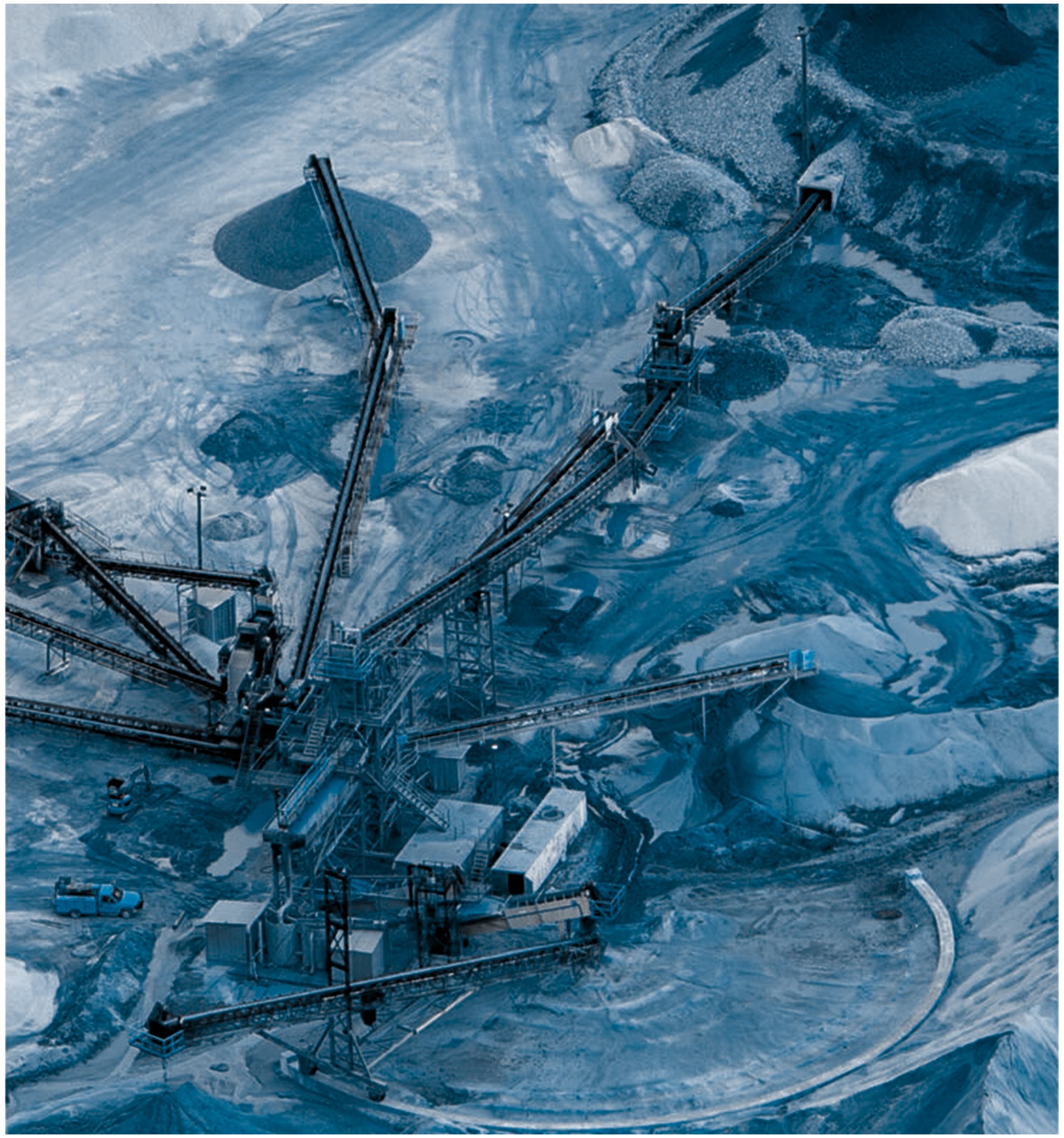


Figure 2. Characterization of the transparent wood microstructure. a) Scanning electron microscopy (SEM) image of the 3D mesoporous balsa wood. Top view SEM images of the b) natural wood and c) delignified wood, showing the thinner wood cell walls after the delignification process. d) Photo of the obtained transparent wood (100 mm × 50 mm × 0.8 mm) with high transmittance and low haze. e,f) SEM images of the polymer-filled transparent wood, showing the dense wood structure. g) Magnified view of the microsized channel walls, in which aligned nanocellulose fibers can be observed.





0.
Business as usual

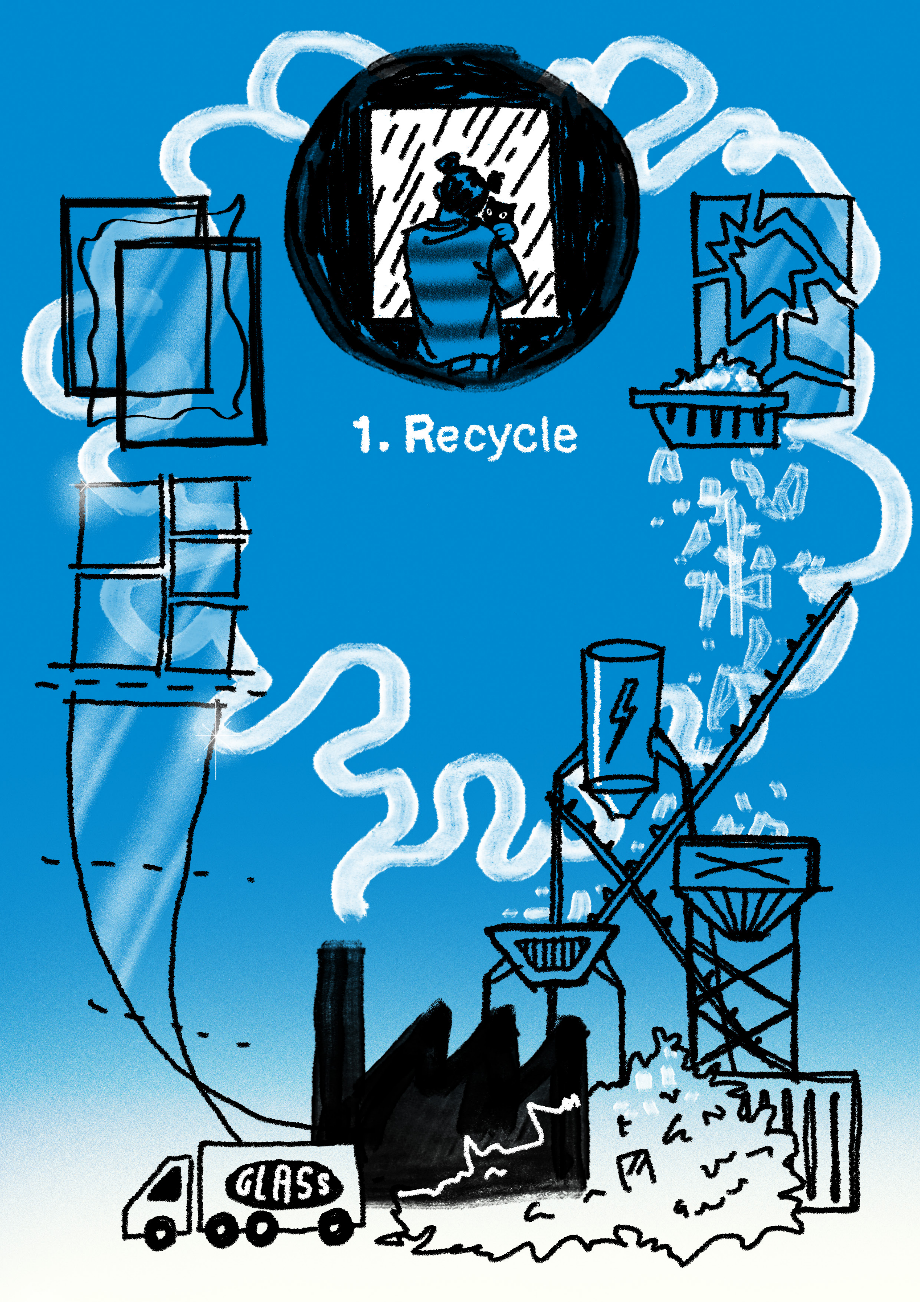
0. business as usual

Sand is the world's second most consumed resource[60]. If sand consumption continues as usual, problems could arise in the near future for construction and glass use. As discussed before, sand scarcity is expected to result in a price surge of up to 30% in the upcoming 20 years. The glass industry is not the largest sand user; concrete and cement consumer significantly more. Hence, changing glass use would probably not solve the sand problem, but not solving the sand problem would force changes in glass use.

Sand extraction is mostly ungoverned in many places, causing numerous largely overlooked environmental and social consequences, according to UNEP[61]. Sand extraction from rivers and marine ecosystems leads to erosion, shrinking deltas, changes of land use, air pollution, groundwater salinisation, and threats to biodiversity. Mining puts health and safety of miners and local communities at risk. Although no linear relationship exists, the connection between material scarcity and conflict has been demonstrated in various cases[62,63,64]. Sand scarcity could create new, or aggravate existing tensions between communities or countries.

Sand scarcity could influence the Netherland as well. On the short term, a surge in sand prices could lead to construction projects being delayed, or cancelled altogether. This could amplify existing housing crises in the Netherlands, and to a higher degree in poorer countries. The threshold for insulating existing buildings by replacing old glazing with modern IGUs would be increased as well, leading to unnecessary energy use. The technical issue of sand scarcity could quickly become a socioeconomic issue: price surges will hit social housing and people with low incomes first.

In the longer term, the glazing value chain will likely start looking for cheaper alternatives. Float glass plants will consider increasing their cullet use, while IGU manufacturing companies might start remanufacturing. This way, economic pressure could lead to sustainable innovation. Leaving this entirely to the free market economy means these mechanisms only start once there is an economic incentive. Damage will be done before things start changing. Looking for alternatives now, while sand scarcity is still manageable, could facilitate a smooth transition to sustainable sand use and prevent unnecessary pains.

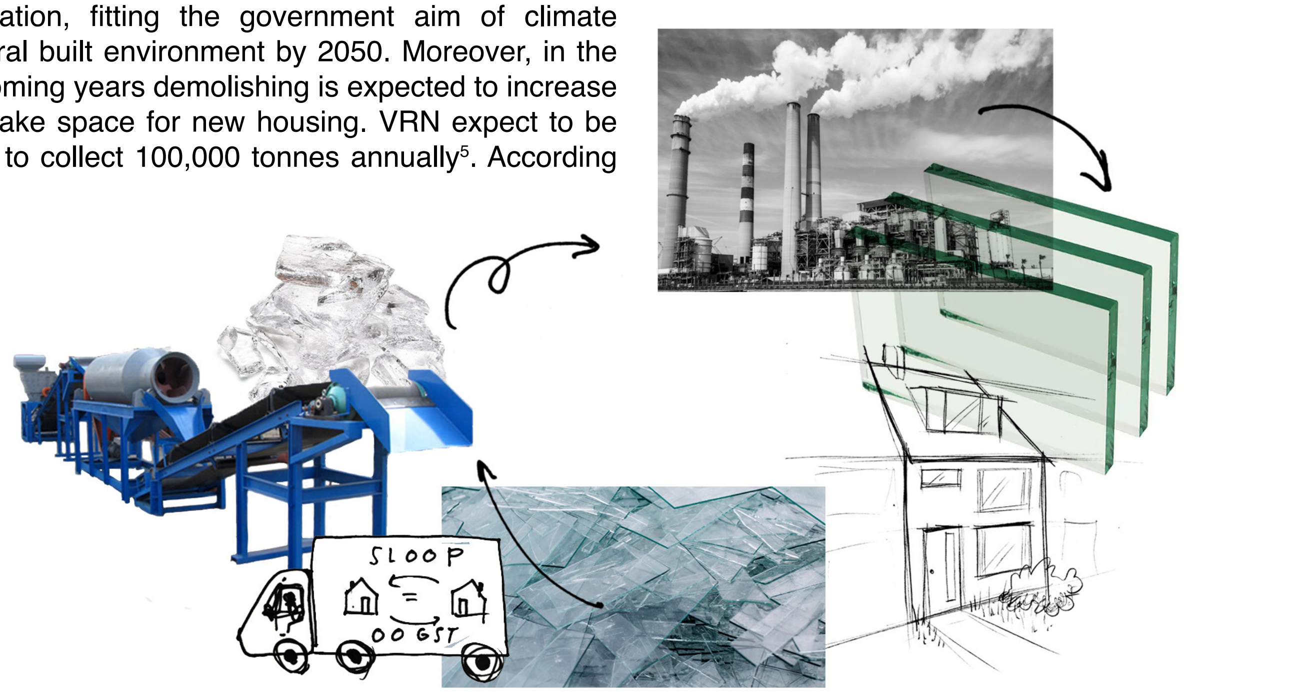


1. recycle

Theoretically, glass can be infinitely recycled. In this scenario, the loop is closed on the largest scale: after use, the product becomes a resource again for a new generation of the same product. Glass panes are created, fulfil their function, are demolished, cleaned, crushed, molten, and become product again. The material never leaves the system. European flat glass manufacturer Saint Gobain aims to use 50% cullet in their process by 2030. So far, less than 1% post-consumer cullet is being used, but to reach their goal they will likely have to change that. What if we would use all secondary float glass in the Netherlands to produce new float glass?

material use
The amount of secondary float glass available in the Netherlands has increased from 120,667 in 2015 to 137,585 tonnes in 2018[5]. According to VRN, 'a large part' of the secondary float glass that is not collected by them comes from production waste, and from renovation and demolition of greenhouses. They state that these sectors have organised their own glass collection for recycling and have no need for VRN's system. The amount actually collected by VRN has increased from 69.998 in 2015 to 90,861 tonnes in 2021, reaching their goal of 70,000 tonnes. The amounts of available and collected glass are likely to continue growing for the upcoming years, largely due to replacing old windows for better insulation, fitting the government aim of climate neutral built environment by 2050. Moreover, in the upcoming years demolishing is expected to increase to make space for new housing. VRN expect to be able to collect 100,000 tonnes annually[5]. According to VRN's 2021 annual report, 8,9% of the collected 'glass' actually consisted of metal, wood, rubble/stone/ceramics, and foils. No other sources mention the presence of other materials in the glass volumes, but it might still mean that VRN will only be able to collect around 91,000 tonnes of pure glass.
Currently, most of the glass collected by VRN ends up being downcycled to packaging (47,551 tonnes) and to insulation products (26.489)[35]. Downcycling is more circular than incineration or disposal, but value is still lost. If VRN would direct the expected 91,000 tonnes of glass back to the float glass industry, that could replace roughly 47% of the resources needed for the 192,000 tonnes of new float glass that are put on the Dutch market annually.

energy
Adding cullet to the float glass production process reduces the energy needed. 47% cullet would decrease the energy consumption of all Dutch-demand float glass with 12,5-15% based on common estimates[77]. As cullet can be imported from neighbouring countries, it might require less transport than virgin resources, which can be imported from all over the world. The crushing and cleaning of cullet also costs energy, but this is assumed to be less than what is needed for processing raw materials.



process
For the Dutch context, the difficult part is that there is no glass produced in the Netherlands, so the project mostly depends on foreign companies.
If VRN were to take care of the collection and transportation, the only change for them would be that they have to deliver the glass to different factories, potentially further away. The preparation of the glass for recycling could be done by float glass manufacturers themselves, or by new cullet factories.
For IGU manufacturers, architects, builders, and users the process would not change.

For recycling, the cullet needs to be filtered first. Saint-Gobain state they can currently process laminated glass, decorative glass such as mirrors and lacquered glass, magnetron and pyrolytic coated glass, their own black enamelled glass, and some coloured glass, depending on the amounts[8]. They mention it is best if the windows remain in one piece for as long as possible, to keep different glass types unmixed. The cullet needs to be sorted by substrate colour and glass type. Transport and storage needs to be carefully managed to prevent contamination.
Coated glass can be recycled as well, as coatings can be burnt off in the remelting process[78]. Laminated glass needs to be aged first for three months, before the glass can be grinded to separate it from the connecting sheets.
Coordination throughout the whole value chain is extremely important for recycling. Manufacturers, collection agencies, and recycling facilities need to work together effectively to avoid contamination and ensure material purity. Good communication is also important for efficient collection and economic viability.

product
In principle, recycling does not change the product. Decreasing the aesthetic demands, perhaps in a separate cheaper or 'extra sustainable' product range, would increase the amount of glass eligible for recycling.
The total costs depend on what is needed to set up the collection and cleaning processes, like initial investments in new machines. When raw resource prices increase, recycling might become more economically attractive.

advantages of recycling

- The product look and performance will stay the same, while it can be marketed as more sustainable
- IGU manufacturers, architects, users, and possibly demolition companies can stick to their existing processes
- Roughly 47% of the flat glass demand can be covered by recycling
- 12,5 - 15% decreased production energy
- Smaller loops increase control and transparency throughout the value chain

disadvantages

- Recycling is the most low-value circular strategy, meaning that for a large part of the material, value is destroyed and rebuilt while it could simply have been maintained. This could be seen as a waste of energy
- International collaboration could be more complicated than a purely Dutch solution, primarily due to logistics, differences in regulations, and an increased number of stakeholders
- As manufacturers, architects, and users won't notice a change in process or product, recycling glass does not challenge unsustainable consumption and construction behaviour

policy options
EU-level collaboration to increase cullet use by float factories

Cross-EU shared recycling infrastructure
As the Netherlands and several other European countries do not have their own float glass factories, EU wide collaboration is needed to set up a high-grade recycling system. Demolition companies, glass recycling organisations, transport companies and float glass factories should be closely involved in the process. The programme could start as a pilot between VRN in the Netherlands and the nearest float lines in Germany (NSG, Saint-Gobain) and/or Belgium (AGC). From there on, it can be expanded to include other regions and float lines. Existing glass recycling organisations, like VRN, would continue most of their activities as usual, but transport glass to different customers than before: either directly to float lines abroad, or to (inter)national hubs. There, the material can be inspected, cleaned, possibly pretreated, divided and then further transported. These recycling organisations would also help setting up new organisations in regions where they do not yet exist.
For an effective recycling system, transportation and cullet processing should be improved. According to Saint-Gobain, it is important to keep secondary panes in one piece for as long as possible[8]. To set up an effective glass recycling system, it should be assessed how much this matters, and alternatively if there are ways around it, as intact disassembly is more costly than breaking the glass.
Together with float factories, ways to improve and upscale the cullet cleaning process should be investigated. The findings should be open-source, so other factories can use the knowledge to improve their own process as well.
The container glass and glass wool industries should be included in the process as well, as high-end float glass recycling takes away a part of their resources. Ideally, increasing their own recycling rate could make up for this.

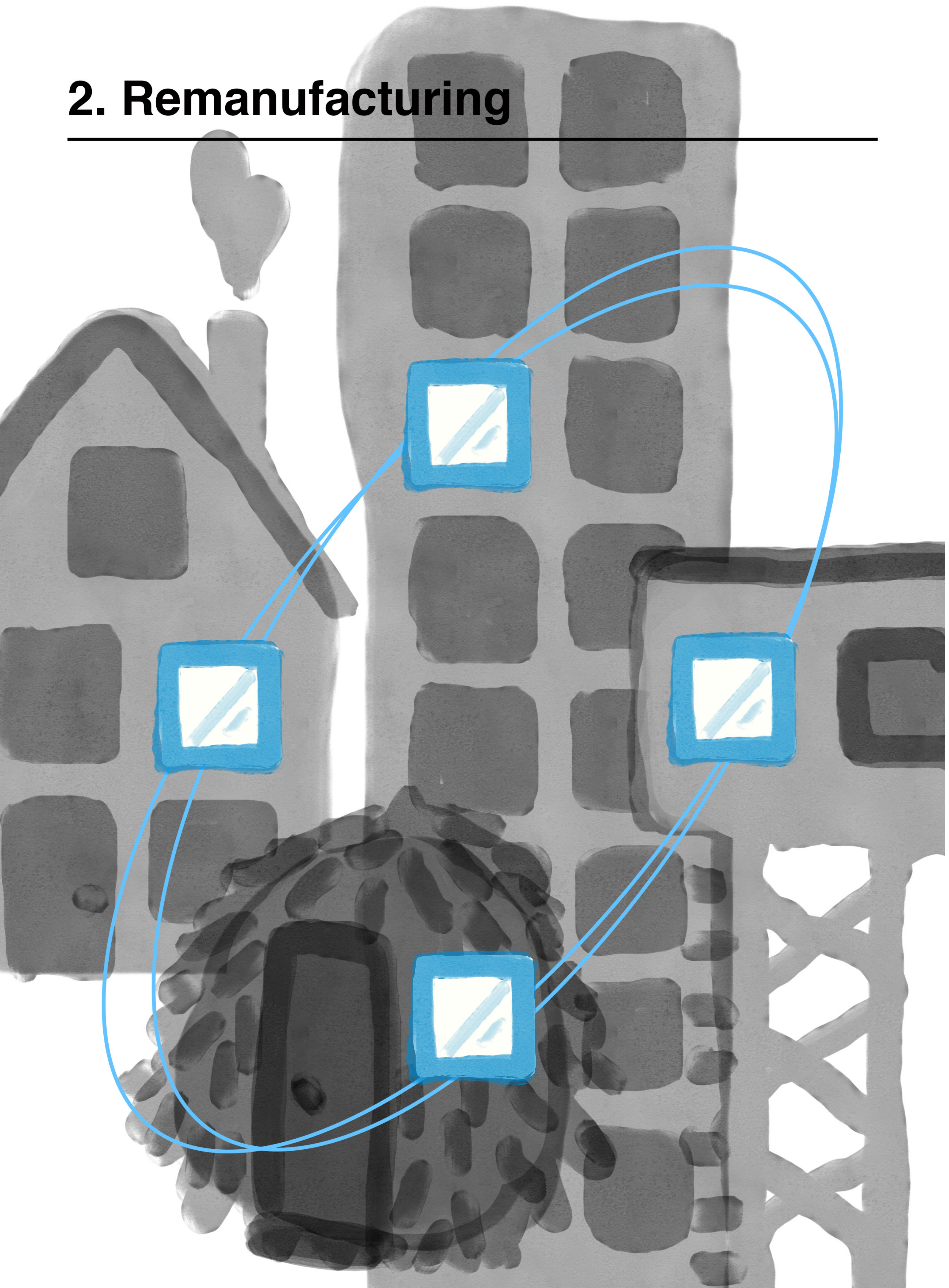
Encouraging waste separation
If international float glass recycling is set up, it makes sense to also include glass from different countries than the Netherlands. Glass separation rates vary per country. There are different policy options to encourage glass separation, with varying success in different regions[79]. This can be attributed partially to the existing policies and regulations. Per country or even per region the most effective pathways should be determined. This is likely a combination of measures like green public procurement, end of waste criteria, pre-demolition audits, selective demolition, landfill tax, raw material extraction tax, traceability systems and take-back centres[79].

Green public procurement
By demanding a certain amount of recycled glass for all public construction projects, the Dutch government can create a demand for circular IGUs, incentivising producers to invest in recycling infrastructure.

Minimum cullet percentage
Once the infrastructure is working and tools are available to other factories to join the system as well, the EU could set a minimum amount of post-consumer cullet that should be used in float glass.

Financing
These plans can (partially) be paid for by EU level Pigouvian taxes: increasing excises on virgin materials used for glass production, invested in recycling infrastructure. Another construction to make recycling more attractive is proposed by the Ex'Tax project: decreasing tax on labour while increasing tax on resources[80].

2. Remanufacturing



2. remanufacturing

The usual failure mechanisms of IGUs are not related to the glass, but rather to the sealant and coating. Hence, maintaining the value of the panes through remanufacturing seems to be an option worth exploring. HvA is working on a remanufacturing project, and GSF offers IGUs with 50% remanufactured glass, 'isoMAX Circu-therm', since 2021. What would happen if all possible glass would be remanufactured?

material use

For estimations of the material that could be saved thorugh remanufacturing, GSF's process is used as a reference. All information about GSF's process came from conversations with the site manager at the remanufacturing plant.

The production line is still in its beginning phase, and the amounts of glass they process are 'rapidly increasing'. In the first quarter of 2023 GSF produced as many IGUs as in the whole of 2022, and for 2023 'at least 1500-2000m2' is expected (41,25-55 tonnes[5]). As of now, about 20% of the harvested glass actually ends up in new IGUs; the rest is recycled. The most complicated and labour intensive part of the process is dismantling the IGU. Currently, this is done by a custom made circular saw installation, but a new, more efficient machine is expected later this year. It is expected that this machine will remove sealants as well, making it possible to reuse even the edges of the glass pane, which have to be discarded in the current process. This machine is expected to speed up the process '10 times rather than 2 times'. Another issue that still needs to be improved is the transportation; an external company takes care of that right now, but it is expensive and slow, so alternatives are being considered. GSF are in the process of getting a CE warranty on their remanufactured IGUs, which could help convince potential clients.

Right now, only the uncoated panes are reused. The most obvious way to increase the amount of glass that ends up remanufactured is to start reusing coated glass as well. Coatings could be chemically stripped or etched off the glass, or potentially just left in place before a new low-e coating or foil is applied. An on-site coating installation would be a larger investment than a foil application installation, but coating is more durable than foil. On the other hand, foil could be replaced more easily.

Depending on damage discard ratios and supply-demand shape misfit, between 19000 and 53200 tonnes of glass could be remanufactured, covering 9,9% to 27,7% of the Dutch annual demand.* For that, the production capacity would need to be up to 1000 times larger. GSF could take the lead in this, but assistance of other factories, either adapting or

***

*20-25% of GSF's turnover comes from replacing IGUs, and the glass for their remanufacturing line is harvested via this service. Panes with the right dimensions are selected based on demand. The total potential is unknown. When separating the IGUs, 5cm is cut off all edges. Remanufactured IGUs are 'around 1m2' on average, for which 1,21m2 of glass is needed. Hence, on average, 17,4% of glass is lost in cutting. Then, the coated panes are discarded, halving the material. Of the material that comes in, it is estimated that 50-70% can be used for remanufacturing, the rest being damaged or otherwise unsuitable. (0,826*0,5*0,5 or 0,7=) between 20,7% - 28,9% of the glass that comes in can be remanufactured. The same amount is added in new, coated panes. The discarded glass is recycled.*

Assuming that

- 76000 tonnes per year are available and selected, corresponding to the amount of glass coming from renovation, demolition, and municipalities, so excluding glass from repair and production.

- New machines allows to use panes without cutting 5cm of the edges

- Coated glass can be reused as coated glass, through (1) optional coating removal, (2) small-scale recoating and (3) low e-foil application.

- Damage discard ratio stays the same (50% - 70%)

- Due to shape differences between supply and demand, up to 50% of the material has to be cut off, and in case of a standardised glass sizes up to 100% can be reused

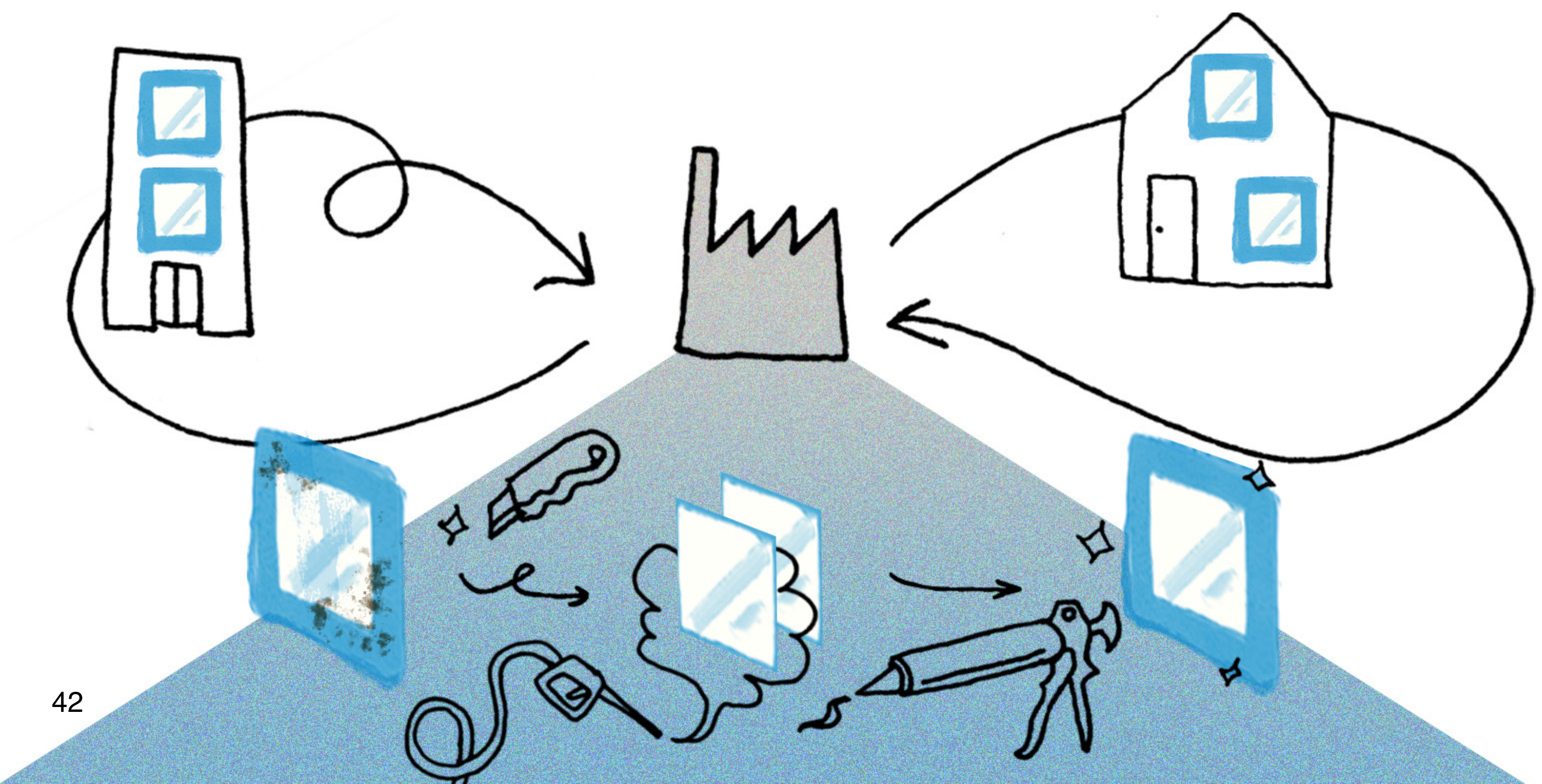
*Then (76000*0,5*0,5) up to (76000*0,70) = 19000 to 53200 tonnes can be remanufactured, or 9,9% to 27,7% of glass can be saved.*

energy

new, would be needed.
For all the new glass not brought onto the market, no manufacturing and transport energy is needed. About 20% less new glass would mean 20% less manufacturing energy. Also, as the process is organised nationally, less international transportation is needed, reducing emissions and lost materials.

process

Window dimensions are usually determined later on in the building design process and vary greatly. Secondary panes can only be used for windows smaller than the original ones, and the more divergent their shape, the more material gets lost. On the medium term, efficiency can be increased by upscaling and centralising. Using a BIM like database, glass dimensions, properties and locations can be tracked in buildings and after use. Once removed, panes can be collected in one or more big hubs, from where glass can be selected with the closest match to the desired dimensions. For this system goes that the bigger, the more efficient, so companies should collaborate on a shared database to align supply and demand streams.
On the long term, the ultimate way to solve the sizing issue would be to introduce a system of standard glass sizes. A range of maybe ten different types would be established, from a small bathroom window to a floor to ceiling panorama IGU. Standardised sizes allow architects to design for remanufacturing, even before the secondary materials are available, minimise material loss and simplify the material flow in the long term. To minimise waste even further, the standardised sizes could be designed to fit current float glass line dimensions, or perhaps even the other way around.



For architects, standardisation will change the design options and process. Glass has to be taken into account earlier on in the process. After use, the demolishers or glass company will have to carefully take out the IGUs again and transport them to the hub or factory. There, they will be dismantled, and a new coating or low-e film will be applied. The IGU is re-assembled, kitted, and filled with gas again.
Companies could also start offering glass as a service: taking back their own material when no longer needed. That would give them more control over the material flow, promotes durable products, and lowers the total cost of ownership for customers. The takeback programme could be arranged entirely by the glass company itself: installs, removal, transport and remanufacturing. Alternatively, expertise and infrastructure from other companies could be used, like demolishers and transport firms.

product

Remanufactured IGUs won't look different than new ones, but standardisation would make them look more uniform.
Currently, GSF charges 5-10% above the market price for their glass, and they are 'not losing money' on the process. Given they only just started and big technical improvements are on their way, the production price can be assumed to be at market level soon. Furthermore, standardisation will likely decrease prices, as it simplifies production logistics.

advantages of remanufacturing

- A smaller value loop decreases transport. Transport of IGUs is a relatively small factor, 2,8% of the carbon footprint according to AGC[5].
- Decreases primary glass production, which is the largest source of CO_2 in the value chain[82]
- A centralised approach allows for optimal material use: if more secondary glass is available, there is a bigger chance of closely approaching the desired size, decreasing cutting waste
- Standardised glass dimensions decrease cutting waste by up to 50% and ease designing with remanufactured IGUs for architects
- The same material, kept in the same loop, can be upgraded with new coatings and other technology once available
- Glass-as-a-service and similar constructions could lower the TCO for users
- Decreases international dependency

disadvantages

- Standardised dimensions limit creative freedom
- Intact IGU removal, quality inspection, and dismantling are labour intensive
- The effect of standardised dimensions would only yield effects after a whole glass life cycle from now, which could be 30 years or more

policy options

Boosting the Dutch glass remanufacturing industry

Green public procurement (GPP)

By demanding remanufactured windows for all public construction projects, the government can create a demand for remanufactured windows, incentivising producers to invest in remanufacturing lines. For non-government construction, requirements for minimal secondary content can be included in the Bouwbesluit.

Extended producer responsibility (EPR)

Giving producers the responsibility for their products during and after their service life would release municipalities and taxpayers from the burden of waste management. Furthermore, it would incentivise producers to change their designs in a sustainable way[54]: end of life handling gets cheaper if products last longer, can be recycled easier, or still hold value for the producer at their end of life. For Dutch producers, national regulations would be sufficient. However, considering half of the IGUs on the Dutch market are imported, EU level regulations would have a more substantial impact, especially since foreign manufacturers might start avoiding the small Dutch market if local regulations become too restrictive.

EPR can be enforced with three instruments: take-back requirements, advance disposal and recycling fees, and deposit-refund systems[55]. The Dutch IGU industry already largely works with advance disposal and recycling fees via VRN, which functions as their producer responsibility organisation (PRO). An addition to this system could exist of a take-back system with differentiated fees. Companies could for example receive discounts when using more reused or recycled content in their products, or when they take steps to encourage repair or reuse. This would incentivise companies to go further than strictly necessary, and covers part of their costs for doing so. On European scale, take-back requirements could be set up for float glass factories. Also, the requirement for recycling targets could be made more stricter by differentiating between downcycling and high-value recycling.

Revising secondary material transportation regulations

When materials are disposed by a person or a company, they immediately classify as waste, regardless of condition. Specific permits are needed to transport waste, which complicates the processing of secondary materials. Reviewing these regulations could facilitate the remanufacturing process[56].

Standardising IGU sizes

Together with architects and large construction clients like housing corporations, a standardised set of glass sizes could be developed. These sizes could be made more attractive than deviating ones by financial incentives or requirements. The larger the scale of implementation, the more effective this measure, so international collaboration would be advisable.

Financing

These plans can (partially) be paid for by national Pigouvian taxes: increasing excises on flat glass panels used for IGU production, invested in remanufacturing infrastructure. A tax shift from labour to resources, as proposed by the Ex'Tax project, would be effective.

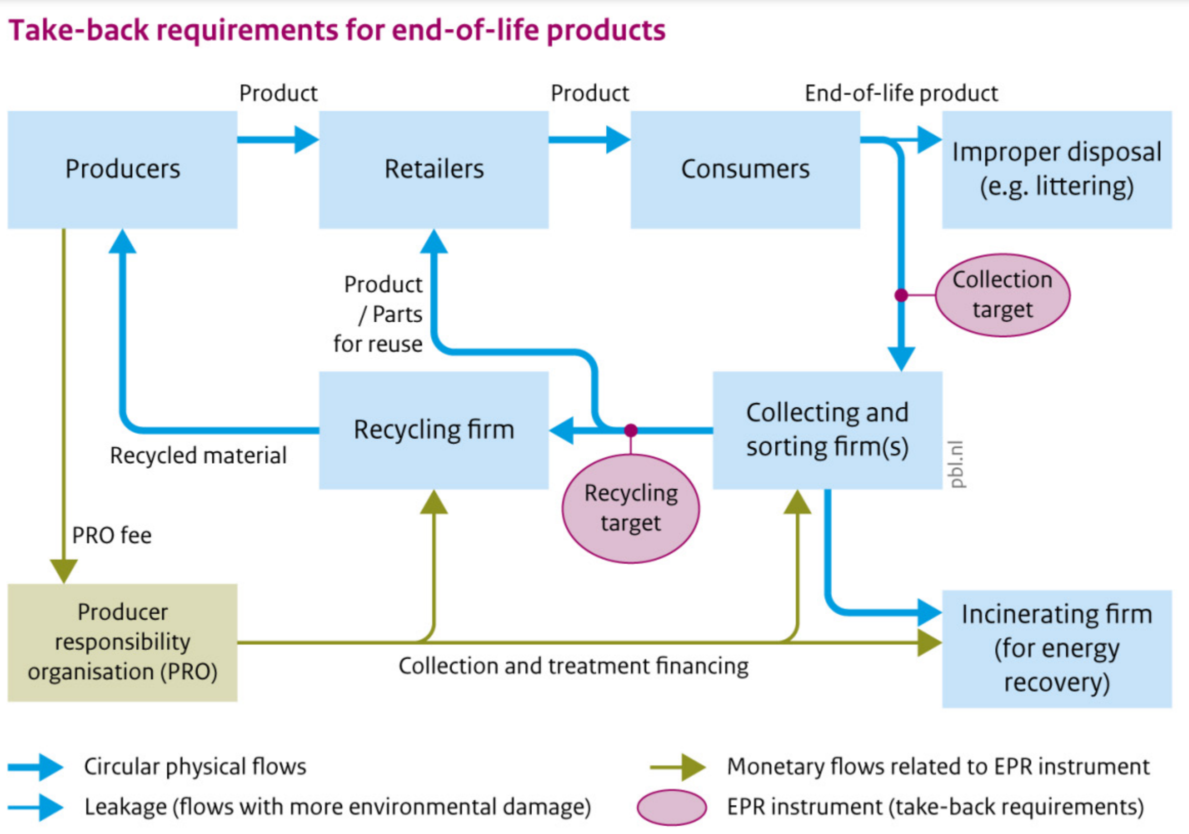


Figure 19 take-back requirements for end-of-life products[57]

3. Reuse

3. reuse

Three steps above remanufacturing on the R-ladder is reuse. Reuse can be more sustainable than remanufacturing when more of the original value of a product is maintained. Reuse-based architecture, like for example Superuse Studios' work, is less a product of the imagination, and more a product of its context: the available materials play a large role in determining the final shape and style of the building. This new aesthetic is both the challenge and the charm of reuse: it is difficult to make people like something different, but when it works, it could inspire a new appreciation for sustainable behaviours in general.

material

Will the harvested glass actually fit in the desired new context? In the previous scenario the glass was adapted to its new destination, whereas in this scenario the new destination itself is adapted to the available glass. In new buildings this would mean designing around the shape of the available panes. In case of renovations, smaller panes could be combined to fit the needed space, like stained glass. This would diminish the amount of glass lost because of differences between supply and demand: less to no glass would have to be cut off to reach desired shapes. Moreover, the amount of secondary glass turned down because of scratches and other imperfections would decrease. In total, this could mean around 57,000 tonnes per year available for reuse, 29,7% of the annual Dutch demand. Reusing entire IGUs would also save the aluminium and kits on the inside, and potentially their frames as well.
Taking GSF as a reference: Glass is pre-selected at their own renovation projects, but only 50-70% of the glass entering their factory can be used. Apparently, at first glance, the glass looks good enough to transport to the factory, but upon closer inspection it is blemished, or it got damaged during transport. For now, it is assumed that 50% less glass is refused, which means 75% is accepted, leading to (76000*0,75=) 57.000 tonnes per year, or 29,7% of the annual demand.

Reusing IGUs in their current form is only possible if their thermal performance is good enough. IGUs with substandard performance can be improved by adding low-e foil, resealing and adding gas, or by combining them with other panes to add an extra layer. This could be done in regional hubs where the glass would also be collected.

energy

The energy use would resemble that of the remanufacturing scenario, with a few changes. For the almost 30% less glass used, no production and international transport is needed. Furthermore, as local sourcing is central to the reuse scenario, national transport might be decreased as well.

process

Reusing glass means that facades have to be designed around the available glass panes. Architects and renovators will have to work with a 'dynamic final design', meaning that based on the found materials the dimensions and characteristics of different building elements can change. Visionary architect firm Superuse Studios already uses this approach, leading to unique and inspiring spaces. These buildings tell the story of a place, of materials finding a new life. On a smaller scale, people have always been reusing windows in greenhouses and other home-made constructions.
A database like BIM could facilitate the material flow for this type of design. It could tell architects the types of glass that will become available, the amounts, shapes, and quality. Knowing this beforehand would help aligning supply and demand. Nesting algorithms can help optimise facades with available panes.

product

Reusing all available glass would require a new aesthetic. From uniform, perfect, anonymous, artificial, commercial and universal, to diverse, imperfect, personal, human-made, wabi-sabi and local. A revival of craft, with the help of modern technologies, will lead to tailor made solutions for each piece of material.
Odd shaped windows that wouldn't be useful for remanufacturing could still be reused. If actually all available glass would be reused, that would decrease about 1/3 of the Dutch glass demand. As for energy use, local reuse would decrease transport and processing energy even more than a more central remanufacturing approach.
The costs of a reused window are hard to estimate. The material itself would likely cost less, but more labour is needed to find it, check its quality, update it if necessary, adapt the design and install it.

advantages of reuse

- Each available glass pane is used at its maximum value

- Requires a responsible way of designing: taking time for individual products, using only with what is available. Effect felt throughout the whole value chain

- Supports an aesthetic communicating sustainability: visually part of a paradigm shift

disadvantages

- Different practice for architects, partially restricting them to available material

- Construction planning more challenging

- Labour intensive

- A 'sustainable aesthetic' will have to compete with more flashy consumerist aesthetics, which is challenging

policy options

Increasing flat glass reuse in Dutch architecture

Green public procurement (GPP)
To stimulate reuse, the government could set a good example by GPP: in this case, requiring locally sourced secondary reused IGUs to be used in public projects.

Physical hubs, digital tracing
To address the construction planning challenges, hubs could be created for glass panes to be stored until they can be used. When glass is brought to the hubs, its dimensions and properties should be registered in a digital system. That way, architects looking to include secondary material in their projects can easily select panes and design around them. These workplaces should also have materials and machines available to repair or upgrade IGUs with lacking insulation value.

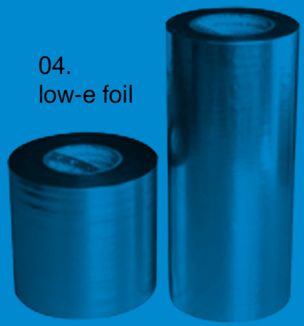
Revising secondary material transportation regulations
When materials are disposed by a person or a company, they immediately classify as waste, regardless of condition. Specific permits are needed to transport waste, which complicates the processing of secondary materials. Reviewing these regulations could facilitate the reuse process.

Stimulating reuse in education
The government should stimulate architecture faculties at TU Delft and various universities of applied sciences (HBO) to include reuse in the curriculum. Students should be introduced to the possibilities and challenges of reusing glass and other construction materials, and encouraged to think of new applications. This should be done in collaboration with the industry to make sure students are up to date with the latest innovations. Furthermore, the practice of dynamic final design should be taught at construction and architecture programmes.

Tax shift
As reuse is more labour intensive than replacing, a tax shift from labour to resources and/or pollution would also be beneficial for this scenario. Tax shifts would be more effective on an EU level than on a national level, as companies might decide to leave a country if tax regulations become unfavourable, which would defeat the purpose of the measure.

01.
Context: the window will be repaired in situ.Demolition is prevented

03.
Vacuum table



04.
low-e foil

05.
gas filler

02.
van for commercial or community repair service

4. Repair

4. repair

A practice that is even better than reusing a product is to not dispose of it in the first place. The most sustainable building is the one that already exists. Through minimising demolition of buildings and maximising care and repair for windows and other components, the use phase is prolonged in this scenario. This requires a different relation between user and product, where the user needs to accept imperfections and provide more care, embracing the wabi-sabi aesthetic. Architects Lacaton & Vassal are an example of this attitude: in many of their projects, they transformed existing buildings rather than demolishing them.

material
60% of flat glass is discarded because of renovation[5]. The most common failure mechanism for IGUs is sealant wear: gas leaks out, increasing thermal transmittance, and allowing condensation to form on the inside. With the right maintenance, the lifetime of IGUs could be significantly prolonged. In the simplest scenario, repair would mean taking out the IGU, resealing it, and refilling the gas. A thermal insulation scanner can be used to check the performance and see if more additions are needed. The HvA Reused IGU project is experimenting with adding glass panes and foils to upgrade old IGUs which don't reach the current insulation norms. This can be done without removing the IGU from its frame. The lifetime of the IGU could be doubled with a single repair session. In theory, if the glass is handled with care (i.e. it is not broken), it could last for centuries, with new sealants, gas and foils every once in a while. If a single pane would be added each time instead of replacing the whole IGU, that would halve the material need. As it is currently unknown which percentage of to be windows removed for renovation would need an extra pane, or whether adding a low-e foil would be enough in some cases, a more exact estimate is not yet possible. Commercial windows typically have a lifespan of 20 to 30 years, while present-day commercial buildings are built for 50-60 years[65]. Right now, 8% of the flat glass is discarded because of demolition. In the repair scenario, these buildings would not be demolished but repaired, saving not only glass but mainly other construction materials, likely with a bigger impact on GHG emissions. It is assumed that the 8% that comes from 'municipalities' can also be repaired or upgraded in situ. In total, repairing all this glass could save 38.000 to 76.000 tonnes of glass per year, or 19,8-39,6% of the demand, depending on whether new panes are added.
With continuous glass repair, at some point other parts of the construction, the aesthetics, or general layout of the building become the limiting factor. If these other parts are then repaired, refurbished or otherwise updated, the entire building can last longer. This would save even more materials and energy.

energy
All the glass that is not replaced does not have to be produced or transported anywhere. When repairing in situ, that does mean that repair tools have to be moved around, which is less efficient than doing all the repair in one place.

process
Glass companies would shift from offering products to repair services. IGUs can be repaired or upgraded locally. First, the window frame is carefully opened and the glass is taken out. In some cases this might not even be necessary. Then low e-films can be applied, the IGU can be resealed and refilled with gas. Then the IGU is placed back and the frame is closed again. Repair is labour intensive
Local repair with equipment in a bus is less efficient than production in a factory. It would be labour intensive, and especially on high buildings it would be challenging.
Product
The glass itself would not change in this scenario. The longer an IGU stays in place, the higher the chance of scratches or other imperfections. The consumer can either embrace these, patch them up themselves, or get them repaired by a professional company (like Glasrenovatie Nederland BV).
At this point, large scale repair is definitely not competitive from a financial point of view. Repair is labour intensive, which is expensive.

advantages of repair

- The optimal value of the product in its context is maintained; most high-value strategy with glass
- Because care and repair are visible in the product, consumers are more directly connected to and aware of its life cycle, which could enhance appreciation and sustainable attitudes

disadvantages

- Repair of individual windows is more inconvenient and labour intensive than replacement
- Repair of individual windows is financially inefficient
- Repaired, 'imperfect' windows are less attractive to consumers
- Warranties make new products more attractive

policy options

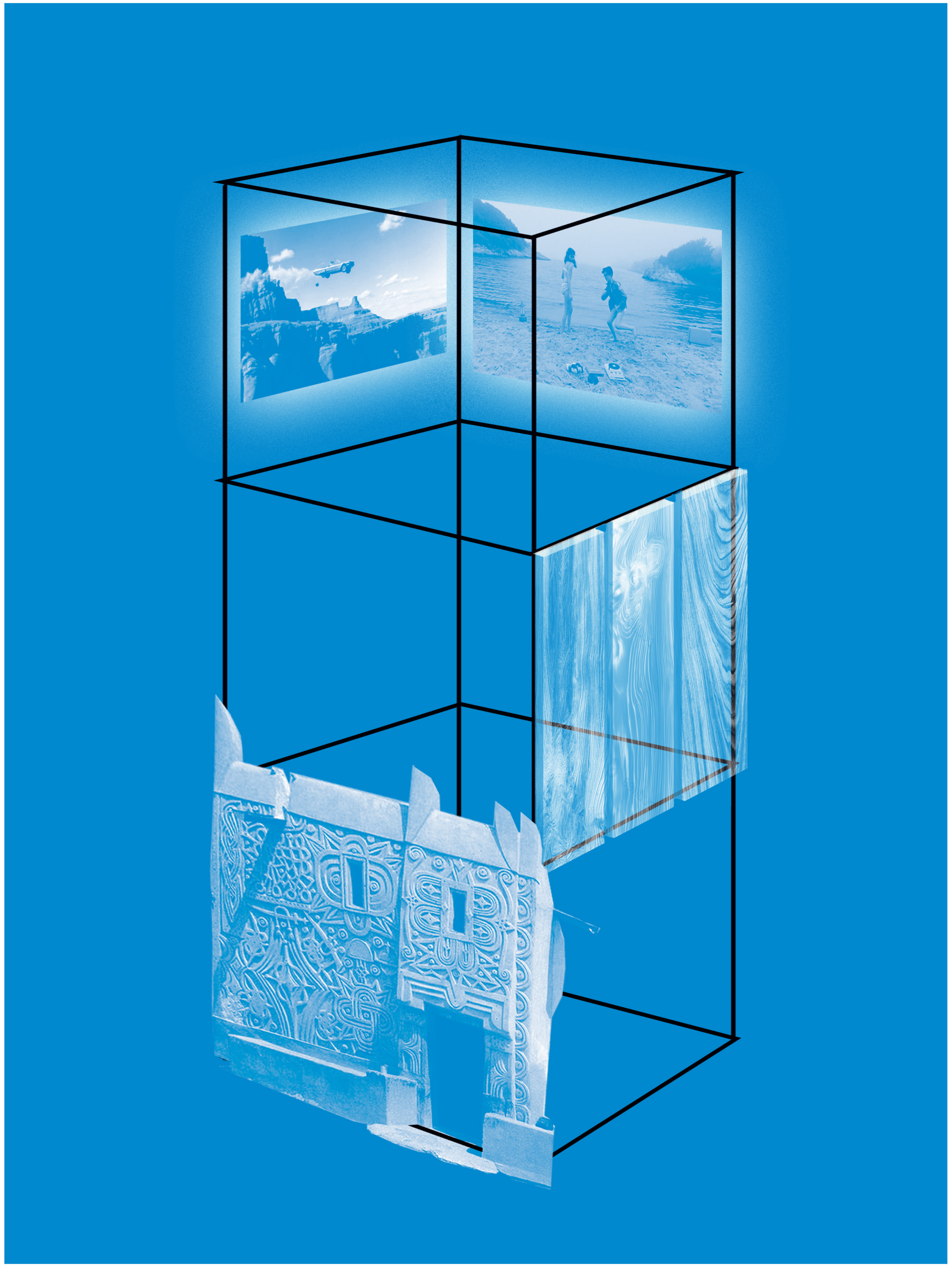
Supporting maintenance of old buildings
Owners of older buildings could get a financial incentive to maintain rather than replace their buildings, similar to old time drivers. This incentive could be a tax discount or a subsidy. To ensure that ageing buildings won't lead to soaring energy use and will actually be taken care of, the incentive could be given in the shape of free or discounted repair services. These services could include IGU repair, but also insulation and sustainable energy installations. This would save other materials than glass as well.

Teaching IGU repair
Citizens should be taught about the possibilities of IGU repair. Community repair centres could be set up where citizens can borrow tools, learn repair skills from each other, and follow workshops by professionals. These could start as a pilot set up together with repair companies.

Preventing demolition
The threshold for demolition could be increased. A building committee (similar to welstandscommissie) could be installed to assess whether demolition is necessary. They will see if renovation or repurposing of the building would be possible. Moreover, they consider whether the aesthetics of the construction will be missed in the cityscape, also anticipating future changes of style to prevent post-demolition regrets. This would be influential on a larger scale than only the glass material flow.

Tax shift
A tax shift from labour to natural resources and pollution, as proposed by the Ex'Tax project, would also benefit repair work. Tax shifts would be more effective on an EU level than on a national level, as companies might decide to leave a country if tax regulations become unfavourable, which would defeat the purpose of the measure.

Green public procurement (GPP)
Including repair in GPP would be possible as well. In that case, the government would not order new buildings anymore, instead repairing and refurbishing existing property, thus generating a demand for repair services and setting an example for sustainable construction.



5. Reduce

5. reduce

Vernacular architecture is building as it traditionally occurs across the world, outside academic tradition. It is made with locally sourced materials and traditional techniques. Light, temperature and ventilation are regulated through passive design: minimal energy is used for it. Vernacular architecture does not have big glass windows, and not only because glass is a relatively new invention. Large windows have only started to make sense after heating became cheap in cold countries, and air conditioning in hot areas.
In the increasingly warm Netherlands, houses start to feel like greenhouses in summer. In rapidly urbanising societies, privacy is increasingly valuable, and windows are often permanently covered by stickers and curtains.
When learning from traditional architecture and taking advantage of up and coming technologies, the dependence on glass on the whole can be decreased. Are alternatives desirable, and sustainable?

the alternatives

First off, the glass stream could be narrowed by reducing the sizes of windows. This would be beneficial for privacy and for energy use in buildings, but would give people less light and view. In the Netherlands, offices, commercial, and other utility buildings contain a relatively high amount of glass per m2 compared to residential buildings[66]. These sizeable glass facades could largely be replaced by other materials without decreasing interior comfort. Row houses contain the least glass[66]. Most houses would still be enjoyably light, and thermally improved, with slightly smaller window surfaces. For this scenario, 20% smaller windows are assumed. Whether that is a sustainable option depends on the material that it is replaced with: its embodied CO_2, but also its thermal insulation.
A possible, slightly dystopian alternative for large windows is presented in Saudi Arabia's Mukaab concept. The central open space inside this gigantic cubic skyscraper is windowless but covered in screens for an 'immersive experience'. Screens could replace windows, in theory, simulating a view in well-insulated, private spaces. However, most screens contain glass. In the following paragraphs, this option is still considered because of its potential for privacy and insulation.

Another option would be to partially replace glass windows with windows made from other materials. Translucent plastics like PVC have been used before in walls that let in daylight but also create privacy and calmness, 'geborgenheid'. Moreover, material scientists have been experimenting with transparent wood recently: thin slices of wood impregnated with a polymer that strips out lignin, making the wood transparent[67]. This material could potentially be used to create a renewable alternative to glass.

material

Making windows 20% smaller could save 38.500 tonnes of glass per year. This means replacing glass with 20% other material. For this to be sustainable in terms of material use, the alternative should have lower CO_2 emissions. When assuming the alternative wall material would be twice as thick as the original glazing, then unfired clay brick, rammed earth, reused brick, and all types of wood (except standard wood window frames) have lower embodied CO_2[12], just like nine different types of insulation material.
The next alternative, replacing windows with screens, would not make glass redundant, as LCD screens contain glass as well. Moreover, they also contain a number of materials that are more damaging to the environment than glass, and are generally harder to recycle due to their complexity[68]. Hence, from a material use point of view this solution is less sustainable.
As for transparent wood, so far, the clarity of the material is less than that of glass, but its transmittance is the same. The wood is about 2,5 times lighter than glass, and the thermal insulation is 2,5 to 5 times higher. While glass is 'slightly stronger', the fracture toughness of the wood (3.03 +- 0.31 MJ m-3) is much higher than standard glass (0.003 MJ m-3), making it safer[69]. So far, a petroleum based polymer has been used in making the material transparent, but biobased options are being researched right now[70]. The environmental impacts of transparent wood are an order of magnitude larger than those of than glass[71], but still better than PE.

energy

After a certain use period, the environmental impact of heating can surpass the impact of the materials used for constructing a building[72]. At that point, estimated to be in the order of magnitude of 15 years, the thermal insulation of a construction material can outweigh its environmental drawbacks. The thermal conductivity of wood, brick and concrete is smaller than that of glazing[73]. Their embodied CO2 is, at worst, still in the same order of magnitude as that of glass. Hence, these materials are energetically favourable.

It goes beyond the scope of this project to precisely compare the energy use of air conditioning or heating to TV screens. It is however estimated that the former use about 10 times as much energy as the latter[74], suggesting that screen use could compare favourably to losing energy via glass windows.

The thermal conductivity of transparent wood is about 40% of that of glass, so energy wise it would be an efficient choice.

Given the environmental impact and insulation values of the alternatives discussed, reducing window surface appears to be the best option to reduce glass, both for material related environmental impact and energy use. This should be done carefully, as light has a large influence on the wellbeing of the people inside the building.

advantages of reduction

- Given there is a better alternative, glass reduction means being less dependent on an unsustainable material chain

- Better thermal performance. In case of smaller windows or replacement by wall-mounted screens from U = 1,65 at max for windows to U = 0,21 at max. The insulation value of transparent wood is up to five times better than that of glass.

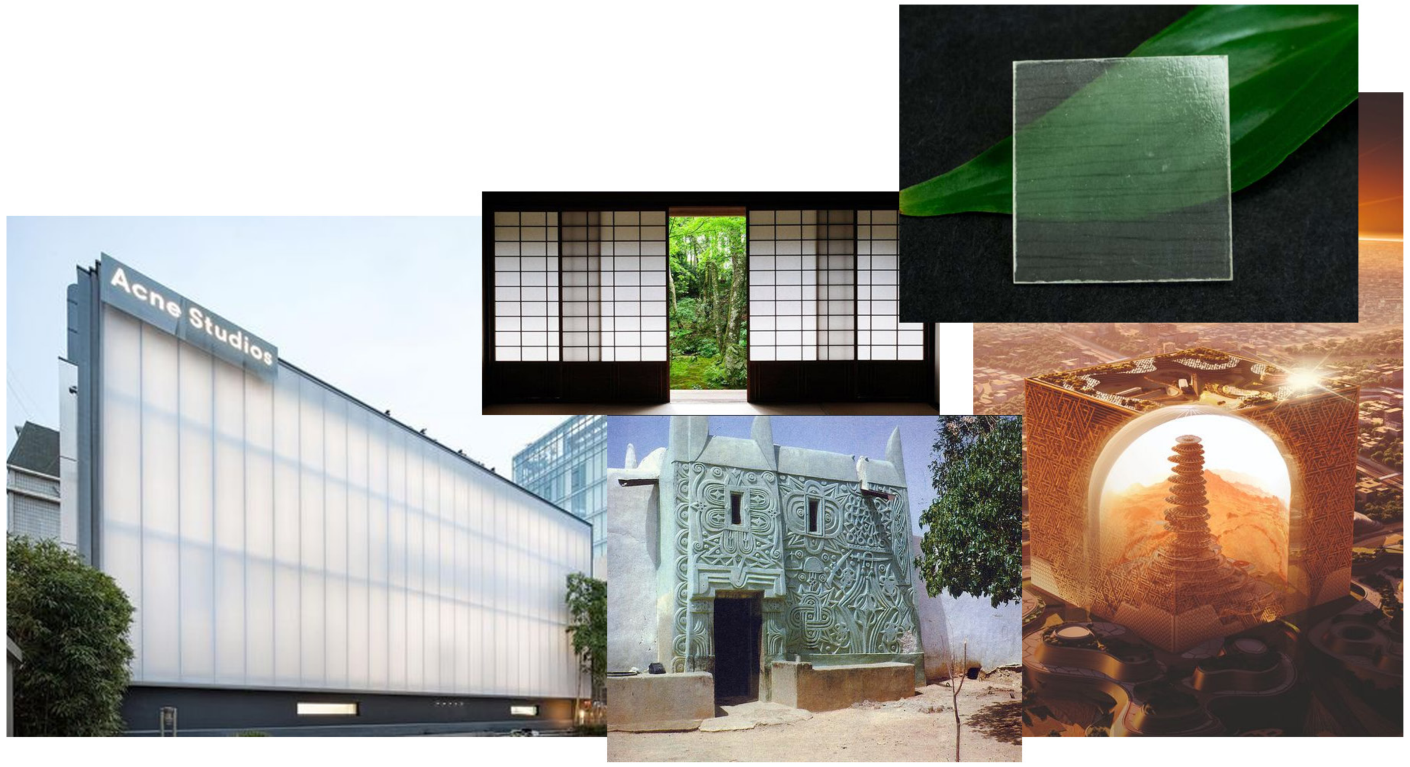
- Increased privacy and cosiness

disadvantages

- Smaller windows give less of a view outside, and allow less light to come in. Alternative translucent materials might give a less clear view outside

- Requires fundamental change in architecture

- Transparent wood is an emerging technology, its use depends on its further development



process

For a change towards less glass, architects would need to design their buildings differently. They should be educated on the impacts of their material choices, possible alternatives, and aesthetic examples as well as a narrative of how smaller windows can be enjoyable and stylish. The emphasis could be on the joys of a warm (in winter) or a cool (in summer) home, or on cosiness and traditional design.

Scientists will most likely continue developing other versions of translucent wood, more sustainable through for example bio based polymers. Once these can compete with glass, IGU manufacturers could adopt it into their business and offer it as an alternative to glass. Otherwise, a completely new supply chain could be set up.'

product

Spaces with smaller windows will be darker. They might feel more closed off, but good architecture can make people appreciate them as more private and cosy rather than uncomfortable.

policy options

Decreasing glass in buildings could be encouraged by connecting a tax to the glass surface of a building, like in 1700s England[75]. However, there are more effective and equitable ways to reach the underlying objectives.

Regulating thermal performance

When avoiding glass for its poor insulation properties, the regulations for average temperature resistance in buildings can be tightened. Currently, the walls of new residential buildings are required to have an Rc value of 4,7 (U=0,21)[76], while doors, windows, and frames can have an Rc value of 0,61 (U=1,65) at max. As the surface of doors, windows, and frames is unlimited, the insulation requirements for walls are mostly in vain. However, when the wall insulation requirements were to include doors, windows, and frames, the insulation requirements could actually control energy use. For that to be possible, the allowed average Rc value for walls should be lowered. When for example taking a maximum of 75% doors, windows, and frames at the current insulation requirements, the minimal Rc value of a wall would be 1,63 (U=0,61). More windows would be allowed, provided the rest of the wall is insulated better. Spaces with a small outside surface to floor surface ratio, like offices and other utility buildings, are relatively energy efficient, but need larger window surfaces to be comfortable. To account for these spaces, the floor surface area should be included in the formula as well. Further investigation is needed for this.

Regulating embodied CO2

When avoiding glass for its embodied CO2, rather than capping the glass surface in buildings, it would make more sense to establish a general standard for embodied CO2 per m2 floor surface, as other materials have a significantly larger footprint than glass. Such a measure would indirectly support sustainable strategies like recycling, remanufacturing and reuse of materials. Regulating embodied CO2 rather than stimulating pre-determined sustainable procedures might increase administrative burdens, which could be a drawback. A substantial advantage on the other hand is that, in the light of advancing scientific insights and technological progress, formulating requirements on this fundamental level leaves space for upcoming sustainable innovations and customised solutions.

Development of new materials

Investing in the development of transparent wood and similar glass alternatives could lead to more sustainable windows, in terms of production energy and insulation. The Dutch government could subsidise research in this direction at technical universities, potentially in combination with material engineering companies.

Green public procurement

GPP in this scenario includes designing government buildings with higher insulation requirements, lower embodied CO2, a cozy rather than exposed aesthetic, and including experimental alternative construction materials.

discussion

overview of scenarios

#	Scenario	Value maintained	Resources needed	Energy	Product	Process	Tech	Labour
0	BAU	Polluted material	192.000 t/y 100%	international transport, glass production, IGU manufacturing, national transport	big shiny diverse windows	Cradle to grave		
1	Recycle	Clean material	down to 52,6%	less international transport, 12,5-15% less production energy needed	big shiny diverse windows	separate collection & cleaning	improving/ upscaling cleaning installations	careful glass collection preferred
2	Remanu-facture	Pieces of material in useful shape	Around 72,3% - 90,1%	no international transport, no glass production	windows in standard sizes	glass as a service	downscaling (un)coating mechanisms, upscaling BIM	careful collection & transport
3	Reuse	product	around 70,3%	no international transport, no glass production, less national transportation, less (re) manufacturing	diverse buildings, irregular shapes	dynamic final design in architecture	glass fitting: upscaling BIM, developing glass nesting algorithms, AI?	careful collection & transport, designing & building slightly more complex
4	Repair	product in context	Around 60,4% - 80,2% more importantly: saving other construction materials	no international transport, no glass production, no national glass transportation, no (re) manufacturing. Added: transportation of machines/mobile services	less shiny, more wabi-sabi	less demolition, more maintenance	potentially downscaling existing machines for mobile reparation stations	repair services for individual windows: most labour intensive scenario
5	Reduce	less glass dependence, better insulation	Entirely depends	same process, smaller role for glass	smaller windows, or windows from different materials	different architecture	developing alternatives like transparent wood (TRL 4 now)	

Table 3: Scenarios summarised

Of all scenarios, most glass would be saved with recycling, as barely any material would have to be dismissed based on its size or condition. However, recycling does save only the minimal amount of value of the products. In general, the higher up the value hill the materials are reintroduced, the stricter the requirements, and the smaller the amount of suitable material.

As the strategies largely use the same segments of secondary glass, they cannot all reach their full capacity. A potential division to aim for would be:

- 19200 tonnes annually, or 10% of the glass demand, made redundant through repair of existing windows
- 10% of the demand covered through reuse
- 10% covered through remanufacturing
- 33400 tonnes, or 17,4% of the demand, covered by recycled glass

This division would save the maximal amount of glass (47,4%), at close to the optimal maintained value, while allowing for some flexibility.

Ideally, to save most value, each glass removal project would start with a decision tree, roughly like this:

- Can the IGUs be maintained in context, optionally with repair?
  if yes, repair and keep in context
  if no, proceed
- Can the IGUs be reused in another context, optionally with repair?
  if yes, transport to reuse hub, register in database, repair if necessary
  if no, proceed
- Can the glass panes of the IGUs be remanufactured into new IGUs?
  if yes, transport to remanufacturing plant
  if no, proceed
- Can the glass be recycled on a high-value level?
  if yes, transport to cullet cleaning or recycling plant
  if not, transport to downcycle plant, for example linked to the glass container or insulation industry

A decision tree like this could be a glass-specific extension to the existing decision tree as developed by Cirkelstad[83]. The addition of reconsidering demolition is also new.

Moreover, a decision tree could be developed for construction of new buildings, to ensure maximal use of high value secondary materials and minimal future waste. This decision tree could roughly look like this:

- Is there an existing building that, with some repair and adaptations, could fulfil the function of the building that needs to be constructed?
  if yes, do not construct, but repair and adapt
  if not, proceed
- Can the window size of the building be decreased without compromising the comfort too much, or are more sustainable window materials available?
  if yes, adopt small window sizes and/or other materials in dynamic final design
  if not, proceed
- Are there secondary IGUs available in the area that could be reused?
  if yes, use these IGUs in the design
  if not, proceed
- Can the building be constructed using remanufactured IGUs in standardised sizes?
  if yes, order standardised remanufactured IGUs
  if standardised sizes do not fit the building, order odd-sized remanufactured IGUs
  if no remanufacturing possible, proceed
- Are standard-sized IGUs made of recycled glass available?
  if yes, order standardised recycled glass IGUs
  if standardised sizes do not fit the building, order odd-sized recycled glass IGUs
  if not, order conventional IGUs

Decision trees like this would ensure maximum value maintenance for the greatest amount of material.

summary of policy suggestions

#	Policy	Recycle	Remanufacture	Reuse	Repair	Reduce
1	Tax shift from labour to resources & pollution	Financial incentive for float glass lines to collect & process cullet rather than using raw materials	Financial incentive for IGU manufacturers to collect & process secondary panes rather than new ones	Financial incentive for architects to collect, repair & reuse secondary panes rather than new ones	Financial incentive for property owners to repair existing windows and buildings rather than construct new ones	Financial incentive for architects to use less polluting materials, and indirectly to build more insulating buildings
2	Green public procurement; differentiated fees	Requiring/ prioritising a certain cullet percentage for government projects; incentive for float lines to increase cullet use	Requiring/ prioritising remanufactured IGUs for government projects; incentive for IGU manufacturers to start using secondary panes	Requiring/ prioritising reused IGUs for government projects; incentive for architects to start using secondary IGUs	Requiring/ prioritising repair of existing buildings for government projects; incentive for architects to look at repair possibilities	Requiring/ prioritising glass alternatives for government projects; incentive for architects and IGU producers to start looking at alternatives
3	pigouvian taxes; differentiated	Financial incentive for float glass lines to collect & process cullet rather than using raw materials	Financial incentive for IGU manufacturers to collect & process secondary panes rather than new ones	Financial incentive for architects to collect, repair & reuse secondary panes rather than new ones	Financial incentive for property owners to repair existing windows and buildings rather than construct new ones	Financial incentive for architects to use less polluting materials, and indirectly to build more insulating buildings
4	extended producer responsibility; differentiating fees	Requiring float glass producers to take responsibility for the life cycle of their products on a basic level, incentivising them to do more	Requiring IGU producers to take responsibility for the life cycle of their products on a basic level, incentivising them to do more	-	-	-
5	encouraging dynamic final design in architecture education	-	-	Teaching and inspiring architects to adapt their design process to allow for more reuse	Teaching and inspiring architects to adapt their design process to allow for more reuse	-
6	demolition committees	-	-	-	Restricting demolition of buildings; stimulate repair, renovation	-
7	encouraging waste separation	Incentivising or requiring demolition companies and IGU producers to correctly dispose of used float glass, increasing cullet supply for float glass lines	-	-	-	-
8	minimum cullet percentage	Requiring float glass lines to use a certain percentage of cullet	-	-	-	-

Table 4a: Effects of policy on scenarios summarised, including effect of policies on other strategies than the one they are meant to support.

#	Policy	Recycle	Remanufacture	Reuse	Repair	Reduce
9	Revising secondary material transportation regulations	Potentially facilitating cullet transport	Facilitating transport of secondary panes	Facilitating transport of secondary IGUs	-	-
10	Standardising IGU sizes	-	Designing a set of standard glass sizes, encouraging their use, hence facilitating future remanufacturing	-	-	-
11	Physical hubs, digital tracing	-	Building physical glass storage spaces and a digital system to trace IGUs, to optimise secondary material flow	Creating physical places to store secondary glass (and other materials), digitally trace building elements to facilitate Dynamic final design	-	-
12	Supporting maintenance old buildings	-	-	-	Teaching, aiding and financially supporting property owners to maintain older buildings	-
13	Teaching IGU repair	-	-	-	Instructing and inspiring home owners to repair and maintain their own IGUs	-
14	Regulating thermal performance	-	-	-	-	Requiring architects to insulate their buildings well
15	Regulating embodied CO2	-	-	-	-	Requiring architects to limit the embodied CO2 of their buildings
16	Development of new materials	-	-	-	-	Investing in development of glass alternatives with lower embodied CO2 and/or higher insulation

Table 4b: Effects of policy on scenarios summarised, continued

It appears that some policies can be used to encourage all discussed sustainable strategies at once, which would be effort-effective: a tax shift, green public procurement, and Pigouvian taxes.

For recycling, international collaboration vital. For other scenarios it is helpful, but not necessary. A local approach, for example organised on municipality level or based around community centres, would best fit the concept of reuse and repair strategies, but a larger system would benefit efficiency.

In general, a balance needs to be found between impact and political viability. A more radical change could lead to bigger impact, but would be harder to reach in politics. A tax shift would encourage all strategies at the same time, but would mean an unprecedented change in an already complex system, which makes implementation difficult. It would probably be unpopular with large polluters, who have significant influence on politics[84]. On the other hand, the social side of this programme, creating jobs and making services more affordable, could be a selling point for voter groups who do not feel a strong link to climate issues. Smaller interventions, like green public procurement, will likely meet less resistance, but their impact might not be enough to reach the desired effect. However, as all strategies are still in their early stages, a better understanding of possibilities and limitations is needed before implementing strict regulations. Smaller interventions and pilots could help develop this knowledge. To still ensure commitment to larger changes, the recommendations flowing from these smaller interventions could be made binding.

impact of scenarios on different stakeholders in the value chain

	Float glass industry	IGU manufacturers	Architects	Users	Demolition companies	Glass recycling organisations
Recycling	Added cleaning operations, changed process	-	-	-	-	Different customer
Remanu-facturing	Decreased sales	Added processes: deconstruction, cleaning, inspection	Optionally: standardised IGU sizes	-	Careful demolition, product registration	Decreased material flow
Reuse	Decreased sales	Decreased sales	Dynamic final design	Different aesthetic in buildings	Careful demolition, product registration	Decreased material flow
Repair	Decreased sales	Decreased sales	Less construction, more renovation	Different aesthetic in buildings	Less demolition	Decreased material flow
Reduce	Decreased sales	Different material, or decreased sales	Different material and/or different style	Different aesthetics in buildings, potentially less daylight	-	Decreased material flow

Table 5: influence of strategies on processes in the float glass value chain

Decreased business
Changed process
Minimally/optionally changed process
- No change

The impact that scenarios have on stakeholders in the float glass value chain can lead to opposition or support, making it harder or easier to move towards a sustainable float glass system.

Glass recycling organisations are impacted in all scenarios. Recycling: different customer, logistics, perhaps treating glass more carefully. Others: less material to handle. However, as VRN is a non-profit foundation, so little resistance expected

Demolition companies would have to change their procedures in case of remanufacturing and reuse, potentially for recycling too. In case of repair, their business would be slightly reduced. No large resistance is expected, as demolition companies have already been shifting towards a different role. Repair is more labour intensive than demolition. In case it would take away jobs from that sector, new and relatively similar ones would be created simulataneously.

Users would be visually impacted in the reuse, repair, and reduce scenarios. Architecture would have a different style, and in case of repair, a slightly different relationship to the product would develop. More traditional and formal building owners might resist to these changes. To convince users, inspiring and attractive examples are important.

Architects are encouraged to change practices in all scenarios except recycling, albeit in different directions. This might be limiting, but also inspiring creativity.

IGU manufacturers face decreased sales in case of reuse, repair and possibly reduce, while they have to change their process for remanufacturing and reducing.

The Dutch business of the international float industry would decrease in all scenarios but recycling; in the suggested combined approach 30% less glass would be sold. Moving companies to increase their cullet use could be challenging.

when can scenarios reach their full potential?

short term
0 - 5 years

Remanufacturing
Existing IGU manufacturing plants have been adapted, and new ones are set up. New float glass demand can get down to around 90% of BAU. From roughly 30 years later, the secondary IGUs can start their third lifetime, and without cutting losses the material demand will drop even further to around 72%.

medium term
5 - 10 years

Recycling
Infrastructure for collection and cleaning is set up. International logistics and supply chain are organised. Recycling processes have been tested, workforce has been trained, and regulations have been adapted. Raw material demand for float glass drops to around 53% of the BAU.

Repair
The technology for repair is available, but repair only makes sense once the transition to up-to-date IGUs has been made. After that, the glass demand can gradually drop to 60-90% of BAU.

long term
> 10 years

Reuse
As the shift towards reuse requires aesthetic and architectural changes, it will take more time to reach its full potential, bringing glass demand down to around 70% of BAU.

Reduce
Decreasing window size requires aesthetic changes. Research is needed to develop alternative materials. The maximum potential of this scenario depends on stylistic, technological, environmental, and political factors.

methods and limitations

Due to the exploratory nature of the project, the methods used were not optimally structured. Interviews were not fully noted down, and their analysis was intuitive. Data was collected without clear intention. As the project balanced between industrial ecology, conceptual design, and policy writing, and each of these fields have their own methods and best practices, the end result lacks some depth in each field. Simultaneously, the unique combination of these fields could be seen as a valuable innovation on itself.

If more time was available, the project would have benefitted from a more in-depth analysis of the material flows, the most prevalent reasons for IGU disposal, the processes needed to prepare secondary IGUs for recycling, remanufacturing, or reuse, and the challenges faced by existing sustainable glass initiatives. On the design side, case studies could have been added to explore and illustrate the possibilities of circular design. The policy suggestions could have been more structured and worked out in more detail. Including focus groups would have been a good way to generate ideas and gather feedback. In general, an additional round of feedback would have been valuable. This round was planned but did not take place due to circumstances.

As to the policy side of the project, the selection of options presented was based on brainstorming and ideas put forward in conversations with industry insiders. Consequently, the suggested set of options is likely incomplete. Due to lack of experience in this direction, the policy proposals are mere concepts, lacking in detail and nuance. The reaction from policy makers throughout the process has been positive. The broadness of the scope was appreciated, and most of the presented information about IGUs and glass as a material stream was new to them. This suggests the project has been a useful exploration.

recommendations for further design and research projects

- Mapping the reasons for IGU disposal to create an understanding of the state of the available secondary material
- Further developing the decision trees for sustainable glass for end-of-life and construction
- Developing a standardised set of IGU sizes
- Working out a Glass-as-a-service business model
- Developing a repair bus with mobile tools for repair and upgrading of IGUs in situ
- Architectural case studies with reused material, following the dynamic final design principles
- Developing a glass hub x repair workshop + digital tracing system
- Designing interior/façade architecture with less glass, and/or glass alternatives

conclusions

1. In what ways could architectural float glass be handled more sustainably?

Five scenarios, based on five strategies for more sustainable handling of float glass, have been explored: recycling, remanufacturing, reuse, repair, and reduction.

1a. Which scenario, or combination of strategies, would be most effective in terms of material saved?

Of all scenarios, most glass would be saved with recycling, up to 47%, as barely any material would have to be dismissed based on its size or condition. However, recycling does save only the minimal amount of value of the products. In general, the higher up the value hill the materials are reintroduced, the stricter the requirements, and the smaller the amount of suitable material. When maintaining most value, through repairing, between 19,8-39,6% could be saved, depending on the technologies available and the willingness to repair. The use of a decision tree for both demolition and construction is suggested, to find the most valuable material application of in each individual situation. A proposal is done for target amounts of glass maintained by each strategy: 19200 tonnes per year through repair, reuse, and remanufacturing each, and 33400 tonnes per year through recycling. No proposal was done for reducing, as the desirability and feasibilty of this strategy need further research first.

1b. Which scenario, or combination of strategies would be most effective in terms of energy saved?

In general, each prevented production step or transportation movement saves energy. Hence, maintaining glass at its highest possible value, and doing so as locally as possible, saves most energy. Repairing existing buildings and IGUs would theoretically save most energy. This only works if the insulation value of the buildings and IGUs is up to standard. The impact of driving a repair van with machinery, that could otherwise stay in a factory and be used more efficiently, should also be taken into account. Due to many uncertainties it is difficult to give a quantitative statement about the energy saved in the reduce scenario.

1c. What would be the influence of different strategies on processes in the float glass value chain?

The higher up the value hill the secondary glass is maintained, the more the float glass value chain would have to change. This introduces a dilemma between ambition and feasibility. The following changes are the most impactful: Recycling would require float glass lines to increase their cullet use. Remanufacturing requires IGU producers to add new functionalities to their production plants and partially revise their business model. For reuse, architects will have to adopt dynamic final design pracices, and work with a more irregular, les controlled aesthetic. For repair, demolition should decrease, and reparation services will have to be set up, most likely by IGU manufacturers. Reducing glass use would require architects to change their designs, users to accept darker interiors, and researchers to develop alternative materials. Process change can be stimulated by the Dutch government through financial incentives and organisational support, and can be organised in a constructive way in collaboration with the respective actors. Decreased business on the other hand could have a negative impact on the actors, which should be considered as well. In general, circular practices are more labour intensive than linear ones. This creates jobs, but also increases prices.

1d. What would be the influence of different strategies on the product: the aesthetics of architecture, and the user's relationship with it?

Aesthetics and product experience remain the same in the recycling scenario. The remanufacturing scenario could lead to a more uniform look on buildings, although that effect is unlikely to be remarkable. Reuse and repair would lead to more diverse, worn, and irregular architecture, aesthetically rooted in its historical and geographical context. Repair could demand a more active attitude from inhabitants if it is arranged in community settings or on individual basis, but can also be taken up by companies, in which case the user experience does not change. The reduce scenario would lead to a different architectural style. Smaller windows could tend more towards cozy and private as opposed to light and open.

2. What policy would be most effective to improve sustainable handling of architectural float glass?
Each of the presented scenarios have their advantages and drawbacks. Overall, maintained value appears to be somewhat inversely proportional to labour and changes in our relation with the product. The reduce scenario restricts architects and dwellers to such a degree that it might be inadvisable. The other scenarios sometimes benefit from the same policies, implemented in slightly different ways. One policy can encourage multiple sustainable processes through diverging fees and feedback.

Green public procurement could be used to create a demand for sustainable glass, and other materials, on different circularity levels. The level of circularity offered could play a role in determining which company lands the tender. GPP could also be organised on an EU level.

Ex'Tax or a similar tax shift from labour to resources/pollution would not only benefit different circular practices related to glass, but also to nearly all other materials, perhaps with an even larger impact. Tax shifts would be more effective on an EU level than on a national level, as companies might decide to leave a country if tax regulations become unfavourable, which would defeat the purpose of the measure.

Pigouvian taxes, excises on scarce or polluting products invested in their own replacement by more sustainable alternatives, are useful for all scenarios. Just like Ex'Tax, this type of tax shift would be more effective on an EU or higher level.

Extended producer responsibility (EPR) with differentiating fees can be used to incentivise producers to strive for maximum levels of circularity. For Dutch companies, national regulations would be enough. However, considering half of the Dutch glass is imported from manufacturers abroad, EPR would be most effective on an EU level: if only the Netherlands connect strict requirements to their import, companies might start avoiding the Dutch market. The large and rich EU on the other hand has more leverage.

Dynamic final design in architecture & construction education, for glass and other materials, promote reuse, and in a broader sense encourage students to reconsider the relationship between existing materials and imagined constructions. The effects of these practices are likely proportional to the scale of their implementation, hence international collaboration would not be vital for success in Dutch context.

Installing demolition committees, or letting existing welstandscommissies assess whether demolition of buildings is strictly necessary, could increase the threshold for demolition and subsequently promote repair, potentially saving various construction materials in large amounts. No 'economies of scale' are expected for this practice, so it could initially be introduced on a national level.

A combination of strategies is likely to be most effective. The larger the scale of implementation, the larger the effect of the policies. An international approach would be necessary for recycling, and remanufacturing with standardisation would strongly benefit from upscaling. The industry should be included in the process as much as possible. The reality of the political climate and financial limitations needs to be taken into account, but preventing is easier than curing.

A set of sustainable scenarios were presented for architectural glass, a high potential, material stream, largely unexplored in this context. The combination of connecting design, construction, and policy has led to a unique new perspective. The policy suggestions help those in charge take steps towards sustainable glass use on the large scale.

Next to float glass, this project could also prove useful for other, potentially more environmentally impactful material streams. Through the strategies discussed in the repair scenario, other construction materials would be maintained simultaneously. Furthermore, the interdisciplinary scenario approach used in this project could be applied to find solutions for other material streams as well.

For me personally, content wise, this was close to an ideal capstone project. It allowed me to dive into multiple topics that I wanted to familarise myself with before leaving university. I gained insight in policy making processes, practiced basic material stream analysis, and experienced strategic design. The project brought me to new ideas about the added value I could have as a designer and where I want to go. On the other hand, it was challenging finding my way in such unfamiliar topics, and I struggled with the lack of structure.

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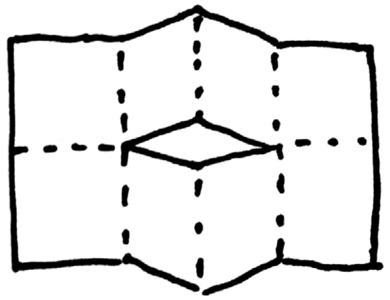
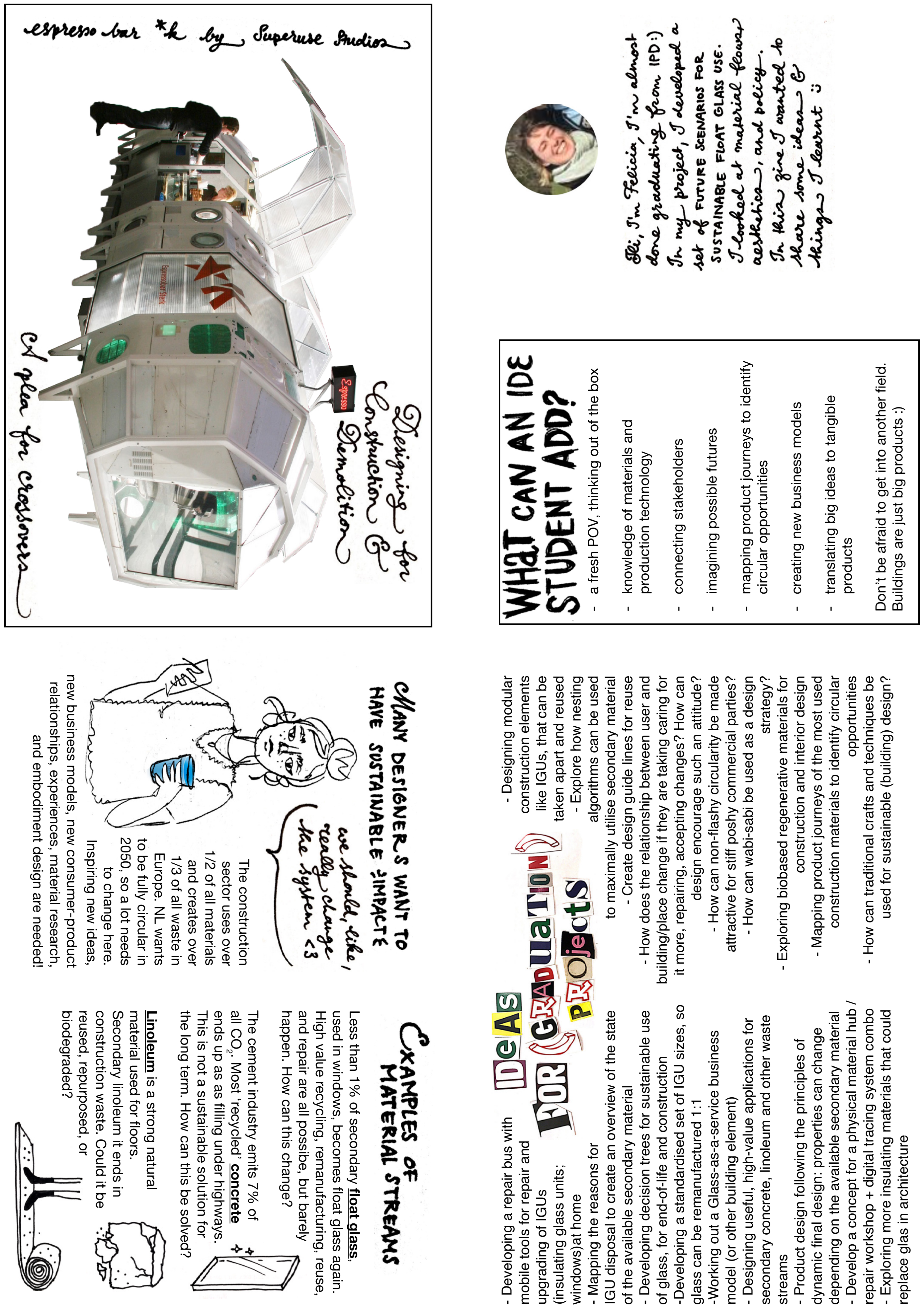
appendix 1
outreach zine

a mini zine ('small-circulation self-published magazine') to share insights from this project with other IDE students, to be spread around the faculty.





espresso bar *k by Superuse Studios

Designing for Construction & Demolition

A plea for crossovers

Hi, I'm Felicia, I'm almost done graduating from IPD :)
In my project, I developed a set of FUTURE SCENARIOS FOR SUSTAINABLE FLOAT GLASS USE.
I looked at material flows, aesthetics, and policy.
In this zine I wanted to share some ideas & things I learnt :)

WHAT CAN AN IDE STUDENT ADD?

- a fresh POV, thinking out of the box
- knowledge of materials and production technology
- connecting stakeholders
- imagining possible futures
- mapping product journeys to identify circular opportunities
- creating new business models
- translating big ideas to tangible products

Don't be afraid to get into another field. Buildings are just big products :)

MANY DESIGNERS WANT TO HAVE SUSTAINABLE IMPACT

we should, like, really change the system <3

The construction sector uses over 1/2 of all materials and creates over 1/3 of all waste in Europe. NL wants to be fully circular in 2050, so a lot needs to change here. Inspiring new ideas, new business models, new consumer-product relationships, experiences, material research, and embodiment design are needed!

EXAMPLES OF MATERIAL STREAMS

Less than 1% of secondary **float glass**, used in windows, becomes float glass again. High value recycling, remanufacturing, reuse, and repair are all possibe, but barely happen. How can this change?

The cement industry emits 7% of all CO_2. Most 'recycled' **concrete** ends up as as filling under highways. This is not a sustainable solution for the long term. How can this be solved?

Linoleum is a strong natural material used for floors. Secondary linoleum it ends in construction waste. Could it be reused, repurposed, or biodegraded?

IDEAS FOR GRADUATION PROJECTS

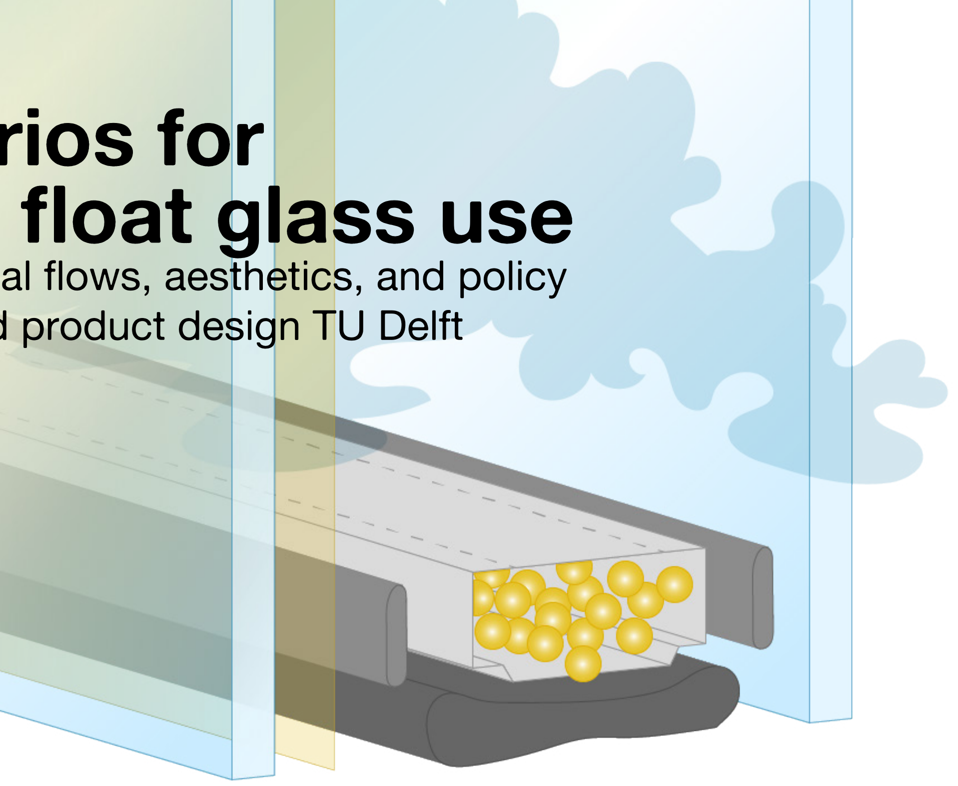
- Developing a repair bus with mobile tools for repair and upgrading of IGUs (insulating glass units; windows)at home
- Mapping the reasons for IGU disposal to create an overview of the state of the available secondary material
- Developing decision trees for sustainable use of glass, for end-of-life and construction
-Developing a standardised set of IGU sizes, so glass can be remanufactured 1:1
-Working out a Glass-as-a-service business model (or other building element)
- Designing useful, high-value applications for secondary concrete, linoleum and other waste streams
- Product design following the principles of dynamic final design: properties can change depending on the available secondary material
- Develop a concept for a physical material hub / repair workshop + digital tracing system combo
- Exploring more insulating materials that could replace glas in architecture

- Designing modular construction elements like IGUs, that can be taken apart and reused
- Explore how nesting algorithms can be used to maximally utilise secondary material
- Create design guide lines for reuse
- How does the relationship between user and building/place change if they are taking caring for it more, repairing, accepting changes? How can design encourage such an attitude?
- How can non-flashy circularity be made attractive for stiff poshy commercial parties?
- How can wabi-sabi be used as a design strategy?
- Exploring biobased regenerative materials for construction and interior design
- Mapping product journeys of the most used construction materials to identify circular opportunities
- How can traditional crafts and techniques be used for sustainable (building) design?

future senarios for sustainable float glass use

an exploration of material flows, aesthetics, and policy
master thesis integrated product design TU Delft
Felicia Snip

An insularion glass unit (IGU)



Over half of the materials in Europe are used in construction, and over a third of all waste is generated there. Float glass, used in windows, is largely unexplored in the context of circularity, but has great potential. It does not age and an be infinitely recyled. Over 100.000 tonnes a year are disposed in the Netherlands, of which less than 10% becomes float glass again. How could the value of glass be maintained? What would the impact of different circular strategies be on the value chain, and the product itself? And how could this be organised on a large scale?

policy recommendations

As a target, saving 19200 tonnes of glass per year through repair, reuse, and remanufacturing each, and 33400 tonnes per year through recycling is recommended. This division saves the maximal amount of glass, at close to the optimal maintained value, while allowing for some flexibility. The development of a decision tree for both demolition and construction is suggested, to find the most valuable material application of in each individual situation. To encourage circular glass use on a large scale, the following policy is recommended:

Green public procurement creating a demand for sustainable glass through government tenders. Points are awarded based on value maintained.

Extended producer responsibility (EPR) with differentiating fees incentivises producers to take steps towards sustainable glass handling: taking back own IGUs, using float glass with a high cullet (glass shards) percentage, using modular design, and offering repair services all lead to financial benefits.

Setting up a recycling pilot with float glass factories in Belgium or Germany, to figure out logistics and improve cleaning facilities. Afterwards, sharing the gained knowledge and setting a required minimum percentage of cullet for European production

Dynamic final design in architecture and construction education teaches a new generation the principles needed for reuse in construction, for glass and other materials

Installing demolition committees, or tasking welstandscommissies to determine whether a building is allowed to be demolished. This increases the treshold for demolition, maintaining aesthetic heritage and material value

Pigouvian taxes: exices can be levied on virgin glass, and the income will be invested in developing circular infrastructure such as cleaning installations and reuse hubs.

On a larger scale, Ex'Tax or a similar tax shift from labour to resources and pollution would benefit a shift to a sustainable construction sector, as most circular practices are relatively labour intensive.

recycling

Float glass contains less than 1% post-consumer glass. Recycling all Ducth float glass could decrease the new glass demand by up to 47%, saving 12,5 - 15% of the production energy. There are no float glass factories in the Netherlands, so international collaboration is needed.

remanufacturing

IGUs, insulation glass units, are usually disposed while the glass is undamaged. The IGU can be dismantled and the glass can be made into new IGUs. When partially standardising glass sizes, no glass will be lost when making windows fit. Remanufacturing could save 9,9 - 29,7% of the glass demand, proportionally decreasing production energy and international transportation. IGU manufacturers could move to glass as a service models, taking back their own IGUs.

reuse

IGUs could also be reused as a whole. With some extra gas and kit, they could be moved to another building. This could decrease the glass demand by around 29,9%. Architects would have to adopt the practice of dynamic final design. A system of physical hubs and digital tracing would facilitate this.

repair

Most value would be maintained by keeping IGUs in their current contex. Mobile repair services could locally add gas, kit and foils. This could save 19,8 - 39,6% of the glass demand. By preventing demolition, other , more impactful materials would be saved as well, like concrete, brick, and steel.

reduce

The option of reducing glass use was considered: IGUs could be made smaller, made of new, alternative transparent materials, or replaced by screens. This strategy would improve insulation, but was rejected because currently available alternatives have a larger environmental impact than glass. The development of transparent wood could create interesting possibilities in the future.

appendix 3
policy handout

vlakglas in de circulaire economie: richting voor beleid

In 2050 moet Nederland circulair zijn. Binnen de bouwsector moet veel veranderen: die gebruikt meer dan 1/3 van de materialen, en creëert meer dan 1/3 van het afval. Architectonisch vlakglas, ramen, is een materiaalstroom waar veel winst te behalen valt.

Per jaar komt er 192.000 ton vlakglas Nederland binnen, en wordt er meer dan 120.000 ton weggegooid. Glas zelf veroudert niet. Slechts 6% van het secundaire vlakglas komt van glasherstel, van de overige 94% is het meeste intact als het wordt weggegooid. Glas kan technisch gezien oneindig hoogwaardig gerecycled worden, maar minder dan 10% van het secundaire vlakglas wordt weer vlakglas. De rest wordt laagwaardig gerecycled. Naast dat er hierdoor veel waarde verloren gaat, dreigt er ook een tekort aan zand om glas van te maken. Dit zou binnen enkele tientallen jaren problemen in de bouw kunnen opleveren.

Er zijn verschillende strategieën om op een duurzamere manier met vlakglas om te gaan:

Recyclen
Door hoogwaardig te recyclen, is er tot 47% minder vlakglas nodig voor Nederland. Hierbij wordt 12,5% tot 15% energie bespaard ten opzichte van nieuw glas. Gezien er geen vlakglasfabrieken in Nederland zijn, is voor recyclen internationale samenwerking nodig.

Remanufacturing
Secundaire glasplaten kunnen gebruikt worden om nieuwe glaspakketten te maken. Dit zou 10% - 27% van het nieuwe glas in Nederland kunnen vervangen, afhankelijk van de staat van het materiaal en hoe goed de vorm van het aanbod past bij de vraag. Door glasafmetingen gedeeltelijk te standaardiseren hoeft er minder weggegooid te worden.

Reuse
Glaspakketten zouden ook in huidige vorm hergebruikt kunnen worden, eventueel met reparaties als low-e folie, extra gas of nieuwe kit. Dit zou tot 30% van het nieuwe glas in Nederland kunnen vervangen. Hiervoor zouden architecten in hun ontwerp rekening moeten houden met de vorm en staat van het beschikbare glas, in plaats van het op maat te bestellen.

Repair
Als glas in context behouden wordt, door het te repareren en sloop te voorkomen, zou de maximale waarde behouden blijven. Een nieuwe folielaag, extra gas of een nieuwe kitrand kan ter plekke aangebracht worden en de isolatiewaarde van het glas verbeteren. Dit zou 20% - 40% nieuw glas kunnen vervangen. In geval van niet-slopen is de milieuwinst door behoud van andere materialen nog vele malen groter. Repareren is arbeidsintensief.

Reduce
Ten slotte zou glasgebruik in het algemeen kunnen verminderen. Glazen ramen zouden kleiner kunnen worden gemaakt, geïnspireerd door traditionele architectuur, of vervangen kunnen worden door andere materialen zoals transparant hout, dat nu door wetenschappers ontwikkeld wordt. Dit kan de isolatiewaarde ten goede komen en huizen meer knusheid en privacy geven. Het effect hiervan op de glasvraag is lastig in te schatten.

Beleidsopties

- Groene openbare aanbestedingen (GPP): eis, of verleen prioriteit aan, duurzaam glas bij overheidsaanbestedingen. Voorkeur zou uitgaan naar reparatie van bestaande gebouwen, dan hergebruik van ramen, dan ramen gemaakt van secundair vlakglas (remanufacturing), dan ramen gemaakt van gerecycled glas.
- Uitgebreide producentenverantwoordelijkheid met voordelen voor elke genomen duurzame stap: producenten krijgen financiële stimuli voor modulair ontwerp, gebruik van secundair glas, terugnemen eigen ramen, werken met gestandaardiseerde formaten
- Pilot opzetten Europese samenwerking gerecycled vlakglas: VRN verbinden aan vlakglasproducenten over de grens, zoals AGC in België of Saint Gobain en NSG in Duitsland. Doel is te onderzoeken in hoeverre secundair vlakglas al gerecycled kan worden binnen de huidige infrastructuur, en wat er nodig is op technisch en logistiek gebied om dat te verbeteren
- Op EU-level onderzoek doen naar en lobbyen voor een minimaal percentage glasscherven voor vlakglasproducenten
- Accijns op nieuwe bouwmaterialen, inkomsten inzetten als subsidies voor circulaire infrastructuur. Specifiek:
    - Nieuw vlakglas belasten, inkomsten inzetten als subsidie voor schoonmaak- en sorteerinstallaties voor secundair glas
    - Nieuwe glaspakketten belasten, ontwikkeling remanufacturing-installaties subsidiëren

- In samenwerking met architecten en glasfabrikanten een set standaardafmetingen voor glas ontwikkelen, zodat individuele glasplaten zonder materiaalverlies hergebruikt kunnen worden, en architecten makkelijk rekening kunnen houden met geremanufactured glas in hun ontwerpproces
- In samenwerking met bouw- en sloopbedrijven fysieke hubs en een digitaal volgsysteem voor secundair vlakglas opzetten, zodat het bewaard en verhandeld kan worden
- In samenwerking met universiteiten en hogescholen hergebruik in architectuur- en bouwonderwijs stimuleren
- Onderhoud van oude gebouwen stimuleren met reparatiesubsidies gekoppeld aan leeftijd gebouw
- Mogelijkheid onderzoeken van sloop voorkomen door aanstelling ‘sloopcommissies’: welstandscommissies, maar dan gericht op duurzaamheid en behoud stadsgezicht
- Minimale isolatiewaarde gehele wand vastleggen in bouwbesluit. Nu zijn de minimale isolatiewaarden van muur en raam los van elkaar gedefinieerd, wat slecht isolerende glazen wanden toestaat
- Embedded co2 in gebouwen onderzoeken en begrenzen
- Investeren in onderzoek naar duurzame alternatieven voor glas
- In samenwerking met gebouweigenaren en de sloop een beslisboom opzetten om te zorgen dat vrijkomend glas zo hoogwaardig mogelijk toegepast wordt
- In samenwerking met de bouwsector een beslisboom opzetten om te zorgen dat nieuwe gebouwen zoveel mogelijk secundaire waarde toepassen
- Op de grote schaal: onderzoek doen naar de mogelijkheid van, en lobbyen voor, een belastingverschuiving: arbeid minder belasten, materiaal en vervuiling meer. Stimuleert een duurzame en sociale economie.

DESIGN FOR our future

TU Delft

IDE Master Graduation

Project team, Procedural checks and personal Project brief

This document contains the agreements made between student and supervisory team about the student's IDE Master Graduation Project. This document can also include the involvement of an external organisation, however, it does not cover any legal employment relationship that the student and the client (might) agree upon. Next to that, this document facilitates the required procedural checks. In this document:

- The student defines the team, what he/she is going to do/deliver and how that will come about.
- SSC E&SA (Shared Service Center, Education & Student Affairs) reports on the student's registration and study progress.
- IDE's Board of Examiners confirms if the student is allowed to start the Graduation Project.

USE ADOBE ACROBAT READER TO OPEN, EDIT AND SAVE THIS DOCUMENT

Download again and reopen in case you tried other software, such as Preview (Mac) or a webbrowser.

STUDENT DATA & MASTER PROGRAMME

Save this form according the format "IDE Master Graduation Project Brief_familyname_firstname_studentnumber_dd-mm-yyyy".
Complete all blue parts of the form and include the approved Project Brief in your Graduation Report as Appendix 1 !

family name: Snip
initials: FF given name: Felicia
student number: 4579526
street & no.:
zipcode & city:
country:
phone:
email:

Your master programme (only select the options that apply to you):
IDE master(s): [x] IPD [ ] DfI [ ] SPD
2nd non-IDE master:
individual programme: - - (give date of approval)
honours programme: [ ] Honours Programme Master
specialisation / annotation: [ ] Medisign
[ ] Tech. in Sustainable Design
[ ] Entrepeneurship

SUPERVISORY TEAM **

Fill in the required data for the supervisory team members. Please check the instructions on the right !

** chair: Erik Tempelman dept. / section: Materials Manufacturing
** mentor: Benjamin Sprecher dept. / section: Design for Sustainability
2nd mentor:
organisation:
city: country:

comments (optional)

Chair should request the IDE Board of Examiners for approval of a non-IDE mentor, including a motivation letter and c.v..

Second mentor only applies in case the assignment is hosted by an external organisation.

Ensure a heterogeneous team. In case you wish to include two team members from the same section, please explain why.

TU Delft

APPROVAL PROJECT BRIEF

To be filled in by the chair of the supervisory team.

chair: Erik Tempelman date: 10 - 03 - 2023 signature: [signed]

CHECK STUDY PROGRESS

To be filled in by the SSC E&SA (Shared Service Center, Education & Student Affairs), after approval of the project brief by the Chair.
The study progress will be checked for a 2nd time just before the green light meeting.

Master electives no. of EC accumulated in total: ____ EC
Of which, taking the conditional requirements into account, can be part of the exam programme ____ EC
List of electives obtained before the third semester without approval of the BoE

[ ] YES all 1st year master courses passed
[ ] NO missing 1st year master courses are:

name: date: - - signature:

FORMAL APPROVAL GRADUATION PROJECT

To be filled in by the Board of Examiners of IDE TU Delft. Please check the supervisory team and study the parts of the brief marked **.
Next, please assess, (dis)approve and sign this Project Brief, by using the criteria below.

- Does the project fit within the (MSc)-programme of the student (taking into account, if described, the activities done next to the obligatory MSc specific courses)?
- Is the level of the project challenging enough for a MSc IDE graduating student?
- Is the project expected to be doable within 100 working days/20 weeks ?
- Does the composition of the supervisory team comply with the regulations and fit the assignment ?

Content: [ ] APPROVED [ ] NOT APPROVED
Procedure: [ ] APPROVED [ ] NOT APPROVED

comments

name: date: - - signature:

Preparing the demolition sector for high-grade reuse of insulation glass

project title

Please state the title of your graduation project (above) and the start date and end date (below). Keep the title compact and simple. Do not use abbreviations. The remainder of this document allows you to define and clarify your graduation project.

start date 13 - 02 - 2023 07 - 07 - 2023 end date

INTRODUCTION **

Please describe, the context of your project, and address the main stakeholders (interests) within this context in a concise yet complete manner. Who are involved, what do they value and how do they currently operate within the given context? What are the main opportunities and limitations you are currently aware of (cultural- and social norms, resources (time, money,...), technology, ...).

The construction sector is Europe's biggest driver of resource consumption and waste generator. Reuse of building materials would greatly improve the sector's sustainability. This project will look into the reuse of insulation glass, which would save a great amount of energy compared to the current standard, downcycling. The Hogeschool van Amsterdam (HvA), together with the glass industry, is currently developing ways to 'upgrade' old insulation glass to meet legal insulation requirements. A challenge they are facing for the implementation of this project is that demolition companies do not yet know how to remove the glass properly: they lack the tools, knowledge and experience. In this project I will explore what is needed to change this, and design a solution that allows demolition workers to remove glass easily, quickly and safely.

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introduction (continued): space for images

TO PLACE YOUR IMAGE IN THIS AREA:

- SAVE THIS DOCUMENT TO YOUR COMPUTER AND OPEN IT IN ADOBE READER
- CLICK AREA TO PLACE IMAGE / FIGURE

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- IMAGE WILL SCALE TO FIT AUTOMATICALLY
- NATIVE IMAGE RATIO IS 16:10
- IF YOU EXPERIENCE PROBLEMS IN UPLOADING, COVERT IMAGE TO PDF AND TRY AGAIN

image / figure 1:

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image / figure 2:

PROBLEM DEFINITION **

Limit and define the scope and solution space of your project to one that is manageable within one Master Graduation Project of 30 EC (= 20 full time weeks or 100 working days) and clearly indicate what issue(s) should be addressed in this project.

Demolition companies lack the knowledge and tools to remove insulation glass from old buildings in such a way that it can be reused. A new process should be designed, introduced and taught, and the right tools should be determined, arranged, or even designed. Safety, ease, value preservation and profitability should be addressed.

ASSIGNMENT **

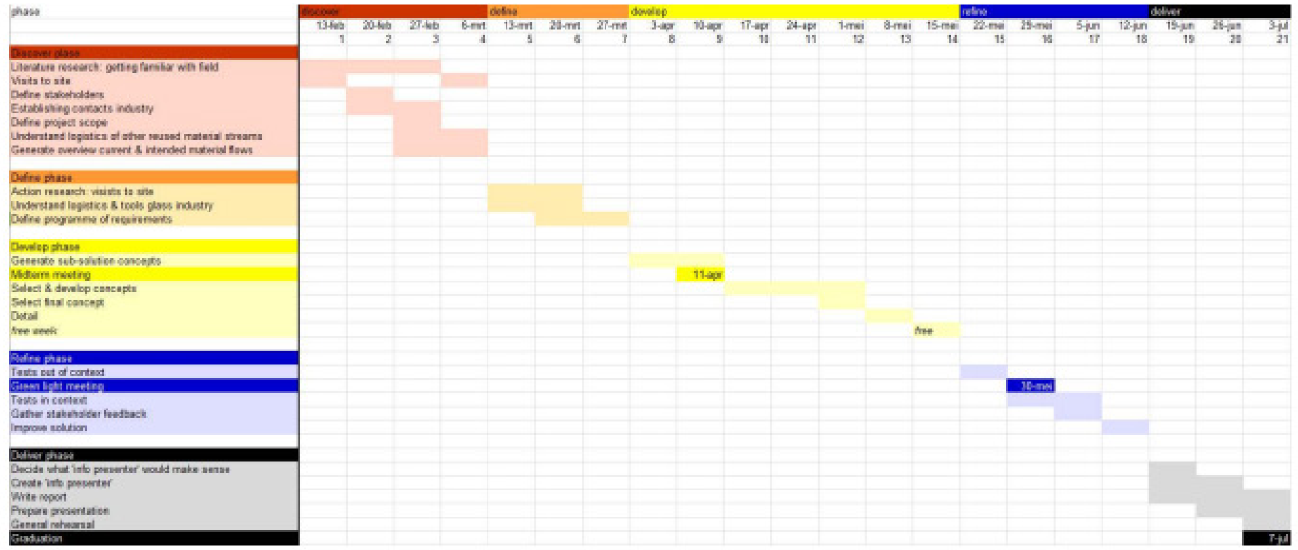
State in 2 or 3 sentences what you are going to research, design, create and / or generate, that will solve (part of) the issue(s) pointed out in "problem definition". Then illustrate this assignment by indicating what kind of solution you expect and / or aim to deliver, for instance: a product, a product-service combination, a strategy illustrated through product or product-service combination ideas, ... In case of a Specialisation and/or Annotation, make sure the assignment reflects this/these.

In this project I will
- research the current demolition practices and compare these to glass industry and -transport practices
- design a solution to help demolition workers to remove glass properly. This can be a tool set, a worksop, an instructive booklet, something else, or a combination.
- assess this process and its impact, and reflect on its applicability to other contexts and material streams.

PLANNING AND APPROACH **

Include a Gantt Chart (replace the example below - more examples can be found in Manual 2) that shows the different phases of your project, deliverables you have in mind, meetings, and how you plan to spend your time. Please note that all activities should fit within the given net time of 30 EC = 20 full time weeks or 100 working days, and your planning should include a kick-off meeting, mid-term meeting, green light meeting and graduation ceremony. Illustrate your Gantt Chart by, for instance, explaining your approach, and please indicate periods of part-time activities and/or periods of not spending time on your graduation project, if any, for instance because of holidays or parallel activities.

start date 13 - 2 - 2023   - -   end date



TU Delft

MOTIVATION AND PERSONAL AMBITIONS

Explain why you set up this project, what competences you want to prove and learn. For example: acquired competences from your MSc programme, the elective semester, extra-curricular activities (etc.) and point out the competences you have yet developed. Optionally, describe which personal learning ambitions you explicitly want to address in this project, on top of the learning objectives of the Graduation Project, such as: in depth knowledge a on specific subject, broadening your competences or experimenting with a specific tool and/or methodology, ... Stick to no more than five ambitions.

I set up this project because of my personal motivation for sustainability and desire to make a direct impact. I want to learn how decisions are made in the real world industry, understand what a designer can bring to the table. I want to learn a strategic, critical way of design, managing the interests of diverse stakeholders. I want to prove that I can apply design methods for significant societal impact.

FINAL COMMENTS

In case your project brief needs final comments, please add any information you think is relevant.