Reversing the Supply Chain: Recovery of IGU Components

Submitted abstract

Re-use of building materials is a response to the climate emergency following the circular economy principles. An informal collaboration has been exploring innovative processes to tackle material recovery from insulating glass units (IGUs). The value of clean cullet in float glass production has already been demonstrated but recovered interlayers, sealants, and spacer materials also have potential industrial uses if economically separated.
We ran successful trials of IGU disassembly, using a robotic arm with force feedback technology, to ensure precision, speed, and consistency. Initial trials had an emphasis on glass recovery from units with various spacer types and edge seal compositions. The quality of recovered glass enables reuse, which scores high on the circular economy scale. Alternatively, the process yields clean cullet suitable for remelting in the float line and supports closed-loop recycling. Low-energy methods of separating laminated glass without crushing are being explored, with a view to yielding high-grade PVB and clean glass/cullet. Future trials will explore smart automation for separate recovery of edge seal materials.
The vision of the collaboration is to support the growth of a new branch of the glass processing industry, in the dismantling of IGUs and recovery of the materials to their producers, reversing the supply chain and closing the loop of materials use.

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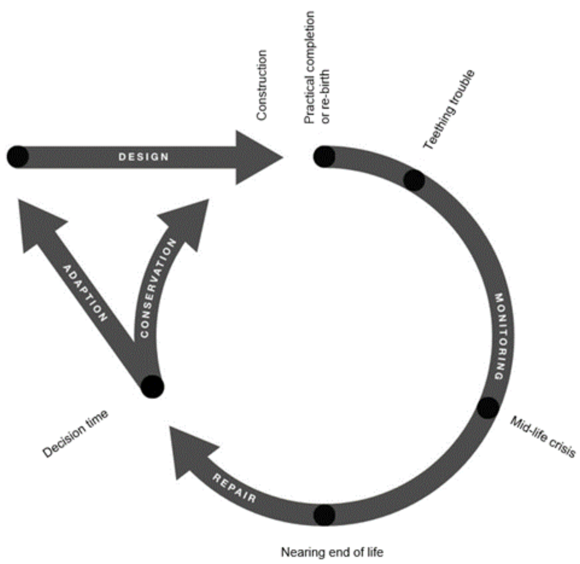
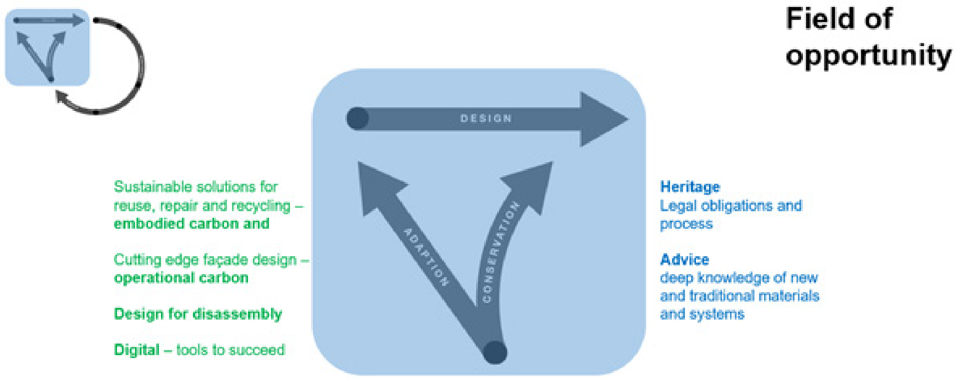
1. Introduction and background

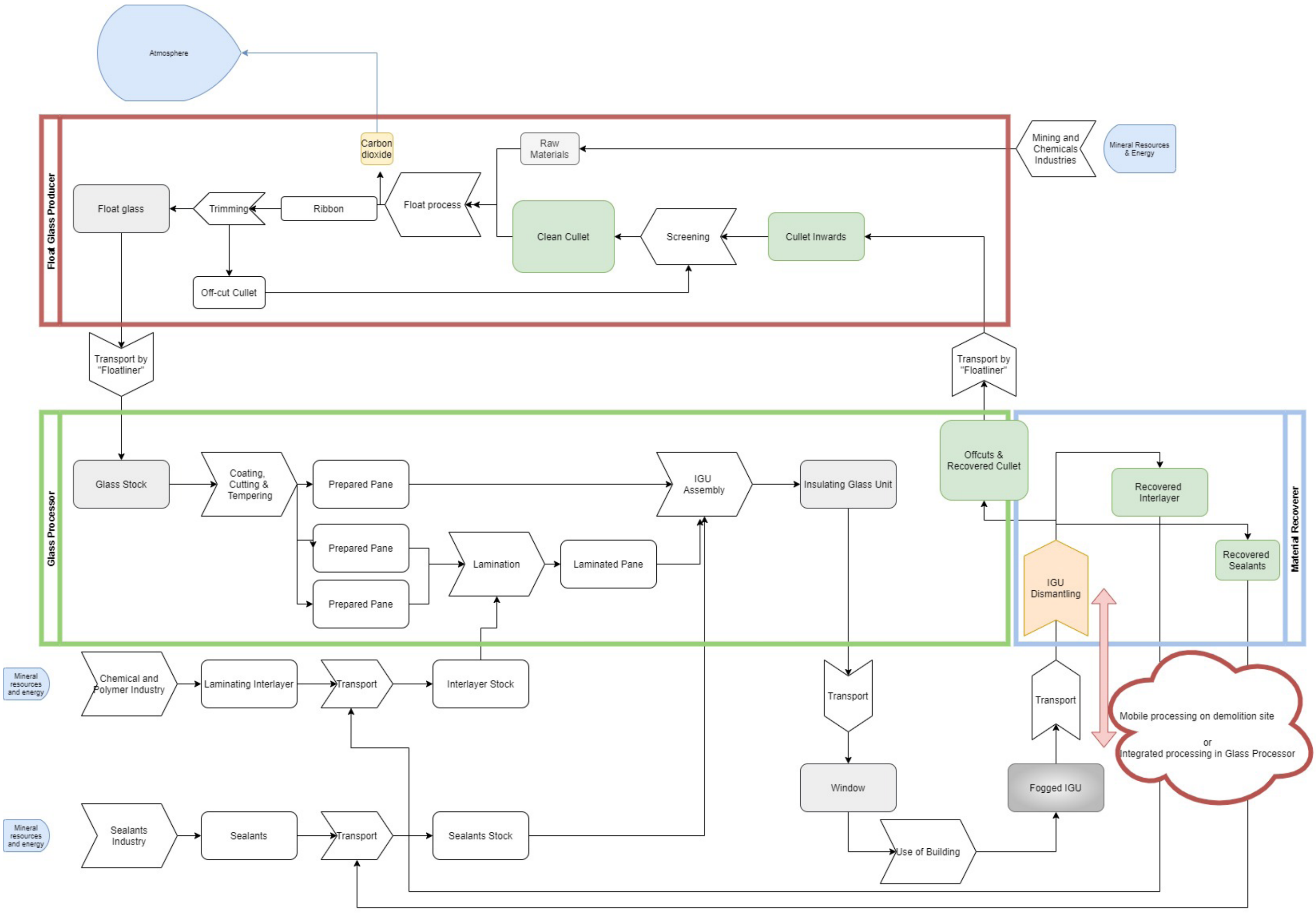
Many leaders around the globe now recognize the current Climate emergency we face. The construction industry and its supply chain contribute circa 40% of the global Green House Gas (GHG) emissions and therefore have a key role in reducing the impact it has on the climate, so sustainable solutions are required to achieve this. The façade with its extremely complex structure is constructed from a variety of materials aiding the performance and operational energy requirements helping to extend the sustainable life of the building and avoiding GHG emissions from premature replacement.
But what of the current building stock of less efficient buildings? How can these materials in situ, be transformed or reused sustainably to reduce landfill, the production of raw material, and the depletion of minerals?
Sustainability and reduction of embodied carbon are gaining momentum as the need to respond to the climate emergency is rightfully moving up the priority list across all industry sectors. In our façade and glass industry questions are being asked about how we can design buildings better. Standard practice and processes are being interrogated to understand the potential for improvement – we are starting to quantify the energy consumption and embodied carbon for each of the processes and steps in glass and façade manufacturing, transportation, installation, and in-service stages. We question set norms and look for a new balance between visual quality, cost and time aspects of a project, by including the sustainability and environmental impact parameters into the mix. It is time to disturb the industry and ask questions like – do we always require laminated/toughened glass? What is the acceptable quality of a product (or number of "imperfections"), when weighed against the GHG emissions generated to achieve it?
Part of the sustainably and embodied carbon agenda is also the principle of circular economy and reuse of materials. The existing building stock is to be viewed as a material bank, where components and materials can be harvested for re-use. The linear processes need to change into circular ones. And with it, the questions are raised: How do we dismantle components that were not designed to be taken apart? And how do we design for disassembly? This will be the focal point of our paper.
The diagram below plots a life of a building, starting with its design, then construction and the in-service period. Despite the repairs which can extend its life, eventually, we reach a decision time: what to do with the building? If we are to follow the circular economy principles and minimise leakage of materials out of this circle, we are broadly left with options of conservation or adaptation to close the loop.

This decision time presents a field of opportunity – a time when engineers can influence the decisions and provide advice, depending on what is right/best for each



specific project - be it heritage-related support to our clients on the route to conservation or through providing advice, experience and drive to innovate and find solutions to reduce embodied carbon of new builds, reuse of components and design for disassembly. Since we are challenging the standard practices, we should not hesitate to look for new emerging technological advancements, and explore innovative processes, by creating cross-industry collaborations and use of technologies in new applications.





Caption for this diagram: Flow diagram showing Material Recovery (blue box) returning materials to the supply chain.

2. The challenge of including igus into the circular economy

Caption for this diagram: Flow diagram showing Material Recovery (blue box) returning materials to the supply chain.
In the UK alone, 200 000 tonnes of glass are currently being sent to landfill each year.
The authors of this paper have carried out extensive study to understand the potential and barriers to glass recycling in the UK and more widely. [1] As an outcome of that research, insulated glass units were identified as one of the most problematic obstacles to reusing or recycling glass.

Typically the framing members that support the glazing units will have an anticipated service life aligned with the building's design life, approximately 50 to 60 years. However, the glazing units will have a service life of only approximately 25-30 years. This is due to moisture getting past the edge seals, degrading the coating and compromising the performance, while the glass panes themselves could have a much longer (possibly indefinite) service life.
The durability of glass within the IGU far exceeds the service life of the IGU, which ends when the system of hermetic sealing fails. Each of the materials involved may have much longer potential life than the service life of the unit. All the materials are effectively limited in life and in value by being bound together in one assembly.

2.1 Current glass recovery process

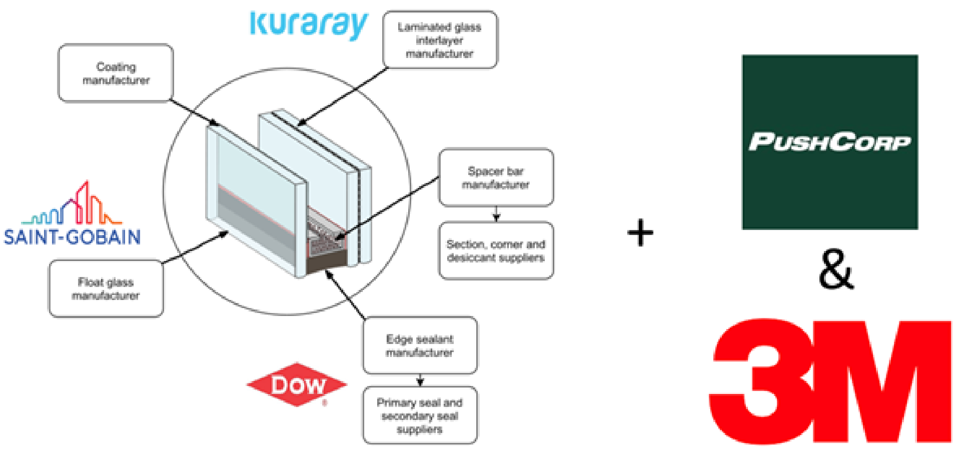
As the demand for clean cullet increases to reduce carbon emissions and gas demand, the value of recycling flat glass becomes more apparent. Currently, if the glass is recovered from an IGU, the process is quite crude – placing a panel over a skip or collection bag the glass is smashed from the frame with a hammer. A lot of panels might not make it past the QC process just because the glass is dirty or because the unit is too small. The yield of cullet is less than 100% because glass always remains attached to sealants and spacers. Some automation of this process has been remarkably successful, for example by Morley Glass in Yorkshire, England in collaboration with Saint-Gobain Glass. However, this process does not enable reuse at all.

2.2 Industry Collaboration is key

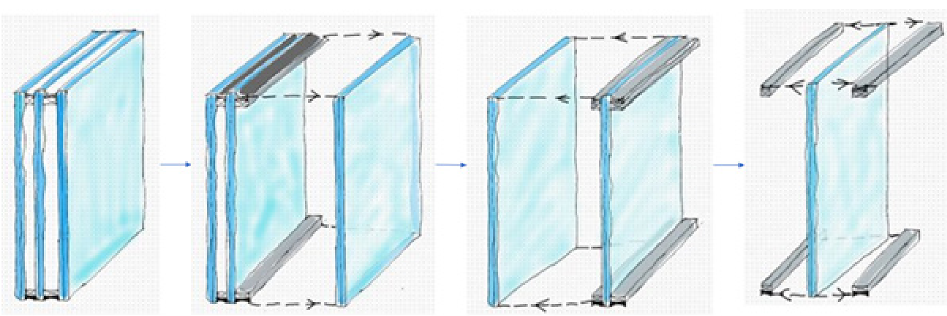
Although there is a proven benefit of recycling IGU to save raw materials and energy, it seems there is a lack of willingness from the main industry actors (glass and metal) to clearly engage. Many reasons could explain this behaviour, such as no developed recycling system or a low efficiency of these processes, or even the absence of a common recycling approach between the different manufacturers with everybody developing his own solution. To accelerate recycling of IGU, a clear alignment within the industry may be needed. When thinking of future systems optimized towards disassembly at end of life, it is important to realize that there will be a cost associated to this, which the project developer may not be willing to pay for, unlike initial sustainability performance assessments. One should always keep in mind that the end-of-life story should not dominate functionality during service lifetime and not push designers away from specific assembly methods with proven performance in order to facilitate dismantling. However, ingenious methods of salvaging materials are required as much as ingenious methods of manufacturing.

3. Collaboration and trials

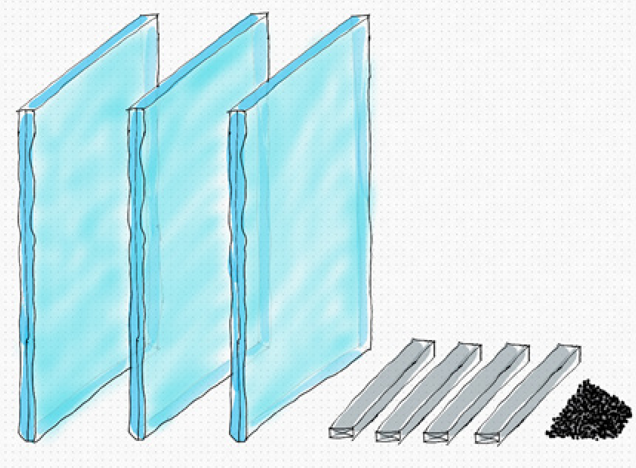
The vision for the trials was to unlock the potential value of individual components in an IGU, aiming for re-use potential or 100% recycling potential, to recover materials that would otherwise be downcycled or sent to landfill. We believe it is by running actual trials and exploring new processes, that a meaningful impact can be made as a response to climate change.
We aimed to connect various parties to share specialist knowledge, understand if the material suppliers would be interested in recovering the individual components, and develop a fruitful collaboration, ending with a trial/proof of concept of taking apart an IGU.
We ran a series of discussions with Saint Gobain, Kuraray, and Dow and all agreed that while there are challenges to be overcome, this is something that the industry will have to address urgently.
The trials were undertaken by PushCorp, a specialist robotics and automation equipment company, based in Dallas Texas. Based on the previous work and experience with them on the Maison Hermes project, we thought using the precise work of robotics technology could provide an answer to the IGU disassembly. The application of robotics would provide precision, automation, and speed. We wanted to develop a method that would be easily replicated in various locations around the world, therefore using simple and available tools attached to a robotic arm.



Shown below are early sketches of how we envisioned the process. Cutting through the primary seal, pulling the glass panes apart, recovering the spacer, glass panes, and silicone. The goal was to trial different spacer configurations in samples provided by Saint-Gobain and record the success rate in obtaining clean and good quality components, reliability in not damaging the glass, and the speed and ease of glass handling.



TGU sample — Separate a one pane of glass from the unit — Separate the second pane of glass from the unit — Separate the spacers from the glazing



As we started the trials, it became apparent that recovering the spacer and silicone will require more individually specialized processes, which will take time and investment beyond our proof of concept approach. Additionally, realizing glass has the highest value in the buildup the trials focused on recovering the glass.

As the façade industry is assessing how IGUs can be dismantled and their high-value components, such as glass or metal recovered, Dow is willing to act as an enabler.

To reinforce the attractiveness of a recyclable system to the industry, it is important to ensure that each element can be recycled and valorized, including silicone. Therefore, Dow is preparing to recycle the silicones reclaimed from the bonding and secondary sealing of the IGU. Several options to reintegrate these silicones into the production line process are currently being evaluated. This process will save raw material usage but also avoid the high energy required for the initial transformation of silica into silicone metal. Similar to other manufacturers, these studies will most probably lead to the development of quality criteria requirements to allow injecting recycled silicone in the production. It is indeed crucial to ensure the origin and composition of the waste silicone.

4. Final method and output

The final process can be found on YouTube: https://www.youtube.com/watch?v=72Oxh2OvNwk

PushCorp advised on the best choice of motor and spindle to be used for the application. The specific motor was chosen due to the speed required for the trail and for its high torque that enables it to maintain a constant speed while in contact with the part.

The selected spindle is a passive unit, and the same orientation was used throughout the whole process, making it a great fit for passive compliance. This can, of course, be altered, if the end-user decided they wanted to articulate to multiple sides of the part or needed to follow a complex curved part. In that case, an active compliance unit would be the preferred choice, where internal sensors allow it to compensate for orientation changes in real-time, allowing one to apply a constant force through whole motion.

The tools required for the process are abrasives and a cutter that are put on the spindle.

Using a 3M cutoff wheel (7-inch diameter 3M Cubitron II cutoff wheel), the first step was to slice through the outer sealant and spacer. The units were repositioned to repeat this step on all four sides of a DGU to separate it into two separated glass panes with residual sealant material and aluminum spacer on each pane. As an alternative to the cut-off wheel, abrasive wheels were trailed and worked well with soft spacers, however, not with the more traditional ones that include metals (aluminium or stainless steel) Therefore, the cut-off wheel is the most universal approach and easiest to be adopted at these early stages. Additionally, it is faster than using abrasive wheels.

In the second stage, a ½" end mill was attached to the spindle, just above the glass pane, to remove the aluminum spacer. The glass pane was laid on a flat surface, putting it into a repeatable position.

Lastly, abrasive wheels were used to remove the silicone. First, a 3M Multi-Finish wheel was used. Its high conformability and moderate aggressiveness removed the silicone without damaging the glass. To refine the scratch pattern a finer, 3M EXL Pro deburring wheel was used. However, depending on the end user's finish requirements, the final step could be omitted.

The quality of recovered glass was very good, and no panes broke during trials. Smooth, clean glass panes were ready for reuse, or alternatively, the process yields clean, high-quality cullet suitable for remelting in the float line and supports closed-loop recycling.

5. Further studies and next steps towards circular future

Running the trials and successfully disassembling an IGU is just the first step. This section outlines the next steps in order to make the process completely circular, provides suggestions of how the disassembly can be implemented in the current system, and proposes how to generate motivation across the industry to start undertaking this work.

It is also an invitation, to anyone who would like to collaborate on taking this trial to the next stage.

Further trial needs to be undertaken to ensure the maximum yield of high-quality components from the IGUs. How can the spacer bars be recovered? Is there a way to remove the silicone in order to recycle it into new components? The method developed for the dismantling of the IGU can further benefit from over 50 years of expertise in façade inspection, deglazing, and SSG repair exercises. The Global Silicones Council, of which Dow is a member, are assessing silicone recycling opportunities.

5.1 Laminated glass

A significant part is, of course, the challenge of laminated glazing, which, like IGU, is a major barrier to reuse or recycle glass. Although laminated cullet can be offset against fuel in the glass melting stage, this wastes the considerable amount of energy invested in the synthesis of interlayer polymers. A thermal method of delamination has been developed by Delam [2], and ongoing university research such that at Cambridge by Rebecca Hartwell [3] is pursuing the challenge of separating interlayers cleanly and efficiently from glass. Our collaboration briefly explored ultrasonic methods but without success.

As a leading manufacturer of architectural interlayers used in laminated safety glass, Kuraray has committed to achieve a Net Zero Carbon position and as a group has committed to the research, development, and delivery of sustainable solutions within our organization.

5.2 Improvements in tracking materials

Closer attention to the labelling and the identification of components within the IGU asset would help define the makeup of components, particularly the type of interlayer, PVB, Ionoplast, acoustic and varying adhesion levels etc. The glass types and surface treatments, the spacer bar composition and sealant polymer composition are all part of a golden thread of information that could possibly be identified by a QR code or within a BIM data base.

5.3 Current market/industry expectations

The availability of a 100% recycled PVB is already manufactured by Kuraray however the market is influenced more by optimal clarity and the increase in the use of low iron glass is testament to that, requiring the clearest of interlayers only possible with a very limited use of recycled content. The industry may need to tolerate a different level of clarity when using recycled material.

5.4 Quality of recovered materials

Of course, the recovered glass will have to be tested/certified and approved as suitable for reuse.

This presents an opportunity to develop standard testing and workflows to aid in providing certainty to the owners of the secondhand glass and ensure they receive a warranty for the product.

Besides the structural integrity of the glass, any coatings on the existing panes need to be considered – can they remain? Is there a way to remove them? Is there a possibility to upgrade them?

This will in turn feed into the reuse vs recycling debate, together with the unit size, type of glass, etc.

It is unlikely there is a silver bullet that will provide an answer for every project. The circumstances need to be evaluated on every project and weighted against a series of parameters and limitations – type of glass? Age of the building.? Availability of original specifications? To name a few.

Therefore, strong knowledge, broad skillset and tools to be able to assist the client to take the best path are what we need to develop as engineers.

5.5 Reversing the supply chain

The disassembly of components should become standard practice across the industry. The dismantling of IGUs could be implemented by adaptation of familiar machinery. Can the machinery be upgraded or modified to serve both assembly and disassembly? What are the challenges that would have to be resolved? Alternatively, and to provide facilities on demolition sites to minimize transportation emissions, or to aid smaller, local repair jobs, a pop-up station could be developed on-site or a portable "robot unit" deployed. Imagine a truck or a large van turning up at your building site, where a couple of DGUs have failed because of poor drainage - or just reached the end of their service life – and they can be de-glazed, separated and cleaned, then re-assembled?

Finally, looking back at the questions at the beginning of the paper (in a true circular fashion), there is much more to the sustainable future and responding to the climate emergency.

The industry needs to keep asking difficult questions, form new collaborations to collect and analyze the data, and to ensure we do build a better future.

Watch this space for more!

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