



Master Thesis

Circular Glass Implementation in Dutch Façade Glass Refurbishments

Author: K. Q. D. Tinneveld
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Thesis

Circular Glass Implementation in Dutch Façade Glass Refurbishments

By

K.Q.D. Tinneveld

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Supervisor:	Dr. ir. H.R. Schipper,	TU Delft
Thesis committee:	Dr. ir. H.R. Schipper,	TU Delft
	Dr. ir. M.G.C. Bosch-Rekvelde,	TU Delft
	Dr. J. Cupač,	TU Delft

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Preface

This thesis was written in partial fulfilment of the requirements for the Master of Science in Civil Engineering at Delft University of Technology. The implementation of circular glass in Dutch façade refurbishments is explored in this thesis.

The motivation for the research topic comes from an interest in sustainability and a potentially missing link in projects where circular solutions already appear technically feasible. Glass offers several circular route options. Still, new IGUs remain the default option and glass façades are downcycled and/or treated as waste. The key challenge is not primarily technical feasibility.

The output of this research is intended to be practically applicable. To achieve this the thesis is structured around three complementary research components. First, a systematic literature review is conducted to investigate technical, economic and environmental feasibility compared with new IGUs, the default option. Second, a desk-based analysis of the regulatory framework and relevant standards is performed. Finally, a desk-based stakeholder roles, responsibilities and supply-chain analysis is conducted to identify implementation drivers and barriers in practice. These findings are subsequently complemented by an empirical evaluation through semi-structured stakeholder interviews.

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Summary

This thesis investigates the technical, regulatory and stakeholder-related responsibility conditions under which circular glass can be effectively implemented in façade glass replacements in the Netherlands. The focus of the research is on façade glass refurbishments in existing buildings, particularly on insulated glass units (IGUs), as these are commonly replaced during renovation and maintenance projects. New IGUs remain the default choice in practice while circular glass routes exist. It is argued that the main challenge is not only technical feasibility, but the ability to implement circular glass as an accepted, traceable and contractually defensible product.

The research was structured around three complementary sub-questions. First, sub-question 1 examined different available circular glass routes and compared them with new IGUs in terms of technical, economic and environmental feasibility through a systematic literature review. Second, sub-question 2 examined the regulatory conditions through a desk-based regulatory and standards analysis. Finally, sub-question 3 examined different stakeholders, barriers, drivers and responsibility structures through a desk-based stakeholder roles and responsibilities analysis, complemented by five semi-structured stakeholder interviews for empirical evaluation.

The findings of the first sub-question indicate that for façade refurbishments several circular glass routes are relevant. Direct reuse is the highest-value circular route, which is possible when the recovered glass is technically defensible and suitable for a new application. The circular route of remanufacturing is relevant when direct reuse at product level is not possible, but some components can still be used in a new or adapted product. High-quality closed-loop recycling is a relevant circular route when higher-value routes are not feasible, while downcycling remains the fallback route. These routes are conditionally feasible, depending on glass condition, yield, process control, logistics, documentation and acceptance requirements.

The regulatory and standards analysis indicates that the implementation of circular glass does not necessarily require fundamentally different technical performance requirements compared with new IGUs. The main difference lies in the availability and reliability of the documentary evidence. New standardised IGUs are supported by product documentation, performance declarations, warranties and established acceptance routines. Circular glass needs to close this documentary gap by being delivered as a traceable and auditable product with sufficient evidence. Therefore, circular glass should be approached as a product consisting of glass and supporting evidence (i.e. “glass + evidence”).

The desk-based stakeholder roles and responsibilities analysis, which is complemented by five semi-structured stakeholder interviews, shows that the implementation depends on coordinated responsibilities across the reverse supply chain of circular glass. The findings suggest that stakeholders do not reject circular glass primarily based on technical infeasibility, but because of organisational, documentary, warranty and

acceptance difficulties in practice. The main barriers are yield loss due to damage, contamination, missing traceability, weak standardisation of evidence, unclear liability and warranty logic, vague procurement requirements and conservative market behaviour. The main drivers are controlled recovery, early procurement clarity, traceability, stakeholder role clarity, quality assurance and stronger standardisation.

The combined findings of the three sub-questions are translated into a preliminary implementation kit consisting of the following four elements: circular route decision logic, a regulatory evidence checklist, a preliminary Responsible, Accountable, Supportive, Consulted and Informed (RASCI) responsibility matrix, and stop-and-go gate logic. These four elements could help project teams determine which circular route is suitable, which evidence is required, who is responsible and when certain stop-and-go decisions should be made. The implementation kit is not intended as a formal certification system or a legal approval tool. The implementation kit is intended to provide a practical decision-support framework that makes circular glass implementation more explicit, auditable and manageable.

The main research question of this thesis can therefore be answered as follows. Circular glass can be effectively implemented in façade glass replacements in the Netherlands when the following three conditions are met simultaneously:

1. A technically defensible circular route must be available.
2. Circular glass must be supported by traceable and auditable evidence.
3. Governance across the reverse supply chain must be structured through early procurement clarity, controlled recovery, stakeholder role clarity and staged decision-making.

The overall conclusion is that circular glass implementation is not primarily constrained by the absence of possible circular glass routes, but by the absence of sufficiently standardised processes for preserving the material value, documenting performance and allocating different responsibilities. In other words, circular glass should not be treated as glass material alone, but as **‘glass + evidence + responsibility’**. This thesis therefore recommends incorporating the ambition to apply circular glass early in project requirements and tender documents, using staged stop-and-go moments, working with traceable product information and developing more standardised evidence requirements for circular glass. Finally, the proposed implementation kit should be tested and evaluated in future research through real façade refurbishment projects.

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1 Introduction

1.1 Background and problem

1.1.1 Background and scientific context

Glass façades in buildings have a double relevance regarding sustainability in refurbishment projects. The first is their influence on operational energy demand for maintaining indoor comfort. The second is their embodied environmental impact due to the production of new flat glass. Flat glass requires high temperatures to produce. This makes new insulating glass units (IGUs) energy-intensive and a product with significant carbon relevance (Geboes et al., 2024). Replacing existing glazing with technically higher-performing units in refurbishment projects can reduce the operational energy demand of the building but may significantly increase embodied environmental impact. Therefore, the end-of-life strategy of the existing glazing is increasingly important.

With respect to circularity, architectural glass in building façades is, in principle, a material with high potential for re-entry into the value chain. However, existing glass still often ends up in low-value circular glass routes. In this thesis, *circular glass* refers to recovered façade glass that is retained through a circular glass route: direct reuse, remanufacturing or high-quality closed-loop recycling. It is frequently treated as waste or downcycled, while higher value circular glass routes are often technically feasible. The evidence required to demonstrate direct reuse potential primarily emerges from strength testing. These strength tests show that reused panes can often retain sufficient strength capacity (Cupać et al., 2024). Screenings and decision-support methods are being developed to support feasible implementations of circular glass. These could enable practical workflows which can be used when committing to direct reuse (Veer et al., 2023). Practical methodologies for the characterisation of flaws and strength of naturally aged glass are being developed, as these assessments are currently still mainly performed in laboratory settings (Sofokleous, 2022).

Another circular route, when direct reuse is not feasible, is the remanufacturing of IGUs. This method assesses IGUs at component level, because some of the components may no longer meet the required performance while other components can still be reused. Usable parts can be combined into circular IGUs supported by evidence of their technical performance. In this chain specifically, but also for direct reuse, the roles of the supply-chain and organisations are particularly important. In addition, acceptance criteria must be established and agreed upon to deliver a product with warranties and predictable costs, which remains challenging (Geboes et al., 2024).

When these circular glass routes are not feasible, the use of high-quality closed-loop recycling could provide an alternative circular route. The usable yield strongly depends on the quality of the collected and sorted glass (Smith & Abdoli, 2023).

Although circular glass routes can be applied, façade refurbishments also depend on

different factors such as the existing technical configuration, disassembly potential, aesthetic requirements (Teeuwen, 2023). Based on this context, this thesis investigates not only the material-related challenges and potential of circular glass in façade refurbishments, but also the implementation challenges related to regulatory and stakeholder responsibilities.

1.1.2 Problem statement

Currently, façade refurbishments still follow the concept of “remove and replace with new units”, while the circular value of removed units often remains unused and the units are downcycled. This gives rise to two problems:

1. Full replacement triggers production of new IGUs, which is energy and emission intensive. These impacts may undermine the sustainability benefits of refurbishment (Geboes et al., 2024).
2. Removed glass that is treated as waste or low-grade recycling material loses both functional value and quality. This may also include units with acceptable existing evidence or units that can be screened or tested to demonstrate acceptable performance. Degradation could be managed through certain screening or prediction approaches (Sofokleous, 2022; Veer et al., 2023).

Although circular glass routes exist, they are not implemented at scale. Organisational and/or contractual barriers are still present for implementation to succeed on a larger scale (Geboes et al., 2024). This results in actors in these projects choosing new IGUs as a safe default, even when circular glass routes could be feasible.

1.2 Decision context and research gap

The research gap is not whether technically feasible circular glass routes exist, but the conditions under which these circular glass routes can be successfully implemented in Dutch façade refurbishment projects. The direct reuse and remanufacturing circular glass routes must be supported by sufficient performance evidence, a clear allocation of stakeholder responsibilities and transparent handover documentation to become realistic alternatives to new IGUs. Therefore, this research focuses on how circular glass can be accepted, transferred and implemented in practice.

The thesis addresses the gap through three connected dimensions. First, technically feasible circular glass routes and the evidence required for their implementation are assessed. Second, the *regulatory acceptance* conditions and documentary evidence required for circular glass implementation are examined. Here, regulatory acceptance refers to acceptance based on evidence, which is sufficient, traceable and auditable. Third, stakeholder responsibilities and the supply-chain conditions required for practical implementation in façade refurbishment projects are analysed.

1.3 Research question and sub-questions

Based on the identified research gap in the previous section, the following main research question is formulated:

"Under which technical, regulatory and stakeholder-related responsibility conditions can circular glass be effectively implemented in façade glass replacements in the Netherlands?"

To answer this main research question the following sub-questions 1, 2 and 3 are formulated:

1. What methods for circular glass are currently available in façade refurbishments, and how do they compare to new insulated glass units (IGUs) in terms of technical, economic, and environmental feasibility?
2. What is the regulatory assessment framework for implementing circular glass in existing buildings?
3. Which stakeholders and supply-chain actors are identified as key to the implementation of circular glass, and what barriers, drivers and responsibility logics are associated with them?

Together, these three sub-questions examine which circular glass routes are technically, economically and environmentally feasible through sub-question 1, under which regulatory conditions the implementation of circular glass can be performed through sub-question 2, and how the implementation of circular glass can be organised with stakeholder roles and responsibility structures through sub-question 3. These findings together provide the basis for answering the main research question.

1.4 Scope and delimitations

The thesis is about the practical implementation of circular glass replacement in glass façades in existing Dutch buildings. In the following paragraphs the scope and delimitations are mentioned.

1.4.1 Context and application

This research focuses on (circular) glass façade refurbishments in existing buildings. Glass façades are defined as the glass elements in the building envelopes including the curtain walls and window systems. Also, façades with limited windows are included where glass replacement is relevant.

The scope is limited to buildings in the Netherlands, specifically standard commercial and residential buildings constructed between 1960 and the present (although glass replacement will usually only be realised for buildings which are at least a couple of years old). This specification is mentioned to exclude extraordinary special cases but is not treated explicitly. Buildings that have specialised functions, such as hospitals, laboratories or others, are excluded. Also, monuments are excluded due to their (very)

specific and diverse requirements. The primary focus is on the Dutch context but also references from other countries mainly from Europe may be used for comparison reasons where relevant. The primary focus was on Dutch sources, but international sources were used where relevant sources were limited. Skylights and sloped glazing systems are excluded which means the analysis is limited to vertical glass façades.

1.4.2 Product and technical scope

The focus in this thesis is on the most used glass type in façade refurbishments, which is Insulated Glass Units (IGUs). New IGUs are considered as the default in this thesis. Key technical characteristics of these systems are analysed for comparison.

Primarily the research is conducted at the product level, focusing on the glass components within façades. The associated elements such as frames, sealants, and fixings are only considered if they are relevant to the performance of the glass or if they influence the direct reuse. The broader building context is only included to contextualise refurbishment practices and not to perform a full building performance evaluation. Also, the scope is limited to non-structural glass applications.

1.4.3 Regulatory and institutional scope

The desk-based regulatory and standards analysis and the stakeholder roles and responsibilities analysis are limited to the Dutch context. This includes relevant Dutch standards and regulatory frameworks such as the Construction Products Regulation (CPR), the Dutch Building Quality Assurance Act (Wet kwaliteitsborging voor het bouwen; Wkb) and the environmental assessment frameworks MKI (Milieukostenindicator) and MPG (MilieuPrestatie Gebouwen).

The stakeholder roles and responsibilities analysis is desk-based and uses interviews for empirical evaluation. The focus is on professional stakeholder actors involved in façade refurbishments. Those who are responsible for aspects such as decision-making, recovery, specification, delivery, quality assurance and acceptance within the reverse supply chain are included. End-users and occupants are excluded from the desk-based stakeholder roles and responsibilities analysis; the focus is limited to the implementation conditions within professional practice.

1.4.4 Circularity and environmental scope

The three main circular glass routes considered for façade glass in this thesis are direct reuse, remanufacturing, and high-quality closed-loop recycling. *Component-level reuse* is not treated as a separate main circular glass route within this thesis but is considered where applicable as an intermediate option within remanufacturing rather than a separate main circular glass route.

The environmental assessment focuses mainly on the life cycle stages of end-of-life, direct reuse and processing. Initial manufacturing and in-use performance are excluded. A cut-off allocation approach is applied in this thesis; this means that the original production impact of glass is not attributed to subsequent life cycles in the MKI

calculation. Environmental analyses are limited to MKI-based assessments. Detailed life cycle assessments (LCAs) of processes are outside the scope of this research.

1.4.5 Temporal and knowledge boundary

In this thesis the regulatory, market and scientific knowledge available up to and including 2025 is considered.

1.5 Ethics and data protection

This thesis includes semi-structured stakeholder interviews with relevant professional stakeholders for empirical evaluation of the desk-based analyses. The interview participation is voluntary and is based on informed consent which is signed before each interview. No sensitive personal data were collected and all interview results presented in the thesis are anonymised.

The ethical and data protection procedures used are documented in the following appendices: Interview participant information & consent form (Appendix E), Interview protocol (Appendix F), Data Management Plan (DMP) (Appendix G) and Human Research Ethics (HREC) (Appendix H).

Artificial intelligence (AI) tools such as ChatGPT were used for language editing and presentation preparation for progress meetings. AI was not used to generate research findings, conduct analyses or draw conclusions.

1.6 Relevance and contribution

This research is relevant from environmental and practical perspectives. While the previous studies mainly focused on the technical feasibility of circular glass, this thesis also addresses the regulatory and stakeholder-related implementation conditions required for the implementation of circular glass in façade refurbishment projects.

Glass façades have a considerable embodied environmental impact. Replacing existing glazing with new IGUs requires new energy-intensive glass production. Technically feasible circular glass routes such as direct reuse, remanufacturing and high-quality closed-loop recycling may reduce the environmental impact. The Dutch MKI and MPG frameworks provide the basis for the assessment of these potential environmental benefits.

From a practical perspective, although IGUs are capable of meeting the technical requirements defined in EN standards, implementation can still fail due to organisational and contractual issues (traceability, liability, warranty and approval).

From a regulatory perspective, the Construction Products Regulation (CPR) and the broader Dutch compliance context make verifiable evidence and traceability at handover relevant for acceptance and accountability in practice. Therefore circular glass needs to

be sufficiently documented and defensible as an alternative to CE-marked products (Overheid.nl, 2019).

Less attention has been spent on the practical implementation conditions compared with the technical feasibility of circular glass routes. Different implementation conditions are required for a feasible implementation of circular glass in façade refurbishment projects. This thesis addresses this gap by integrating technical feasibility, regulatory requirements and stakeholder responsibilities into a preliminary *implementation kit*, which is a decision-support framework for structuring the implementation of circular glass.

The findings of this thesis are synthesised into a preliminary implementation kit consisting of four elements: a circular route decision logic, a regulatory evidence checklist, a preliminary Responsible, Accountable, Supportive, Consulted and Informed (RASCI) responsibility matrix and stop-and-go gate logic. The implementation kit is intended for stakeholders involved in façade refurbishment projects such as asset managers/owners, property managers, façade engineers, (main) contractors, glass processors/remanufacturers, quality assurance (QA) / Life Cycle Assessment (LCA) advisors and insurers.

Overall, this thesis contributes by integrating the acceptance based on standards, environmental assessment, economic assessment, Dutch procurement and the responsibility allocation into an implementation-oriented framework for circular glass.

1.7 Thesis outline

This thesis is structured into eight chapters.

Chapter 1 introduces the background, problem statement, research gap, research questions, scope and relevance of the study. Chapter 2 presents the research approach with the research methodology. Chapters 3 to 5 address three complementary sub-questions. Chapter 3 investigates the technical, environmental and economic feasibility of circular glass routes through a systematic literature review methodology. Chapter 4 examines the regulatory and standards-related conditions for the implementation of circular glass through a desk-based assessment methodology. Chapter 5 analyses stakeholder roles, barriers, drivers and responsibility structures through a desk-based stakeholder roles and responsibilities analysis.

Building on these findings, Chapter 6 integrates these results into a preliminary implementation kit complemented by semi-structured stakeholder interviews for empirical evaluation. Chapter 7 discusses the findings, implementation kit, limitations and practical implications of the research. Finally, Chapter 8 presents the conclusions, answers the different research questions and provides recommendations for future research and practice.

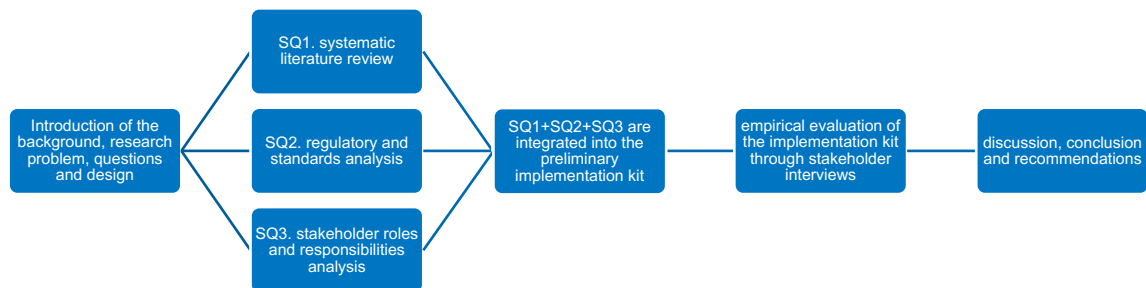
2 Research methodology

2.1 Research design

This section describes the overall research design adopted in this thesis. This thesis adopts a multi-method research design to answer the research question. The selected research design is a combination of qualitative research methods. Together these methods address the technical, regulatory and stakeholder-related aspects of circular glass implementation. To answer each sub-question a different methodological approach is required, reflecting the different types of knowledge needed to answer the overall research question. The selection and justification for the different methodologies for each sub-question are discussed in the following Sections 2.2.1-2.2.4. The approach is shown in Figure 1 with a flow chart overview.

In addition to the desk-based components, five semi-structured stakeholder interviews were conducted and used as an empirical evaluation. These interviews help to evaluate the desk-based analyses from a practical perspective.

Figure 1. Overview of the research design and methodological approach.



2.2 Research methods per sub-question

The methods used to address each sub-question are described in this section.

2.2.1 Research method sub-question 1: Systematic Literature Review (SLR)

The methodology used for answering sub-question 1 is a systematic literature review (SLR) following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 reporting guideline. PRISMA 2020 is used to ensure transparent and reproducible reporting of identification, screening, eligibility assessment and inclusion of sources (Page et al., 2021).

Appendix A presents the complete SLR protocol, search strings and PRISMA flow diagram. In Table 1 a compact overview is given of the SLR design.

Table 1. A compact overview of the systematic literature review (SLR) design.

Element	Approach used in this thesis
Reporting standard	PRISMA 2020
Databases	Scopus, ScienceDirect, TU Delft Repository, Springer
Period / language	2000–2025; English and Dutch
Search focus	IGU or flat glass circular glass routes (direct reuse, remanufacturing, high-quality closed-loop recycling) façade context feasibility evidence (EN/ISO, cost, LCA/EPD/MKI/MPG).
Inclusion criteria	- real façade and building contexts in buildings - technical: EN/ISO-standard aligned evidence - economic: cost per square metre and barriers/drivers - environmental: LCA, EPD, MKI and MPG based (with context)
Exclusion criteria	- lab-only studies which are not transferable - (marketing) claims without data - outcomes which are not extractable
Grey literature	Only included if the methods and data are transparent and sufficient.
Quality appraisal	- credibility assessment - traceability to tests/standards - data complete - transparent boundaries - potential conflicts
Data extraction	Route types, glass types, context, EN/ISO standards evidence, yields, logistics, cost boundaries, environmental indicators and modelling choices
Normalisation	Where feasible: - outcomes expressed per accepted square metre - key drivers such as yield and logistic assumptions when recorded explicitly
Environmental baseline	- Cut-off as baseline - Module D reported separate (where available) - lifetime-share is out of scope
Synthesis	Structured synthesis with route-based evidence Meta-analysis is not performed because of high heterogeneity.

Intentionally the systematic literature review (SLR) was limited to studies containing extractable and implementation-relevant evidence. This selection ensured that the SLR focused on practical evidence relevant to the technical, economic and environmental feasibility of circular glass in façade refurbishments. Broader conceptual discussions on circularity are therefore avoided.

The review resulted in a relatively limited number of seven studies, which are shown and summarised in Appendix A through the PRISMA 2020 flow diagram and the evidence extraction tables. This relatively limited number of included studies should not only be interpreted as a limitation, but it is also an indication of the current state of the field. The review intentionally focused on façade glass related studies with extractable technical, economic and/or environmental evidence. Consequently, broader circularity related publications, conceptual discussions or non-extractable claims were excluded. The relatively limited yield therefore reflects the present scarcity in this field of standard-aligned and implementation-oriented relevant evidence.

2.2.2 Research method sub-question 2: regulatory and standards analysis

A desk-based regulatory and standards analysis approach is used to answer sub-question 2. A desk-based research approach is appropriate because this sub-question is not concerned with new empirical testing but with formal acceptance conditions primarily defined by standards, regulations and guidance documents. The method consists of a systematic collection including a review and structured synthesis of normative and policy sources to develop a practical *regulatory assessment framework* for evaluating the regulatory evidence gaps including the corresponding stakeholder responsibilities. The objective is to develop a framework which is auditable for the evaluation of regulatory evidence gaps and the corresponding stakeholder responsibilities.

For each of the included sources, information was systematically extracted regarding its scope and applicability, mandatory and/or recommended requirement type, evidence requirements, responsible actors, handover requirements and relevance for the different circular glass routes. This structured extraction approach ensures that the resulting framework is transparent, auditable and reproducible. Appendix B provides the complete extraction log.

Subsequently, the extracted data were synthesised into three complementary outputs. First, a regulatory assessment framework links the regulatory acceptance requirements to the corresponding evidence items. Second, a comparison is made between the regulatory requirements which are applicable to the new IGUs and circular glass. A distinction is made between non-negotiable requirements and manageable differences in both the evidence and acceptance requirements. Third, a regulatory evidence checklist is developed to identify the evidence required. This helps to determine whether circular glass units or batches are supported by a sufficiently complete and auditable *evidence package*. An evidence package is a structured collection of information which is traceable and auditable and linked to a glass unit or batch. Such a complete evidence package overview supports handover.

The framework distinguishes between legally binding requirements, common contractual or procedural requirements which are commonly applied in practice and implementation measures which are proposed in this thesis. Consequently, the framework should be understood as an auditable interpretation tool. It should not be understood as a substitute for project-specific legal, contractual or insurance assessments.

2.2.3 Research method sub-question 3: Stakeholder roles and responsibilities analysis

To answer sub-question 3, a desk-based stakeholder roles and responsibilities analysis is used to identify the actors, barriers, drivers and responsibility structures relevant to circular glass implementation. Semi-structured stakeholder interviews are additionally conducted as an empirical evaluation to complement and contextualise the desk-based analysis. The semi-structured stakeholder interviews are further explained in Section 2.2.4.

For each source, the information was extracted on relevant stakeholders, barriers, drivers, responsibility implications, evidence requirements, procurement considerations and handover requirements. These insights were subsequently grouped into recurring themes to develop a stakeholder map, a barrier-driver overview and a responsibility framework.

Appendix C provides a compact overview of the methodological approach and the analytical framework used for the desk-based stakeholder roles and responsibilities analysis.

2.2.4 Semi-structured stakeholder interviews

Semi-structured stakeholder interviews were conducted as an empirical evaluation to complement the desk-based analysis. The interviews mainly support sub-question 3 by evaluating and contextualising the desk-based findings, such as stakeholder roles, barriers, regulatory acceptance, responsibility allocation and practical implementation conditions. The interviews also cover topics related to sub-question 1 and sub-question 2 where relevant.

The participants were selected based on professional experience in façade refurbishments and/or circular construction. Selection criteria included professional experience in façade refurbishments, circular construction, façade engineering, glass processing, property/asset management, quality assurance, or related regulatory and implementation processes. The focus was on stakeholders with at least practical or technical knowledge on one of the three research dimensions (technical feasibility, regulatory acceptance, or stakeholder roles and responsibilities). The interview sample included the following stakeholders based on the classification used in this thesis: QA/LCA advisor, public client, main contractor, and asset owner/property manager. Other stakeholder perspectives from insurers, certification bodies, and glass manufacturers were not directly represented in the collected interview sample. Therefore, findings related to these stakeholder groups should be interpreted with caution.

In total, five interviews were conducted. The interview protocol is provided in Appendix F. The interview sample was limited, and not all stakeholder groups were represented. Therefore, the findings should be interpreted as a qualitative empirical evaluation. The findings should not be interpreted as sector-wide evidence.

The interviews followed a semi-structured format based on three main dimensions (technical feasibility, regulatory acceptance and stakeholder roles and responsibilities). Ethical procedures including informed consent, data management, HREC documentation and anonymisation are further described in Appendices E, G and H. To inform the participants and obtain consent before the interviews, the participant information and consent form in Appendix E was used. The interview protocol in Appendix F was used during the interviews. The results are reported in Appendix F.

The methodological research approach described in this chapter provides the basis for the analyses presented in the following chapters. Chapter 3 presents the findings on the

technical, economic and environmental feasibility of the identified circular glass routes. Chapters 4 and 5 subsequently address the regulatory and stakeholder-related dimensions, in other words sub-question 2 and sub-question 3.

3 Technical, economic and environmental feasibility

This chapter presents the findings related to sub-question 1: “What methods for circular glass are currently available in façade refurbishments, and how do they compare to new insulated glass units (IGUs) in terms of technical, economic, and environmental feasibility?”. The aim is to identify and compare the circular glass routes relevant to façade refurbishments.

Different circular glass routes for glass in façade refurbishments are compared with new IGUs (the default) based on the available technical, economic and environmental evidence, using a systematic literature review.

3.1 Review context and comparison framework

This section introduces the technical background required to interpret the findings of the performed systematic literature review. It is explained why façade glass is relevant from a technical, economic and environmental perspective. Also, it introduces the main façade glass types, circular glass routes and presents the Dutch environmental assessment instruments which are used throughout this thesis.

3.1.1 Façades and building performance

Glass façades have an environmental impact in several ways. They influence both the operational energy performance and the embodied environmental impact of buildings. Therefore, glazing is an important consideration in façade refurbishment projects.

The glass façade influences solar gains (g-value) and heat loss (U-value). These factors directly influence the energy consumption and comfort of the building and are often drivers to reduce energy consumption and increase comfort during renovations. In practice, the performance of the façade depends on the configuration of the façade in combination with the way the building is operated (Gosztonyi et al., 2016).

Flat glass used in IGUs has a high embodied energy because a substantial amount of energy is required for its production. Avoiding new production can therefore be environmentally favourable (Geboes et al., 2024). Glass and aluminium façade framings are therefore relevant in discussions of embodied CO₂ (Teeuwen, 2023).

Glass replacement affects operational performance, depending on the performance of the new unit. At the same time, new embodied environmental impacts can be avoided by applying technically feasible circular glass routes. This does require the recovered glass to be assessed appropriately before the most suitable circular glass route can be selected (Geboes et al., 2024; Smith & Abdoli, 2023).

3.1.2 Types of façade glass

There is not just one type of façade glass. Different glass types and glazing systems provide different performance characteristics and differ in their suitability for different circular glass routes. In Table 2 an overview is provided of the main façade glass types, their typical applications and their relevance for circular glass implementation.

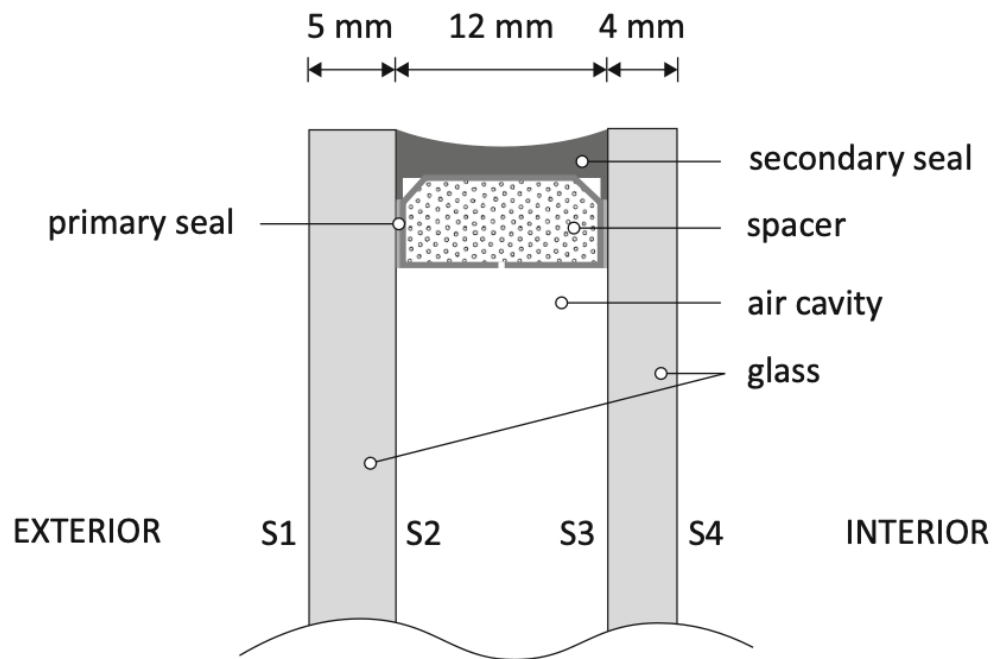
Table 2. Overview of different types of glass used in façades.

Glass type	What it is	Typical façade uses	Circular relevance
Float (annealed) glass	Standard soda-lime flat glass panes. Often the base for other types of glass.	The base for other types of glass. Often used as monolithic in older building façades.	For direct reuse, the available documentation is often insufficient for existing glass. The evidence may originate from available documentation and can be complemented by a condition assessment. Strength assessment methods for used glass could also be added where required. For remanufacturing, cutting to adjust the size or removing damaged edges may be part of the process. For high-quality closed-loop recycling purpose, sorting quality must be sufficient to achieve an adequate material yield. Otherwise, downcycling may be required.
Heat-strengthened / Tempered (safety) glass	Glass which is heat-treated to introduce compressive stresses resulting in a higher mechanical strength performance. When it breaks it breaks in small fragments	Façade areas with impact/fall (safety) risks because of the higher strength performance.	After tempering, the tempered glass cannot be cut or resized as this results in glass fragmentation. Consequently, remanufacturing options are limited because reused panes must remain in their original dimensions.
Laminated glass	Multiple panes bonded with an interlayer.	Façade areas with acoustic/security selected zones.	The interlayers complicate high-quality closed-loop recycling which may increase the likelihood of downcycling unless the glass is appropriately processed.
Coated glass (low-e / solar-control)	Float glass with a thin functional coating applied to improve thermal insulation (U-value) and/or its solar control performance (g-value).	Usually applied or chosen during renovations when thermal and/or solar performances need to be improved.	The coatings complicate high-quality closed-loop recycling, as the removal or separation of the coating is often required before the glass can be used for high-quality closed-loop recycling.
Insulating Glass Unit (IGU)	A sealed unit consisting of multiple panes, a spacer, sealants and an insulating gas cavity.	These are widely used in façades of buildings. They are often replaced during renovations or refurbishments when their performances no longer meet project requirements.	For direct reuse, the available documentation is an important source of evidence. On its own it is often insufficient. Depending on the project context, the complete unit may also need to be inspected and/or assessed. For remanufacturing, the processes including disassembly and combining new components to assemble a new IGU require documented quality assurance to satisfy warranty and/or certification requirements. For high-quality closed-loop recycling, sorting quality must be sufficient to achieve an adequate material yield; otherwise, downcycling may be required.

Note. Float (annealed) glass and insulating glass units (IGUs) are primarily based on (Cupać et al., 2024; Veer et al., 2023). Heat-strengthened/tempered (safety) glass and laminated glass are primarily based on (Sofokleous, 2022). Coated glass (low-e/solar-control) is primarily based on (Gosztonyi et al., 2016; Teeuwen, 2023). Circular relevance is primarily based on (Geboes et al., 2024; Smith & Abdoli, 2023).

Although several façade glass types are presented for completeness in Table 2, this thesis focusses on insulating glass units (IGUs). In Figure 2 the typical composition of an IGU is illustrated, which is used throughout this thesis.

Figure 2. Detail of an IGU composition example.



Note. Reproduced from (Cupać et al., 2024).

3.1.3 Circular glass routes

Circular glass means to keep façade glass at a high value instead of replacing it with new IGUs. This can be achieved at a product level through direct reuse, remanufacturing or component-level reuse, or at a material level through high-quality closed-loop recycling. In Table 3 the different routes are explained (Geboes et al., 2024; Smith & Abdoli, 2023; Teeuwen, 2023). Although component-level reuse is included in the overview for completeness, it is not treated as a main circular glass route in this thesis because it is considered to be an intermediate option within remanufacturing rather than a separate main circular glass route.

Based on the different characteristics and constraints of the circular glass routes presented in Table 3, several recurring implementation factors can be identified which determine a successful implementation in practice. Across all the circular glass routes, three factors consistently emerge from the literature.

Traceability is essential because the well-documented units and batches facilitate acceptance by providing traceable evidence for warranties, certifications and regulatory compliance. Design details that allow disassembly can increase recovery yield (Smith & Abdoli, 2023; Geboes et al., 2024).

A well-designed *reverse supply chain* organises the recovery, assessment, processing and return to use of recovered glass. It helps preserve the quality of the recovered glass and increase its suitability for different circular glass routes (Geboes et al., 2024; Teeuwen, 2023).

Table 3. Circular glass routes overview for façade glass.

Route	What it is	When it works	Key constraints
Direct reuse	Reinstallation of intact panes or units in the same or another building.	When the conditions/specifications of the units or panes meet the requirements needed.	Process control and quality assurance (warranties, certifications and market acceptance).
Remanufacturing	Disassembly of an IGU and replacement of parts that do not meet the requirements	When the conditions/specifications of the main glass elements meet the requirements needed and are usable.	Process control and quality assurance (warranties, certifications and market acceptance).
Component-level reuse (intermediate option)	Collect and use parts which are still usable and use them in other units.	When the conditions/specifications of the recovered components meet the requirements needed and are compatible for the reuse in another assembly/system.	More labour-intensive, compatibility issues due to existing sizes, and separation issues.
high-quality closed-loop recycling	Clean, sorted glass returned to flat-glass production for the possibility of high-quality closed-loop recycling.	When sorted/separated correctly.	Controlled recovery and sorting without contamination. Coating/interlayers have a negative influence on the closed-loop feasibility which may increase downcycling.
Downcycling	Crushed glass in low-value applications. Does not return to the flat-glass production loop.	When sorting is not performed or the sorting is mixed/contaminated such that high-quality closed-loop recycling is not feasible.	The loss of high-value function. No closed-loop.

Note. The routes direct reuse and remanufacturing are primarily based on (Geboes et al., 2024; Teeuwen, 2023). The routes high-quality closed-loop recycling and downcycling are primarily based on (Smith & Abdoli, 2023; Teeuwen, 2023).

3.1.4 Dutch decision instruments: EPD, MKI and MPG

Environmental comparisons between circular glass routes are based on an allocation approach to determine how environmental impacts and benefits are assigned over multiple life cycles. There are two common allocation approaches in environmental assessments. The cut-off approach considers only impacts and benefits within the current life cycle. Other life cycles such as end-of-life, recycling and direct reuse benefits are reported separately. In contrast, the quality/lifetime-share approach distributes both the impacts and benefits over different use phases.

The baseline of this thesis is the cut-off allocation type. The original production will not be considered as a fraction for a MKI calculation (NEN, 2019; Stichting Nationale

Milieudatabase, 2025). This approach is consistent with the Dutch environmental assessment methodology.

Table 4 provides an overview of Environmental Product Declaration (EPD), MKI and MPG, which are instruments used in the Netherlands to quantify the environmental impact. These Dutch decision-support instruments include the information relevant for environmental comparisons of the circular glass routes.

Table 4. Overview of EPD, MKI, and MPG.

Instrument	Scale	Measures	Used here for
EPD	Product	Module-based (A-D) life cycle inventory	Ability to use this as a data foundation for MKI and MPG determination
MKI	Product and/or Component	Environmental cost expressed per square metre	Ability to compare circular glass routes per (accepted) square metre with the default (new units)
MPG	Building	Total material performance	Ability to show the (material) impact of glazing choices

Note. Based on Dutch environmental assessment instruments used as contextual inputs and not as direct results of the SLR.

These instruments together provide a consistent environmental basis for comparing the circular glass routes which are discussed in this chapter. Therefore they are used in the following sections to support a transparent and structured environmental comparison between circular and the conventional façade glass solutions.

3.1.5 Comparing circular glass routes to new IGUs (feasibility)

The previous sections introduced the main façade glass types, circular glass routes and environmental assessment. Building on these the circular glass routes are compared with new IGUs using a consistent set of technical, economic and environmental feasibility criteria. In Table 5 the circular glass routes are compared with new IGUs based on technical, economic and environmental feasibility.

Table 5. Feasibility summary per dimension.

Dimension	What we need to check in circular glass and will compare with new IGUs	When circular glass routes win	Main risks/pitfalls
Technical	The technical requirements are met (same as new IGU) and if the recovered glass is usable in a façade.	If the technical requirements can be met for different circular glass routes.	-uncertainties about properties can lead to default. -Process losses during different phases can lower the yield -Coatings or interlayers may complicate it and result in a higher downcycling risk.
Economic	The cost per accepted square metre of circular glass including all costs (such as dismantling, storage, inspection, logistics)	If the total costs are the same or less than the costs of new IGUs, this depends often on how well it is organised and controlled.	-additional process steps can result in higher costs. -quality assurance and acceptance can result in

Dimension	What we need to check in circular glass and will compare with new IGUs	When circular glass routes win	Main risks/pitfalls
			higher costs, for instance warranties or certifications. -Process losses can lower the yield per accepted square metre.
Environmental	The environmental impact per accepted square metre for different circular glass routes compared with new.	If the environmental impact per accepted square metre is lower than the impact of new IGUs.	-different scenario and/or end-of-life assumptions. -lower environmental benefits due to process losses which end up in downcycling.

Note. Based on (Geboes et al., 2024; Veer et al., 2023; Teeuwen, 2023).

The different dimensions presented in Table 5 are the evaluation framework for the remainder of this chapter. The following sections compare the earlier identified circular glass routes with new IGUs from different perspectives, such as technical, economic and environmental. These findings form the basis for the implementation conditions developed in the next chapters.

3.2 Findings from the systematic literature review

This section presents the results of the performed systematic literature review (SLR), which was described in Chapter 2. The findings are organised according to the selection of the study, the available evidence per circular glass route and feasibility dimension, and the main technical, economic and environmental outcomes.

3.2.1 Study selection

The systematic literature review provided seven studies that met the inclusion criteria after applying the screening procedure based on PRISMA 2020. Initially, a total of 140 records were retrieved from the selected databases. After removing the duplicates and unretrievable reports and applying the screening and exclusion criteria, seven relevant studies remained. Those seven studies are referred to as S1-S7. This overview is shown in Table 6. The detailed setup of the SLR, including protocol, quality appraisal and audit trail, is further detailed in Appendix A.

Table 6. PRISMA results summary overview.

Stage	n
Records identified from different databases	140
Excluded due to duplicates	-2
Excluded due to abstract screening	-91
Excluded due to unretrievable reports	-9
Excluded due to exclusion criteria after assessing text	-31
Total outcome of included studies (sum of 140-2-91-9-31=7)	7 (S1–S7)

3.2.2 Evidence maps for different circular glass routes and feasibility dimensions

In Table 7 the different evidence retrieved from the studies (S1-S7) for each route is shown. The available evidence is unevenly distributed across both the circular glass routes and the feasibility dimensions. The circular route direct reuse (units or components) is primarily supported by technical strength evidence studies. Remanufacturing is mainly supported by implementation-process evidence. High-quality closed-loop recycling and downcycling routes are primarily supported by scenario-based environmental models.

Table 7. Evidence maps for different circular glass routes and feasibility dimensions.

Circular route	Technical feasibility evidence	Economic feasibility evidence	Environmental feasibility evidence	Implementation and/or quality assurance
Direct reuse	S2, S3, S4 and S6 Strength screening and/or prediction and performance context of renovation.	-	Energy consumption driven context.	Only (limited) implicit
Remanufacturing	S1 feasibility of process.	S1 case shown with $\pm 10\%$ higher price compared with new.	Only qualitative	S1 quality assurance and their responsibility needed for warranties and/or certifications
Component-level reuse	S7 façade system constraints	-	Only (limited) qualitative	S7 limitations and constraints with disassembly and compatibility.
high-quality closed-loop recycling	S7 contaminations	-	S5 LCA numbers based on scenario	Only (limited) discipline of sorting mentioned indirectly.

Note. Based on sources S1-S7, which corresponds to S1 (Geboes et al., 2024), S2 (Cupać et al., 2024), S3 (Veer et al., 2023), S4 (Sofokleous, 2022), S5 (Smith & Abdoli, 2023), S6 (Gosztonyi et al., 2016) and S7 (Teeuwen, 2023).

3.2.3 Key outputs (technical feasibility)

The studies S2-S4 provide the strongest performance evidence for assessing the feasibility of reusing aged glass. A key insight is that the direct reuse feasibility is conditional. The surface condition of glass and (conservative) reliability assumptions govern acceptance (Cupać et al., 2024; Veer et al., 2023; Sofokleous, 2022). Specifically for remanufacturing, the study S1 indicates the technical feasibility to be primarily supported by implementation processes, quality assurance and acceptance mechanisms rather than by performance testing (Geboes et al., 2024).

Economic evidence in the included dataset is limited. Only a case-specific cost overview is given in S1 for remanufacturing (Geboes et al., 2024).

Evidence related to environmental feasibility is primarily based on scenario-based models for end-of-life routes. The conclusions of these models depend strongly on assumptions such as allocation, crediting scores and contamination (Smith & Abdoli, 2023; Teeuwen, 2023). In Table 8 the key outputs related to technical feasibility are shown.

Table 8. Technical, economic and environmental key outputs summary overview.

Study and scope	Performance evidence	Economic evidence	Environmental evidence	Key limitation and/or note
S1 Remanufacturing (IGU) cases	Process-level feasibility assessment. No datasets with EN pass or fail checks reported. More focus was on quality assurance (QA), process control, handling the damage risk, warranties or certification.	±10% higher cost for specific case compared with new glass. This is not generalisable.	Avoiding new production approach. No numerical dataset used (LCA/MKI)	-Case specific context limits comparability
S2 Direct reuse of aged window glazing (pane level)	Destructive tests using a coaxial double ring and with an assumed failure percentage of 0,8%: - exposed and/or critical surfaces 17,9 - 19,8 MPa - protected surface 46,3 MPa - new glass (based on EN16612) 21,4 MPa	n/a	n/a	-Strong performance evidence -Less context quantification (costs, logistic, environmental)
S3 Reuse enabling of aged façade flat glass with screening and prediction methods	Mean fracture strength for the following: - new (air side) 134,5 MPa - new (tin side) 87,1 MPa - aged and weathered (larger specimens) 54,6 MPa This proof-of-concept claims the direct reuse potential is about ±70%.	n/a	n/a	-limited successful test -scaling requires significant quality assurance procedures.
S4 Reuse enabling of aged glass with strength prediction.	Surface flaw characterisation was used in a strength prediction method. Observed and reported flaw sizes ranged approximately between 19 µm and 161 µm. The critical defect was not consistently at the largest flaw size.	n/a	n/a	-methodological focus -no datasets of performed projects
S5 End-of-life scenarios (Australia) related to high-quality closed-loop recycling	n/a	n/a	The outcome results are strongly dependent on the different assumptions and system boundaries available.	-Not specific façade or IGU -Case specific context influence comparability
S6 Retrofit performance context during renovation in Sweden Swedish multi-family renovation	Performance results provide contextual insight.	n/a	Heating demand reductions (2 cases each): new window 27-44% solar wall 18–24%	-Not specific for circular IGU but contextual relevance.
S7 Circular reuse on component and system level for a unitised curtain wall	System-level constraints are also present. Glass with coatings, interlayers and/or mixed materials increase the technical effort needed (difficulty) for separation.	n/a	Unless, separations are managed, contamination lowers the yield and can result in downcycling.	-Limited performance datasets.

Note. Based on the sources S1-S7 as defined in Table 7.

3.2.4 Dominant drivers affecting feasibility

Across the included studies S1-S7 there are some recurring drivers which influence the feasibility outcomes of the different circular glass routes. These drivers help explain why it remains difficult to scale up the implementation of circular glass routes (despite technical solutions) and are presented in Table 9.

Table 9. Overview of key drivers for the implementation of circular glass.

Driver	Mentioned in	Why it matters
Process control for warranties and certifications	S1	The remanufacturing route is technically feasible but can be blocked when accountability and acceptance criteria are not established.
Governing surface conditions	S2	The conservatism level is governing and should be arranged in the acceptance criteria.
Execution of screening and quality assurance (QA) procedure	S3 and S4	Upscaling of promising methods could fail when procedures are fragile.
Consistent system boundary and allocation conditions in environmental claims	S5	All credits, boundaries and allocations need to be transparent such that scores can truly be comparable.
Separation control managing	S7	The feasibility of high-quality closed-loop recycling strongly depends on separation and contamination is critical. Contamination may result in downcycling.

Note. Based on the sources S1-S5 and S7 as defined in Table 7.

3.3 Synthesis

3.3.1 Synthesis across circular glass routes

The presented results in Section 3.2 show that the available evidence differs considerably between the identified main circular glass routes. This section synthesises the evidence by identifying the main implementation implications for each circular glass route.

Direct reuse: The key insight of the strongest evidence S2-S4 is that direct reuse potential is conditional. Surface conditions and the (current) conservative acceptance assumptions determine whether reused panes are acceptable. An experimental study by (Cupać et al., 2024) shows that the reuse potential of the panes is highly dependent on surface condition. IGU glass surfaces after approximately 30 years facing the cavity side retained substantially higher bending strength compared with the surfaces facing the interior or exterior. Another key insight gained from S3-S4 is the screening and/or prediction methods. A proof-of-concept study (Veer et al., 2023) suggests that optical assessments (non-destructive) of surface flaws by the identification of excessively damaged panes before the reinstallation can support reuse decisions. These methods show promise, although larger-scale implementation still depends on robust and repeatable quality-assurance procedures (Cupać et al., 2024; Veer et al., 2023; Sofokleous, 2022).

Remanufacturing: The most relevant evidence S1 is mainly focused on the implementation aspects such as processes, traceability and acceptance criteria. In comparison with the circular glass route direct reuse, the available evidence places considerably more emphasis on organisational and procedural requirements. The 10% higher costs compared with new IGUs mentioned were case specific. Costs should be studied for different scenarios with the same parameters to give more accurate conclusions about costs (competitiveness) (Geboes et al., 2024).

Component-level reuse (intermediate option): The most relevant evidence studied was S7 where constraints on a system level were dominant. The compatibility, disassembly and mixed material configurations related constraints can easily increase effort and risks quickly. Research about the system-level façade shows that component-level reuse is often constrained by the connections between elements. This is particularly relevant for interfaces that are difficult to access such as structural sealants covered screw fixings. This increases the time of dismantling and the risk of glazing and/or framing damage. Consequently, component-level reuse is technically defensible, but its feasibility remains strongly dependent on the configuration of the façade system and the specific project context (Teeuwen, 2023).

High-quality closed-loop recycling and downcycling: S5 shows that scenario-based models are highly sensitive to boundary and crediting allocations. High-quality closed-loop recycling depends in practice on the performed separations. S7 shows coatings, interlayers and other contaminations can result in downcycling which makes the separation discipline more important. The available evidence indicates that successful high-quality closed-loop recycling does not only depend on recycling technology, but also on an effective separation process with transparent environmental modelling assumptions (Smith & Abdoli, 2023; Teeuwen, 2023).

3.3.2 Which route based on conditions (interim decision rules)

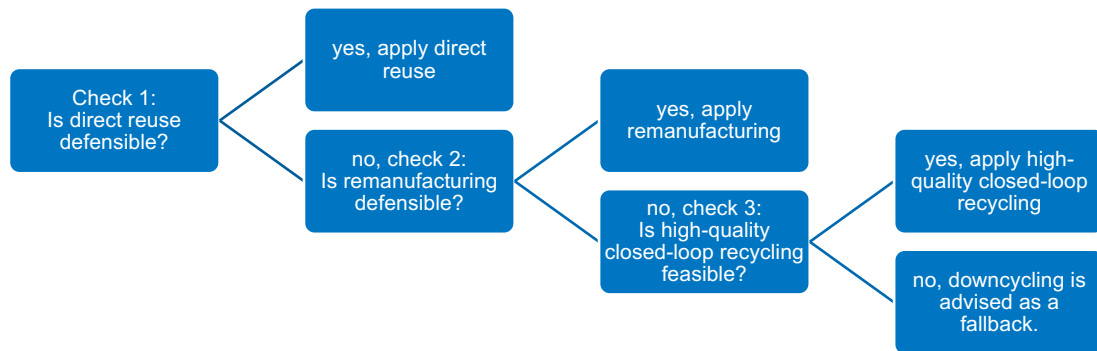
The synthesis demonstrates that not a single circular route is universally applicable. Instead, the literature indicates that the circular glass route selection depends on a sequence of technical, organisational and environmental conditions. Based on Table 8 and Table 9 (key outputs and drivers) the route choices can be expressed as “simple” conditions which are shown in Table 10. This is also presented schematically in a *circular route decision logic* flow diagram in Figure 3. The circular glass route choices are structured in this circular route decision logic. It determines which circular glass route is most suitable under specific conditions.

The route choice logic shows that higher-value routes can only be considered feasible when they are technically defensible, operationally manageable and supported by sufficient evidence. When these conditions cannot be satisfied, the circular glass route selection shifts towards lower-value options, with downcycling as the fallback route (Smith & Abdoli, 2023). As explained already in the methodology, component-level reuse is not included as a separate decision step.

Table 10. Overview of the circular route decision logic.

Step	Circular route condition check	If YES	If NO
1	Is direct reuse defensible? What is necessary: the governing surface condition needs to be acceptable under (conservative) criteria, and a robust quality assurance (QA) and screening are needed.	Direct reuse	Proceed to Step 2
2	Is remanufacturing defensible? What is necessary: the process control, traceability and agreed warranty/acceptance at handover.	Remanufacturing	Proceed to Step 3
3	Is high-quality closed-loop recycling feasible? What is necessary: high quality of separation and an LCA with transparent boundary conditions and crediting.	high-quality closed-loop recycling	Downcycling as fallback

Figure 3. Flow chart of the circular route decision logic.



3.3.3 Robustness, limitations and sensitivities

Several recurring limitations are shown by the evidence. These limitations should be considered when interpreting the findings. The technical reuse possibilities are relatively strong (S2-S4) while the economic evidence remains scarce (S1), and the environmental evidence is mainly based on scenario-based models (S5). This imbalanced evidence from S1-S7 cannot provide generalisations for different circular glass routes, costs per square meter for different routes and/or MKI comparisons between different circular glass routes.

The implementation is not only influenced by technical performance, but also by dominant drivers shown in Table 9 and quality assurance procedures, acceptance criteria, traceability, environmental modelling assumptions and separation quality.

3.4 Answer to sub-question 1

sub-question 1. “What methods for circular glass are currently available in façade refurbishments, and how do they compare to new insulated glass units (IGUs) in terms of technical, economic, and environmental feasibility?”

Three main circular glass routes relevant for façade refurbishments are identified based on the performed systematic literature review:

1. Direct reuse of recovered glass panes/units.
2. Remanufacturing with controlled and approved refurbishment.
3. High-quality closed-loop recycling, with downcycling as a fallback when separation quality is insufficient.

Direct reuse appears technically feasible under specific conditions such as surface condition, screening and/or conservative QA acceptance (Cupać et al., 2024; Veer et al., 2023; Sofokleous, 2022). Remanufacturing also appears to be technically feasible at the process level, but its feasibility is mainly determined by process control, traceability and acceptance mechanisms (Geboes et al., 2024). Component-level reuse is constrained by the disassembly and compatibility at the façade system level (Teeuwen, 2023). High-quality closed-loop recycling depends primarily on effective separation and transparent environmental assessment assumptions (Smith & Abdoli, 2023).

The economic evidence within the included studies was very limited. The only evidence found was a case-specific comparative remark that remanufactured IGUs cost approximately 10% more than new IGUs. No robust route-wide comparison in €/m² was available in the included studies (Geboes et al., 2024).

The environmental evidence was indirect and largely based on scenario-based models. The ranking per route depends strongly on system boundaries and crediting/ allocation choices used (Smith & Abdoli, 2023). The separation quality of glass with coatings, interlayers, or mixed materials determines whether high-quality closed-loop recycling is feasible. Where contamination occurs, downcycling might be a risk (Teeuwen, 2023). Direct reuse and remanufacturing may reduce environmental impact by avoiding new production, but the available evidence used does not provide consistent comparable quantified results per route expressed in CO₂-eq/m² or MKI (Geboes et al., 2024).

Overall, the literature suggests that circular glass in façades is not primarily constrained by its technical feasibility. Instead, it is the ability to demonstrate quality, traceability and regulatory acceptance. Circular glass routes therefore require additional evidence, responsibility allocation and quality assurance before they can become broadly applicable in practice. This is different compared to new IGUs. These implementation conditions provide the basis for the remaining sub-questions. In Chapter 4, sub-question 2 examines the regulatory acceptance requirements, while in Chapter 5 sub-question 3

investigates the stakeholder roles, barriers, drivers and responsibilities required for a successful implementation.

4 Regulatory assessment framework

This chapter presents the findings related to sub-question 2: “What is the regulatory assessment framework for implementing circular glass in existing buildings?”. The aim is to identify the legal and regulatory conditions that influence the use of circular glass in existing buildings.

The previous chapter already showed that the technical feasibility of circular glass alone is insufficient for successful implementation in practice. Besides the technical performance, literature identified traceability, quality assurance, responsibility allocation and regulatory acceptance as recurring implementation conditions. These implementation conditions provide the starting point for the desk-based regulatory assessment.

This chapter translates these earlier determined implementation conditions into a regulatory assessment framework which is auditable for circular glass in existing buildings. The framework clarifies which aspects should be demonstrated at handover to deliver an accepted circular glass product (“product = glass + evidence”) (European Union, 2024; Overheid.nl, 2019). A comparison between the new IGUs and circular glass will be made. The assessment is based on three complementary layers; EN/ISO (performance evidence), EU CPR and Dutch Wkb (regulatory and liability logic evidence), and EPD-based MKI and MPG (environmental and procurement evidence) (NEN, 2019; Stichting Nationale Milieudatabase, 2025; European Commission, n.d.).

A desk-based method is used to synthesise different normative sources into three deliverables: a requirements-to-evidence map overview, a comparison between the baseline requirements for new IGUs and circular glass, and a regulatory evidence checklist. These three deliverables specify which specific evidence is required to demonstrate compliance and under which specific regulatory conditions circular glass can be accepted when it is used as a product in façade refurbishments in the Netherlands (NEN, 2019; Stichting Nationale Milieudatabase, 2025; European Commission, n.d.).

4.1 Regulatory analysis and assessment framework

Implementing circular glass in façade refurbishments is not primarily a technical problem. It is more an acceptance and evidence problem as circular glass is more likely to be accepted in practice when it can be proven that it meets relevant performance requirements and is supported by traceable and verifiable documentation (European Union, 2024; Overheid.nl, 2019). In the Dutch context, these implementation conditions can be translated into three complementary evidence layers. Together these complementary evidence layers determine whether circular glass can be accepted in practice:

1. Performance evidence based on EN/ISO standards
2. Regulatory and liability logic evidence based on CPR regulations from the EU
3. Environmental and procurement evidence based on EN15804 and an EPD based assessment context (NEN, 2019; Stichting Nationale Milieudatabase, 2025; European Commission, n.d.).

4.1.1 Acceptance concept of “product = glass + evidence”

Regulatory acceptance refers to the ability to use circular glass within a refurbishment project and to receive a project approval at handover. This requires a traceable and auditable evidence package to support acceptance, rather than technically suitable circular glass alone. This makes the product auditable and provides a basis for clarifying responsibilities across the circular glass supply chain. The CPR requires performance declarations and responsibility allocations for placing construction products on the market, where applicable. The Wkb also emphasizes the verifiability of evidence at handover (European Union, 2024; Overheid.nl, 2019). This concept for acceptance is most applicable to the circular glass routes direct reuse and remanufacturing as recovered glass still remains part of a product- or component-level application. For the circular route high-quality closed-loop recycling, acceptance depends more on material quality, sorting purity and suitability as input for new glass production.

The regulatory assessment framework developed in this thesis should be interpreted as an auditable decision-support framework for acceptance on project-level, not as a formal certification or legal approval route.

4.1.2 Acceptance structure based on three layers

A layered structure is used in this thesis to create auditable project requirements (European Union, 2024; Overheid.nl, 2019; NEN, 2019). These layers form the three-layer acceptance structure which is also used within the regulatory assessment framework. These three layers are:

1. **Performance evidence (EN/ISO standards)**
All aspects which need to be shown about the IGUs including the glazing are durability, moisture or gas, optical or thermal properties, coating durability, visual quality and safety (if relevant). The different standards are presented in Table 12.
2. **Regulatory and liability logic evidence (EU CPR and Dutch Wkb standards).**
Aspects which need to be present to meet the regulations in a Dutch project context are traceability, responsible party, verifiable evidence at handover and implications for when products are remanufactured and reintroduced to the market (European Union, 2024; Overheid.nl, 2019; Overheid.nl, 2018).
3. **Environmental and procurement evidence (EN 15804 including EPD standards).**
All aspects which are relevant for comparing the environmental impacts across

life cycles and claiming circularity depending on modelling choices, which are life cycles, system boundaries, allocation and crediting choices, reuse/recycling, model assumptions, scenario comparability and transparency of different claims related to sustainability (NEN, 2019; Stichting Nationale Milieudatabase, 2025; European Commission, 2020; European Commission, n.d.).

The regulatory evidence checklist which is developed in this chapter is intended to structure implementation in practice but does not have formal legal status.

In Table 11 a conceptual acceptance framework used in this thesis to assess acceptance requirements for circular glass is shown. Its purpose is to function as the link between normative sources and practical deliverables.

Table 11. The three-layer acceptance structure for circular glass.

Layer	Core purpose	What needs to be evidenced	Typical evidence items	Primary source (type)
Performance evidence (EN/ISO)	It should perform as required.	performance aspects relevant to IGUs, glazing and application	Declarations based on EN/ISO standards	Standards EN/ISO
Regulatory and liability logic evidence (CPR+Wkb)	It should be clear who is responsible and if it is auditable at handover.	traceability, responsibility allocation choices and a verifiable evidence package	Declaration of Performance (DoP) with CE where applicable in the evidence package. Roles assigned.	Regulations and the national laws and guidance
Environmental and procurement evidence (EN 15804+EPD)	It should be clear how the environmental impact is compared and reported.	Consistency of life cycles. Assumption regarding the benefits of recycling and reuse.	LCA and EPD modules. Allocation and crediting choices	Standards based (EN15804 and EPD) rules and guidance

Note. Conceptual framework based on a synthesis of the EN/ISO standards, the CPR, environmental assessment methods based on EN 15804 and EPD.

4.1.3 Regulatory assessment framework

In Table 12 the acceptance requirements across the three regulatory layers are summarised. For each of these requirements, the table identifies the evidence expected in practice and the corresponding primary regulatory or normative source(s).

Table 12. Regulatory assessment framework for circular glass acceptance.

Layer	Core acceptance question	Acceptance requirement	Evidence expected in practice (typical evidence items)	Primary anchor sources
Performance (EN and ISO)	“Does it perform as required for the intended façade application?”	Optical and solar properties (light and solar characteristics) should be known and compatible with the intended use	Calculation reports and tests aligned with glazing standards for solar/light properties. Should be linked to unit and/or batch.	EN 410 (NEN, 2011)
		Thermal performance (U-value) should be known and compatible with the intended use.	Calculation outputs and input assumptions need to be documented. Should be linked to each unit and/or batch and with	EN 673 (NEN, 2011)

Layer	Core acceptance question	Acceptance requirement	Evidence expected in practice (typical evidence items)	Primary anchor sources
			corresponding configuration.	
		IGU durability and performance (sealed-unit functionality) should be known and compatible with the intended use.	Test evidence and/or declarations related to the IGU standard parts (for instance visual quality and durability-related testing where applicable).	EN 1279-1 (NEN, 2018) EN 1279-2 (NEN, 2018) EN 1279-3 (NEN, 2018) EN 1279-4 (NEN, 2018)
		Coated glass durability and functional coating performance (coatings) should be known and compatible with the intended use.	Coating class/type and durability testing evidence. With potential conditions and/or limitations stated.	EN 1096-2 (NEN, 2012)
		Float glass base product tolerances/identity should be known and compatible with the intended use.	Identification and specification references in float glass product baseline.	EN 572-2 (NEN, 2012)
		Emissivity evidence (if relevant for thermal modelling and/or verification) should be known and compatible with the intended use.	Emissivity determination evidence.	EN 12898 (NEN, 2019)
		Safety evidence (if relevant) should be known and compatible with the intended use.	Safety-related evidence aligned to intended use. Constraints need to be explicitly stated for placement relevance.	EN 14179-1 (NEN, 2016)
		Acoustic performance (if relevant) should be known and compatible with the intended use.	Acoustic test and rating evidence	ISO 10140-2 (International Organization for Standardization, 2021) and ISO 717-1 (International Organization for Standardization, 2020)
Regulatory and liability (CPR and Wkb)	“Is the responsibility clear and is the deliverable product auditable at handover?”	Product responsibility should be clearly defined when placed on the market	A product identity which is traceable, evidence package, clarity in responsibility and especially on who is responsible for the performance declaration logic of the product.	CPR (European Union, 2024)
		Verifiable quality evidence is available at delivery (auditability).	A complete evidence package which is auditable per unit/batch.	Wkb (Overheid.nl, 2019) and Besluit bouwen werken leefomgeving (Bbl) (Overheid.nl, 2018)
Environmental and procurement	“How is the environmental impact structured	Environmental impacts are structured and reported in life-cycle	LCA/EPD structure. Transparent boundaries and assumptions for	EN 15804+A2 (NEN, 2019) and Bepalingsmethode

Layer	Core acceptance question	Acceptance requirement	Evidence expected in practice (typical evidence items)	Primary anchor sources
(EN 15804 incl. EPD context)	and compared for decisions and/or tenders?"	format suitable for comparison across different scenarios.	comparability with other options.	Milieuprestatie Bouwwerken (Stichting Nationale Milieudatabase, 2025)
		Circularity ambitions and sustainability reporting context	Framing/definitions used in procurement and reporting.	CEAP (European Commission, 2020) and Level(s) (European Commission, n.d.)

Together, these three layers define the core acceptance logic developed in this thesis for assessing circular glass in refurbishment projects. The performance layer defines what must be evidenced about the unit. The regulatory and liability layer defines who must be accountable and what must be auditable at handover. The environmental and procurement layer defines how environmental impacts and circular credits are structured for comparability (European Union, 2024; Overheid.nl, 2019; NEN, 2019; Stichting Nationale Milieudatabase, 2025).

4.1.4 Baseline and the circular acceptance delta

The *circular acceptance delta* refers to the difference between the evidence and the acceptance conditions which are typically available for new IGUs and those that must be established for circular glass. The acceptance requirements of circular glass can be divided into two different categories, which are non-negotiable requirements and manageable deltas (European Union, 2024; Overheid.nl, 2019; NEN, 2019). Non-negotiable requirements are criteria which need to be met as they define safety and/or performance matters. These core requirements need to be satisfied and transparently documented. Manageable deltas are aspects that may be acceptable when appropriately justified as these aspects do not determine safety or the performance. These manageable deltas could for instance be visual imperfections and/or placements in less sensitive zones.

The current baseline of applying new IGUs typically comes with standardised documentation. The circular route products need to close the evidence gap. There is a need for an evidence package which shows comparable products relevant for different stakeholders in the chain (European Union, 2024; Overheid.nl, 2019).

In Table 13 the framework is translated into what is typically mandatory (non-negotiable) and what is not (some delta ranges could be acceptable). Between new IGUs and circular glass, a key difference is the availability and the reliability of technical information. This makes the circular acceptance delta mainly documentary and evidence-based (Poncelet & Nasseredine, 2021).

Table 13. Circular acceptance delta between new IGUs and circular glass.

Acceptance domain	Default baseline (new IGU)	What changes based on the circular route (direct reuse or remanufacturing)	Non-negotiable or manageable delta	Anchor sources
Identity and traceability	A standardised identity and documentation of the product at delivery.	The identity and traceability must be reconstructed and linked. Provenance and handling history are also required to support acceptance.	Non-negotiable: At handover the units and/or batches must have a traceable and auditable evidence package.	CPR (European Union, 2024) and Wkb (Overheid.nl, 2019)
Availability of performance evidence	The availability of the performance evidence is typically specified and documented.	The evidence of circular glass may be incomplete. The acceptance relies on what can be evidenced in the circular configuration.	Non-negotiable: The evidence must cover performance aspects which are relevant for the intended project.	EN 410 (NEN, 2011), EN 673 (NEN, 2011), EN 1279-1 (NEN, 2018), EN 1279-2 (NEN, 2018), EN 1279-3 (NEN, 2018) and EN 1096-2 (NEN, 2012)
Durability of IGU evidence	The performance is standard evidenced for the IGU.	Circularly produced IGUs need evidence which can demonstrate the performance of the rebuilt IGU configuration.	Non-negotiable: Performance requirements must be defensible and auditable for the units.	EN 1279-1 (NEN, 2018), EN 1279-2 (NEN, 2018), EN 1279-3 (NEN, 2018), EN 1279-4 (NEN, 2018), CPR (European Union, 2024) and Wkb (Overheid.nl, 2019)
Optical and/or thermal modelling	The inputs (which are consistent) are typically specified and documented.	Regarding the configuration, inputs should be verified with assumptions explicitly stated.	Manageable delta: Minor deviations can still be managed with placement with the documentation.	EN 410 (NEN, 2011), EN 673 (NEN, 2011) and EN 12898 (NEN, 2019)
Coatings	The type and performance of the coating is specified and documented	Evidence of the durability of the coating and condition becomes critical. This can influence placement.	Manageable delta: Performance and durability should be evidenced but minor appearance deviations can be manageable by appropriate placement.	EN 1096-2 (NEN, 2012)
Critical safety requirements	The safety is met and specified and documented.	The safety (evidence) for circular products still must match the intended placement requirements.	Non-negotiable: Safety-required locations should not accept relaxation in performance (evidence).	EN 14179-1 (NEN, 2016), CPR (European Union, 2024) and Wkb (Overheid.nl, 2019)
Acoustics (if required)	The acoustic performance is specified and documented.	If acoustics is a requirement the circular glass units do have to provide equivalent evidence. Placement in another zone with no acoustic requirement could be an alternative.	Non-negotiable: provide acoustic evidence if acoustic performance is required	ISO 10140-2 (International Organization for Standardization, 2021) and ISO 717-1 (International Organization for Standardization, 2020)

Acceptance domain	Default baseline (new IGU)	What changes based on the circular route (direct reuse or remanufacturing)	Non-negotiable or manageable delta	Anchor sources
Environmental comparability (regarding procurement)	The environmental claims are structured according to EPD requirements.	Claims about circularity depend strongly on the system boundary and crediting choices made. Transparency offers true comparability.	Non-negotiable: System boundaries and assumptions should be transparent for comparability.	EN 15804+A2 (NEN, 2019), Bepalingsmethode Milieuprestatie Bouwwerken (Stichting Nationale Milieudatabase, 2025) and Level(s) (European Commission, n.d.)

4.1.5 Regulatory evidence checklist

Regulatory acceptance is a practical way to operationalise acceptance. A traceable evidence package linked to units and/or batches can be part of the project dossier (European Union, 2024; Overheid.nl, 2019). The evidence package should contain at least the following elements: the identification and provenance per unit and/or batch (including provenance and handling/storage records), the performance evidence documents based on EN and ISO (including tests, calculations and declarations), the classification and the intended placement (such as zoning areas for visual tolerances if relevant), and the responsibilities and the roles (who issued and/or verified which evidence, and who eventually signs off).

Circular glass will become project-ready when the evidence package is complete and traceable. This emphasises the need to document the relevant product information and the corresponding performance to enable future circular route feasibility for direct reuse and recycling (Platform CB'23, 2023).

In Table 14 the regulatory assessment framework from Table 12 is translated into a *regulatory evidence checklist*, which is a checklist that can be used to identify and verify the required evidence for acceptance at handover. This checklist is intended to function as an evidence index for individual units and/or batches.

Table 14. Regulatory evidence checklist (at unit or batch level at handover).

Unit / batch ID	Evidence item part	Minimal required content	Linked layer	Demanded framework / guidelines
☐	Identification and provenance	For each unit and/or batch an ID. Provenance from which building or project. Basic configuration description. Photographs and/or product markings where available.	Regulatory and liability	CPR (European Union, 2024) and Wkb (Overheid.nl, 2019)
☐	Handling and storage records	Date of removal, the storage conditions, notes of damage, who handled what and when.	Regulatory and liability	Wkb (Overheid.nl, 2019)

Unit / batch ID	Evidence item part	Minimal required content	Linked layer	Demanded framework / guidelines
☐	Configuration statement	A complete overview of the composition and specifications.	Performance	EN 1279-1 (NEN, 2018), EN 1279-2 (NEN, 2018), EN 1279-3 (NEN, 2018), EN 1279-4 (NEN, 2018) and EN 572-2 (NEN, 2012)
☐	Optical and/or solar evidence (if relevant)	Declared or calculated solar/light characteristics.	Performance	EN 410 (NEN, 2011)
☐	Thermal evidence (if relevant)	Declared or calculated U-value. Should be complete with inputs and including emissivity if relevant.	Performance	EN 673 (NEN, 2011) and EN 12898 (NEN, 2019)
☐	Coating evidence (if relevant)	Coating type and class and its durability evidence with the condition assessment notes.	Performance	EN 1096-2 (NEN, 2012)
☐	IGU evidence package	The evidence of the relevant requirements of the delivered IGU	Performance	EN 1279-1 (NEN, 2018), EN 1279-2 (NEN, 2018), EN 1279-3 (NEN, 2018) and EN 1279-4 (NEN, 2018)
☐	Safety evidence (if relevant)	The evidence of the safety-related requirements aligned to intended placement. If an exclusion is relevant, this should be stated.	Performance	EN 14179-1 (NEN, 2016)
☐	Acoustic evidence (if required)	The evidence of the acoustic performance.	Performance	ISO 10140-2 (International Organization for Standardization, 2021) and ISO 717-1 (International Organization for Standardization, 2020)
☐	Responsibility map structure	All responsibilities should be assigned for the different relevant roles for evidence provision and/or verification.	Regulatory and liability	CPR (European Union, 2024) and Wkb (Overheid.nl, 2019)
☐	Environmental assumptions reported for decision files	The boundary and crediting approach used for comparisons should be stated.	Environmental and procurement	EN 15804+A2 (NEN, 2019), Bepalingsmethode Milieuprestatie Bouwwerken (Stichting Nationale Milieudatabase, 2025) and Level(s) (European Commission, n.d.)
☐	Placement/classification description (projects-specific)	The intended façade zone and/or placement logic with relevant constraints stated.	Multiple layers integration	EN 410 (NEN, 2011), EN 673 (NEN, 2011), EN 1279-1 (NEN, 2018), EN 1279-2 (NEN, 2018), EN 1279-3 (NEN, 2018) and Wkb (Overheid.nl, 2019)

4.2 Synthesis

4.2.1 Synthesis across the regulatory assessment framework

The regulatory analysis shows that the regulatory acceptance of circular glass depends on more than only technical performance. The three outputs developed in the chapter together demonstrate how normative requirements can be translated into an auditable evidence framework for circular façade glass refurbishment projects in the Netherlands.

Once the technical feasibility is established, the availability of an auditable and traceable evidence package remains a main barrier. In practice a circular glass product may be rejected because it lacks a standardised evidence package that demonstrates compliance with relevant performance, regulatory and environmental requirements (European Union, 2024; Overheid.nl, 2019).

The regulatory analysis indicates that the three connected layers together determine whether circular glass can be accepted as a product for a project (European Union, 2024; Overheid.nl, 2019; NEN, 2019). The performance layer defines what should be demonstrated, the regulatory and liability layer defines who is responsible and/or what should be auditable and the environmental and procurement layer defines how environmental impacts and/or circularity claims should be reported to be comparable.

4.2.2 Main implementation implications

The proposed framework distinguishes requirements which cannot be relaxed and requirements that may allow flexibility.

The framework shows that some requirements are non-negotiable while other requirements have a manageable delta. The core performances, safety, traceability and auditability are non-negotiable and should always be satisfied and documented. Manageable deltas may be considered to be minor visual deviations or placement in less sensitive façade zones provided that these manageable deltas are transparent, documented and compatible with the intended application (European Union, 2024; Overheid.nl, 2019).

This distinction allows circular glass to be assessed in a structured and realistic manner. It is strict for the necessary aspects but flexible where justified (see Table 12, Table 13 and Table 14). Consequently, the principal implementation challenge is to demonstrate compliance through an evidence package that supports the project acceptance, not to reduce regulatory requirements. The revision of the CPR is expected to strengthen the requirements for life-cycle relevant information, environmental performance and reuse declarations (SGS Search, 2023).

4.2.3 The interpretation of the regulatory assessment framework

The proposed regulatory assessment framework translates the normative requirements into a practical acceptance framework on a project level. It structures existing standards, regulations, and environmental assessment methods into an auditable decision-support

framework for circular façade glass. No additional regulatory requirements are introduced.

The framework therefore supports implementation by translating corresponding regulatory requirements into three practical deliverables, which are:

- A regulatory assessment framework linking acceptance requirements to evidence.
- A comparison between the baseline requirements for new IGUs and circular glass. A distinction between non-negotiable requirements and manageable deltas.
- A regulatory evidence checklist supporting project handover and auditability.

4.3 Answer to sub-question 2

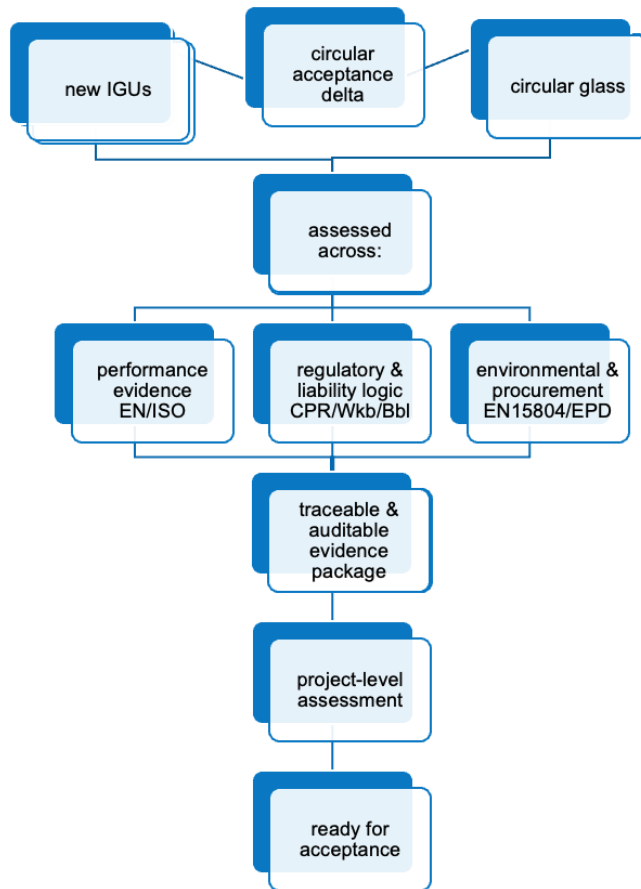
sub-question 2. “What is the regulatory assessment framework for implementing circular glass in existing buildings?”

The desk-based regulatory and standards analysis shows that the implementation of circular glass in existing building façades requires an auditable regulatory assessment framework. This auditable regulatory assessment framework needs to consist of three complementary layers. The first layer addresses the performance evidence based on the EN and/or ISO standards. It specifies which technical characteristics of the glazing product should be demonstrated. The second layer addresses the regulatory and liability requirements based on the CPR and the Dutch Wkb. The traceability, responsibility allocation and auditability at project handover are defined. The third layer addresses the environmental and procurement requirements based on the EN 15804 and EPD principles. It ensures a transparent and comparable environmental reporting (European Union, 2024; Overheid.nl, 2019; Stichting Nationale Milieudatabase, 2025).

Figure 4 summarises the regulatory assessment framework. Both the new IGUs and the circular glass are assessed across three complementary evidence layers. The circular acceptance delta represents the difference between new IGUs and circular glass in the availability and auditability of evidence. The circular acceptance delta does not represent different or reduced performance requirements.

In the framework it is indicated that circular glass can be considered ready for acceptance when sufficient evidence is available for all three complementary layers. This also includes the relevant performance evidence, a traceable and auditable evidence package with clearly assigned responsibilities and transparent environmental assumptions which are suitable for comparison.

Figure 4. Regulatory assessment framework flow diagram compared with new IGUs.



Circular glass does not have fundamentally different performance requirements in comparison with new IGUs. Instead, the principal differences are determined by the availability and auditability of the supporting evidence that is needed. New IGUs are generally delivered with standardised documentation. Circular glass requires additional provenance information, circular route-specific evidence and clearly allocated responsibilities throughout the reverse supply chain before it can be accepted as an equivalent deliverable product (Overheid.nl, 2018; Overheid.nl, 2019; European Union, 2024).

Overall, the regulatory assessment framework which is developed in this thesis demonstrates that a successful implementation of circular glass depends not only on technical performance, but also on the ability to demonstrate this performance through a complete, traceable and auditable evidence package. The three outputs, which were presented in Table 12, Table 13 and Table 14, operationalise this framework by translating regulatory requirements into a practical set of implementation tools for façade refurbishment projects.

These findings provide the foundation for answering sub-question 3 through the desk-based stakeholder roles and responsibilities analysis, which is presented in Chapter 5. In Chapter 5 the responsibilities, barriers, drivers and interactions across the actors responsible for producing, verifying and accepting the evidence are analysed.

5 Stakeholders, barriers and responsibilities

This chapter presents the findings related to sub-question 3: “Which stakeholders and supply-chain actors are identified as key to the implementation of circular glass, and what barriers, drivers and responsibility logics are associated with them?”. The aim is to identify the main stakeholders, implementation barriers and drivers, and the responsibility structure relevant for circular glass implementation.

Chapters 3 and 4 showed that circular glass implementation is not only a technical problem. Chapter 3 demonstrated that circular glass routes exist and are conditionally feasible based on different factors such as yield, condition, QA and other route-specific constraints. Chapter 4 demonstrated that circular glass acceptance depends on the availability of traceable and auditable evidence packages. Together, the findings indicate that implementation also depends on the corresponding stakeholder coordination, procurement choices, documentary continuity and clear responsibility allocation.

These implementation aspects are consistent with the broader literature about circular construction. Organisational fragmentation, weak collaboration and a lack of standardisation are recurrently identified as major barriers to circular glass implementation (Charef et al., 2021; Giorgi et al., 2022).

Building further on these findings, this chapter examines the implementation of circular glass from a stakeholder and governance perspective. A desk-based stakeholder roles and responsibilities analysis is performed to identify main stakeholders, implementation barriers and drivers, and the responsibility structure. This is required to achieve the practical implementation of circular glass in façade refurbishment projects.

5.1 Analytical framework for the stakeholder roles and responsibilities analysis

This section introduces the analytical perspective used to structure the desk-based stakeholder roles and responsibilities analysis. The reverse supply chain context, analytical themes and governance concepts used to interpret the results are defined.

5.1.1 Dynamics of stakeholders and the reverse supply chain

Circular glass implementation requires a reverse supply chain. The conventional supply chain which is used for new IGUs in façade refurbishments does not include the additional steps which are necessary for circular glass. In conventional refurbishment projects, new IGUs are procured, installed and handed over through a standardised routine. The additional steps which are introduced for circular implementation are procurement intent, controlled recovery, protected storage and transport, inspections for

classification, circular route selection (direct reuse, remanufacturing or high-quality closed-loop recycling) and a handover with a defensible evidence package.

Figure 5 illustrates the reverse supply chain in façade refurbishment projects. This is considered to be a potentially circular chain as the material source is recovered glass from existing façades. This could be processed into acceptable circular glass in façade refurbishments through different steps which are described in the illustration. The source building of the recovered glass and the circular glass receiving building do not necessarily need to be the same. It could also be stored and applied in another refurbishment project after being processed into an acceptable circular glass product.

Figure 5. Circular concept of the reverse supply chain for circular glass.



Literature specifically about glass shows that this chain is difficult to organise because of factors, such as disassembly complexity, logistic costs, limited collaboration and/or conservative behaviour. The broader construction literature confirms that circular implementation depends on the interaction between different stakeholder actors across the chain rather than solely on the material potential (Geboes et al., 2023; Geboes et al., 2024; Teeuwen, 2023; Giorgi et al., 2022). The stakeholder groups and their responsibilities are presented in Section 5.2.1. Their roles cover the principal decisions concerning procurement, technical assessment, recovery, processing, evidence preparation, risk allocation and final project acceptance.

Together these different actors influence whether circular glass is specified, recovered, documented, accepted or rejected. Literature regarding circular procurements shows that collaboration, decision-making power and exchanging information across different project phases are decisive for the outcome of the implementation (Ababio et al., 2025).

5.1.2 Analytical themes

Three complementary analytical themes are used to structure this desk-based analysis. These analytical themes were derived by grouping recurring barriers and/or enabling conditions which are identified across the reviewed literature about glass-specific and circular construction. Together, they capture different conditions. These conditions are physical, organisational and behavioural and determine whether circular glass can progress through the reverse supply chain.

Technical and logistical conditions concern circular glass removal, storage, classification, processing and reinstallation with sufficient yield and quality. Issues which are relevant are breakages, contaminations, dimensional fit, separation structure and material condition. In circularity and construction material reclamation literature these different issues are specifically recognised (Geboes et al., 2023; Geboes et al., 2024; Teeuwen, 2023).

Organisational and contractual conditions concern stakeholder role clarity, liability, warranties, procurement structure and the availability of an acceptable evidence package at handover. Literature about insurance suggests that direct reuse becomes more accepted when responsibilities, technical information and risk allocation are clarified. The concerns about liabilities and warranties should be treated as stakeholder roles and responsibilities and not reasons to exclude glass automatically (Bougrain, 2023). In literature about circular-construction the organisational barriers are among the most persistent. When the responsibilities which depend on multiple stakeholders are fragmented, these barriers are particularly persistent (Charef et al., 2021; Giorgi et al., 2022; Ababio et al., 2025).

Social and market conditions concern conservative decision-making, trust, visual tolerances and acceptance of residual uncertainty. Although circular solutions may be technically feasible, they can still be rejected because the stakeholders consider them less familiar or more difficult to justify than standard new IGUs which are familiar. The conservative behaviour is a recurring barrier in the circular (glass) construction (Geboes et al., 2023; Giorgi et al., 2022).

Some uncertainties affect more than one theme. While the condition of the glass is mainly a technical and logistical issue, testing, documentation, warranties and acceptance are mainly organisational and contractual issues.

5.1.3 Governance concepts

Three governance concepts are used to structure this chapter.

The RASCI matrix is a tool used in processes to assign different roles and responsibilities. The matrix assigns the roles Responsible, Accountable, Supportive, Consulted and Informed to key implementation steps. This is relevant because the reverse supply chain introduces additional interfaces. The responsibilities may become fragmented. This RASCI matrix is developed as part of the implementation kit in Chapter 6.

Quality assurance (QA) does not only refer to testing but also to aspects such as inspection, classification, labelling, record-keeping and the consistency between the (physical) product and the related evidence. Therefore, instead of being treated as a single final inspection, quality assurance is treated as a chain-wide process.

Regulatory acceptance follows the logic of “product = glass + evidence” presented in Chapter 4. In other words, circular glass becomes an acceptable project-ready product when it is supported by a traceable evidence package. Literature regarding traceability strongly supports this. Data continuity is a critical condition for circular glass/material in the construction (Ranasinghe et al., 2024; Giorgi et al., 2022).

5.2 Findings from the stakeholder roles and responsibilities analysis

The findings are organised into three outputs, which are the key stakeholders and their implementation responsibilities, recurring barriers and drivers, and a preliminary responsibility logic for the corresponding reverse supply chain of circular glass.

5.2.1 Key stakeholders and implementation responsibilities

Based on the literature circular glass implementation depends on a chain of stakeholders rather than only one decisive stakeholder (Geboes et al., 2024; Giorgi et al., 2022).

Eight principal stakeholder groups were identified because they repeatedly perform or influence decisions concerning procurement, technical assessment, recovery, processing, evidence preparation, risk acceptance and project handover. Additionally, actors such as transport and storage providers, installers and material suppliers, may also support implementation on processes where they influence handling, traceability or delivery. However, they are not treated as primary decision-making actors in this analysis.

In Table 15 a summary is shown of the eight different stakeholder groups, their core implementation roles, what they need to confirm and the principal concern when they are insufficiently involved.

Table 15. Overview of stakeholders relevant for circular glass implementation.

Stakeholder	Core role relevant for implementation	What they need to confirm	Main concern if not sufficiently involved
Asset owner or property manager	Sets the ambition, risk appetite and cost–performance balance.	The circular option is credible, defensible and aligns with project objectives.	The perceived risk or weak business case can result in the safer default to be chosen.

Stakeholder	Core role relevant for implementation	What they need to confirm	Main concern if not sufficiently involved
Public client or procuring authority	Sets the procurement requirements and tender logic.	Circular criteria need to be auditable, enforceable and compatible with procurement procedures.	The delivery of the project can be affected if the circular ambitions remain too vague.
Designer or façade engineer	Assesses the technical suitability of the different circular glass routes for the intended application.	Assesses whether circular glass routes are technically suitable for the intended project application.	Exclusion of circular glass routes due to specification uncertainty.
Main contractor	Coordinates the execution, interfaces and eventually the handover.	A manageable risk, responsibility structure and delivery requirements.	Gaps between responsibilities may arise at delivery and handover.
Selective dismantling contractor	Recovers the glass under controlled conditions.	Recovery can be performed without excessive breakage, contamination or handling losses.	Yield loss, damages or contaminations influence the route values.
Processor or remanufacturer	converts recovered glass into usable products through inspection, processing and documentation.	If a specific route is technically workable and organisationally repeatable.	A non-repeatable circular route or insufficiently documented process.
QA or LCA advisor	structures the evidence and performs the environmental comparison.	Data needs to be sufficiently complete, traceable and transparently comparable.	Weak evidence package and weak comparability for environmental purposes.
Insurer or quality controller	Assesses if residual uncertainty is acceptable at handover.	The minimum evidence needed, accountabilities and conditions for sign-off at handover need to be clear.	Circular option could be rejected as it can be perceived as too risky or insufficiently evidenced.

Note. Stakeholder roles, recovery, processing, logistics and collaboration are based on (Geboes et al., 2023; Geboes et al., 2024; Teeuwen, 2023). Organisational and stakeholder-related barriers are based on (Charef et al., 2021; Giorgi et al., 2022). Procurement and collaboration are based on (Ababio et al., 2025). Information continuity and traceability are based on (Ranasinghe et al., 2024). Insurance and liability considerations are based on (Bougrain, 2023).

The stakeholder overview indicates that not a single stakeholder actor controls the full implementation process. Instead implementation depends on the continuity of decisions and evidence between procurement, recovery, assessment, processing and handover.

5.2.2 Barriers

The thematic synthesis of the reviewed literature did result in three recurring barrier clusters, which are the technical and logistical barriers, the organisational and contractual barriers and the social and market barriers. These different clusters are analytical groupings, which means that they are not exclusive categories. Several barriers, particularly quality uncertainty and traceability, affect more than one of these analytical clusters.

Technical and logistical barriers include breakage during removal, poor storage, contamination, limited dimensional compatibility and weak separation discipline. These barriers directly influence the feasibility of the circular route. The main drivers however are controlled recovery, protected storage, circular route specific handling and clear

identification of units and/or batches (Geboes et al., 2023; Geboes et al., 2024; Teeuwen, 2023).

Organisational and contractual barriers include unclear liabilities, weak evidence continuity, missing standardisation and vague requirements for procurement. These barriers directly influence the sign-off even when the material itself is technically usable. In circular construction literature the organisational barriers are repeatedly reported as dominant. Similar barriers are mentioned in circular procurement literature (Sajid et al., 2024). The main drivers however are early procurement clarity, predefined evidence package requirements and clearer allocation of responsibilities (Charef et al., 2021; Giorgi et al., 2022; Ababio et al., 2025; Ranasinghe et al., 2024).

Social and market barriers include conservativeness, low trust and unwillingness to accept residual uncertainties. These barriers encourage stakeholders to return to the safer default option new IGUs. The main drivers are transparency, repeatable procedures, precedent projects and clearer accountability (Geboes et al., 2023; Giorgi et al., 2022; Charef et al., 2021). Table 16 summarises the barriers.

Table 16. Barriers and corresponding practical enablers.

Barrier	Why it matters	Practical enabler
Damage and yield loss	The accepted yield m ² decreases and costs rise	Controlled recovery and protected storage
Contaminations	Weakens closed-loop quality	Controlled separations to increase quality
Missing traceability	Prevents reliable classification and reduces the confidence	Unit and/or batch identifications and audit trail records
Weak evidence standardisation	Acceptance at handover becomes more difficult	Standardisation of regulatory acceptance template
Unclear liabilities and warranties	Discourages the acceptance by owners and contractors	Preliminary RASCI and a clear sign-off logic
Vague procurement requirements	Circular ambition does not affect delivery	Explicit requirements regarding circular route and evidence package requirements
Conservativeness and low trust	Encourages fallback to the safer default new products	Transparency in communication and repeatable workflows to gain trust

Note. Based on the literature (Geboes et al., 2023; Geboes et al., 2024; Teeuwen, 2023; Charef et al., 2021; Giorgi et al., 2022; Ranasinghe et al., 2024; Ababio et al., 2025).

5.2.3 Implementation drivers

A case-based study specifically concerning remanufactured IGUs suggests that the implementation can be strengthened through five practical levers: assigning a reuse coordinator, conducting an early feasibility study, involving a complementary specialist network from the beginning, specifying the reuse ambitions in the tender or offer documents and organising pragmatic locally organised logistics (Geboes et al., 2024).

5.2.4 Preliminary responsibility logic

Based on the desk-based stakeholder roles and responsibilities analysis, the following preliminary responsibility structure is proposed:

The owner-side actor and/or public client should define the ambition and procurement logic. The designer or façade engineer should assess the technical suitability and the corresponding placement logic. The selective dismantling contractor should be responsible for a controlled recovery, initial identification and protected storage. The processor or remanufacturer should be responsible for the classification and determination of the circular glass route including route-specific processing and the generation of relevant performance evidence. QA and/or LCA support should maintain documentary consistency and support comparable technical or environmental verification.

The responsibility for handover and the corresponding final project acceptance should be assigned explicitly at contractual and project level. This is a responsibility which may rest with the main contractor or another contractually designated party.

Instead of being assessed only at the end of the project during handover, regulatory acceptance should be incorporated throughout the reverse supply chain. A stakeholder-centric procurement perspective also indicates that an effective implementation of circular glass depends not only on assigning roles but also on collaboration capabilities such as coordination, trust, technical knowledge, decision-making power and sharing information across the project chain (Geboes et al., 2024; Giorgi et al., 2022; Ranasinghe et al., 2024).

This preliminary responsibility logic provides the analytical input for the RASCI matrix and staged stop-and-go gate logic which are developed in Chapter 6. These implementation tools are introduced there and consequently evaluated through the semi-structured stakeholder interviews.

5.3 Synthesis

5.3.1 Circular glass as a reverse supply chain coordination challenge

The desk-based analysis has identified the main stakeholders, barriers, drivers and responsibility structures which are relevant to the implementation of circular glass. These findings suggest that the implementation of circular glass is best understood as a reverse supply chain instead of an isolated technical decision.

Circular construction requires integration between forward and reverse supply chains through network coordination, information exchange and material-flow management. As illustrated in Figure 5, for circular glass, recovery, identification, classification, storage, processing and reinstallation must be organised as one connected process in this reverse supply chain. Although a technically feasible route may exist, the implementation still depends on whether material value, evidence and accountability are preserved throughout the reverse supply chain (Geboes et al., 2024; Ranasinghe et al., 2024).

This interpretation connects the findings of Chapters 3, 4 and 5. In Chapter 3 the conditional technical feasibility of the circular glass routes was established. Chapter 4 established the need for an evidence package which is auditable. In Chapter 5, the actors

and their coordination mechanisms which are required to maintain the evidence from procurement to handover were identified.

5.3.2 Main implementation implications

Instead of only identifying a technically defensible route, the analysis indicates that circular glass implementation requires a coordinated reverse supply chain process with the preservation of material value, evidence and responsibility from dismantling to handover.

Four main implementation implications can be derived, which are:

1. The circular ambition must be defined early. The stakeholder groups owners and public clients need to translate the circular ambitions into procurement requirements. This should occur before technical and contractual decisions become fixed (Geboes et al., 2024; Ababio et al., 2025).
2. The recovery and evidence preparation must be treated as one continuous process throughout the reverse supply chain. Identification, storage, classification and processing directly affect both the material quality and the evidence available eventually at handover (Geboes et al., 2024; Ranasinghe et al., 2024).
3. The responsibilities must be allocated before the corresponding activities begin. It becomes more difficult to correct the responsibility gaps when they are identified only at final handover (Charef et al., 2021; Giorgi et al., 2022; Ababio et al., 2025).
4. Traceability requires an enabling information structure. Basic digital systems, unit or batch identifiers, audit trails and material or product records can support the continuity between recovery, assessment, evidence package preparation and its final acceptance (Ranasinghe et al., 2024; De Wolf et al., 2024; Giorgi et al., 2022).

If circular glass is to progress beyond pilot projects, further standardisation is required in at least four different areas. These areas are controlled recovery, traceability, regulatory acceptance and responsibility allocation (Geboes et al., 2023; Ranasinghe et al., 2024; Charef et al., 2021).

5.3.3 The interpretation and scope of the desk-based analysis

The stakeholder and responsibility structure developed in this chapter is not a universally applicable model, but an analytical proposal based on literature. The exact allocation of different responsibilities will depend on the requirements for handover, procurement route, contractual relationships and intended circular route.

The roles which are related to recovery, processing and public procurement are relatively visible in the reviewed literature while insurers, certification bodies, suppliers and final quality controllers are less consistently described. The proposed responsibility logic should be treated as a structured starting point which still requires project-specific interpretation and practical evaluation.

In Chapter 6, an evaluation is presented after the implementation kit and its circular route decision logic, regulatory evidence checklist, preliminary RASCI matrix and stop-and-go gates have been introduced.

5.4 Answer to sub-question 3

sub-question 3. "Which stakeholders and supply-chain actors are identified as key to the implementation of circular glass, and what barriers, drivers and responsibility logics are associated with them?"

The key stakeholders are the asset owner or property manager, public client, designer or façade engineer, main contractor, selective dismantling contractor, processor or remanufacturer, QA or LCA advisor and insurer or quality controller. Also relevant are transport and storage parties, suppliers and installers where they influence handling, traceability, delivery and final acceptance. These stakeholders were considered as secondary or supporting but not primary or key. Circular glass implementation therefore depends on coordinated decisions across the reverse supply chain rather than on one isolated actor (Geboes et al., 2024).

The main barriers are damage and yield loss, contamination, missing traceability, weak evidence standardisation, unclear liability and warranty arrangements, vague procurement requirements and conservative market behaviour. The desk-based analysis indicates that circular glass is rejected because it is less familiar, less standardised and more difficult to document, warrant and accept than new IGUs. It is not primarily rejected because it is technically infeasible. The main drivers are controlled recovery, early procurement clarity, traceability, role clarity and stronger standardisation of regulatory and governance procedures (Geboes et al., 2023).

Existing or newly developed digital tools could support traceability from recovery to handover. This could be digital tools such as QR codes, material passports, BIM-related data and product registration systems (De Wolf et al., 2024; Ranasinghe et al., 2024). Public clients could create demand and allow circular glass to be used in controlled refurbishment projects by acting as launching customers (Ababio et al., 2025).

The main responsibility logic structure is that different responsibilities must be distributed across the whole reverse supply chain of relevant stakeholders. The accountability at handover must remain clear for acceptance. The responsibility logic identified in this chapter forms the basis for the preliminary RASCI matrix and stop-and-go gate logic developed in Chapter 6 (Ranasinghe et al., 2024; Ababio et al., 2025; Geboes et al., 2024). In practical terms, the implementation of circular glass requires early project requirements, controlled recovery, technical assessment by processors or manufacturers, and final evidence and quality assurance at handover.

Overall, circular glass implementation is best understood as a governance and coordination challenge across the reverse supply chain. Circular glass routes which are

technically feasible become implementable when early client demand, controlled recovery, traceable evidence, clear responsibility allocation and staged decision-making are organised as one coordinated process. Without this coordination, the circular glass routes which are technically feasible remain difficult to document, guarantee and accept in practice.

The responsibility logic structure which is identified in this chapter is operationalised through the preliminary RASCI matrix and stop-and-go gate logic developed in Chapter 6.

6 Developing an implementation kit

In this chapter the combined findings of the thesis are interpreted to determine what they mean for the feasibility of an effective implementation of circular glass in Dutch façade refurbishments. This chapter translates the findings into a connected preliminary implementation kit. Circular glass routes already exist but remain difficult to implement as standardised alternatives.

First, the implementation kit is introduced and explained in Sections 6.1, 6.2 and 6.3. Subsequently the semi-structured stakeholder interviews are presented as an empirical evaluation in Section 6.4. This sequence ensures that the implementation kit is fully introduced and explained before the semi-structured stakeholder interview findings are interpreted.

The implementation kit consists of four connected elements, which are the circular glass route decision logic, the regulatory evidence checklist, the preliminary RASCI matrix and the stop-and-go gate logic. These four connected elements together translate the technical, regulatory and stakeholder-related findings into a structured project process.

6.1 The implementation gap: “from material potential to an accepted product”

A key finding of this thesis is that the technical options are not the only or principal barriers to circular glass implementation. The circular glass routes direct reuse, remanufacturing and high-quality closed-loop recycling are all conditionally feasible. Converting these circular glass routes into acceptable and manageable project solutions appears to be the more decisive challenge.

If a pane is technically reusable, this does not necessarily mean that it is a project-ready solution. In other words, construction practice does not operate solely on the technical possibilities. Circular glass becomes usable only when its condition, selected circular glass route, evidence package and responsibility allocation are sufficiently clear for design, procurement, execution and handover.

The new IGUs are part of a standardised market structure. In this market structure the specifications of the new IGUs are known, declarations are available and responsibilities are relatively clear. These conditions are therefore largely met by default. Circular glass, however, still needs to establish a comparable level of certainty.

The findings in this thesis suggest that circular glass is disadvantaged not only by the uncertainties of the material, but also by the institutional asymmetry between the circular glass product and new IGUs. New IGUs benefit from established routines, accepted evidence structures and clear responsibility allocation. To achieve a comparable legitimacy for circular glass, additional assessment, documentation and coordination must be performed. This helps explain why new IGUs remain the safer default, even

though circular glass routes technically may be feasible and/or environmentally relevant (Geboes et al., 2024; Cupać et al., 2024).

These combined results show that the implementation problem is not solely technical, regulatory or organisational. It concerns the process of translating a material potential into a product which is technically defensible, acceptable from a regulatory perspective and organisationally manageable. The concept of “product = glass + evidence” is the central condition for circular glass to move from material potential to an acceptable product.

6.2 Standardisation: “the condition for scaling”

Standardisation is an important scaling condition when uncertainty remains a principal implementation barrier. This does not mean that every project should be treated identically. Existing façades differ in condition, configuration and performance requirements. The procedures which are used to assess, document and accept circular glass routes should become more predictable and repeatable.

This corresponds with the European standardisation agenda for circular construction. This agenda identifies standards as essential for safety, consistency, reliability and market uptake. For circular glass, this supports the need for a standardised procedure concerning recovery, performance evidence, traceability and responsibility allocation (European Commission, Joint Research Centre, 2024).

The findings of this thesis indicate that at least four different forms of standardisation are needed.

The recovery process should be treated as an activity to preserve its value rather than as a side effect of demolition. Breakage, contamination, weak identification and poor storage influence the recovery yield, circular glass route feasibility and the eventual acceptance. Higher-value circular glass routes may already fail before the technical assessment starts if circular value is lost during the recovery.

The regulatory evidence structure should become more standardised. Chapter 4 showed that acceptance does not depend solely on the physical product. Identity, provenance, relevant performance information and circular glass route-specific evidence must be traceable and sufficiently clear. Recreating this evidence package for every project result in slow, uncertain and difficult to defend implementation.

The allocation of responsibilities should be standardised at process level. The risk of fragmented responsibilities increases throughout the reverse supply chain as more interfaces are introduced due to the circular glass routes. Unclear responsibilities reduce trust and weaken acceptance.

The procurement language and its requirements should become more explicit and repeatable. Circular glass may otherwise already be excluded in an early stage (even before assessments) because it is not considered in the project brief, tender logic or

specification. Procurement requirements should be established at an early stage to enable circular glass routes later in the process.

These findings suggest that scaling will not occur through technical improvements alone. The performance evidence remains important for aspects like yield and circular glass route-specific performance, but the organisational effort may be equally decisive. Broader circular construction literature also repeatedly identifies traceability, role clarity and standardisation as enabling conditions for implementation (Charef et al., 2021; Ranasinghe et al., 2024).

6.3 The practical meaning of the “implementation kit”

The combined findings in this thesis are translated into a practical preliminary implementation kit. This provides a structured response to the implementation gap identified in this thesis. It is not a validated industry model, formal certification or legal approval tool.

The implementation kit is intended to be a preliminary decision-support framework which connects the conditional feasibility of the different circular glass routes, the evidence required for the acceptance and the allocation of responsibilities throughout the reverse supply chain.

6.3.1 Compact overview of the implementation kit

A compact overview is shown in Table 17 of the four implementation kit elements, including their purpose and main outputs.

Table 17. Compact overview of the implementation kit.

Implementation kit element	Basis in this thesis	Purpose	Main output
Circular route decision logic	sub-question 1	To determine which circular glass route is the most suitable for the recovered façade glass under the specified project conditions.	The circular route decision logic is presented in Table 10 and Figure 3.
Regulatory evidence checklist	sub-question 2	To identify the evidence which is required to support the acceptance of the circular glass eventually at project handover.	The regulatory evidence checklist is presented in Table 14.
Preliminary RASCI matrix	sub-question 3	To clarify how all the different responsibilities may be allocated during the procurement, recovery, assessment, processing, evidence preparation and handover.	The preliminary RASCI matrix is presented in Chapter 6.
Stop-and-go gate logic	Synthesis of sub-questions 1,2 and 3	To provide staged decision moments at which the selected circular glass route can continue, be adjusted, be downgraded or be rejected.	The integrated reverse supply chain process is presented in Figure 6 and Appendix D.

6.3.2 Implementation kit element I: Circular route decision logic

The circular route decision logic supports the selection of the most suitable circular glass route for application in façade refurbishments.

The circular route decision logic begins with the highest-value route and proceeds stepwise to a lower-value route when the feasibility criteria are not met based on the required technical, organisational or evidence conditions. The purpose is to make the reasoning behind route selection explicit and auditable, not to guarantee that a circular route will be feasible.

The highest value route direct reuse can be considered only when the condition and performance of the recovered glass can be sufficiently assessed. If this cannot be defended for direct reuse, remanufacturing can be considered next where usable glass panes can be incorporated into a remanufactured IGU through a controlled process. When these product-level routes are not feasible, the next route is high-quality closed-loop recycling which remains possible if separation quality and contamination requirements can be met.

6.3.3 Implementation kit element II: Regulatory evidence checklist

The regulatory evidence checklist is valuable for making acceptance operational. Acceptance should not be a vague final judgement. It clarifies which evidence should be included with a project-ready circular product at handover. This improves auditability and reduces dependence on ad hoc interpretation.

This checklist follows the logic of a material passport, as it preserves relevant product information for current use, recovery and reuse. It supports the maintenance of valuable information across the reverse supply chain (Building as Material Banks, 2017).

The regulatory evidence checklist should be initiated at the start of the project rather than being completed only at handover. The information regarding provenance and identification originates during inventory and recovery, the performance evidence is generated during assessment and processing, and responsibility and sign-off information are added during handover. Therefore, the evidence package represents the accumulated evidence throughout the complete process.

6.3.4 Implementation kit element III: Preliminary RASCI matrix

The importance of the preliminary RASCI matrix lies in clarifying responsibilities and accountability throughout the reverse supply chain before the corresponding activities are performed.

The recovery, classification, evidence generation and handover should be connected activities for circular glass to be delivered reliably. The RASCI matrix therefore assigns the roles to the steps in the main process identified in Chapter 5. These roles assigned are Responsible, Accountable, Supportive, Consulted and Informed.

In Table 18 the preliminary RASCI matrix is presented which is developed based on the responsibility logic identified in Chapter 5. It translates this responsibility logic into role allocations across the main implementation activities.

Table 18. Preliminary RASCI Matrix regarding circular glass implementation.

Activity	Asset owner or property manager	Public client	Designer or façade engineer	(main) Contractor	Selective dismantling contractor	Processor or remanufacturer	QA or LCA advisor	Insurer or quality controller
1. Define the intention of circular ambition and procurement	A	R+S	C	I	I	I	C	I
2. Assess the technical suitability and the circular route options	C	I	A+R	C	C	C	S	I
3. Plan a controlled recovery and storage	I	I	C	A	R	I	S	I
4. Recover, label and store the units and/or batches	I	I	I	C	A+R	I	S	I
5. Inspection, classification and determine circular route	I	I	C	C	S	A+R	S	C
6. Remanufacture or process and generate the specific route evidence	I	I	C	C	I	A+R	S	C
7. Compile evidence package and verify the regulatory acceptance	I	I	C	A	I	S	R	C
8. Deliver the project, sign off and hand it over	C	I	C	A+R	I	S	S	C

Note. The symbols are R = Responsible, A = Accountable, S = Supportive, C = Consulted and I = Informed.

The matrix should be interpreted as a starting point for a project. It should not be interpreted as a fixed contractual model. The final accountable actor may differ based on the different procurement strategies and/or contractual structures. The responsibility for final acceptance and handover should not be assumed but always be explicitly assigned.

6.3.5 Implementation kit element IV: Stop-and-go gate logic

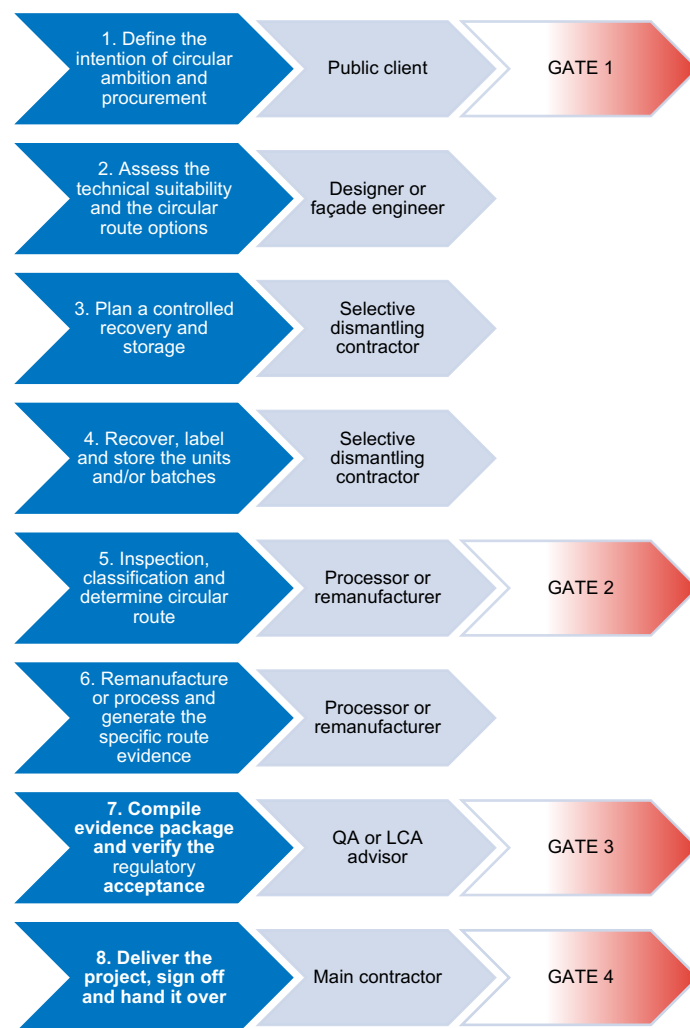
The reverse supply chain which is proposed contains eight connected implementation steps including four different principal gates. The steps are described from start to finish:

1. The client and/or asset owner defines the circular ambition and procurement requirements.
2. The designer or façade engineer assesses the technical suitability and potential circular glass routes.
3. A controlled recovery, identification, storage and transport are planned.
4. The glass is recovered, labelled and stored under specific controlled conditions.
5. The recovered glass is inspected and classified.
6. The feasible circular glass route is determined. Based on this, the glass is reused, remanufactured or used for recycling. The route-specific evidence is generated.
7. The evidence package is compiled and assessed with the regulatory evidence checklist.
8. The project is delivered, accepted and handed over by the contractually accountable actor.

The *stop-and-go gate logic* uses predefined decision moments to determine whether a selected circular glass route should continue, be adjusted, downgraded or stopped. The stop-and-go gate logic is relevant because circular glass implementation should not be treated as an all-or-nothing ambition. The structured decision moments are required to continue, adjust, downgrade or stop the selected circular glass route. This reduces avoidable effort by allowing the selected circular glass route to be reassessed when new information becomes available during recovery, inspection or evidence preparation.

Four gates are proposed. Gate 1 assesses whether the circular ambition, the procurement requirements and the resources are sufficiently clear to continue. Gate 2 follows a physical inspection and classification and determines if the intended circular glass route remains technically feasible to continue. Gate 3 assesses whether the evidence package is sufficiently complete and auditable for the project acceptance. Gate 4 represents the final project sign-off and handover. Together, these four gates structure the implementation process from procurement to final handover.

Figure 6. Reverse supply chain process for circular glass in façade refurbishments.



Note. The figure presents a preliminary process model rather than an empirically validated industry procedure.

Where Figure 5 shows the reverse supply chain conceptually, Figure 6 operationalises the reverse supply chain into steps, the suggested gates for stop-and-go moments including corresponding responsible actors.

These artefacts reframe the implementation of circular glass into a managed project process instead of solely a material decision. The practical relevance of these artefacts is not that they remove uncertainty completely, but that they reduce the risk of circular glass routes failing because of an insufficiently organised reverse supply chain.

6.4 Evaluation

6.4.1 The scope and interpretation of the semi-structured stakeholder interviews

To empirically evaluate the desk-based findings including the preliminary implementation kit, five semi-structured stakeholder interviews were conducted. These interviews were not used to formally validate the implementation kit. Instead, they were used to evaluate the identified barriers, responsibilities, circular route decision logic, evidence requirements and decision moments. The interviews assessed whether the participants considered the implementation kit to be recognisable and/or practically relevant.

Four out of the five interviews were based on audio recordings while one interview was processed using field notes. All the interview data were pseudonymised, and the participants are randomly referred to as P1, P2, P3, P4 and P5. The participant group included different professional perspectives related to building maintenance, sustainability and circularity policy or advice, construction and project management, façade refurbishment and property management. The anonymised participant overview and the detailed coding matrix are presented in Appendix F.

Not every stakeholder group which was identified in Chapter 5 was represented in the interview sample. Particularly, insurers, certification bodies and glass processors or remanufacturers were not represented directly. Therefore, findings concerning insurance, certification, warranties or processing should not be interpreted as confirmed by representatives of these stakeholder groups. The interview analysis focuses on the recurring agreements, practical nuances and differences in emphasis rather than treating isolated statements as generally representative. These interview findings are reported as cross-case patterns in the next section.

6.4.2 Cross-case interview findings

It was indicated by the interviews that circular glass is not primarily considered to be impossible from a technical perspective. Instead, the participants generally described circular glass as more difficult to organise, document, warrant and accept than the new IGUs.

Table 19 presents the anonymised cross-case comparison between the five interview participants. It shows the recurring findings, differences and role-specific observations of the interviews per analytical theme.

Table 19. A compact anonymised cross-case matrix of the interview results per theme.

Analytical theme	P1	P2	P3	P4	P5	Cross-case interpretation
Current practice	Linked sustainability projects during maintenance to circularity potential	Circularity is recognised relevant but not yet the standard	Emphasised both the project and execution logic	Linked façade refurbishments to glass replacements	Linked sustainability projects to circularity potential	Circular glass is recognised to be not yet the standard practice. It must connect/adapt to existing refurbishment moments.
Technical and logistical feasibility (sub-question 1)	Mentioned the damage risks and logistic processes needed	Emphasised the feasibility due to process conditions	Mentioned the risks during execution	Mentioned practical project-specific limitations	Mentioned practical project-specific limitations	Damage, yield, storage, transport and handling are mentioned as (key) risks across the interviews.
Regulatory acceptance and liability (sub-question 2)	Mentioned the need for a clear documentation for proof	Emphasised the link between traceability and acceptance	Linked the acceptance to warranty and allocated responsibilities	Emphasised clear documentation	Linked the acceptance to a clear documentation for confidence	Circular glass needs an auditable evidence package to become accepted
Stakeholder roles and responsibilities (sub-question 3)	Emphasised that the responsibility allocation must be clear	Early ambition is emphasised	Emphasised the contractor and its execution responsibility	The coordination between actors was mentioned	Emphasised a practical and clear coordination	Responsibility allocation must be organised early and agreed upon
Implementation kit	Saw practical relevance	Saw relevance for structured decisions	Saw relevance for a controlled implementation	Saw relevance for project organisation	Saw relevance but mentioned the need for project-based evaluation	The relevance was recognised but it was seen as preliminary.

These cross-case findings are synthesised in Table 20, which summarizes the main identified interview findings including their practical relevance.

Table 20. A compact overview of the main interview findings.

Theme	Main interview finding	Interpretation and practical relevance
Current practice	Façade glass replacement is usually linked to maintenance or refurbishment moments. New IGUs remain the default because they are familiar, available and easier to justify in projects.	The established position of new IGUs was broadly recognised by the participants. The perceived readiness of circularity differed based on the circular route and perspective.
Technical and logistical	Breakage, scratches, contamination, edge damage, storage and transport were identified as important practical risks. Recycling was generally considered	Recycling was generally considered to be the most familiar. Direct reuse and remanufacturing were associated

Theme	Main interview finding	Interpretation and practical relevance
feasibility. (sub-question 1)	to be the most familiar and currently still the most practicable circular route, whereas direct reuse and remanufacturing were associated with stricter process-control requirements.	with stricter process-control requirements for assessment, handling and process control.
Regulatory acceptance and liability (sub-question 2)	The participants emphasised the importance of documentation, traceability, warranties and clear acceptance criteria. Circular glass products were considered difficult to defend without a reliable evidence package.	The need for evidence was broadly agreed on, although the documentation which is required and the responsible sign-off party both remained dependent on the project and contract.
Stakeholder roles and responsibilities (sub-question 3)	Participants indicated that the different responsibilities for recovery, testing, documentation, warranty and final acceptance must be clarified early.	The need for early role clarity was broadly recognised. Not a universal allocation of the final accountability emerged.
Implementation kit	The implementation kit elements (circular route decision logic, regulatory evidence checklist, RASCI matrix and stop-and-go gates) were considered practically relevant. They should be understood as preliminary tools that require further project-based evaluation.	The interviews did not demonstrate the completeness, general applicability or effectiveness of the implementation kit in real projects.

Across these different professional perspectives, the agreement was the strongest on the importance of traceable evidence and an early responsibility allocation. The differences mainly concerned the maturity of the circular glass routes and the allocation of final accountability.

6.4.3 An evaluation of the implementation kit

After the discussion on the implementation conditions, a compact overview of the implementation kit which can be seen in Appendix I was presented to the participants. Participants considered the four elements understandable, relevant and potentially useful in façade refurbishment practice. In Table 21 these reflections were translated into implications for the further positioning of the implementation kit.

Table 21. Stakeholder interview evaluations of the proposed implementation kit.

Element	Interview evaluation	The resulting implication
Circular route decision logic	The interview participants recognised that the feasibility of the circular route depends on damage, contamination, yield, storage, transport and process control.	The selection of the circular glass route should remain conditional. It should be reassessed after dismantling, inspection and classification.
Regulatory evidence checklist	It was emphasised by participants that circular glass is difficult to accept without traceability, clear acceptance criteria and warranty logic.	Circular glass should be supported by an auditable evidence package at handover.
Preliminary RASCI matrix	The responsibilities must be clarified early for recovery, testing, documentation, warranty and acceptance.	The allocation of responsibilities should be made explicit before recovery and procurement decisions are finalised.
Stop-and-go gate logic	Because circular glass routes may become infeasible during recovery, sorting or evidence preparation, staged decision-making was supported by participants.	At predefined decision moments, the process should allow the circular glass route to continue, be adjusted, be downgraded or be rejected.

Element	Interview evaluation	The resulting implication
Overall implementation kit	The implementation kit was considered to be practically relevant. However, further evaluation is still required based on projects.	The kit should be positioned as a preliminary decision-support framework. It is not a formal certification or approval tool.

Note. The interviews provide different indicative professional reflections. The interviews are not a formal validation of the implementation kit.

The practical relevance of traceable evidence, early responsibility allocation and staged decision-making is supported by the interviews. Also, it was shown that the exact application remains dependent on the specific project. A practical context is added to these desk-based findings. It is not demonstrated that the implementation kit is complete, legally sufficient or generally applicable.

6.5 A synthesis and current status of the implementation kit

The four different elements of the implementation kit should be interpreted as structured thesis outputs. These thesis outputs have been evaluated through relevant professional stakeholder reflections which have not been tested yet through an application in a real refurbishment project. Therefore, the implementation kit should not be understood as a validated industry model but a preliminary decision-support framework.

These four implementation kit elements are interdependent. The circular route selection depends on evidence preparation, while the evidence preparation may remain incomplete without a clear responsibility allocation. Throughout the project process, the stop-and-go gate logic connects these elements.

Based on the combined findings and the performed interview evaluation, the following conclusions about the implementation kit can be drawn. First, conditional decision-making is supported. The selected circular route is allowed to change when new information becomes available. Second, the implementation kit elements should not be applied only at handover as final check but throughout the project process, from procurement to handover. Third, the implementation kit does not replace technical assessment, regulatory interpretation, contractual agreements or professional judgement but it reduces organisational ambiguity.

Overall, the findings of Chapters 3, 4 and 5 are translated through the implementation kit into a connected process from procurement to handover. By connecting technical feasibility, regulatory evidence, stakeholder responsibilities and staged project decisions, the movement from a material potential to an acceptable circular product is supported.

Chapter 7 discusses the broader meaning, robustness and limitations of the implementation kit and research findings.

7 Discussion

This chapter discusses the meaning of the combined findings in relation to the existing literature, reflects on the contribution and current status of the implementation kit, and considers the validity, limitations and transferability of the research. The discussion focuses on what this thesis adds to the current understanding of the implementation of circular glass in Dutch façade refurbishments.

7.1 Interpretation of the findings

The main finding of this thesis is that the implementation of circular glass is not limited by the absence of relevant circular route options, which are direct reuse, remanufacturing and high-quality closed-loop recycling. Although their feasibility is conditional, a circular route becomes realistic only when it is technically defensible, sufficiently documented and organisationally manageable.

The contribution of this thesis is the integration of the technical feasibility, regulatory acceptance and stakeholder responsibilities into an implementation oriented perspective. The identification of new circular glass routes is not the contribution of this thesis. Circular glass does not necessarily require fundamentally different performance requirements compared to new IGUs. It generally requires additional evidence regarding provenance, performance, traceability and responsibility before it can be accepted as a project deliverable. This integration of the different dimensions extends the technical focus of previous studies on circular glass towards the practical conditions which are required for implementation.

This finding is consistent with the earlier studies showing that the circular glass routes are technically defensible but conditionally dependent. It is demonstrated by research on direct reuse that the remaining strength and surface condition can support the decision for direct reuse when suitable assessment and screening methods are applied (Cupać et al., 2024; Veer et al., 2023; Sofokleous, 2022). It is shown by research on remanufacturing that the recovered panes can be incorporated into new remanufactured IGUs. However, process control, quality assurance, warranties and acceptance arrangements remain important for implementation (Geboes et al., 2024). Similarly, high-quality closed-loop recycling depends on the separation quality, contamination and recovery yield (Smith & Abdoli, 2023).

Instead, this thesis connects the technical potential which was identified in earlier studies to the regulatory evidence and corresponding stakeholder responsibility. Whether individual routes may be technically or environmentally feasible is mainly explained by previous studies. This thesis adds that these circular glass routes become a practical project alternative when the three conditions are addressed together. The circular glass route must be technically defensible, the product must be supported by traceable and auditable evidence, and the corresponding responsibilities must remain clear throughout the reverse supply chain.

In other words, circular glass should not be approached as glass material alone. A circular route may still fail if the evidence, traceability, warranties or responsibility remain unclear. It should be understood as a combination of the material, corresponding evidence and responsibility. The technical feasibility determines whether a circular route can be considered, regulatory acceptance determines whether it can be defended as a product and the different stakeholder responsibilities determine whether it can be organised in practice.

The desk-based regulatory and standards analysis shows circular glass does not have fundamentally different performance requirements compared with new IGUs. In principle, the differences lie in the availability, continuity and auditability of supporting evidence. Circular glass must reconstruct a comparable certainty through provenance information, route-specific evidence and clear responsibility allocation while new IGUs enter refurbishment projects through established documentation, warranties and acceptance procedures.

This supports the concept which is developed in this thesis. The concept is that an acceptable circular product must consist of “glass + evidence + responsibility”. The evidence package alone does not determine who produces, verifies, maintains and accepts the evidence. Therefore the addition of the responsibility is important. The desk-based stakeholder roles and responsibilities analysis shows that if activities are not assigned at an early stage responsibilities and coordination may become fragmented. In circular construction, fragmented collaboration, unclear responsibilities and weak standardisation are identified as recurring implementation barriers (Charef et al., 2021; Giorgi et al., 2022; Ranasinghe et al., 2024).

Also, the findings show that circular glass routes must not be considered as fixed alternatives without considering the corresponding project conditions. Although direct reuse is preferred from a circularity perspective, the recovered glass should be suitable and acceptable for its intended application. If direct reuse is not possible, remanufacturing may be considered if the material value is still preserved. If the higher value circular route options are not feasible, high-quality closed-loop recycling functions as a relevant material-level circular route.

Overall, the findings of this thesis shift the focus from whether circular glass is technically feasible to how it could be a project solution which is acceptable and manageable. The new IGUs benefit from the existence of established evidence, procedures and responsibilities, while the circular glass routes require this to be organised separately. Therefore, for a wider implementation more standardised recovery procedures, evidence requirements, procurement language and responsibility structures are important.

7.2 Reflection on the implementation kit

The findings in this thesis are translated into a practical structure referred to as the implementation kit. The different elements from this implementation kit help to make circular glass implementation more explicit and auditable.

The implementation kit is the main contribution of this thesis. It connects the findings of the three sub-questions into one process for a project. The circular route decision logic addresses which circular glass route is feasible, the regulatory evidence checklist addresses what must be documented for acceptance, the preliminary RASCI matrix addresses how the different responsibilities may be allocated and the stop-and-go gate logic addresses when the selected circular glass route should be reassessed based on new information. The value of this integration is that the four implementation kit elements are interdependent as described in Chapter 6.

This kit should still be interpreted as a preliminary decision-support framework. It is not a certification system, legal approval tool or fully validated industry model.

The value of the implementation kit lies in structuring decisions, evidence requirements and responsibilities from an early project stage. The implementation kit does not determine legal compliance, certify the recovered glass performance or replace specific technical, contractual and insurance assessments for projects. Therefore, the final application of the implementation kit remains dependent on the context of the project, the procurement strategy and the involved stakeholders.

The semi-structured stakeholder interviews supported the practical relevance of the four different proposed implementation kit elements, in particular traceable evidence, early responsibility allocation and staged decision-making. However, the semi-structured stakeholder interviews did not demonstrate that the implementation kit is complete, legally sufficient or generally applicable. Therefore, further project-based evaluation is required to determine whether the implementation kit is understandable, complete and practically usable for a real circular glass façade refurbishment project.

7.3 Validity and limitations

The findings of this thesis and the implementation kit should be interpreted in relation to the research design including its boundaries. First this section considers how the validity and reliability of the analysis were supported. Subsequently, it discusses the main methodological and analytical limitations.

7.3.1 Validity and reliability

The validity and reliability of this thesis are strengthened through the combination of three complementary methodologies, which are a systematic literature review (sub-question 1), a desk-based regulatory and standards analysis (sub-question 2) and a desk-based stakeholder roles and responsibilities analysis (sub-question 3).

An additional empirical evaluation of the practical relevance of the desk-based findings including the preliminary implementation kit has been provided by performing the five semi-structured stakeholder interviews. The findings emerged across multiple research components concerning traceability, quality assurance, responsibility allocation and staged decision-making.

The validity of sub-question 1 is supported by a structured PRISMA 2020-based review (Appendix A) with explicit search strings, inclusion and exclusion criteria and a transparent selection process.

The reliability of sub-question 2 is supported by a structured extraction logic (Appendix B) linking requirements in an overview to evidence items and source types.

The validity of sub-question 3 is supported by a structured synthesis (Appendix C) of stakeholder, responsibility and circular construction literature which resulted in explicit outputs on barriers, drivers and responsibilities.

The supporting appendices Appendix A, B and C make the analytical process traceable. In Appendix A the selection and appraisal of the performed SLR is documented. Appendix B presents the normative and standards extraction into a requirement-to-evidence mapping. In Appendix C the analytical framework for the stakeholder roles and responsibilities analysis is documented. The protocol for the semi-structured stakeholder interviews and the relevant cross-case results are presented in Appendix F.

The central implementation logic is supported and contextualised through the methods used. They do not demonstrate that every element of the proposed implementation kit will function as intended in a real circular glass façade refurbishment project. Therefore, these presented findings should be interpreted as analytically supported and empirically evaluated, not as universally validated.

7.3.2 Methodological and analytical limitations

The base of the evidence is unevenly spread across the technical, economic and environmental aspects. The performance evidence is stronger than the economic evidence and the environmental evidence is often scenario-dependent.

The SLR resulted in seven eligible studies which contain extractable evidence relevant for implementation. This limited number of studies partly reflects the inclusion criteria being strict, but it also indicates the scarcity of directly applicable specific research on circular glass in façades. Consequently, in this thesis a structured and conditional comparison is provided between the circular glass routes and new IGUs. It does not provide a definitive quantitative ranking.

The economic and environmental outcomes remain dependent on specific project assumptions, such as the recovery yield, storage, logistics, testing, processing losses, allocation choices and avoided production. Therefore, the circular glass route decision logic cannot determine in advance which circular glass route will have the lowest cost or the lowest environmental impact as it depends on different project specific assumptions.

The regulatory and standards analysis was desk-based. No formal legal assessment, certification and/or insurance evaluation was performed. The regulatory evidence checklist should therefore not be interpreted as a proof that a circular glass product automatically satisfies every applicable requirement. Instead, it should be interpreted as a structured project-support tool.

A further limitation concerns the limited number of semi-structured stakeholder interviews. The participants were purposively selected based on their professional expertise relevant to the research subject. Therefore, the findings should not be interpreted as statistically representative or sector-wide evidence, but as indicative professional reflections. Insurers, certification bodies and glass processors or remanufacturers are also relevant stakeholders which were not directly represented. Therefore, the findings concerning these stakeholder groups should be interpreted with caution.

The implementation kit was not followed in an actual circular glass refurbishment project starting from procurement through dismantling, assessment, processing, evidence preparation and finally handover. Therefore, this research cannot demonstrate whether all the proposed gates are necessary, whether the responsibilities can be contractually allocated as proposed and/or whether the regulatory evidence checklist is complete and is sufficient for every circular glass route.

Façades differ considerably and can be very project-specific. There are many different existing building conditions, façade typologies, performance requirements and storage possibilities. The framework developed in this thesis should therefore be interpreted as a structured decision-support framework. It is not a universal procedure for all projects.

7.4 Transferability

The findings of this thesis are context-dependent and cannot automatically be applied to other contexts. The focus of this thesis was on façade glass refurbishments in the Netherlands. Although the general logic for implementation may also be useful elsewhere, local regulations, standards, procurement routines and market conditions may differ.

7.5 Implications for further research

The implementation kit should be tested and evaluated in real façade refurbishment projects to determine whether its elements are understandable, complete and practically usable.

The transferability of the framework to other countries and sectors with different regulatory, procurement and market conditions should be assessed through further research.

The economic and environmental evidence should also be strengthened in further research. More comparable data are needed from projects on costs per accepted square metre, the recovery yield, storage, logistics, testing, remanufacturing, warranty implications and environmental impacts under different scenarios.

In addition, future stakeholder research should include insurers, certification bodies, glass manufacturers, processors and warranty providers.

Future research could also examine the integration of the implementation kit presented in this thesis into procurement documents and digital product information systems.

The next chapter presents the answer to the research question, final conclusions and recommendations which are based on this discussion.

8 Conclusions & recommendations

The following research question is addressed in this thesis *“Under which technical, regulatory and stakeholder-related responsibility conditions can circular glass be effectively implemented in façade glass replacements in the Netherlands?”*.

This thesis approached the main question through three sub-questions on feasibility, regulatory acceptance and conditions regarding stakeholders and governance. These findings together show that circular glass implementation is not solely constrained by the absence of circular glass routes. The difficulty of organising circular glass routes as technically defensible, traceable, acceptable and repeatable project solutions is the greater constraint.

8.1 Conclusions

8.1.1 Answer to sub-question 1

What methods for circular glass are currently available in façade refurbishments, and how do they compare to new insulated glass units (IGUs) in terms of technical, economic, and environmental feasibility?

In this thesis three main circular glass routes are identified for façade glass refurbishments, which are direct reuse, remanufacturing and high-quality closed-loop recycling. Component-level reuse is treated as an intermediate option within remanufacturing rather than as a separate main circular glass route. Downcycling remains a fallback route when other routes are not considered to be feasible.

The findings show that these circular glass routes are conditionally feasible, not automatically. Direct reuse is the circular glass route which preserves the highest product value when the condition and performance of the recovered glass can be assessed and defended sufficiently. When direct reuse is no longer possible but (valuable) components remain suitable, remanufacturing may be considered. When higher value routes are no longer feasible or attractive, high-quality closed-loop recycling remains a relevant material-level route.

Circular glass routes do not primarily fail because they are technically impossible, but because uncertainties may remain too high to justify implementation. These uncertainties concern glass condition, recovery yield, process control, documentation and acceptance.

8.1.2 Answer to sub-question 2

What is the regulatory assessment framework for implementing circular glass in existing buildings?

The desk-based regulatory and standards analysis showed that the implementation of circular glass depends on the following three connected acceptance layers:

1. performance evidence
2. regulatory and liability logic evidence
3. environmental and procurement evidence

Compared with new IGUs, there are not fundamentally different core performance expectations for circular glass. The main difference lies in the availability, continuity and auditability of the supporting evidence. While new IGUs arrive with standardised documentation, circular glass still needs to close the documentary gap with a traceable and auditable evidence package.

The main conclusion is that circular glass becomes an acceptable product when it is organised as “product = glass + evidence”. In practice, this means the following needs to be traceable and auditable at handover: provenance, identification, relevant performance information, circular route specific evidence and accountability.

8.1.3 Answer to sub-question 3

Which stakeholders and supply-chain actors are identified as key to the implementation of circular glass, and what barriers, drivers and responsibility logics are associated with them?

The desk-based stakeholder roles and responsibilities analysis shows that the implementation of circular glass depends on the coordination across a reverse supply chain involving several relevant stakeholders. The key stakeholder actors are the client or asset owner side, public client, designer or façade engineer, main contractor, selective dismantling contractor, processor or remanufacturer, QA or LCA advisor, and parties which are involved in warranties, verification and final acceptance.

The main barriers are damage and yield loss, contamination, missing traceability, weak standardisation of evidence, unclear liability and warranty logic, vague procurement requirements and conservative market behaviour. The main drivers are controlled recovery, early procurement clarity, traceability, stakeholder role clarity and stronger standardisation of procedures.

The semi-structured stakeholder interviews provided empirical support for the practical relevance of these desk-based findings by showing that circular glass may be technically feasible while remaining difficult to organise, document, warrant and accept in practice.

The main conclusion is that the implementation of circular glass is best understood as a governance and coordination problem. To create a more implementable circular glass product, responsibilities should be clearly organised through the complete reverse supply chain. Responsibilities for recovery, classification, processing, evidence generation, verification, warranties and final acceptance should be explicitly allocated while the accountability at handover must remain clear.

8.1.4 Answer to the main research question

Under which technical, regulatory and stakeholder-related responsibility conditions can circular glass be effectively implemented in façade glass replacements in the Netherlands?

Circular glass can be effectively implemented in Dutch façade refurbishments when three conditions are simultaneously met.

1. A circular route which is technically defensible must be available. This requires the recovered glass to be suitable for direct reuse, remanufacturing or high-quality closed-loop recycling under the project-specific conditions.
2. The regulatory acceptance must be organised. Circular glass must be delivered as a traceable and auditable product supported by sufficient evidence.
3. The governance needs to be sufficiently structured across the reverse supply chain. Early procurement choices, controlled recovery, role clarity and staged decision-making are necessary to preserve both value and accountability throughout the process of the reverse supply chain.

The proposed preliminary implementation kit in this thesis provides structure for organising these conditions. It connects circular glass route selection, evidence requirements, responsibility allocation and stop-and-go decision moments. It should be tested and evaluated in real façade refurbishment projects before it can be considered to be an established industry model.

The overall conclusion of this thesis is therefore that the implementation of circular glass becomes more realistic when technical uncertainty, documentary evidence gaps and governance ambiguity are systematically converted into evidence, traceability and responsibility logic.

The stakeholder interview evaluation supported this combined conclusion by indicating that circular glass implementation requires more than technical feasibility alone. It also depends on a controlled recovery, standardised evidence, and a clear allocation of responsibilities across the reverse supply chain. Therefore, circular glass products should be approached as **“glass + evidence + responsibility”** for implementation.

8.2 Recommendations

8.2.1 Recommendations for practice

The client and/or asset owner should take the first step in the reverse supply chain by defining the ambition for circular glass during the initiation of the project and procurement. Subsequently, the following recommendations describe how the other actors should contribute to the implementation process.

1. Circular glass should already be addressed by the client or asset owner at the start of a project instead of addressing it during the execution phase. Circular glass routes need to be explicitly mentioned in procurement documents and project briefs, otherwise the default new IGUs will remain the usual choice.
2. At an early project stage, the client, designer or façade engineer and a designated QA role should establish the minimum evidence requirements. Units and/or batches should be linked to a minimum evidence package from an early stage, which should be maintained throughout the process (recovery, assessment, processing and handover). This could potentially be supported by (existing) traceable product information tools such as batch identification, QR codes, material passports or equivalent registration systems.
3. Recovery should be a value-preserving activity. To preserve the possibility of higher value circular glass routes it is essential to have controlled recovery, protected storage, circular route-aware handling and early labelling. These activities should be coordinated before dismantling begins by the dismantling contractor and processor or remanufacturer.
4. Both the client and contracting parties should clarify the allocation of responsibilities across the reverse supply chain. A tool such as a preliminary RASCI matrix can help to identify who is responsible for different activities such as recovery, classification, evidence generation, verification, warranties, acceptance and final accountability.
5. Apply staged stop-and-go decision moments. To reduce avoidable effort, projects should use explicit decision moments, during procurement, after dismantling, after inspection and classification, after route-specific processing, during evidence preparation and before handover.

8.2.2 Recommendations for policy and sector development

1. At the sector level, further standardisation regarding circular glass is needed for workflows, particularly regarding traceability, classifications and minimum documentary requirements. Industry associations, standardisation bodies, public clients and market participants should collaborate in the development of these workflows.
2. Clearer market conventions are needed for circular glass route specific acceptance, warranties and accountability. Otherwise, circular glass is unlikely to scale effectively if each project must renegotiate the same basic implementation questions.
3. Digital traceability deserves more attention to significantly improve the practicality of circular implementation. This is for instance relevant for reuse-

oriented documentation systems, structured audit trail records and more consistent data continuity.

4. Precedent projects should be documented more systematically in terms of technical outcomes but also procurement, governance and handover logic.
5. It is recommended to develop more standardised evidence requirements for circular glass products, including minimum documentation for technical performance, traceability, quality assurance, warranty and handover. To support market development, public clients could act as launching customers by allowing pilot projects in controlled façade refurbishment contexts.

8.2.3 Recommendations for further research

1. More empirical project-based evidence is needed in further research on breakage, contamination, rejection rates, accepted yield and cost per accepted square metre across different project types.
2. The implementation kit developed in this thesis, including the circular route decision logic, regulatory evidence checklist, preliminary RASCI matrix and stop-and-go gate logic, should be tested and evaluated in practice through pilot projects or case-based applications.
3. Responsibility and warranty models require deeper study beyond establishing their importance as done in this study. The most suitable contractual allocation of responsibilities for recovery, processing, evidence generation, warranties, acceptance and handover should be evaluated in further research.
4. Digital traceability tools that can support information continuity across the complete reverse supply chain require additional research.
5. Circular route-specific environmental and MKI comparisons should be transparently refined under consistent assumptions in Dutch practice. This should include comparable assumptions regarding the recovery yield, transport, processing, allocation and avoided production.
6. Further research should include a broader stakeholder sample, including insurers, certification bodies, glass manufacturers, processors, remanufacturers and warranty providers. The practical acceptance of the proposed implementation logic should be evaluated across these stakeholder perspectives.

8.3 Final synthesis

The core message of this thesis is that the barrier to circular glass implementation in façade refurbishments in the Netherlands is not particularly technical. The lack of sufficiently organised implementation conditions is a more persistent barrier.

Circular glass routes can only become credible alternatives to new IGUs when they are supported by sufficient evidence, traceability and clear responsibilities. In other words, circular glass implementation is not solely a material issue, but also a documentary and organisational one.

Circular glass becomes more viable when it is no longer treated as only a promising exception but as a product which can be specified, justified, delivered and accepted in a

structured way. When these conditions are established from the beginning of a project and maintained throughout the reverse supply chain during procurement, recovery, assessment and handover, circular glass can move from a project-specific exception towards a more repeatable alternative in Dutch façade refurbishment practice.

Alphabetical glossary of key terms

Auditability

The ability to verify that evidence to be complete, traceable and sufficiently documented.

Circular acceptance delta

The difference between the evidence and acceptance conditions typically available for new IGUs and those that must be established for circular glass.

Circular glass

Recovered façade glass that is retained through a circular glass route, which could be direct reuse, remanufacturing or high-quality closed-loop recycling.

Circular route decision logic

A structured decision logic used to determine which circular glass route is most suitable under specific conditions.

Component-level reuse

An intermediate reuse option in which suitable components from an existing glazing system are reused. It may form part of a remanufacturing process but is not treated as a separate main circular glass route in this thesis.

Controlled recovery

The planned removal, handling and storage of recovered glass to preserve its condition and circular value.

CPR (Construction Products Regulation)

An EU regulatory framework governing construction products placed on the market.

Cut-off approach

An approach in an environmental assessment which excludes burdens from previous life cycles.

Direct reuse

A circular route which reuses recovered glass panes and/or units without substantial reprocessing needed.

Downcycling

A route where glass is recycled in a lower valued application.

EPD (Environmental Product Declaration)

A standard document with environmental impacts reported over the life cycle of a product.

Evidence package

A structured collection of traceable and auditable information linked to a glass unit or batch and used to support assessment and acceptance.

High-quality closed-loop recycling

Recovered glass fragments are sorted and returned to the production of flat-glass. The controlled sorting determines the quality.

IGU (Insulating Glass Unit)

A sealed unit of two or more panes separated with a spacer and cavity.

Implementation kit

A preliminary decision-support framework consisting of four connected elements for a structured implementation of circular glass in façade refurbishment projects.

MKI (Milieukostenindicator)

An indicator for the environmental impact as a single cost-based score in the Netherlands.

MPG (Milieuprestatie Gebouwen)

An indicator for the environmental performance of materials at building level in the Netherlands.

Provenance

Information about the origin of a recovered glass unit or batch, such as the building or project from which it originates.

Quality assurance (QA)

A procedure which is used to verify, document and control quality and compliance.

RASCI matrix

A tool used in processes to assign different roles and responsibilities.

Regulatory acceptance

The extent to which the circular façade glass can be accepted in a refurbishment project based on sufficient, traceable and auditable evidence.

Regulatory assessment framework

An auditable framework which is used for a specific project to structure the assessment of regulatory acceptance requirements based on the corresponding evidence for circular glass.

Regulatory evidence checklist

A structured checklist which may be used to identify and verify the evidence which is required for the assessment and acceptance of circular glass units at handover.

Remanufacturing

A controlled rebuilding process in which suitable glazing components are reused where appropriate.

Reverse supply chain

The connected process through which recovered glass moves from procurement and controlled recovery through identification, assessment, processing and evidence preparation towards the final handover.

Stop-and-go gate logic

A staged decision logic used to determine whether a selected circular route should continue, be adjusted, downgraded or rejected at predefined project moments.

Traceability

The ability to identify and track a unit, batch and/or evidence throughout the process.

Wkb (Wet kwaliteitsborging voor het bouwen)

A Dutch quality assurance framework relevant to verifiable compliance at handover.

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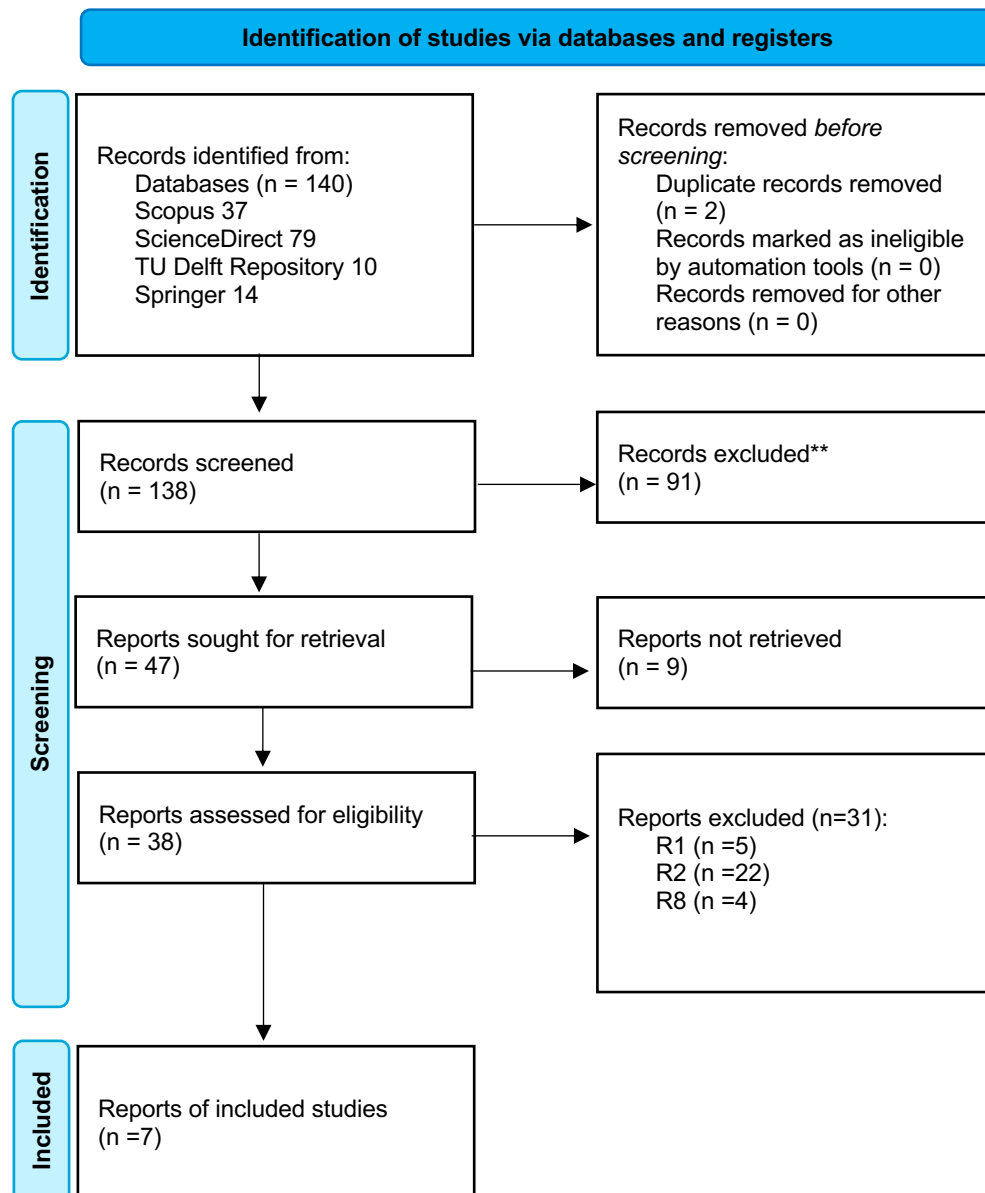
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Appendix A - Systematic Literature Review protocol (sub-question 1)

A.1 PRISMA flow diagram

In Figure 7 the flow diagram of the performed systematic literature review can be seen.

Figure 7. Flow diagram of systematic literature review (SLR).



Note. PRISMA 2020-style flow diagram. Source: (Page et al., 2021) licensed under CC BY 4.0. To view a copy of this license, visit <https://creativecommons.org/licenses/by/4.0/>

A.2 Search strategy and database log

The search log for each database is shown in Table 22 and it was performed by using four concept blocks:

- Glass / IGU
- Circular route
- Façade context
- Feasibility evidence (standards: EN/ISO/LCA/EPD/MKI/MPG and costs)

Table 22. Database search log.

Database	Date searched	Years covered	Final query (copy/paste exact database syntax) *	Records retrieved (n)
Scopus	22-12-2025	2000–2025	TITLE-ABS-KEY(("insulating glass unit" OR "insulated glass unit" OR IGU OR glazing OR "flat glass" OR "architectural glass") AND (reuse OR reused OR re-use OR remanufactur* OR refurbish* OR reclaim* OR "second-life" OR "closed loop" OR "closed-loop" OR cullet OR recycl*) AND (façade OR facade OR "building envelope" OR "curtain wall*" OR window* OR fenestration) AND ("EN 1279" OR "EN 410" OR "EN 673" OR "EN 1096" OR "EN 15804" OR LCA OR "life cycle" OR EPD OR MKI OR MPG OR cost* OR feasibility OR "quality assurance" OR traceability)) AND (PUBYEAR > 1999 AND PUBYEAR < 2026) AND (LANGUAGE(English) OR LANGUAGE(Dutch))	37
ScienceDirect	22-12-2025	2000–2025	("insulating glass unit" OR IGU) AND (reuse OR remanufacture OR circular) AND (facade OR "curtain wall")	79
TU Delft repository	22-12-2025	2000–2025	("insulating glass unit" OR "insulated glass unit" OR IGU OR glazing OR "flat glass" OR "architectural glass" OR "window glazing") AND (reuse OR reused OR "re-use" OR remanufactur* OR refurbish* OR reclaim* OR "second-life" OR "closed loop" OR "closed-loop" OR cullet OR recycl*) AND (facade OR façade OR "building envelope" OR "curtain wall" OR "curtain wall*" OR window* OR fenestration) AND ("EN 1279" OR "EN 410" OR "EN 673" OR "EN 1096" OR "EN 15804" OR "EN 16612" OR "glass strength" OR strength OR bending OR "bending strength" OR ageing OR aging OR "surface quality" OR microscopy OR "double ring" OR "coaxial double ring" OR "quality assurance" OR traceability OR LCA OR "life cycle" OR EPD OR MKI OR MPG OR cost* OR feasibility)	10
Springer	22-12-2025	2000–2025	("insulating glass unit" OR "insulated glass unit" OR IGU OR glazing OR "flat glass" OR "architectural glass" OR "insulated glazing") AND (reuse OR reused OR "re-use" OR remanufacture OR remanufacturing OR refurbish OR refurbished OR refurbishment OR reclaim OR reclaimed OR "second-life" OR "closed loop" OR "closed-loop" OR cullet OR recycle OR recycled OR recycling) AND (façade OR facade OR "building envelope" OR "curtain wall" OR "curtain walls" OR window OR windows OR fenestration) AND ("EN 1279" OR "EN 410" OR "EN 673" OR "EN 1096" OR "EN 15804" OR LCA OR "life cycle" OR EPD OR MKI OR MPG OR cost OR costs OR feasibility OR "quality assurance" OR traceability OR "gas retention" OR "dew point")	14

Note. Database syntax was adapted to the search functionality of each database.

A.3 Screening and eligibility with full-text exclusions

An overview in Table 23 of different reasons why sources were excluded during the SLR.

Table 23. Exclusions with reasons.

Reason code	Reason (definition)	Count (n)	Examples (optional: 1–2 short examples)
R1	Not a façade/building-envelope context	5	Not particularly in a building and/or façade context. For instance, industrial production, bottles, containers, etc.
R2	Not about circular glass routes (direct reuse/remanufacturing/ high-quality closed-loop recycling)	22	Often about technicalities of glass and/or windows but not particularly about the circular glass routes which are relevant for this study.
R3	Lab-only study with no transferability to refurbishment practice	-	
R4	No extractable outcomes (technical/economic/environmental)	-	
R5	Claims/marketing without transparent method/data	-	
R6	Not within time window/language after full-text check	-	
R7	Duplicate/overlapping publication (most complete version kept)	-	duplicate
R8	Not about IGU / architectural glass / glazing	4	Sometimes about sustainability of buildings but not particularly about the glass façades.
R9	Other	-	
	Total excluded at full text	Nex=31	

Note. Multiple reasons could sometimes be applicable for one source. If so, the main reason was chosen.

A.4 Data extraction

Together Table 24 and Table 25 are used for specific data extraction in the SLR for the sources S1–S7.

Table 24. Data extraction overview relevant for performing SLR.

Field	Variables to extract if available (per source)
Bibliographic	Source ID, author(s), year, title and publication type (peer/grey).
Context	Country and/or region, building typology, façade type and context.
Glass type used	IGU, float (annealed) glass, heat-strengthened/tempered safety glass, laminated glass and/or coated glass (low-e/solar control). Noted thickness/composition if present.
Circular route	(direct or component level) reuse, remanufacturing, high-quality closed-loop recycling and/or downcycling.
Technical outcomes	Based on EN/ISO evidence mentioned, pass/fail outcome or ranges and/or possible failure modes.
Yield and logistics	(acceptance) Yields, breakage loss, dismantling approach choice, storage boundary conditions, separation management and transport conditions.
Economic outcomes	Specific cost data reported per m ² , unit or a TCO, boundary condition choices (what was included) and key cost drivers.
Environmental outcomes	Indicators used such as LCA/EPD/MKI/MPG, system boundary choices, allocation (cut-off) choices, and if possible, results per m ² .
Key limitations	Data gaps, specific assumptions, transferability and/or possible conflict of interest.

Table 25. Data extraction SLR overview filled in per source.

ID	Context	Glass type	Circular route(s)	Technical outcomes	Yield and logistics	Economic outcomes	Environmental outcomes	Key limitations and/or notes
S1	Façade refurbishment cases in EU with circular reuse or remanufacturing focus	IGU	Direct reuse and remanufacturing	Process-level feasibility assessment. No datasets with EN pass or fail checks reported. More focus was on quality assurance (QA), process control, handling the damage risk, warranties or certification.	Process logistics and roles across stakeholders described.	Cost of remanufactured IGU $\pm 10\%$ higher compared with new IGU for specific case.	Qualitative motivation and context mentioned	Much qualitative evidence used. Cost evidence not fully transparent for analysis and comparison.
S2	Reuse strength potential of aged façade glass.	(used) Float glass	Direct reuse	Destructive tests using a coaxial double ring and with an assumed failure percentage of 0,8%: - exposed and/or critical surfaces 17,9 - 19,8 MPa - protected surface 46,3 MPa - new glass (based on EN16612) 21,4 MPa	Not the focus	N/A	No LCA/EPD used	Strong strength evidence but no chain evidence.
S3	Fracture based prediction method to support reuse of aged façade glass	(used) Float glass	Direct reuse	Mean fracture strength for the following: - new (air side) 134,5 MPa - new (tin side) 87,1 MPa - aged and weathered (larger specimens) 54,6 MPa This proof-of-concept claims the reuse potential is about $\pm 70\%$.	Implied method approach.	N/A	No LCA/EPD used	Still Proof-of-concept which needs validation and acceptance to eventually scale-up.
S4	Prediction method for the strength of aged glass	Aged glass	Direct reuse	Surface flaw characterisation was used in a strength prediction method. Observed and reported flaw sizes ranged approximately between 19 μm and 161 μm . The critical defect was not consistently at the largest flaw size.	Not the focus	N/A	No LCA/EPD used	A lab-based thesis (grey) with limited real data.
S5	End-of-life scenario LCA analysis in Australia.	Glass waste	high-quality closed-loop recycling	N/A	Implicitly reflected in scenario study.	N/A	LCA results for each scenario.	Not specifically façade and/or IGU. Useful as recycling context evidence.
S6	A façade renovation of family building in Sweden	Façade glass	Remanufacturing and direct reuse	Performance results provide contextual insight.	No reuse yields related numbers	Qualitative context mentioned	Contextual environmental evidence	Performance context of façade refurbishment. Not specifically IGU reuse or remanufacturing.
S7	System-level circularity analysis of aluminium curtain wall façades	Façade glass	Direct reuse	On a system-level constraints are also present. Glass with coatings, interlayers and/or mixed materials increase the technical effort needed (difficulty) for separation.	Disassembly of systems are discussed.	Qualitative context mentioned	Qualitative context mentioned	Strong context related to façade systems. Limited EN based evidence.

The limited number of included studies is interpreted as a finding in itself. It indicates that directly applicable, façade-glass-specific evidence remains scarce.

A.5 Quality appraisal

In Table 26 and Table 27 the quality of sources S1-S7 is assessed based on credibility.

Table 26. Credibility checklist.

Criterion	S1	S2	S3	S4	S5	S6	S7
Traceability (claims are linked to tests and/or standards and with a transparent method)	P	Y	Y	Y	Y	P	P
Complete data (extractable values and clear)	P	Y	P	P	Y	P	P
Boundary conditions transparency (costs, environmental scope and crediting assumptions stated)	P	P	P	P	Y	P	P
Comparability (default new IGU comparator defined or inferable)	P	P	P	P	Y	P	P
Bias or conflict (non-promotional purpose and/or conflicts stated)	Y	Y	Y	Y	Y	Y	Y
Transferability (relevant to thesis façade refurbishment in practice)	Y	P	P	P	P	P	Y

Note. Y=yes and P=partial.

Table 27. Quality appraisal summary (per included source).

Source ID	Circular route(s)	Evidence domains (Technical, economic or environmental)	Overall credibility	Key concern in short
S1	Remanufacturing	Technical, Economic (partial) and environmental (qualitative)	Medium	Cost specific only one case and the comparability based on which boundary conditions affect the interpretation.
S2	Direct reuse	Technical	High	No cost, LCA, or chain feasibility-based evidence. But high value performance evidence.
S3	Direct reuse	Technical	Medium	Proof-of-concept implicit method with limited validation.
S4	Direct reuse	Technical	Medium	Grey literature. Limited practice accepted level quality assurance.
S5	high-quality closed-loop recycling	Environmental	High	Not façade or IGU specifically. Only relevant for high-quality closed-loop recycling context, not direct reuse/remanufacturing.
S6	Direct reuse	Technical and Environmental	Low–Medium	Mainly performance context and limited to IGU direct reuse/remanufacturing.
S7	(component) reuse	Technical	Medium	Limited EN/IGU based.

A.6 overview of included studies

A short summary overview of the sources S1-S7 is given in Table 28.

Table 28. SLR included studies overview.

Source ID	Reference in APA (full reference can be found in the reference list.	Peer or grey	Circular route(s)	Main outcomes relevant in this thesis.
S1	(Geboes et al., 2024)	Peer	Remanufacturing	Stakeholder network value. Barriers in feasibility for implementation. Consideration of quality assurance, warranties and certifications.
S2	(Cupać et al., 2024)	Peer	Direct reuse	Strength analysis distribution of aged glass. Screening feasibility for reuse.
S3	(Veer et al., 2023)	Peer	Direct reuse	Strength degradation assessment analysis. Uncertainty decision-making implications.

Source ID	Reference in APA (full reference can be found in the reference list.	Peer or grey	Circular route(s)	Main outcomes relevant in this thesis.
S4	(Sofokleous, 2022)	Grey	Direct reuse	A technical assessment method based on flaws in aged glass.
S5	(Smith & Abdoli, 2023)	Peer	high-quality closed-loop recycling	Comparison between disposal/recycling scenarios based on an LCA.
S6	(Gosztonyi et al., 2016)	Peer	Direct reuse	Renovation of a façade in practice as contextual insight.
S7	(Teeuwen, 2023)	Grey	Direct reuse (and component level reuse)	System-level façade circularity; disassembly/assembly and material route implications (incl. downcycling risks due to coatings/interlayers)

Appendix B - Extraction log and evidence mapping (sub-question 2)

B.1 Purpose and scope

This appendix shows the audit trail of the desk-based assessment of the legal, regulatory and normative sources regarding Chapter 4. These sources were translated into regulatory acceptance requirements for the implementation of circular glass during façade refurbishments in the Netherlands. It is limited to the regulatory acceptance logic of circular glass and not project-specific cases. It is meant to show the operationalization principle of product = glass + evidence.

B.2 The source hierarchy and rules for interpretation

The following source hierarchy is applied to ensure the consistency in the desk-based assessment:

- **Law and regulation:**
The law and regulations define the obligations, responsibilities, traceability, and the logic at handover.
- **Normative standards:**
The normative standards define which type of evidence (declaration, calculation or test) must be shown for different performance aspects.
- **Policy and guidance sources:**
Policies and guidance show the supportive interpretation and the context of procurements.

Below the interpretation rules are shown:

- Only requirements relevant to intended façade application were included.
- The evidence needs to be able to link to specific units or batches.
- Safety, traceability, auditability and other (core) functional performances are treated as non-negotiable.
- Minor visual deviations are treated as potentially manageable if they are transparently documented and compatible with the intended usage.
- Environmentally related claims must have transparent boundary conditions to be accepted and allow comparability.

B.3 Source linked to requirement and evidence matrix for circular glass acceptance

In Table 29 the core audit trail is shown of the desk-based regulatory assessment. The main sources used for sub-question 2 are shown and linked to their corresponding requirements and evidence items which are expected in the project evidence package.

Table 29. Sources linked to corresponding requirements and evidence overview.

Acceptance layer	Requirement or topic	Main source	Evidence item in the evidence package
Regulatory and liability logic evidence	Product responsibility structure and putting product on the market	CPR (European Union, 2024)	- Responsibility structure identifies responsible actor. - Evidence package of the product - Declaration logic (if relevant)
	Product traceability, handover auditability and provenance	Wkb (Overheid.nl, 2019) and Bbl (Overheid.nl, 2018)	- Identification of units and/or batches - Provenance - Records of handling and/or storing - Complete set at handover
Performance evidence	Optical and solar relevant properties	EN 410 (NEN, 2011)	- A calculation, test result or a declaration linked to the units and/or batches.
	Thermal transmittance coefficient (U-value)	EN 673 (NEN, 2011)	- Complete calculation or report of the U-value with composition considered.
	Emissivity (if relevant)	EN 12898 (NEN, 2019)	- Emissivity determination of the linked configuration
	IGU properties quality and visual quality	EN 1279-1 (NEN, 2018)	- Configuration properties evidence - Record of visual assessment
	Durability (Moisture-related)	EN 1279-2 (NEN, 2018)	- Requirements of moisture penetration evidence
	Gas retention and concentration tolerance	EN 1279-3 (NEN, 2018)	- Gas retention requirements evidence
	Edge sealing performance	EN 1279-4 (NEN, 2018)	- Evidence of edge sealing (components) specifications
	Evaluation of conformity	EN 1279-5 (NEN, 2018)	- Evidence about conformity
	Durability and integrity of coating	EN 1096-2 (NEN, 2012)	- Identification of the coating - An assessment of the condition - Evidence about durability
	Identity and tolerances of float glass	EN 572-2 (NEN, 2012)	- Identification of the float glass - dimensional evidence (if relevant)
	Safety evidence (if relevant)	EN 14179-1 (NEN, 2016)	- Safety evidence for the intended placement
	Acoustic evidence (if relevant)	ISO 10140-2 (International Organization for Standardization, 2021) and ISO 717-1 (International Organization for Standardization, 2020)	- Acoustic rating evidence
Environmental and procurement evidence	Environmental comparability demands reporting structure	EN 15804+A2 (NEN, 2019)	- Structure of reporting including aspects as modules, assumptions, allocation choices and comparability
	Context related to circularity and procurement	CEAP (European Commission, 2020), Level(s) (European Commission, n.d.) and Bepalingsmethode Milieuprestatie Bouwwerken (Stichting Nationale Milieudatabase, 2025)	- Contextual reference for procurement structure - Contextual reference for reporting of sustainability

B.4 Contribution and limitation

This matrix shows how documentary requirements from specific sources were translated into practical evidence package elements. The key difference between new IGUs and circular glass is availability, traceability and evidence structure. This usually determines the acceptance criterion of circular glass. This interpretative framework does not replace legal, contractual, insurance and/or compliance assessment for specific projects.

Appendix C - Stakeholder roles and responsibilities framework (sub-question 3)

C.1 Purpose and scope

A summary of the desk-based stakeholder roles and responsibilities analysis is made in this compact appendix to support Chapter 5. Stakeholders, barriers/drivers and stakeholder roles and responsibilities are summarised.

The purpose of this appendix is to transparently show:

- Which sources are used in this analysis
- Which analytical themes are used in this analysis
- Which stakeholders and barrier/driver findings are used in this analysis

The appendix functions as a methodological and analytical support for sub-question 3 in Chapter 5 rather than as a separate empirical chapter.

C.2 Source overview

Three source groups were used for sub-question 3, these are mentioned in Chapter 5.

1. **Glass-specific circularity and façade sources**
2. **Circular-construction and governance literature**
3. **Internal thesis for context sources**

A compact overview of the sources used for sub-question 3 in Chapter 5 is given in Table 30.

Table 30. Compact source overview relevant for sub-question 3.

Source	Main relevance for sub-question 3
(Geboes et al., 2023)	Circular glass barriers, collaborations, logistics and the conservativeness of the sector
(Geboes et al., 2024)	Remanufacturing, network logic value and implementation levers
(Teeuwen, 2023)	Context of constraints, disassembly and compatibility relevant for façades
(Giorgi et al., 2022)	Barriers and drivers relevant for stakeholders in circular construction
(Charef et al., 2021)	Barriers regarding the organisational structure in circular construction
(Ranasinghe et al., 2024)	Continuity of information and traceability
(Ababio et al., 2025)	Procurement and collaboration logic relevant for stakeholders
(De Wolf et al., 2024)	Digital workflow, Digital Product Passports (DPPs), matchmaking, tracking and tracing and the enabling infrastructure relevant for reuse.

C.3 Analytical framework

Chapter 5 is structured around three analytical themes which were already explained. They are summarised below:

1. **Technical and logistical conditions**
2. **Organisational and contractual conditions**
3. **Social and market conditions**

These analytical themes can be seen in Table 31.

Table 31. Compact coding structure used in Chapter 5.

Analytical theme	Typical sub-themes
Technical and logistical conditions	- breakage - storage - yield - contamination - compatibility - classification
Organisational and contractual conditions	- liability - procurement - accountability - evidence continuity - warranties
Social and market conditions	- trust - conservativeness - perceived risk - acceptance of circular route options
Governance related translation	- RASCI implications - regulatory acceptance - handover relevance

C.4 Stakeholder matrix

The identified stakeholder groups relevant for circular glass are shown in Table 15.

C.5 Barrier and driver synthesis

The main identified barriers and drivers from Chapter 5 are summarised in Table 16.

C.6 Main synthesis statement

The desk-based stakeholder roles and responsibilities analysis suggests circular glass implementation depends on the interaction between the following three conditions:

1. Control of the technical condition and reverse supply chain logistics
2. Clarity regarding documentary, contractual and acceptance requirements.
3. The coordination of different stakeholders and their responsibilities across the reverse supply chain.

This appendix complements the previous statement that circular glass becomes more implementable when it is organised as “product = glass + evidence” supported by role clarity, traceability and standardisation.

Appendix D - Preliminary RASCI and implementation artefacts (sub-question 3)

D.1 Purpose and scope

This appendix supports Chapters 5 and 6 by presenting a preliminary responsibility structure and compact implementation artefacts for circular glass in façade refurbishments. It is derived from the combined findings on technical feasibility, regulatory acceptance, and stakeholder roles and responsibilities, and is intended as a structured starting point rather than a final validated industry model.

The appendix contains the following

- a preliminary RASCI matrix.
- a compact explanation overview of the different (main) responsibility allocation.
- an overview of stop-and-go gates.

D.2 Preliminary RASCI matrix

See Table 18

D.3 Brief explanation of the different responsibility allocations

The implementation logic derived in this thesis is used to develop the preliminary RASCI matrix. The intention of this preliminary matrix is to reduce responsibility gaps especially between the recovery, processing, evidence package creation and handover phases.

- **The owner side actors and the public clients** define the ambition and the procurement requirements.
- **Designers and façade engineers** perform assessments for the technical and functional suitability.
- **Main contractors** coordinate the delivery and perform the handover.
- **Dismantling contractors** retain the value during recovery.
- **Processors or remanufacturers** have the responsibility for classification, circular route specific processing and creating evidence.
- **The quality assurance (QA)** helps maintain consistent documentation.
- **Insurers or quality controllers** are relevant for residual risks and the final acceptability.

D.4 Stop-and-go gates

Four different stop-and-go gates are proposed in Table 32 to support a more disciplined implementation. The FCRBE does not prescribe a stop-and-go gate logic model, but the logic is consistent with the concept of a reclamation audit. The reclamation defined by FCRBE audit is an operation in buildings scheduled for partial or total demolitions with the aim of identifying building materials with (high) reuse potential. This audit eventually results in a reclamation inventory including information relevant for reuse, such as dimensions, quantities, condition, environmental impact, technical characteristics and/or disassembly recommendations. These inventories are used by FCRBE as a decision-support framework

regarding the feasibility and effectiveness of reusing products/materials. The need for an early identification, documentation and decision-making per stage before moving further in the reverse supply chain is supported by FCRBE (Deweerd & Mertens, 2020).

Table 32. Stop-and-go gates relevant for circular glass implementation.

Gate	Triggered moment	Main necessary evidence needed	Main decision choice
G1	During the definition of the project and procurement. Before recovery activities begin	The circular ambition, procurement requirements, availability of the resources, preliminary responsibility allocation and evidence requirements	Continue with the circular ambition, revise the procurement approach or stop the intended circular route
G2	After inspection and classification	Suitability of the selected circular route, classification results and traceability status	Choose a specific circular route (direct reuse, remanufacturing or high-quality closed-loop recycling) or reject
G3	After remanufacturing or processing for specific route	Documentary readiness after updated technical assessment and a route-specific preparation regarding the corresponding evidence	Approve, rework, downgrade the circular route or reject it
G4	Before handover	Complete evidence package and a clear sign-off logic at handover	Handover or hold

D.5 Main statement about implementation

When decisions are taken stepwise and clarified in front of the handover about responsibilities, implementation becomes more manageable. The feasibility of implementation of circular glass increases when uncertainties are being reduced about recovery control, traceability, regulatory acceptance and role clarity.

Appendix E - Interview participant information & consent form

Both the participant information and the consent form are based on the template given by TU Delft called “5 ICTG-Informed Consent templates and guide” which could be downloaded from the TU Delft website.

Participant information v1.0 (08-05-2026)

You are being invited to participate in a research study titled Circular Glass Implementation in Dutch Façade Glass Refurbishments. This study is being done by K.Q.D. Tinneveld from the TU Delft Faculty of Civil Engineering and Geosciences. No other external collaborating partners or funding body are involved. This research is conducted as part of an MSc thesis at Delft University of Technology.

The purpose of this research study is to investigate under which (technical, regulatory and stakeholder-related responsibility) conditions circular glass can be implemented in façade glass refurbishments in the Netherlands and will take you approximately 30 - 60 minutes to complete. The (interview) data will be used for analysing the MSc thesis, can also be used anonymised in the final thesis which may possibly be publicised in the TU Delft Repository. We will be asking you to answer interview a set of questions about façade glass refurbishment practice, different circular glass routes, regulatory acceptance, stakeholder responsibilities, barriers, drivers and practical implementation conditions.

As with any online activity, the risk of a breach is always possible. To the best of our ability, your answers in this study will remain confidential. We will minimise any risks by using TU Delft OneDrive for storage and restricting the access to only the student researcher and (if needed) the academic supervisor. Findings will be pseudonymised and anonymised before usage in the thesis. This is a semi-structured interview, not an anonymous survey. Only limited personal data will be collected, such as names, email addresses, professional roles, employer or organisation, signed consent forms and, if applicable, audio recordings. Names of persons, companies and/or identifiable projects will not be published.

No (raw) research dataset will be made publicly available. Only anonymised findings may be used and included in the thesis.

Your participation in this study is entirely voluntary, and you can withdraw at any time. You are free to omit any questions. Within two weeks after the interview you are allowed to withdraw your consent. After anonymisation it may no longer be possible to exclude individual contributions.

For questions about the research, you may contact:

Student researcher:

K.Q.D. Tinneveld

MSc Civil Engineering, Delft University of Technology

K.Q.D.Tinneveld-1@student.tudelft.nl

Academic supervisor:
Dr. ir. H.R. (Roel) Schipper
Faculty of Civil Engineering and Geosciences, Delft University of Technology
H.R.Schipper@tudelft.nl

A signed informed consent will be obtained before the interview.

Consent form v1.0 (08-05-2026)

PLEASE TICK THE APPROPRIATE BOXES	Yes	No
A: GENERAL AGREEMENT – RESEARCH GOALS, PARTICIPANT TASKS AND VOLUNTARY PARTICIPATION		
1. I have read and understood the study information dated 08-05-2026, or it has been read to me. I have been able to ask questions about the study and my questions have been answered to my satisfaction.	☐	☐
2. I consent voluntarily to be a participant in this study and understand that I can refuse to answer questions, and I can withdraw from the study at any time, without having to give a reason.	☐	☐
3. I understand that taking part in the study involves participating in a semi-structured interview of approximately 30 - 60 minutes. The interview will be conducted online or in person. With my separate consent, the interview may be audio-recorded and transcribed for analysis. If I do not consent to audio recording, written notes may be taken instead.	☐	☐
4. I consent the use of audio recording during the interview.	☐	☐
5. I understand that the study will end 31-08-2026	☐	☐
B: POTENTIAL RISKS OF PARTICIPATING (INCLUDING DATA PROTECTION)		
6. I understand that taking part in the study also involves collecting specific personally identifiable information (PII) including my name, email address, professional role, employer or organisation, signed consent form and, if applicable, audio recording. Also, Personally Identifiable Research Data (PIRD) including my interview responses, professional views, experiences and examples related to circular glass implementation and façade refurbishment. There is a small potential risk of my identity being revealed.	☐	☐
7. I understand that the following steps will be taken to minimise the threat of a data breach and protect my identity in the event of such a breach. Interview data will be stored securely in TU Delft OneDrive; access will be restricted to the student researcher and (if needed) the academic supervisor and interview findings will be anonymised or pseudonymised before being used in the thesis. Names of persons, companies and identifiable projects will not be published.	☐	☐
8. I understand that personal information collected about me that can identify me, such as my name, contact information or traceable data, will not be shared beyond the study team.	☐	☐

PLEASE TICK THE APPROPRIATE BOXES	Yes	No
9. I understand that the (identifiable) personal data I provide will be destroyed by the end of the project.	☐	☐
C: RESEARCH PUBLICATION, DISSEMINATION AND APPLICATION		
10. I understand that after the research study the de-identified information I provide will be used for thematic analysis regarding the research question	☐	☐
11. I agree that my responses, views or other input can be quoted anonymously in research outputs	☐	☐

Signatures

Name of participant [printed]

Signature

Date

I, as researcher, have accurately read out the information sheet to the potential participant and, to the best of my ability, ensured that the participant understands to what they are freely consenting.

Researcher name [printed]

Signature

Date

Study contacts details for further information:

K. Q. D. Tinneveld (e-mail: *K.Q.D.Tinneveld-1@student.tudelft.nl*)

Appendix F - Interview protocol and results

F.1 Purpose of the interviews

The semi-structured stakeholder interviews to complement the desk-based analyses were conducted with the aim to obtain practical insights into the implementation of circular glass in Dutch façade refurbishments. The interviews were used mainly to evaluate and contextualize the findings from the desk-based analysis.

Primarily the interviews support sub-question 3 but will also provide supporting insights for other sub-questions.

F.2 Justification for performing a semi-structured interview

In this thesis, a semi-structured interview approach was chosen because the implementation of circular glass is a practice-dependent and a relatively underdeveloped topic. The research covers different aspects (technical, regulatory and stakeholder-related) which require structured comparisons for exploring insights from stakeholders.

Because the main themes were known in advance semi-structured stakeholder interviews were selected. Specific experiences and/or practical barriers experienced could differ per stakeholder role. A consistent interview approach is used with also room for potential follow-up question for clarification. For built environment research this is suitable where qualitative methods are commonly used to study and analyse the professional practice, project processes and stakeholder perspectives (Fellows & Liu, 2022; Naoum, 2019) .

Interview results were thematically analysed using the three main dimensions of this thesis (technical feasibility, regulatory acceptance and stakeholder roles and responsibilities) which enabled comparisons across respondents while still allowing role-specific insights of stakeholders to be included.

F.3 Interview questions and analysis structure

Three themes (technical feasibility, regulatory acceptance and stakeholder roles and responsibilities) were used as a structure to analyse for the interviews. The findings were compared with the desk-based analysis.

The interview protocol based on the different analytical themes is summarised in Table 33.

Table 33. Interview protocol based on analytical structure.

Section number	Main focus / analytical theme	Interview questions	Corresponding relation to the thesis
1	Background and current practice	1.1 Could you please briefly describe your professional role and relevant experience with façade refurbishments, glass replacement and/or circular construction? 1.2 How are façade glass replacements typically organised in refurbishment projects, based on your experience?	To establish the context and current baseline relevant to circular glass (implementation) of the participant

Section number	Main focus / analytical theme	Interview questions	Corresponding relation to the thesis
		1.3 Why are new insulated glass units (IGUs) commonly selected in refurbishment projects from your experience?	
2	Technical and logistical feasibility	2.1 To what extent are you familiar with circular glass routes of IGUs (such as direct reuse, remanufacturing or high-quality closed-loop recycling)? 2.2 Which circular glass route do you consider to be the most realistic for façade refurbishment projects in the Netherlands, and under which conditions? 2.3 Which technical performance and/or quality conditions must be demonstrated/evidenced before recovered façade glass can be reused or remanufactured? 2.4 Which (logistical) risks during dismantling, storage, transport or processing could reduce the feasibility of the different circular glass routes? 2.5 How should recovered glass be inspected, classified and/or tested before it can be accepted for specifically the circular glass routes direct reuse or remanufacturing?	This corresponds to the dimension technical feasibility treated in sub-question 1. <i>This also supports sub-question 3 by identifying logistical risks, quality-control needs and reverse supply chain conditions.</i>
3	regulatory acceptance and liability	3.1 Which documents and/or evidence would you require before accepting circular glass in a refurbishment project? 3.2 How does the acceptance process for circular glass differ from the acceptance of new IGUs based on your view? 3.3 Where do you think the main liability, warranty or insurance concerns are for circular glass? 3.4 Which relevant stakeholder should be responsible for the verification and approval of the required evidence at handover?	This corresponds to the dimension regulatory acceptance treated in sub-question 2. <i>This also supports sub-question 3 by identifying responsibility, liability and handover concerns.</i>
4	Stakeholder roles and governance	4.1 Which relevant stakeholders are the most critical for a successful circular glass implementation and why do you think this? 4.2 How should the different responsibilities be allocated across the reverse supply chain (which is from the removal to eventually the final handover)? 4.3 How can procurement requirements positively encourage or negatively discourage the use of circular glass in refurbishment projects? 4.4 What are (the most) important organisational or contractual barriers relevant to the implementation of circular glass? 4.5 Which possible measures do you think would help to make circular glass more widely applicable in practice?	This corresponds to the dimension stakeholder roles and responsibilities treated in sub-question 3. <i>This supports sub-question 3 by examining stakeholder roles, procurement conditions, responsibility allocation and governance barriers in the reverse supply chain.</i>
5	Practical implementation and evaluation	5.1 Do you recognise the four different elements of the implementation kit as relevant for the implementation of circular glass in façade refurbishment projects? 5.2 Is the circular route decision logic (element 1 of implementation kit) realistic in practice with the following circular glass routes: direct reuse, remanufacturing, high-quality closed-loop recycling and downcycling as fallback? 5.3 Does the regulatory evidence checklist include the most important evidence needed for acceptance at handover, and are there (important) documents missing?	<i>This supports the implementation kit (Chapter 6) by assessing the practical relevance of the proposed implementation kit and identifying conditions for implementation in practice.</i>

Section number	Main focus / analytical theme	Interview questions	Corresponding relation to the thesis
		5.4 Does the preliminary RASCI matrix allocate the different stakeholder roles and responsibilities in a realistic way, do you agree on your role specification? 5.5 Are the proposed stop-and-go gates useful decision moments during a façade refurbishment project? 5.6 Which part of the proposed implementation kit would be the most difficult to apply in practice, and why? 5.7 What would you change, add or remove to make the implementation kit realistically more useful for real projects?	
6	Closing the interview	6.1 Do you have any (final) comments or recommendations regarding the interview about the implementation of circular glass in façade refurbishment projects?	

Answers were analysed thematically using the three dimensions described above.

F.4 Interview participants, data handling and coding approach

In this thesis five semi-structured stakeholder interviews were conducted. Four interviews were audio-recorded and processed with the written interview notes combined with the transcriptions. One interview was processed using only the written interview notes because no audio recording was available. Before the analysis, all interview data were pseudonymised. The participants are therefore referred to as P1, P2, P3, P4 and P5.

The selection of the participants was based on their professional experience with either refurbishment projects, building maintenance, sustainability, circular construction and/or project implementation. The interviews were used in this thesis as an empirical evaluation and contextualisation layer for the desk-based findings.

Table 34. Overview of interview data used for analysis by coded participants.

Participant code	General role (description)	Data sources used
P1	QA / LCA advisor	Audio transcript + Interview notes
P2	Public Client + QA / LCA advisor	Audio transcript + Interview notes
P3	Main contractor	Audio transcript + Interview notes
P4	Asset owner / property manager	Audio transcript + Interview notes
P5	Asset owner / property manager	Interview notes

Note. P1 to P5 are pseudonymised participant codes. Raw transcripts, field notes and consent forms are not included in this thesis report because they contain potentially identifiable interview data.

The transcripts and interview notes combined were coded using a structured coding matrix. This coding structure followed the protocol of the interview based on the three main analytical dimensions, as well as the empirical evaluation of the proposed implementation kit.

The coding process followed the following four steps:

1. The interview data were organised per interview participant, and this was linked to the corresponding interview questions.
2. Responses were coded based on the analytical themes of the interview protocol
3. A cross-case comparison was made (Table 19) between the coded participants P1 to P5 to identify the recurring findings, differences and role-specific observations.
4. The findings were synthesised in Table 20. These findings were compared with the desk-based analysis.

F.5 Compact anonymised interview results matrix

The findings were synthesised in Table 19.

F.6 Cross-case synthesis and limitations

The performed interviews broadly support the findings from the desk-based analysis. Three implementation conditions were repeatedly confirmed across the different interviews: controlled recovery and logistics, sufficient evidence for regulatory and project acceptance, and early allocation of the stakeholder responsibilities. The participants also emphasised that the implementation of circular glass does not only depend on technical feasibility, but also on traceability, quality assurance, warranty logic, procurement requirements and clear stop-and-go gate logic. The interview sample was limited, and not all stakeholder groups were covered. Therefore, the findings should be interpreted as an empirical evaluation instead of sector-wide evidence.

Appendix G - Data management plan (DMP)

Based on DMPonline (<https://dmponline.tudelft.nl/>), the following data management plan is created based on the template “TU Delft Data Management Plan template 2025”. The download is given below:

Plan Overview

A Data Management Plan created using DMPonline

Title: Circular Glass Implementation in Dutch Façade Glass Refurbishments

Creator: Kilian Tinneveld

Principal Investigator: K. Q. D. Tinneveld

Data Manager: K. Q. D. Tinneveld

Project Administrator: K. Q. D. Tinneveld

Affiliation: Delft University of Technology

Template: TU Delft Data Management Plan template (2025)

Project abstract:

This master thesis investigates the implementation of circular glass in façade glass refurbishments in the Netherlands. The technical feasibility, documentary/regulatory acceptance and stakeholder/stakeholder roles and responsibilities are examined through the following methodologies: systematic literature review, desk-based analysis and semi-structured stakeholder interviews. These semi-structured stakeholder interviews are used as an empirical evaluation to the practical applicability of an implementation kit which consists of a regulatory evidence checklist, responsibility logic and stop-and-go gates.

ID: 203850

Start date: 01-07-2025

End date: 30-09-2026

Last modified: 12-05-2026

Circular Glass Implementation in Dutch Façade Glass Refurbishments

0. Administrative questions

1. Provide the name of the data management support staff consulted during the preparation of this plan and the date of consultation. Please also mention if you consulted any other support staff.

Armstrong, L., Data Steward at the faculty of Civil Engineering and Geosciences, has reviewed this DMP on 12-05-2026.

2. Is TU Delft the lead institution for this project?

Yes, the only institution involved

1. Data/code description and collection or re-use

3. Provide a general description of the types of data/code you will be working with, including any re-used data/code.

Type of data/code	File format(s)	How will data/code be collected/generated? <i>For re-used data/code: what are the sources and terms of use?</i>	Purpose of processing	Storage location	Who will have access to the data/code?
Interview audio recordings (if consent is given)	.mp3	Generated during the interviews, only with the participant's explicit consent, using an audio recorder on my mobile phone. The recording will be transferred to TU Delft OneDrive as soon as possible after the interview, after which the copy on my mobile phone will be deleted.	To support a more accurate transcription and the analysis.	TU Delft OneDrive	The researcher K.Q.D. Tinneveld (student) and academic supervisor H.R. Schipper (track coordinator) only (if needed).
Interview transcripts and/or notes	.pdf	Created from the audio recordings, if available, using the transcription function in MS Word. If needed, the transcription will be checked and corrected manually. The full transcripts may initially contain personal or organisational identifiers. These identifiers will be removed or pseudonymised during analysis. The full transcripts will not be published.	To conduct an analysis of the different stakeholder perspectives on circular glass implementation.	TU Delft OneDrive	The researcher K.Q.D. Tinneveld (student) and academic supervisor H.R. Schipper (track coordinator) only (if needed).
Informed consent forms	.pdf	Completed and signed by the participants (before performing the interview).	To document participation being voluntary, consent for recording and permission to use anonymised findings.	TU Delft OneDrive (stored separately from other files)	The researcher K.Q.D. Tinneveld (student) and academic supervisor H.R. Schipper (track coordinator) only (if needed).
Participant contact information details	.xlsx / email	Collected through emails and/or professional communication for arranging the interviews.	For scheduling the interviews and, if needed, for asking possible clarification.	TU Delft OneDrive (stored separately)	The researcher K.Q.D. Tinneveld (student) and academic supervisor H.R. Schipper (track

				from other files)	coordinator) only (if needed).
Anonymised interview transcripts and/or anonymised interview results	.pdf / .docx	Created from the full interview transcripts and/or notes by removing names, contact details, company-specific identifiers and other information that could directly or indirectly identify participants. Before publication of the thesis, the link between participants and the data used in the thesis will be removed so that the presented findings are anonymised.	To present and discuss the interview findings in the thesis without identifying individual participants or organisations.	TU Delft OneDrive (stored separately from other files). And (if relevant) included in the thesis document.	The researcher K.Q.D. Tinneveld (student), academic supervisor H.R. Schipper (track coordinator) only (if needed) and thesis readers/examiners (anonymised findings may be made publicly available as part of the published thesis).

II. Storage and backup during the research process

4. How much data/code storage will you require during the project lifetime?

- < 250 GB

5. Where will the data/code be stored and backed-up during the project lifetime? (Select all that apply.)

- TU Delft OneDrive

III. Data/code documentation

6. What documentation will accompany data/code? (Select all that apply.)

- Procedure – A description of data processing procedure(s) (such as laboratory setup, simulation workflows).
- Data – Methodology of data collection

IV. Legal and ethical requirements, code of conducts

7. Does your research involve human subjects or third-party datasets collected from human participants?

If you are working with a human subject(s), you will need to obtain the HREC approval for your research project.

- Yes – please provide details in the additional information box below

Based on semi-structured stakeholder interviews, the interviews collect professional stakeholder opinions and experiences about circular glass implementation in façade refurbishments. No vulnerable participants or sensitive personal data will be involved. I have not yet applied for the intended HREC approval. The participation is voluntary and based on informed consent. The results will be anonymised and/or pseudonymised.

8. Will you work with personal data? (This is information about an identified or identifiable natural person, either for research or project administration purposes.)

- Yes

Limited personal data will be processed for interview administration and research purposes. Including the names, email addresses, professional roles, consent forms and if consent is given, audio recordings. No sensitive personal data will be collected. Personal data will be stored securely with restricted access, and the results of the interviews will be anonymised or pseudonymised in the thesis.

9. Will you work with any other types of confidential or classified data or code as listed below? (Select all that apply and provide additional details below.)

If you are not sure which option to select, ask your [Faculty Data Steward](#) for advice.

- No, I will not work with any other types of confidential or classified data/code

10. How will ownership of the data and intellectual property rights to the data be managed?

For projects involving commercially-sensitive research or research involving third parties, seek advice of your [Faculty Contract Manager](#) when answering this question.

This is an internal TU Delft master thesis project. Data will be managed by the student researcher under supervision. Only anonymised findings will be used in the thesis.

11. Which personal data or data from human participants do you work with? (Select all that apply.)

- Other types of personal data or other data from human participants – please provide details below

- Proof of consent (such as signed consent materials which contain name and signature)
- Audio recordings
- Job title and/or employer
- Telephone number, email addresses and/or other addresses as contact details for administrative purposes
- Names as contact details for administrative purposes

Interview data will consist of professional opinions of the participants and their experiences regarding circular glass implementation in façade refurbishments. Interviews will be audio recorded (even when the meeting is by digitally teams). Contact details, job title/employer and signed consent forms will be collected for administrative and research-related purposes. Personal data will not be intentionally collected beyond what is necessary for the research. Any personal or organisational details mentioned during the interview will be removed or pseudonymised during transcription and analysis.

12. Please list the categories of data subjects and their geographical location.

The data subjects are professional stakeholders involved in façade refurbishment, circular construction or related built-environment practice. Participants are expected to be located primarily in the Netherlands.

13. Will you be receiving personal data from or transferring personal data to third parties (groups of individuals or organisations)?

- No

16. What are the legal grounds for personal data processing?

- Informed consent

17. Please describe the informed consent procedure you will follow below.

The participants will receive an information sheet and consent form before the interview (which is also shown in the appendix of the thesis). They will be informed about the following:

- the research purpose
- voluntary participation

- data usage
- confidentiality
- their right to withdraw

The written consent will be obtained before the interview, and audio recording will only take place if separate consent is explicitly given.

A (blank) consent form is also shared in the appendix of the thesis.

18. Where will you store the physical/digital signed consent forms or other types of proof of consent (such as recording of verbal consent)?

Signed consent forms will be stored digitally in TU Delft OneDrive. It will be stored separately from the interview data. The access is restricted to only the student researcher and (if needed) the supervisor.

If consent forms are signed physically, the signed consent forms are also stored in a secure place in a locked cabinet.

19. Does the processing of the personal data result in a high risk to the data subjects? (Select all that apply.)

If the processing of the personal data results in a high risk to the data subjects, it is required to perform a [Data Protection Impact Assessment \(DPIA\)](#). In order to determine if there is a high risk for the data subjects, please check if any of the options below that are applicable to the processing of the personal data in your research project.

- None of the above apply

The project interviews are low risk with professionals. It is without sensitive personal data, vulnerable participants, large-scale processing, profiling or automated decision-makings.

23. What will happen with the personal data used in the research after the end of the research project?

- Anonymised or aggregated data will be shared with others

The raw personal data will not be shared. Further, the audio recordings will be deleted after its transcription. Only anonymised (if needed) findings may be used in the thesis.

24. For how long will personal research data (including pseudonymised data) be stored?

- Personal data will be deleted at the end of the research project

25. How will your study participants be asked for their consent for data sharing?

- In the informed consent form: participants are informed that their personal data will be anonymised and that the anonymised dataset is shared publicly

No personal interview data will be shared as a dataset in the thesis. The consent form states that only anonymised findings may be used in the thesis.

V. Data sharing and long-term preservation

27. Apart from personal data mentioned in question 23, will any other data be publicly shared?

Please provide a list of data/code you are going to share under ‘Additional Information’.

- I do not work with any data other than personal data

29. How will you share research data/code, including those mentioned in question 23?

Select all that apply and provide additional details below.

- I am a bachelor's / master's student at TU Delft, and I will share the data/code in the body and/or appendices of my thesis/report in the TU Delft Repository

Only anonymised interview findings will be potentially included in the thesis. The raw interview data, full transcripts, consent forms and contact details will not be published.

30. How much of your data/code will be shared in a research data repository?

- Not applicable - No data/code will be shared in a repository

31. When will the data/code be shared?

- As soon as corresponding results (papers, theses, reports) are published

32. Under what licence(s) will the data/code be released?

- Other – please explain below

The thesis will be shared through the TU Delft Repository under the default copyright conditions. No research dataset or code will be released.

VI. Data management responsibilities and resources

33. If you leave TU Delft (or are unavailable), who is going to be responsible for the data/code resulting from this project?

My academic supervisor is Dr. ir. H.R. (Roel) Schipper, with email address H.R.Schipper@tudelft.nl

.

34. What resources (for example financial and time) will be dedicated to data management and ensuring that data will be FAIR (Findable, Accessible, Interoperable, Re-usable)?

TU Delft OneDrive and standard TU Delft tools will only be used for secure storage and documentation.

35. Which faculty do you belong to?

- Faculty of Civil Engineering and Geosciences (CEG)

Appendix H - Human Research Ethics (HREC)

HREC checklist form from the TU Delft website was downloaded and filled in regarding the HREC approval which was received on 09-06-2026. The filled in checklist needed for this request can be seen in this appendix.

Delft University of Technology HUMAN RESEARCH ETHICS CHECKLIST FOR HUMAN RESEARCH (Version January 2022)

IMPORTANT NOTES ON PREPARING THIS CHECKLIST

1. An HREC application should be submitted for every research study that involves human participants (as Research Subjects) carried out by TU Delft researchers
2. Your HREC application should be submitted and approved **before** potential participants are approached to take part in your study
3. All submissions from master's Students for their research thesis need approval from the relevant Responsible Researcher
4. The Responsible Researcher must indicate their approval of the completeness and quality of the submission by signing and dating this form OR by providing approval to the corresponding researcher via email (included as a PDF with the full HREC submission)
5. There are various aspects of human research compliance which fall outside of the remit of the HREC, but which must be in place to obtain HREC approval. These often require input from internal or external experts such as Faculty Data Stewards, Faculty HSE advisors, the TU Delft Privacy Team or external Medical research partners.
6. You can find detailed guidance on completing your HREC application here
7. Please note that incomplete submissions (whether in terms of documentation or the information provided therein) will be returned for completion **prior to any assessment**
8. If you have any feedback on any aspect of the HREC approval tools and/or process, you can leave your comments here

I. Applicant Information

PROJECT TITLE:	Circular Glass Implementation in Dutch Façade Glass Refurbishments
Research period: <i>Over what period of time will this specific part of the research take place</i>	01-07-2025 till 30-09-2026
Faculty:	Faculty of Civil Engineering and Geosciences
Department:	Civil Engineering
Type of the research project: <i>(Bachelor's, Master's, DreamTeam, PhD, PostDoc, Senior Researcher, Organisational etc.)</i>	Master's thesis
Funder of research: <i>(EU, NWO, TUD, other – in which case please elaborate)</i>	None. This thesis is part of the completion the MSc thesis at Delft University of Technology.
Name of Corresponding Researcher: <i>(If different from the Responsible Researcher)</i>	Kilian Tinneveld
E-mail Corresponding Researcher: <i>(If different from the Responsible Researcher)</i>	K.Q.D.Tinneveld-1@student.tudelft.nl
Position of Corresponding Researcher: <i>(Masters, DreamTeam, PhD, PostDoc, Assistant/ Associate/ Full Professor)</i>	Master's thesis
Name of Responsible Researcher: <i>Note: all student work must have a named Responsible Researcher to approve, sign and submit this application</i>	Dr. ir. H.R. (Roel) Schipper
E-mail of Responsible Researcher: <i>Please ensure that an institutional email address (no Gmail, Yahoo, etc.) is used for all project documentation/ communications including Informed Consent materials</i>	H.R.Schipper@tudelft.nl
Position of Responsible Researcher: <i>(PhD, PostDoc, Associate/ Assistant/ Full Professor)</i>	Coordinator's track Structural Engineering (MSc Civil Engineering)

II. Research Overview

NOTE: You can find more guidance on completing this checklist [here](#)

a) Please summarise your research very briefly (100-200 words)

What are you looking into, who is involved, how many participants there will be, how they will be recruited and what are they expected to do?

Add your text here – (please avoid jargon and abbreviations)
This Master thesis investigates the implementation of circular glass in Dutch façade glass refurbishments with the on technical feasibility, documentation, stakeholder responsibilities and practical barriers. Different methodologies are combined such as a systematic literature review, a desk-based analysis and about 5 voluntary semi-structured stakeholder interviews with relevant professional stakeholders mainly recruited through professional networks.

b) If your application is an additional project related to an existing approved HREC submission, please provide a brief explanation including the existing relevant HREC submission number/s.

Add your text here – (please avoid jargon and abbreviations)
Not applicable.

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- c) **If your application is a simple extension of, or amendment to,** an existing approved HREC submission, you can simply submit an HREC Amendment Form as a submission through LabServant.

III. Risk Assessment and Mitigation Plan

NOTE: *You can find more guidance on completing this checklist [here](#)*

Please complete the following table in full for all points to which your answer is “yes”. Bear in mind that the vast majority of projects involving human participants as Research Subjects also involve the collection of **Personally Identifiable Information (PII)** and/or **Personally Identifiable Research Data (PIRD)** which may pose potential risks to participants as detailed in Section G: Data Processing and Privacy below.

To ensure alignment between your risk assessment, data management and what you agree with your Research Subjects you can use the last two columns in the table below to refer to specific points in your Data Management Plan (DMP) and Informed Consent Form (ICF) – **but this is not compulsory**.

It’s worth noting that **you’re much more likely to need to resubmit your application if you neglect to identify potential risks**, than if you identify a potential risk and demonstrate how you will mitigate it. If necessary, the HREC will always work with you and colleagues in the Privacy Team and Data Management Services to see how, if at all possible, your research can be conducted.

If YES, please complete the Risk Assessment and Mitigation Plan columns below.				Please provide the relevant reference #		
ISSUE	Yes	No	RISK ASSESSMENT – what risks could arise? <i>Please ensure that you list ALL of the actual risks that could potentially arise – do not simply state whether you consider any such risks are important!</i>	MITIGATION PLAN – what mitigating steps will you take? <i>Please ensure that you summarise what actual mitigation measures you will take for each potential risk identified – do not simply state that you will e.g. comply with regulations.</i>	DMP	ICF
A: Partners and collaboration						
1. Will the research be carried out in collaboration with additional organisational partners such as: - One or more collaborating research and/or commercial organisations - Either research, or a work experience internship provider¹ ¹ If yes, please include the graduation agreement in this application		x				
2. Is this research dependent on a Data Transfer or Processing Agreement with a collaborating partner or third-party supplier? If yes, please provide a copy of the signed DTA/DPA		x				
3. Has this research been approved by another (external) research ethics committee (e.g.: HREC and/or MREC/METC)? If yes, please provide a copy of the approval (if possible) and summarise any key points in your Risk Management section below		x				
B: Location						
4. Will the research take place in a country or countries, other than the Netherlands, within the EU?		x				
5. Will the research take place in a country or countries outside the EU?		x				
6. Will the research take place in a place/region or of higher risk – including known dangerous locations (in any country) or locations with non-democratic regimes?		x				
C: Participants						
7. Will the study involve participants who may be vulnerable and possibly (legally) unable to give informed consent? (e.g., children below the legal age for giving consent, people with learning difficulties, people living in care or nursing homes,).		x				
8. Will the study involve participants who may be vulnerable under specific circumstances and in specific contexts, such as victims and witnesses of violence, including domestic violence; sex workers; members of minority groups, refugees, irregular migrants or dissidents?		x				
9. Are the participants, outside the context of the research, in a dependent or subordinate position to the investigator (such as own children, own students or employees of either TU Delft and/or a collaborating partner organisation)?		x				

<i>If YES, please complete the Risk Assessment and Mitigation Plan columns below.</i>					<i>Please provide the relevant reference #</i>	
ISSUE	Yes	No	RISK ASSESSMENT – what risks could arise? <i>Please ensure that you list ALL of the actual risks that could potentially arise – do not simply state whether you consider any such risks are important!</i>	MITIGATION PLAN – what mitigating steps will you take? <i>Please ensure that you summarise what actual mitigation measures you will take for each potential risk identified – do not simply state that you will e.g. comply with regulations.</i>	DMP	ICF
<i>It is essential that you safeguard against possible adverse consequences of this situation (such as allowing a student's failure to participate to your satisfaction to affect your evaluation of their coursework).</i>						
10. Is there a high possibility of re-identification for your participants? (e.g., do they have a very specialist job of which there are only a small number in a given country, are they members of a small community, or employees from a partner company collaborating in the research? Or are they one of only a handful of (expert) participants in the study?	x		Participants may be indirectly identifiable, due to their specialised roles combined through quotes or (project) examples.	All data findings will be used anonymised or pseudonymised. Quotations will only be used if they cannot be reasonably traceable to the participant. No names of persons, companies and projects will be shared.		
D: Recruiting Participants						
11. Will your participants be recruited through your own, professional, channels such as conference attendance lists, or through specific network/s such as self-help groups	x		A minor risk may be created for participants to feel obliged to participate when recruitment takes place through own professional network.	Participation is voluntary and will be made clear through an information sheet and consent form. Participants can refuse, skip questions or withdraw without consequences.		
12. Will the participants be recruited or accessed in the longer term by a (legal or customary) gatekeeper? (e.g., an adult professional working with children; a community leader or family member who has this customary role – within or outside the EU; the data producer of a long-term cohort study)		x				
13. Will you be recruiting your participants through a crowd-sourcing service and/or involve a third-party data-gathering service, such as a survey platform?		x				
14. Will you be offering any financial, or other, remuneration to participants, and might this induce or bias participation?		x				
E: Subject Matter Research related to medical questions/health may require special attention. See also the website of the CCMO before contacting the HREC.						
15. Will your research involve any of the following: • Medical research and/or clinical trials • Invasive sampling and/or medical imaging • Medical and In Vitro Diagnostic Medical Devices Research		x				
16. Will drugs, placebos, or other substances (e.g., drinks, foods, food or drink constituents, dietary supplements) be administered to the study participants? <i>If yes see here to determine whether medical ethical approval is required</i>		x				
17. Will blood or tissue samples be obtained from participants? <i>If yes see here to determine whether medical ethical approval is required</i>		x				

If YES, please complete the Risk Assessment and Mitigation Plan columns below.				Please provide the relevant reference #		
ISSUE	Yes	No	RISK ASSESSMENT – what risks could arise? <i>Please ensure that you list ALL of the actual risks that could potentially arise – do not simply state whether you consider any such risks are important!</i>	MITIGATION PLAN – what mitigating steps will you take? <i>Please ensure that you summarise what actual mitigation measures you will take for each potential risk identified – do not simply state that you will e.g. comply with regulations.</i>	DMP	ICF
18. Does the study risk causing psychological stress or anxiety beyond that normally encountered by the participants in their life outside research?		x				
19. Will the study involve discussion of personal sensitive data which could put participants at increased legal, financial, reputational, security or other risk? (e.g., financial data, location data, data relating to children or other vulnerable groups) <i>Definitions of sensitive personal data, and special cases are provided on the TUD Privacy Team website.</i>		x				
20. Will the study involve disclosing commercially or professionally sensitive, or confidential information? (e.g., relating to decision-making processes or business strategies which might, for example, be of interest to competitors)	x		Participants could unintentionally mention (commercially or professional) sensitive information such as decision-making processes, project examples, responsibilities warranties and/or other business-related practices.	The participants will be asked not to mention (commercially or professional) sensitive information. When sensitive information is mentioned, the details, names and/or identifiable projects will be removed or generalised during the transcription/reporting.		
21. Has your study been identified by the TU Delft Privacy Team as requiring a Data Processing Impact Assessment (DPIA)? <i>If yes, please attach the advice/ approval from the Privacy Team to this application</i>		x				
22. Does your research investigate causes or areas of conflict? <i>If yes, please confirm that your fieldwork has been discussed with the appropriate safety/security advisors and approved by your Department/Faculty.</i>		x				
23. Does your research involve observing illegal activities or data processed or provided by authorities responsible for preventing, investigating, detecting or prosecuting criminal offences <i>If so, please confirm that your work has been discussed with the appropriate legal advisors and approved by your Department/Faculty.</i>		x				
F: Research Methods						
24. Will it be necessary for participants to take part in the study without their knowledge and consent at the time? (e.g., covert observation of people in non-public places).		x				
25. Will the study involve actively deceiving the participants? (For example, will participants be deliberately falsely informed, will information be withheld from them or will they be misled in such a way that they are likely to object or show unease when debriefed about the study).	x					

ISSUE	If YES, please complete the Risk Assessment and Mitigation Plan columns below.		Please provide the relevant reference #	
	Yes	No	MITIGATION PLAN – what mitigating steps will you take? <i>Please ensure that you summarise what actual mitigation measures you will take for each potential risk identified – do not simply state that you will e.g. comply with regulations.</i>	DMP ICF
26. Is pain or more than mild discomfort likely to result from the study? And/or could your research activity cause an accident involving (non-) participants?		x		
27. Will the experiment involve the use of devices that are not 'CE' certified? <i>Only, if 'yes': continue with the following questions:</i>		x		
- Was the device built in-house? - Was it inspected by a safety expert at TU Delft? <i>If yes, please provide a signed device report</i>				
If it was not built in-house and not CE-certified, was it inspected by some other, qualified authority in safety and approved? <i>If yes, please provide records of the inspection</i>				
28. Will your research involve face-to-face encounters with your participants and if so, how will you assess and address Covid considerations?	x		A face-to-face interview is a minor health risk.	If preferred interviews could also be conducted online. Normal hygiene measures will be followed for in person interviews.
29. Will your research involve either: a) "big data", combined datasets, new data-gathering or new data-merging techniques which might lead to re-identification of your participants and/or b) artificial intelligence or algorithm training where, for example biased datasets could lead to biased outcomes?		x		
G: Data Processing and Privacy				
30. Will the research involve collecting, processing and/or storing any directly identifiable PII (Personally Identifiable Information) including name or email address that will be used for administrative purposes only? (e.g.: obtaining Informed Consent or disbursing remuneration)	x		Directly identifiable information (PII) data such as names, email addresses and/or signed consent forms are collected for the administration and consent.	TU Delft OneDrive will be used to store data securely and access is restricted to only the researcher and (if needed) the academic supervisor. The consent forms will be stored separately from the interview data.
31. Will the research involve collecting, processing and/or storing any directly or indirectly identifiable PIRD (Personally Identifiable Research Data) including videos, pictures, IP address, gender, age etc and what other Personal Research Data (including personal or professional views) will you be collecting?	x		The interview responses may contain PIRD-related (Personally Identifiable Research Data) professional views and/or examples. These could indirectly be linked to identify participants, organisations or projects.	The names of persons, companies and/or other identifiable projects will not be published. Data will be anonymised and/or pseudonymised in the report.
32. Will this research involve collecting data from the internet, social media and/or publicly available datasets which have been originally contributed by human participants		x		

H: More on Informed Consent and Data Management

NOTE: You can find guidance and templates for preparing your Informed Consent materials) [here](#)

Your research involves human participants as Research Subjects if you are recruiting them or actively involving or influencing, manipulating or directing them in any way in your research activities. This means you must seek informed consent and agree/ implement appropriate safeguards regardless of whether you are collecting any PIRD.

Where you are also collecting PIRD and using Informed Consent as the legal basis for your research, you need to also make sure that your IC materials are clear on any related risks and the mitigating measures you will take – including through responsible data management.

Got a comment on this checklist or the HREC process? You can leave your comments [here](#)

IV. Signature/s

Please note that by signing this checklist list as the sole, or Responsible, researcher you are providing approval of the completeness and quality of the submission, as well as confirming alignment between GDPR, Data Management and Informed Consent requirements.

Name of Corresponding Researcher (if different from the Responsible Researcher) (print)

K. Q. D. Tinneveld

Signature of Corresponding Researcher

Date: 08-05-2026

Name of Responsible Researcher (print)

Signature (or upload consent by mail) Responsible Researcher:

Date: 12-05-2026 H.R. Schipper

V. Completing your HREC application

Please use the following list to check that you have provided all relevant documentation

Required:

- **Always:** This completed HREC checklist
- **Always:** A data management plan (reviewed, where necessary, by a data-steward)
- **Usually:** A complete Informed Consent form (including Participant Information) and/or Opening Statement (for online consent)

Please also attach any of the following, if relevant to your research:

Document or approval	Contact/s
Full Research Ethics Application	After the assessment of your initial application HREC will let you know if and when you need to submit additional information
Signed, valid <u>Device Report</u>	Your <u>Faculty HSE advisor</u>
Ethics approval from an external Medical Committee	TU Delft Policy Advisor, Medical (Devices) Research
Ethics approval from an external Research Ethics Committee	Please append, if possible, with your submission
Approved Data Transfer or Data Processing Agreement	Your <u>Faculty Data Steward</u> and/or TU <u>Delft Privacy Team</u>
Approved Graduation Agreement	Your master's thesis supervisor
Data Processing Impact Assessment (DPIA)	TU <u>Delft Privacy Team</u>
Another specific requirement	Please reference/explain in your checklist and append with your submission

Appendix I - Compact overview of the implementation kit

In this Appendix a compact overview of the implementation kit is presented which is a part of the semi-structured stakeholder interviews. This was used during the interviews to ask questions about the implementation kit. The implementation kit translates the findings of this thesis into a practical structure for assessing whether circular glass can be implemented in façade refurbishment projects.

The implementation kit is based on the following principle:

product = glass + evidence

In other words, the physical circular glass product can only be accepted when supported by sufficient, traceable and auditable evidence.

The four different connected elements of the implementation kit are summarised in Table 35.

Table 35. A compact overview of the different implementation kit elements.

Element	Purpose	Main output including reference to the thesis
1. Circular route decision logic	To determine which circular route is most suitable for recovered façade glass.	See Table 10 and Figure 3
2. Regulatory evidence checklist	To define which evidence is needed to support the acceptance at handover.	See Table 14.
3. Preliminary RASCI matrix	To clarify the stakeholder roles and their responsibilities during the implementation of circular glass.	See Table 18.
4. Stop-and-go gate logic	To provide certain decision moments to determine whether the circular route can continue or whether a fallback route is needed.	See Table 32 and Figure 6.

Together, these elements are connected by the three main implementation conditions used in this thesis which support decision-making in practice:

technical feasibility + regulatory acceptance + stakeholder roles and responsibilities

This implementation kit is not intended to function as a formal certification system or legal approval tool. The purpose is to be used as a preliminary implementation kit to discuss with stakeholders whether the proposed circular route decision logic, evidence requirements, responsibility allocation and decision gates are understandable, complete and usable in façade refurbishment practice.

