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EDITED BY
Akila Pramodh Rathnasinghe,
Northumbria University, United Kingdom

REVIEWED BY
Lucio Blandini,
University of Stuttgart, Germany
Shashwat S.,
Ulster University, United Kingdom

*CORRESPONDENCE
Ruben Van Vooren,
ruben.van.vooren@vub.be

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Redefining façade renovation studies: ten building blocks from ten case studies to reuse façade products

Ruben Van Vooren[1,2]*, Esther Geboes[1] and Waldo Galle[1,3]

[1]Department of Architectural Engineering, Vrije Universiteit Brussel, Brussels, Belgium, [2]Bureau Bouwtechniek, Antwerp, Belgium, [3]VITO Nexus, Flemish Institute for Technological Research, Mol, Belgium

Circularity is increasingly recognized as a strategy for sustainable façade renovation. However, actual reuse of façade products remains rare, limited to pioneering projects that overcame recurring challenges. This paper analyzes ten recent façade renovation projects to identify actionable levers (i.e., actions, considerations and process tools to overcome recurring challenges) enabling reuse. Through qualitative coding of actions observed in the case studies, we distilled 30 levers into ten building blocks that should guide practitioners. In addition, the documentation of the case studies in ten project sheets could inspire practitioners and could serve as a starting point for other researchers using different lenses. Together, our findings contribute a practical framework to shift from a tabula rasa approach to façade renovations to one that values existing products.

KEYWORDS

case studies, circularity, façade, feasibility, levers, reuse, study process

1 Introduction

Façade renovations, driven by technical degradation, energy performance upgrades, and aesthetic changes, release large quantities of façade products. These are often energy- and carbon-intensive, costly, and durable. Current renovation and waste management practices largely discard these products, wasting their embodied economic, technical, and environmental values. To address this, value retention options such as reuse, refurbishing, remanufacturing, and repurposing (Reike et al., 2018; Van Vooren and Galle, 2024) offer alternatives. Table 1 provides an overview of the definitions of these four value retention options, supplemented by an illustrative example for insulated glazing. For the purposes of this study, the term *reuse* is employed as an overarching concept encompassing all four options. Due to several challenges, today the reuse of façade products is only observed in a limited number of pioneering projects. This research addresses the research gap on levers which can be implemented on a project level to overcome the recurring challenges to the reuse of façade products.

1.1 Challenges to reusing façade products

Recent literature has extensively examined challenges (often referred to as *barriers*) to circular construction (Munaro and Tavares, 2023). These studies apply varying

TABLE 1 Value retention options specific to post-consumer façade products.

Value retention option	Definition (ISO 59004:2024) - example for an insulated glazing unit (IGU)
Direct reuse	Use a product or its component parts after their initial use, for the same purpose for which they were originally designed - *reapply an IGU 'as-is', with only cleaning as a minor treatment.*
Refurbish	Restore an item, during its expected service life, to a useful condition for the same purpose with at least similar quality and performance characteristics - Re-injecting argon gas into the cavity of an IGU
Remanufacture	Return an item to a like-new condition from both a quality and performance perspective using an industrial process - *assemble a reclaimed glass pane with a new coated glass pane into an IGU*
Repurpose	Adapt a product or its component parts for use in a different function than it was originally intended for, without making major modifications to its physical, chemical or mechanical structure - *reapply an IGU from a façade into interior walls (with lower requirements)*

TABLE 2 challenges to the reuse of façade products, based on Van Vooren and Galle (2024).

Theme	Challenge
Uncertainties:	• Circular knowledge gap: the lack of awareness or understanding among actors about available value retention options beyond direct reuse, such as refurbishing, remanufacturing or repurposing; • Technical uncertainties: The lack of knowledge on the existing façade (products) leading to uncertainties on technical performance (and no guarantees or warranties); • Aesthetic uncertainties: Uncertainties related to the visual outcome of circular inventions, such as how the products will look or be perceived after reconditioning; • (general) procedural uncertainties: Uncertainties related to the necessary steps to be taken, how long these will take, and who needs to be involved; • Procedural uncertainties about material acquisition: Uncertainties related to the timing of purchasing image-defining reclaimed façade products, before building application (financing difficulty) or after (uncertainty to the design); • Financial uncertainties about study process: Uncertainties related to how much the study process will cost; • Financial uncertainties about implementation: Uncertainties related to how much the implementation will cost;
Financial:	• Study process cost: insufficient budget for circular studies. For example, not having the budget to investigate different value retention options; • Implementation cost: insufficient budget for circular implementation. For example, careful dismantling test proved too labor-intensive;
Human:	• Behavioral: Differences in motivation, mindset, or ambition among actors. For example, some of the project partners do not share the same circular ambitions;
Market demand:	• Salvaging: Limited market demand for reclaimed façade products;
Market offer:	• Sourcing: Limited market offer of reclaimed façade products; • Processing: Limited amount of contractors that offer circular activities, such as dismantling, cleaning, refurbishing, *etc.*,;
Procedural:	• Timing: Insufficient time for study process (e.g., finding new destinations) and/or execution (e.g., careful dismantling) • Storage: Insufficient storage space available
Environmental:	• Environmental balance: Environmental impacts of circular processes that outweigh their intended benefits. For example, additional emissions, energy use, or material inputs from steps like sanding or recoating;
Functional compatibility	• Functional mismatch: Mismatch between new demands and existing products. For example, the new function of a building requires larger openings in the façade.

categorizations and emphasize different dominant challenges, such as political and technological factors (ibid.), legislative constraints (Knoth et al., 2022), or systemic issues like capitalism (Lambec et al., 2024). While these studies include more nuance, the diversity of the dominant challenges shows that the literature on circularity challenges is far from uniform. This variation underscores the importance of considering the specific scope of each study.

The scope of this research focuses on today's reuse (a specific circular strategy) of façade products (a specific segment of construction products) within northwestern Europe (a specific geographic region). Although prior studies have addressed related aspects, this exact scope remained unexplored. For instance, Hartwell, Macmillan and Overend (2021) addressed façade systems in the UK, but combined today's reuse with design for future circularity. Similarly, Makkink (2021) and Knoth et al. (2022) investigated reuse challenges in NW-Europe (Brussels and Norway, respectively) but without a façade-specific focus.

To address this gap, our previous work analyzed recurring challenges in Belgium related to the reuse of insulating glazing (Geboes et al., 2022) and façade products more broadly (Van Vooren and Galle, 2024). As this paper targets façade products in general, the latter study (ibid.) provides the most relevant foundation. The survey and practitioner interviews which were used to define the challenges built on the existing literature. It identified several *uncertainties* as crucial recurring challenges, alongside technical issues and cost implications. Building on these findings, we further elaborate on uncertainties by categorizing them into seven subtypes, derived from the same dataset. A complete list of recurring challenges to façade reuse, including definitions, is presented in Table 2.

1.2 Existing reuse levers and frameworks

Several researchers have proposed frameworks and tools to address challenges to reuse. To explore these, two recent literature reviews on circular renovation processes are studied. Despite growing interest in circular construction (Ashrafi et al., 2025), knowledge gaps persist regarding reuse levers applicable at the project level.

Fernandes and Ferrão (2023) link specific reuse challenges to potential levers across the micro-, meso-, and macro-systems level (Kirchherr et al., 2017). However, this approach risks overlooking opportunities at the micro level, that is, within individual projects. For instance, to address economic challenges, Fernandes and Ferrão (2023) recommend tax shifts from labor to materials and tax exemptions for reclaimed products. The multitude of supporting references indicate that this is indeed a significant lever at the macro-systems level. Nevertheless, Gorgolewski (2018) also identified a project-level lever to reuse: collaboration with non-profit training programs to lower labor costs and create local job opportunities.

Ashrafi et al. (2025) conducted a systematic review of 121 papers on circular renovation, identifying three main phases: planning (i.e., documenting existing products), assessing (i.e., estimating reuse potential) and routing (i.e., defining new destinations). For each phase, they discuss the methods, approaches, and tools encountered in literature, but they acknowledge that "there may be additional aspects to explore" (ibid.). An aspect which could be explored in more detail, could be, for instance, reclamation inventories. Ashrafi et al. note that detailed reclamation inventories are labor-intensive because they are often created manually, suggesting acceleration through advanced technologies. Yet, recent studies propose alternative approaches. Lambec et al. (2025), for example, advocate splitting audits into progressive phases of continuous refinement, challenging the assumption that detailed information is required from the start to facilitate reuse decision-making in renovation practice. Such a distinction between a *quick audit* and a *supplementary audit* has been longer applied in practice (Smeyers et al., 2021).

The previous examples illustrate additional aspects which could be explored in research on circular renovation projects. Recent literature, as reviewed by Ashrafi et al. (2025), predominantly adopts hypothesis-driven approaches, often proposing innovations such as digital tools to support circular practices. In contrast, empirical studies typically examine existing processes and actions in practice, relying on retrospective case study analysis as a main research method.

1.3 Case study research on reuse projects

In the past decades, pioneering projects have successfully implemented the reuse, refurbishment, remanufacturing, or repurposing of façade products. These projects demonstrate that recurring challenges can be overcome, but how? Several researchers have examined design process characteristics that facilitate reuse, primarily through case study analyses of such projects.

In *Building with Reclaimed Components and Materials*, Addis (2006) analyzed 11 case studies, addressing building preservation, component reuse and material recycling for a broad audience of project actors. The book discusses different aspects of the study process (e.g., decision criteria and material sources) and shows how these might differ from *normal* projects. On a façade level, Addis discusses the state-of-the-art reuse and recycling potential of different façade products such as bricks, stone panels, glazing and metal sheeting, illustrated by UK case studies. Given the time elapsed since its publication, it may, however, not fully reflect contemporary contexts, such as energy performance regulations, the offer of the reclamation market or emerging circular expertise.

Similarly, research by Liz Ogbu, presented in the book *Design for Reuse Primer* (Public Architecture, 2010), distilled lessons from 14 case studies in the USA and Canada into actionable guidelines for practitioners. Gorgolewski (2018) expanded the scope further in *Resource Salvation: the architecture of reuse*, analyzing 19 case studies across the USA, Canada, Australia, the Netherlands, Belgium and the UK, and discussing drivers and levers for reuse within design processes.

Despite their key contributions to the field, these three publications address reuse levers at a general building level - covering structure, envelope, services, and interiors - rather than focusing specifically on façades. Moreover, the 44 projects studied by Addis (2006), Public Architecture (2010) and Gorgolewski (2018) were completed more than a decade ago. Consequently, a knowledge gap persists regarding recent practices of reusing façade products.

1.4 Research objectives

This study addresses a research gap at the intersection of façade renovation practices and the reuse of construction products. Specifically, there is limited insight into project-level levers that enable the reuse of façade products. To fill this gap, this research pursues two objectives. First, it aims to provide inspiration to practitioners and reduce perceived risks, thereby increasing the perceived feasibility of reusing façade products within large-scale renovation projects. As noted by Küpfer, Bastien-Masse and Fivet (2022), risk perception among clients and designers is a major determinant in the implementation of reuse strategies.

Second, it aims to answer the following research question:

> Which actionable levers can be used in the study phase of large-scale façade renovation projects in NW-Europe to overcome recurring circular challenges and enable the reuse of façade products?

These two research objectives are addressed through case study research on pioneering façade renovation projects. To minimize bias, we deliberately refrain from conducting a systematic literature review at this stage. Instead, our analysis is grounded in empirical observations from the case studies (see Section 2). Following the comparative analysis, a focused

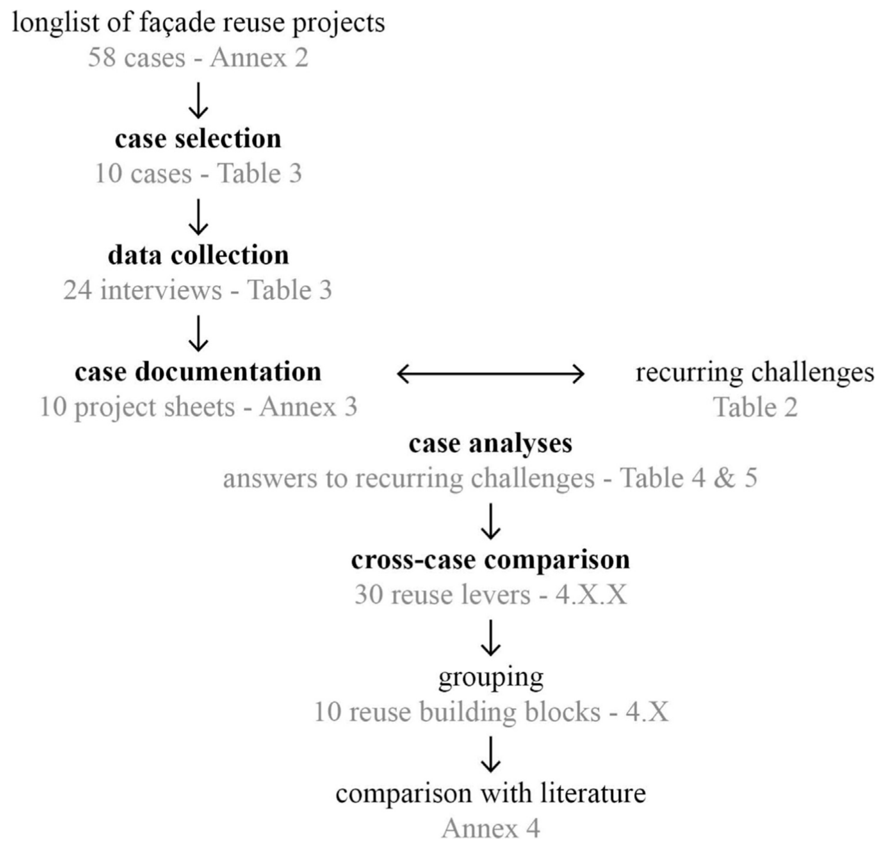

FIGURE 1
Research methodology.

literature review will position our findings within existing research (see Section 4.11).

2 Methodology

This study adopts a multiple-case study methodology to investigate how recurring challenges in façade reuse can be overcome. Case studies are particularly suited for answering *how* questions (Yin, 2009) and for generating practical insights from real-life examples (Flyvbjerg, 2006). Moreover, particularly in the context of circular construction, practitioners demand exemplary projects (Cambier, 2022). The case study approach aligns with our objectives to inspire practitioners by documenting diverse pioneering projects and identifying actionable levers. Figure 1 provides an overview of our research methodology. An extended version of the Methodology section, including additional operational details is included in Supplementary Material S1.

2.1 Case selection

A longlist of 58 projects in north-western Europe was compiled based on evidence of circular ambitions during façade interventions (see Supplementary Material S2). From this, ten cases were selected for in-depth analysis, following Miles et al.'s (2014) recommendation of 5–10 cases for cross-case comparison. Selection was guided by three criteria:

- Scope: façade interventions as part of renovation, excluding demolition or new build;
- Recency: projects completed within the last 6 years to ensure actor availability for interviews;
- Diversity: variation in façade products, reuse strategies, and implementation contexts to capture niche practices relevant to sustainability transitions (Geels, 2019).

Actor availability influenced the final selection, introducing an element of convenience sampling. The resulting set includes both on-site and off-site reuse cases, covering a range of technical and organizational approaches. Table 3 provides an overview of the cases, including the abbreviations which will be used throughout the paper.

2.2 Data collection

Data were gathered through desk research and semi-structured interviews with key actors (minimum two per case). Desk research provided baseline information on project characteristics and reuse ambitions, while interviews reconstructed the sequence of actions

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TABLE 3 Overview of the selected cases.

Project + function	Value retention option + façade product	Off-site/ On-site	Location	Interviewees
MULTI (MU) Offices	Reusing 44 tons of blue limestone elements Repurposing 49 tons of granite panels Repurposing 1.3 km of alu. Façade covers	On-site Off-site On-site	Belgium	Client Architect Reuse advisor: A. Vande capelle
U-square (US) Mixed-use, university	Reusing 85 m^3 of bricks Reusing 85 m of blue limestone plinths Repurposing 127 double glazing units	On- and off-site On-site On- and off-site	Belgium	Internal circ. Advisor Architect Reuse advisor to contractor
Centre pompidou (CP) Museum	Repurposing 178 curved single glazing panes	Off-site	France	Façade engineer: R. Ménard Circ. Researcher: C. De Wolf Reused furniture manufacturer
Betsy perk (BP) Elderly home	Remanufacturing 251 m^2 of double glazing	Off-site	Netherlands	General contractor IGU assembler: M. Rood and H.-J. Horring
K.118 (K118) Offices	Reusing 44 alu. triple glazed windows Reusing 12 alu. double glazed windows Reusing 609 m2 of alu. trapezoidal sheeting	Off-site Off-site Off-site	Switzerland	Architect
Nij smellinghe (NS) Hospital	Reusing 15.000 m^2 of fiber cement panels	On-site	Netherlands	Architect product advisor (orig. Manuf.)
Commerzbank/Hotel Ruby Luna (CB) Hotel	Refurbishing 3.200 m^2 of alu. sandwich panels	On-site	Germany	Façade engineer Façade contractor
Basler Kantonalbank (BKB) Offices	Reusing 405 aluminum panels Refurbishing 192 aluminum windows	On-site On-site	Switzerland	Client Architect: D. Vaner
Stuttgart-Feuerbach (SF) Swimming pool	Remanufacturing 60 double glazing units	On-site	Germany	Heritage department Façade engineer
Empire state building (ESB) Mixed-use	Refurbishing 6.514 double glazing units	On-site	USA	IGU assembler: K. Surace IGU assembler: A. Yanez and K. Nelson

and decisions during study and implementation phases. Interviews focused on factual events to minimize bias, and discrepancies were resolved through follow-up interviews or email validation. The collected information was synthesized into individual project sheets.

2.3 Data analysis

Data analysis proceeded in two stages:

- Within-case analysis: identifying how each case addressed recurring challenges to reuse of façade products (see Table 2).
- Cross-case comparison: applying qualitative coding to categorize case-specific answers as reuse levers. Coding started with combining six circular economy dimensions (Pomponi and Moncaster, 2017) with renovation phases and evolved iteratively through continuous comparison over a period of 26 months. Initial coding was jointly performed by two researchers; subsequent coding was refined through peer debriefing and comparison with reference works (Addis, 2006; Public Architecture, 2010; Gorgolewski, 2018). This process yielded 30 levers grouped into 10 building blocks, which form the basis for the discussion in Section 4.

2.4 Reliability and validity

Reliability and validity was ensured through multiple strategies. These measures strengthen the consistency and trustworthiness of the qualitative analysis:

- Data triangulation: interviews with different actors, supplemented by project documentation;
- Researcher triangulation: joint coding of initial cases and peer debriefing with a senior researcher in the field of circular construction;
- Participant validation: sharing project sheets and draft findings with interviewees;
- Comparison to literature: highlighting gaps and original contributions from this research.

2.5 Limitations

As with most qualitative case studies, findings aim for analytical rather than statistical generalization. Context-specific factors such as regulations or market conditions were not systematically analyzed but may influence transferability. Additionally, only one off-site reuse case involved image-defining façade products, limiting

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TABLE 4 Overview of how recurring challenges were dealt with in five case studies involving off-site reuse of façade products (i.e., sourcing from or salvaging for other projects).

Challenge	Multi	U-square	Centre pompidou	Betsy perk	K.118
Uncertainties					
Circular knowledge-gap	Reuse advisor, inventory	Reuse advisors, inventory	Engagement façade engineer, academics?	General contractor knew reman. Company	Architect is reuse expert
Technical	Archival research, tests, early-involved experts	Tests, advisors, fit-for-use	Repurposing with lower demands	Clear acceptance criteria, 10 years warranty	orig. Technical data sheets, material tests
Aesthetic	Processing tests	Processing tests, mock-ups	NA	Client and contractor visit reman. hall	Mock-up discussion with authorities during building applic. Process
Procedural (general)	Reuse advisor, de-construction team, tests, early-involved experts	Advisors, mock-ups, clear descriptions in tendering	Dismantling by faç. Contractor, engagement faç. ir	Remanuf. Company takes up entire study and impl. Process	Architect = reuse expert, purchasing mandate for quick decision-making
Procedural (material acquisition)	During execution, contractor *via* reseller	During execution, contractor *via* reseller	After design approval, interior designer and contractor *via* own network	During execution, *via* remanuf. Company	Before building application by architect with sourcing mandate
Financial (study process)	Reuse advisor: Price/h + cap	Indiv. Engagement	Individual engagement	NA (studies by reman. Company)	Collectively shared uncertainty
Financial (implementation)	Tests, early-involved experts, (de)constr. Team	Processing tests, reseller-advisor, tests during tendering	Free storage at façade contractor	Clear 10% additional costs	Detailed cost est. based on reuse experience of arch.
Costs					
Study process	Exclusive project, reuse as lever	2% additional fee for design team, award, individual engagement	Individual engagement, partly funded publication	Free studies by remanufacturing company (acquisition cost)	10%–15% advance pay-ment to finance scouting + prepurchasing
Implementation	Exclusive project, reuse as lever in negotiations with authorities	Award (€), on-site processing, clear reuse ambitions	add. Cost careful dis-mantling offset by sale, supply boxes reused for reclamation	Semi-automation of processing + still making financial losses, project-level cap	Limited add. Total cost (2%), decision-making on project level instead of product level
Behaviour					
Misaligned ambitions	2% goal, reuse meetings, archival research, exhibition, poster, book (afterwards)	Clear reuse ambitions, reports by reuse advisor (to contractor)	Publication, PR argument, indiv. Engagement	Client and contractor visit reman. hall	Visionary client, reuse network of architect, book (afterwards)
Market demand					
Salvaging	Acquisition and storage of granite by reseller without new destination	Project-to-project, own network of reuse advisor	p2p, *via* keynote lecture, mails and calls from own network of enfineer	glass remanuf. Company reclaims and supplies	NA (Active sourcing, not salvaging)
Market offer					
Sourcing	Via granite reseller from network of reuse advisor, direct contact	Via brick reseller, contractor (reclam. Clause)	Interior designer and contractor heard of opportunity *via* different contacts	glass remanuf. Company reclaims and supplies	Directly contacting building owners *via* Baugespann, platforms, resellers
Processing	'Linear' actors	Brick reseller cleans, 'linear' actors	'Linear' actors (faç. Contr.), circ. Interior company	glass remanuf. Company *via* general contractor	Reuse network of architect
Procedural					
Timing	Long study phase	Parallel studies and implementation	Indiv. Engagement	Phased impl. (Dismantl. + Install. From previous project)	Reclaimed products already purchased before building application
Storage	On-site basement + resellers	On-site, phased implementation	On-site + façade contractor as intermediary	Reman. Company as intermediary/reseller	Warehouses: Storage rental + bail contract
Other					
Environmental balance	Focus on large batches (mass), no LCA	On-site processing, (no LCA)	Local reuse, general envir. Argumentation in publication (no LCA)	(No LCA, EPD not yet made)	Limiting processing, swiss carbon database of mat. and processes
Functional mismatch	Resizing + reversing products, terrace system allowing differences in thickness	'Fit-for-use', repurposing (lower demands)	Repurp. (Lower demands), interior design based on available products	Resizing, 1 reused pane +1 new coated pane	Doubling windows, incr. Tolerances, façade design allowing dimensional differences, form follows availab.

insights into challenges related to the building application and acquisition of reclaimed façade products.

3 Results

3.1 A diversity of contexts

As explained under Section 1, we aimed for a diversity among the case studies on several aspects. First of all, the ten cases involved a wide range of façade products which were reused: aluminum cladding panels, blue limestone elements, granite façade panels, fiber cement panels, bricks, aluminum sandwich elements, aluminum windows, double glazing, and single glazing (see Table 3). Moreover, also different value retention options were applied on these products: direct reuse, refurbishing, remanufacturing and repurposing. Furthermore, the selection balances on-site and off-site implementation of the products, with five projects representing each product flow. Also a geographical diversity (within NW-Europe) was achieved, as the projects were located in Belgium (MU, US), France (CP), the Netherlands (BP, NS), Germany (CB, SF), Switzerland (BKB, K118), and the USA (ESB). Most of the projects were commissioned by private organizations and only two by public commissioners (US, SF). Finally, as the cases are pioneering projects (pushing the boundaries of circular construction practice), they should not be interpreted as general façade renovation practices. However, as they took place in the same (legal, technical and socio-economical) context, they are deemed representative to the scope of this research, i.e., large-scale façade renovation projects in NW-Europe.

3.2 Inspirational project sheets

The project sheets of the ten case studies are provided in Supplementary Material S3 as Supplementary Material. To increase the readability of the project sheets, actors are bundled in four groups with a corresponding color: clients in green, designers and advisors in yellow, contractors and suppliers in red, and authorities in purple. The color code next to every action in the timeline indicates which particular actor(s), listed on the left page, conducted the action. The timeline is split into the design phase and the execution phase, which should both be read vertically. Although the processes are presented on the timelines as sequences of individual actions, it should be noted that in practice, they often took place in an iterative way. As the architect of MU put it: "... the reality of a design and implementation process is far more complex, nuanced, back-and-forth, teamwork, feedback, feedforwarding, investigating, manipulating, inspiring, directing... than can be indicated by an infographic code ...".

3.3 Answers to recurring challenges and reuse levers

Tables 4, 5 show how the case studies dealt with the recurring challenges related to the reuse of façade products. Table 4 summarizes answers of the five projects which involved off-site reuse, i.e., applying products originating from another façade. Table 5 shows the answers of the projects which only reused façade products available on-site, i.e., from the existing façade. As explained in Section 1, this data was used for a cross-case analysis through coding.

The final result of this coding process is a set of 30 levers which could be applied on a project level to enable the reuse of façade products. Table 6 shows which of the levers were observed in which case studies.

4 Discussion: reuse building blocks for façades

Although the projects involved different product flows and contexts, similarities emerged in the answers to recurring challenges. The resulting levers are discussed in this chapter, grouped per reuse building block. Together, these provide an answer to our research question: "Which actionable levers can be used in the study phase of large-scale façade renovation projects in NW-Europe to overcome recurring circular challenges and enable the reuse of façade products?" Just as many reuse challenges are interrelated (Fernandes and Ferrão, 2023), so too are many of the levers. Nevertheless, the coding process revealed sufficient conceptual differentiation to justify treating them as separate levers for reuse. Consequently, cross-references to related levers will be made throughout the discussion. In the context of reuse in construction, such cross-referencing between themes and levers is considered an effective way to unravel (a part of) the systemic complexity, as demonstrated by Stricker et al. (2022). It should be noted that the observations used to illustrate the identified levers are only a selection of all case observations. Additional examples can be found by combining Tables 4–6. Finally, this section concludes by examining how insights from the ten case studies confirm or extend existing knowledge in the literature.

4.1 Get and keep everyone on board

The pioneering reuse projects succeeded through collaboration among many actors. To achieve this, it is crucial to get and keep everyone on board for reuse. Several process tools were observed to spark and sustain the engagement of project partners.

4.1.1 Engagement tools

The initiative for reuse in a project may come from any actor around the table, and sometimes from unexpected angles such as the original manufacturer (NS). Its success will initially depend on the ability to engage other actors around the table. 1nternal engagement tools, such as presentations of reference projects (MU), production hall visits (BP), mock-up discussions (BKB), and design workshops (CB) were observed and proved effective to engage others. Also external communication (see Section 4.10) reinforced engagement. In MU, regular reuse meetings, organized throughout the main study phase, helped to keep focus. However, when meetings became infrequent at the end of the study phase and new people joined the project, several reuse pathways were abandoned.

TABLE 5 Overview of how recurring challenges were dealt with in five case studies involving (only) on-site reuse of façade products (i.e., no sourcing from or salvaging for other projects).

Challenge	Nij smellinghe	Commerzbank	Basler Kantonalbank	Stuttgart-feuerbach	Empire state building
Uncertainties					
Circular knowledge-gap	orig. Manuf. Suggests reuse	Faç. Engineer. + Original faç. Contr., design workshop	Architect previously carpenter initiates reuse ideas	glass specialist heritage dept., IGU assembler, technical advisor	IGU assembler
Technical (legal)	Other test reports, orig. Manuf., shared liability (2 years)	contractor's archive, tests (anodization, fire, glue), 10 y guarantee	Archival research, orig. Faç. Contr., orig. manuf.s, audit, refurbishing	techn. feas. Study, early-involvment IGU re-assembler, study on techn. Lifespans	original data sheets, measure U-value, 10 years guarantee
Aesthetic	On-site mock-up	Processing tests, mock-up (off-site and on-site)	Processing tests, comparative mock-up	Mock-ups	Cleaning tests
Procedural (general)	Processing tests, construction team, orig. Manuf.	Faç. Engineer. + faç. Contr., processing tests, mock-up involving sub-contractors	feas. Study, faç. Engineer. + faç. Contr., processing tests, mock-up	Heritage dpt. specialist coordinates, techn. feas. Study, mock-ups by glass studio + mandatory collab. IGU re-assembler and method	Processing tests, IGU assembler takes up entire study and impl. Process, engagement manuf. Engineer,
Financial (study process)	(Free advisory of orig. Manuf.)	Faç. Contr. Partly covered expenses for study phase as acquisition cost	Hourly rate for experimental part (mock-ups), description of indiv. Processing steps	Reuse mandatory (heritage), uncertainty allowed	Cost estimation by IGU assembler
Financial (implementation)	Reclamation rate through audit, cost estimation constr. Team	Mock-up, back-ups: price fixed for new elements	Cost estimation by façade consultant, mock-up	Cost estimations in feas. Study by glass specialist	Cost estimation by IGU assembler
Cost					
Study process	Free advisory of orig. Manuf.	Faç. Contr. Partly covered expenses for study phase	Reuse studies part of feas. Study on façade renovation options, detail mock-ups	Coordination by glass specialist from heritage dpt. (no project cost)	Free studies by remanufacturing company (acquisition cost)
Implementation	(Cost = new) local contr., constr. Team, alignment logistics	Renegotiation after 1st assignment, reuse required + copying more expensive	Cost savings through small interventions vs. new	Partial compensation *via* subsidy, process optimization by contractors	add. Costs reuse, long-term operational cost savings
Behavior					
Misaligned ambitions	(Circ. Ambitions), external communication *via* articles and videos	Reuse mandatory (heritage), lever to close plinth	Reuse drivers client, book (launch), mock-up convinces contractor impl. + 'training in maint.'	Reuse mandatory (heritage), IGU re-assembler involved early, heritage dpt. coordinates, book chapter	Reuse drivers client, on-site exhibition, workshop
Market offer					
Processing	'Linear' actors	'Linear' actors, specialized faç. Maint. Company	Local contractors from network of client (bank)	'Linear' IGU assembler, glass studios, network glass specialist	'Linear' IGU assembler
Procedural					
Timing	Phased implementation	NA (long execution, but reuse required)	On-site processing	Parallel implementation	Overnight phased impl., on-site processing
Storage	On-site	Storage at façade contractor	On-site storage on each floor	On-site +3 glass studios	On-site
Other					
Environmental balance	Limited processing, local, no coating, (no LCA)	NA (no reuse driver)	Limited processing, on-site, LCAs after project	NA (no reuse driver)	Workshop energy measures, on-site processing
Functional mismatch	No requirement of new image, resizing panels	new sandwich + interior insulation	Window refurbishment	1 reused pane +1 new coated pane to achieve Ug-value	Upgrading U-value, large quantities with same sizes

TABLE 6 Overview of the observations of reuse levers in the case studies.

Reuse building blocks / Case studies / Reuse levers	MU	US	CP	BP	K118	NS	CB	BKB	SF	ESB
4.1 get and keep everyone on board										
Engagement tools	x	x	x	x	-	-	x	x	-	-
Set collective ambitions	x	x	-	-	-	-	x	-	x	x
Consider individual reuse drivers	x	x	x	x	x	x	x	x	x	x
4.2 Define clear responsibilities										
Allocating time and money	x	x	-	x	x	-	-	x	-	-
Reuse coordinators	x	x	(x)	-	x	-	-	-	(x)	-
Clear descriptions, back-ups and clauses	-	x	-	-	-	-	x	x	x	x
Warranties and liabilities	-	-	-	x	-	x	x	-	x	x
4.3 Revalue and assess the existing										
Reclamation inventories	x	x	x	-	x	x	-	-	-	x
Archival research	x	-	-	-	-	x	x	x	x	x
Material tests	-	x	-	-	-	-	x	-	x	x
Feasibility studies	-	x	-	-	x	x	x	x	x	x
4.4 Gather the right experts and co-create										
Consider diverse specialists	x	x	x	x	x	x	x	x	x	x
Search for a win-win	x	-	-	-	-	x	x	x	x	-
Build a network	x	x	x	x	x	-	x	x	x	x
4.5 Experimental study and design process										
Façade audits and workshops	-	x	-	-	-	x	x	x	-	-
Small-scale processing tests	x	x	-	-	x	x	x	x	x	x
Experimental 1:1 mock-ups	-	x	-	-	x	x	x	x	x	-
4.6 Explore diverse sources										
New intermediaries for multi-comp. Prod.	-	-	-	x	-	-	-	-	-	-
Existing resellers of traditional materials	x	x	-	-	x	-	-	-	-	-
Direct exchange between projects	-	x	x	-	x	-	-	-	-	-
4.7 Creative and critical design										
Versatile and flexible design	x	x	-	-	x	-	-	-	-	-
Form follows availability	-	-	x	-	x	-	-	-	-	-
Adjusting the product or the expectations	x	x	x	x	x	x	x	x	x	x
4.8 Build on local tools, spaces and skills										
On-site reconditioning and storage	x	x	x	-	-	x	-	x	x	x
A local restoration market	x	x	-	-	-	-	-	-	x	-
Activating reuse-inexperienced actors	x	x	x	-	x	x	x	x	x	x
4.9 Ensure for smart planning										
Aligning the forward and reverse logistics	-	-	x	x	-	x	-	-	-	-
Phased planning	-	x	-	x	-	-	-	-	-	x
Parallel planning	-	x	-	-	-		-	-	x	-
4.10 share the story	x	x	x	-	x	x	-	x	x	x

4.1.2 Set collective ambitions

Because projects can span years with many actors and may involve actor or staff changes, continuous alignment of the collective drivers for reuse, i.e., why they are doing an extra effort, is critical. For example, in MU three architects with each a different expertise were involved. In CP, a façade engineer changed jobs. Clear, collective reuse ambitions can keep everyone aligned throughout the project. To avoid mixing up goals and means, these ambitions should remain flexible on how to achieve them. As such, they can be defined through open, market-challenging tenders or assignments (both for services or works). In line with the FCRBE framework (Chaussebel et al., 2023), the ambitions can be open or specific, and qualitative or quantitative, resulting in four combined strategies. Examples include:

- Open-qualitative: ambition of *maximal reuse* by the client (K118);
- Open-quantitative: 2% reuse goal of inflow mass - a core circularity indicator from ISO 59020 (2024) - defined during early design phase (MU);
- Specific-qualitative: result-based specifications on glass treatment, including detailed method, but allowing proposal of other process in contactor's offers (SF);
- Specific-quantitative: 60% reclamation rate for on-site bricks, included as requirement in tendering for works (US).

4.1.3 Consider individual reuse drivers

As the case studies illustrate, people may value different benefits of reuse. Making these individual drivers transparent among project partners helped to define shared reuse ambitions, and maintaining commitment to reuse decisions. Drivers which were observed include:

- Heritage value: iconic façade products with high embodied cultural value (CP, SF);
- PR/marketing on sustainability image of the project and the actors involved (CP, BP, NS);
- Reduced environmental impact, with a particular focus on global warming potential (K118);
- Reduced implementation time and cost of on-site reuse in comparison to a complete façade renewal (BKB);
- On-site employment of local contractors which saves carbon, time and money and allows to work with trusted contractors and invest in local companies (BKB client is a local bank and US client is a regional development corporation);
- Training of employees in reuse or maintenance works (contractor in BKB);
- Leverage in discussions with local authorities who value heritage aspects (e.g., heritage department in CB) or circularity in general (chief city architect in MU);
- Reduced risk of negative response to the building application as façade image might remain close to existing through on-site reuse (NS);
- Build knowledge on the long-term behavior of products and on reuse processes (original manufacturer in NS).

4.2 Define clear responsibilities

As the recurring challenges show (see Table 2), reuse comes with additional tasks, responsibilities, and risks. In some cases, clear agreements on timeframes, responsibilities, and fees were used to prevent misaligned expectations. In contrast, a lack of contractual clarity also led to disputes (e.g., on the expected result of a cleaning process in CB). Moreover, back-ups and clauses were defined to anticipate risks inherently to reuse (e.g., on material shortfalls). Also different types of warranties and liabilities were observed to mitigate risks associated with uncertainties on the technical characteristics of reused products.

4.2.1 Allocating time and money

Addis (2006) points out that the overall project planning will quite likely be longer for reuse than *normal*. Although no direct comparisons were made with conventional project planning, several projects (e.g., BKB, SF) provided additional time to thoroughly study the existing façade and its products (see Section 4.3). After all, it takes time during the study phase to reduce the time and risks of the execution phase - *Reculer pour mieux sauter*, in French. In some projects, also an additional financial renumeration was provided. For example, in US a 2% additional fee for reuse-related tasks was allocated to the design team (in reference to business-as-usual linear renovation projects). However, when closing the contracts, it might still be uncertain how much additional time and money will be required for the reuse processes. Therefore, contracts should allow flexibility. The studied cases assured this by including a fixed price per reused component (BP) or hourly rates for architects (BKB) and advisors (MU), with maximal expenses defined upfront.

4.2.2 Reuse coordinators

Appointing one or more reuse coordinators helped to follow-up reuse ambitions during the entire project and to coordinate (a part of) the additional tasks. In addition to a supervisory role, they also received an executive role, covering tasks like material scouting (K118) or writing reuse specifications (SF). In K118, their tasks were extended to material assessment, organizing logistics, and even material acquisition, for which they received a purchasing mandate with a prepaid budget, allowing for quick decision-making. In the cases, the reuse coordinators were either external advisors with particular reuse expertise (US, MU) or conventional actors around the table, such as the architect (K118, BKB). Yet, some of them lacked a clear assignment. Roles were often taken voluntarily, driven by personal motivation (CP, SF). Although this role can be shared by different actors, a clear assignment of reuse tasks is needed to avoid exploitation of motivated individuals.

4.2.3 Clear descriptions, back-ups and clauses

Just as the tendering for services, the tender documents for works clearly described what was expected. A clear description of works - well developed during the study phase - allowed contractors to properly estimate the costs (e.g., BKB), reducing the related uncertainties and hence allowing them to provide better offers. However, it also proved beneficial to include a certain flexibility in the technical descriptions. For instance, although the cleaning process of the glazing in SF was extensively studied in advance, the tendering allowed glass studios to propose a different approach if this could achieve the same results.

Several project teams planned back-ups for shortfalls or replacements. If, for example, on-site reclamation during execution would fall shorter than estimated, pre-defined methods and responsibilities were present to rely upon. In US, contractors were responsible for sourcing bricks from the reclamation market and proving their technical suitability if the target of 60% on-site reclamation was not met. This implies the need for and communication of a proper study on the expected reclamation rate (see Section 4.5.2). Storing surplus products can also reduce risks on replacements. Although this was only observed for refurbished insulated glazing (ESB), this might be especially relevant for rare façade products.

4.2.4 Warranties and liabilities

In Belgium (i.e., the authors' home country), new façade products often come with a 10-year warranty, while for second-hand products a legal minimum of only 1 year is required (Belgian Federal Government, 2004). As such, the seller might not want to provide an extended warranty due to, for instance, uncertainties on the technical characteristics of the product. In some cases, resellers provided extended warranties through a strict product selection (brick reseller in US) or remanufacturing processes (IGU re-assembler in BP). However, in most cases there was no reseller to provide a warranty. To deal with this, the façade engineer made a study on hypothetical warranty periods (SF), the original manufacturer signed a 2-year shared liability contract with the contractor and the client (NS), or the current (and original) façade contractor even provided a 10-year warranty on the installed products beyond their liability on the installation itself (CB). Such confidence in the existing products was based on assessments of the products characteristics, in relation to the requirements (see Section 4.3).

4.3 Revalue and assess the existing

In coherence with Fernandes and Ferrão (2023), the circular case studies started with characterizing the existing situation, rather than assuming complete replacement. More particular, they revalued and assessed the existing façade systems and products, exposing diverse qualities. The cases revealed different actions to do so: creating reclamation inventories, consulting archival documents and performing material tests, which can be part of a broader feasibility study. The outcomes of these actions were used to engage project partners on reuse (see Section 4.1.1), and facilitate decision-making.

4.3.1 Reclamation inventories

Several projects documented the reuse potential of on-site available façade products in reclamation inventories. These had different forms, depending on the scope and the target audience. For example, in the CP renovation, an extensive inventory was published only for the iconic curved glass panels, additionally demonstrating their application versatility. In accordance with the state-of-the-art approach to reclamation inventories (Lambec et al., 2025), the inventories were made through a process containing different steps of refinement. When it was not clear from the start which products had the highest reuse potential, an initial quick-audit was conducted, followed by a more detailed one on a selection of products (MU). This approach allowed to save time and costs compared to documenting all products equally in-depth from the start.

The estimation of the reuse potential can be based on a set of criteria or by analogy, i.e., by looking at commonly reclaimed construction products (Smeyers et al., 2021). While the latter proved valuable for traditional materials such as bricks and hardstone (US), it should be noted that today many façade products are not commonly available on the reclamation market. Therefore, the reclamation potential of aluminum façade covers (MU), glazing (US, CP), windows (K118), aluminum panels (K118) and fiber cement panels (NS) was assessed based on a set of criteria. For example, the size of a batch (e.g., the large scale of ESB) or the estimated reclamation rate (e.g., 85% in NS) both informed the financial viability (as general costs such as site installation need to be divided over the actually reclaimed products). The financial viability on its term informed a part of the reuse potential of a particular product.

4.3.2 Archival research

Archival research supported the technical assessment of the façade products and helped to understand the initial design intent. For example, original documentation from the archives of the initial client and façade contractor supported the reuse study in MU and CB, respectively. In the ESB project, original specification documents of the windows were used to make a first estimation of the energy performance. In K118, historical technical data sheets were used to estimate the U-value of the glazing. In addition to historical documentation, also repositories with contemporary data were used. For example, in NS, test reports from other recent projects - which were shared by the original manufacturer - informed the technical assessment of the existing fiber cement panels.

4.3.3 Material tests

Material tests confirmed performances of the existing products. In SF, the curvature of the reused glass panes was measured to estimate the service life of the remanufactured glazing. In ESB, the thermal performance of the existing glazing - U_g, a recurring uncertainty on reclaimed IGUs - was assessed in a thermal test chamber. In CB, tests included glue composition analysis, anodization thickness measurements, and fire safety tests of the sandwich assembly. In US, samples of bricks were tested on frost resistance, water absorption, density and compressive strength. Based on these tests, batches could be defined corresponding to different application requirements. As such, it could be assured that the bricks were fit for their particular new application.

4.3.4 Reuse feasibility studies

Reuse feasibility studies were conducted in several projects, facilitating decisions on which particular products to reuse, for which purpose, and through which particular operations. While Ashrafi et al. (2025) only discussed *reusability* (i.e., feasibility) criteria, in the cases the reuse decision-making was also based on the *desirability*, in accordance with Timm et al. (2023). Therefore, these studies used technical, financial, logistical, aesthetical and environmental criteria, aligned with the (personal or organizational) drivers of the decision-makers involved (see Section 4.1.3). In addition, some actors showed a critical attitude towards:

- The criteria selection, by including criteria that decision-makers might overlook, such as the environmental impact. In BKB the environmental impact was addressed intuitively without making specific calculations. Only in K118 carbon calculations were made (comparing new, reused and refurbished façade products), with an easy-to-use national carbon database, responding to actors who value quantified impacts;
- The use of criteria. To address the financial challenge to reuse, in K118 and BP, a financial cap was set at the project level, rather than rejecting the additional reuse costs on a product level. This enabled the implementation of labor-intensive reuse processes. In addition this approach also supported the highest circular strategy, *refuse* (Reike et al., 2018), by rejecting (technically unnecessary) finishing layers or product treatments while searching for cost savings (K118).

4.4 Gather the right experts and co-create

In the cases, substantial knowledge about reuse processes was found to already exist, but it is spread across different actors. Early involvement of supply-chain actors and reuse experts helped integrate their expertise on materials, logistics, costs, *etc.* This, in turn, reduced technical, organizational and financial uncertainties in the projects right from the start. Although *interdisciplinary* *collaboration of diverse experts* has been highlighted as a reuse lever (Kozminska, 2019), it remained unclear *which* actors are relevant for reuse processes of façade products and how to involve their knowledge. These aspects were illustrated by the cases.

4.4.1 Consider diverse specialists

Some cases relied on the knowledge of reuse-specific actors such as resellers (MU, US), remanufacturers (BP), material scouts (K118) or reuse advisors (MU, US). Most cases, however, relied on the *linear* façade value chain for technical, financial or logistical expertise. In addition to general contractors, façade contractors and demolition contractors, also manufacturers (NS, BKB), glass assemblers (BP, SF, ESB), processors (anodization company in MU or glass studio in SF), miners (MU), specialized façade planners (BKB), transport companies (K118), and research institutes (SF) were contributing to the reuse studies. In BKB, CB, and NS, original actors, involved in the design and/or construction of the original façade, were approached and provided crucial knowledge on the existing façade products and details.

4.4.2 Search for a win-win

Involving diverse actors can be complex, as clients might be reluctant to get even more actors around the table (Van Vooren and Galle, 2024) and the specialists themselves might be reluctant to share their knowledge. The case studies illustrate that these challenges may be overcome by emphasizing mutual benefits. For example, in NS the original manufacturer provided free advisory to gain more knowledge on their old products and for marketing reasons. They viewed the reuse of their 30-year-old façade cladding as proof of their products' durability and a way to position themselves as a sustainability- and solution-oriented partner to architects. In CB, the original façade contractor partly covered the expenses of the study phase, considering it as acquisition costs for the final renovation project.

If no clear mutual benefits can be found, clear contracts should be made to include the contractor's knowledge during the study phase. During the interview, the façade contractor of CB referred to Pre-Construction Service Agreements (PCSA) as good examples. With a PCSA, contractors are paid for contribution in studies before implementation, without committing to the full project. Alternatively, in MU and NS a continued collaboration from the study phase to the implementation was secured beforehand in the contracts. Depending on the type of expertise, tools and skills that were required, either a *construction team* involving a façade contractor (NS) or a *deconstruction team* involving a demolition contractor (MU) was observed. In addition, literature suggests to include a *method statement* requirement into tendering procedures (Addis, 2006; Ghyoot et al., 2022). This would require contractors to detail how they will meet certain goals, such as achieving a maximum reclamation rate, or how they would approach a challenging part of the reuse operation.

4.4.3 Build a network

As trust is essential for collaboration in construction projects (Rents et al., 2024), most of the actors involved in the case studies built a network of reuse actors. This helped them in finding the right partner(s) for studies on particular products or systems, retrieving offers for study and implementation, and fostering fluent knowledge exchange. For example, the extensive network of the heritage department in SF enabled to find the right glass conservation studios and IGU assembler to participate in the study and the execution of the glass remanufacturing process.

4.5 Experimental study and design process

Co-creation played a key role in the reuse of façade products (see Section 4.4), yet traditional approaches - working in separate *silos* defined by strict contractual boundaries - might hinder collaboration. The case studies applied several process *tools* to enable knowledge exchange between the actors involved through experimental study and design processes.

4.5.1 Façade audits and workshops

In some case studies, early and collective on-site façade audits (NS, BKB, US) and design workshops (CB) helped gather knowledge from original manufacturers, façade contractors, façade planners or resellers with a limited time investment. For example, at the start of the CB project, a design workshop was organized to explore different façade renovation strategies. This involved the 80-year-old engineer of the façade contractor who worked on the project in the '60s at the very start of his career. Furthermore, the workshop allowed to enthuse partners on reuse (see Section 4.1.1), and make them familiar with the limits and challenges to reuse processes.

4.5.2 Small-scale processing tests

Not all reuse knowledge came from existing actors. Some was gathered by performing processing tests, clarifying exact dismantling or reconditioning processes. In MU, BKB, CB, NS and US, several small-scale dismantling tests were executed to assess the practical feasibility and reclamation rates. These first tests gave insights into the financial viability of the entire reuse process. In MU, SF, BKB, CB and NS, particular reconditioning tests were observed, such as recoating existing aluminum (MU), separating and cleaning glass panes (SF), and renewing rubber gaskets from windows (BKB).

4.5.3 Experimental 1:1 mock-ups

When the entire reuse process of dismantling, transportation, reconditioning and reinstallation is tested on a small part of the façade it is defined as a *1:1 reuse mock-up* (Van Vooren and Galle, 2025). In NS, CB, BKB and SF, mock-ups were executed early on in the project as they were used to study the technical, logistical, financial and visual aspects of the reused products. By conceiving these mock-ups as experiments to learn from, rather than as final validation tools, they allowed co-creation of reuse concepts between architects, contractors, and other specialists. In K118, the mock-up also facilitated a discussion with the planning authorities during the application phase. In US, on the contrary, the mock-ups were only organized after the implementation had started, which allowed to involve the actual (sub)contractors who would execute the works.

4.6 Explore diverse sources

Beyond building a network for reuse feasibility studies (see Section 4.4.3), the actors from the case studies also built networks to facilitate matchmaking between offer of and demand for reclaimed construction products. The five case studies with off-site reuse provide examples of matchmaking approaches: through new intermediaries, traditional resellers, or direct exchange.

4.6.1 New intermediaries for multi-component products

Off-site reuse aligns best with conventional design processes through providers of reconditioned products, as they offer clear specifications and warranties (Addis, 2006). For multi-component façade products (e.g., window frames or IGUs), this reconditioning requires specialized knowledge, tools, skills and supplier networks of subcomponents. In BP, for example, the remanufacturing company GSF Glasgroep remanufactured insulated glazing. They also took care of scouting, dismantling, transporting, storing, testing, certification, and warranty. A comparison between BP and ESB (which collaborate with a remanufacturing company), and SF (which operates without such an intermediary) illustrates how involving such an actor can reduce complexity (i.e., the amount of coordination required) when refurbishing or remanufacturing insulated glazing. Although this added value of intermediaries suggests potential opportunities for new business models (especially for high-value products such as windows), today only a limited number of companies are observed offering reconditioned façade products.

4.6.2 Existing resellers of traditional materials

For single-component products, such as bricks or natural stone, resellers were approached in US and MU. It shows that reuse supply lines for traditional construction products are already (or rather, still) established in some countries, as noted for the Netherlands by Gorgolewski (2018). While Opalis.eu maps resellers in Belgium, the Netherlands and France, Cirkla.ch shows an overview of Swiss reuse actors. In addition to scouting, storage, transportation and certification, some resellers may provide additional reconditioning services (see Section 4.8.2). In US, the brick reseller sold cleaned bricks ready for implementation. Yet in MU, the granite purchased from a reseller still required resizing by an additional firm.

4.6.3 Direct exchange between projects

Three case studies demonstrated a direct material exchange with other projects (K118, US, CP). The matchmaking between offer and demand may start from either the demand-side or the offer-side. Respectively, these actions can be called *sourcing* (i.e., seeking reclaimed products) or *salvaging* (i.e., seeking new destinations for reclaimed products) (Van Vooren et al., 2025). In K118, the windows were sourced by the architect *via* owners of buildings due for demolition (found *via* the *Baugespann*) and digital platforms. In US, the reuse advisor of the contractor found new destinations for the insulated glazing by directly contacted contractors, architects, building owners, NGOs, material resellers and other circularity advisors from their own contact list. In addition, they shared information on the glazing *via* offer-based broker platforms for reused construction products. An equally labor-intensive salvaging process was observed in CP. While their efforts succeeded, the financial viability of offer-based matchmaking for reclaimed façade products without intermediaries can be questioned; which added - financial or other - value might a donor project receive in turn for the considerable effort of repurposing their reclaimed façade products? In fact, this question aims to open the discussion on a statement of Addis: 'In practice the reuse of façades is most likely to be successful when it is demand-led.' (Addis, 2006, p. 140)

4.7 Creative and critical design

When reusing existing façade products, functional mismatches may appear between the design requirements and available products (i.e., one of the recurring challenges, *cf.* Table 2). For example, window sizes specified in building application drawings may not match with available products. Therefore, façade renovation projects which integrate products sourced off-site may need to challenge the business-as-usual design approach. In the case studies creative examples were observed. Two alternative design approaches could be distinguished to deal with the uncertainties on the available products: a versatile and flexible façade design (and process) that accommodates for later changes within a certain range, and a façade design based on the reclaimed products which are already purchased (or reserved). In addition, a functional mismatch can be dealt with by either adjusting the product itself, or adjusting the expectations.

4.7.1 Versatile and flexible design

Anticipated changes or variations in the products to be applied were accommodated through versatile and flexible design approaches. In K118, for example, the overall façade design (with staggered façade surfaces) allowed for tolerances on the exact window sizes. Also a wooden façade structure, easy to adjust to the final openings, was used. In MU, a standard tile support system corrected tile thickness variations, enabling the repurposing of granite façade panels which included larger tolerances than new terrace tiles. In US, the back-up clause on the bricks (see Section 4.2.3) defined a range of suitable bricks. While being strict on the minimum technical requirements for the new application, flexibility was included through e.g., increasing color shades to match market availability.

Addis (2006) suggests a two-phased building application procedure to increase the flexibility, starting with an "outline application, followed by a detailed application once materials and components have been found." However, this was not observed in the case studies. Note that only in K118 the off-site reclaimed façade products - such as the windows - impacted the façade image. However, this project's building application was based on façade products which were already acquired, and hence did not require two phases.

4.7.2 Form follows availability

Buying and storing products in advance created certainty on specific product characteristics such as their dimensions or thermal transmittance (although this remained partially uncertain in K118). In K118 and CP this allowed to design with façade products reclaimed off-site according to the principle of *Form follows availability* (Studio Gang Architects, 2011), i.e., based on the exact characteristics of the reclaimed products that will be used. Several repurposing examples were observed in which the design stems from the inherent product characteristics. The architects in K118 applied windows in two layers to compensate for their lower U-value. In US, the design of the interior walls was based on the dimensions of the repurposed glazing, originating from the façade. In CP, the curved glass panes informed the generous design of the meeting rooms of the receiving project, Papillon.

4.7.3 Adjusting the product or the expectations

In the case studies, functional mismatches were often addressed through reconditioning, such as re-anodizing aluminum profiles (MU), resizing limestone and granite (MU), resizing glass panes (BP), increasing the thermal performance of IGUs through remanufacturing (BP, SF, ESB), resizing fiber cement panels (NS) or adjusting hinges and renewing gaskets and fittings of windows (BKB). Instead of adjusting the products, several design teams adjusted the expectations. To avoid reconditioning (saving costs and environmental impact), they questioned the relevance of certain product requirements and widened the acceptable ranges. For example, in K118 visual requirements such as uniformity were questioned, leading to the decision to reuse the aluminum façade panels without recoating them. In SF, the client agreed to tolerate a slight cloudiness in the cleaned glazing.

4.8 Build on local tools, spaces and skills

In many cases, the project team did not have to reinvent the wheel when it came to reuse logistics. Many tools, spaces and skills were already available, be it sometimes hidden. While several cases showed the potential of keeping the products on-site throughout the reuse process, others counted on the local reuse market or involved reuse-inexperienced actors. The opportunity to have local logistics, in contrast to new products which are often dependent on globalized manufacturing chains, showed several advantages. It limits transportation and hence reduces the associated environmental impact, time and costs of the execution, but also allows to invest in local businesses. This was a particular reuse driver for the client of BKB, a local bank (see Section 4.1.3).

4.8.1 On-site reconditioning and storage

Several options were observed for on-site reconditioning and storage. For example, cleaning aluminum panels (BKB), refurbishing aluminum windows (BKB), remanufacturing insulated glazing units (ESB) and cleaning bricks (US) proved to be executable in or around the renovated building. In some cases, like in ESB, heavy machinery can be brought on-site more cost- and time-efficiently than transporting all façade products off-site. In this example, a large oven arrived on site in two parts and was welded together once inside the building. As such, the contractor could install an IGU remanufacturing workshop on one of the floors. This approach was partly driven by high transportation costs within the dense urban context of ESB, and a request for continued use of the office building. Reconditioning on-site of course also implies on-site storage before installation in the same façade. Also in cases which involved off-site reconditioning, the existing building or site was used for intermediary storage of the reclaimed products (MU, NS, US).

4.8.2 A local restoration market

Logistics could also be kept local by looking for the necessary assets required for reconditioning and storage on the local restoration market. For instance, in MU and US, the blue limestone and granite was recut using large circular saws in the workshops of local stonemasons (65 and 90 km from the renovation site, respectively). In BP, the glass studios, specialized in glass restoration, not only possessed the right skills and tools for separating and cleaning the 60-year old glazing (while preserving the existing paintings), but also provided the stillages for transportation and storage space in their workshops.

4.8.3 Activating reuse-inexperienced actors

Where no reuse or restoration market is available (yet), the tools, spaces and skills of (local) reuse-inexperienced actors were used, even when they did not market reuse services. In CB, for example, the façade contractor who originally assembled and installed the façade was also equipped to execute the reverse operations carefully. In addition, manufacturers and assemblers often agreed to refurbish or remanufacture products when explicitly asked (e.g., blinds manufacturer in K118, façade contractor from BKB, and IGU assemblers in SF and ESB). Challenging façade actors (for a first time) on reuse might kick-start further development of circular practices, as observed in BP and K118. However, finding and convincing these actors might also be time-consuming. As with reuse feasibility studies (see Section 4.4.3) and material sourcing (see Section 4.6), several clients, architects and advisors built a network of (local) actors willing to work with existing materials (e.g., BKB, MU, SF).

4.9 Ensure for smart planning

Several examples were found of smart planning which reduced the time, costs and environmental impact of the reuse processes. However, it should be noted they might require additional coordination efforts which should also be accounted for.

4.9.1 Aligning the forward and reverse logistics

Aligning the forward and reverse logistics allowed to optimize the use of expensive resources. For example, tailored boxes for the supply of the new curved glass panes at CP were also used for the reverse transportation of the reclaimed glass panes to the (re) manufacturer and to the new construction site. Similarly, in BP and NS, trucks delivering reconditioned products also transported reclaimed ones back to the workshop. Such a smart alignment of logistics could also be cost-effective for expensive on-site equipment such as cranes. However, this was not clearly observed in the cases.

4.9.2 Phased planning

A phased planning facilitated the exchange of façade products between locations. For example, in US, bricks and limestone elements from one building were reapplied in another building which was renovated later on the same site. Alternatively, the IGUs were repurposed in the same building in a later phase of interior works. In NS, when renovating a particular façade segment, panels were installed which were reclaimed from a previous segment. However, shifting the position of façade products within a project was sometimes prevented by the requirement to reinstall reclaimed elements in their original locations. In BKB, the project team feared possible deformations of the aluminum panels and the attachment system, while in CB, the heritage department insisted on preserving the exact façade appearance.

4.9.3 Parallel planning

A parallel planning can shorten project timelines. This, in turn, might compensate for an extended study phase. In SF, for example, separating the works into three different lots (corresponding to three façades) allowed three glass conservation studios to clean the glass panes in parallel. As such, the labor-intensive cleaning process and required storage space could be divided between the three small-scale artisan workshops. Furthermore, in K118 and US, the study and execution phases overlapped. In K118, material sourcing and acquisition already started during the design phase, while in US studies such as material tests or design iterations only took place during the execution phase.

4.10 Share the story

Reporting on circular efforts and realizations and communicating these externally allowed to valorize additional efforts which were made within the pioneering projects. It contributed to shaping a *sustainability* image of the project or the actors involved, which sometimes was a particular reuse driver (see Section 4.1.3). The cases included diverse examples on how to share the reuse story:

- Written media: books (MU, BKB, K118, CP), book chapters (SF, US), website articles (e.g., BKB, NS, US), academic articles by an involved academic researcher (US), an article in a magazine of a contractor's association (US), and reclamation reports (US);
- Events and spoken media: book launches were used to communicate to a specific set of actors (e.g., the shareholders in BKB) or to a broad audience (MU), lectures (CP, US), guided tours (US), and an exhibition (US);
- Visual media: a construction site banner (ESB), and videos shared on websites of involved actors (e.g., BKB, NS, US) or YouTube (US, ESB, CP);
- Recognition: awards (e.g., US, BKB);
- Reuse design cues: (small) eye-catching reuse applications, e.g., lighting fixtures in the entrance hall of MU made from aluminum façade covers.

Nonetheless, without external funding (e.g., to make a book, in BKB and K118), practitioners often lacked time and money to thoroughly document their projects. Therefore, documenting inspiring examples in project sheets (see Supplementary Material S3) was a distinct research objective. They allow for comparison and highlight the many reuse endeavors involved in these pioneering façade renovation projects.

4.11 Comparison to literature

The 30 reuse levers discussed in Sections 4.1 to 4.10 include diverse actions and considerations. Organized into ten building blocks, they form a framework for addressing recurring challenges to the reuse of façade products at the project level. Collectively, these building blocks provide an answer to our research question. To assess whether they are unique to the ten cases from this study, a comparison is made with existing literature, which can be found in the Supplementary Material (Supplementary Material S4). At a high level, this comparison confirms that many levers proposed in the literature align with findings from the case studies. A more detailed analysis reveals several gaps and additional insights.

Gaps - levers from literature not explicitly addressed in this research:

- Insurance agreements: Addis (2006) notes that many insurance companies allow for the use of reclaimed products if prior agreement is obtained, recommending early engagement;
- Financial opportunities: Gorgolewski (2018) suggests collaboration with non-profit training programs for material processing to reduce labor costs and create job opportunities;
- Digital approaches: Ashrafi et al. (2025) list actions such as creating *as-built 3D models*, *collecting data with digital tools* and *evaluating material reusability digitally* as optional, but reuse-enhancing levers;
- Creating own stock: Ashrafi et al. (2025) highlight anticipating future material demands for material exchanges between projects that are managed under a unified framework, which they define as meso-level reuse.

Additions - original contributions of this research:

1. Framework development

Reuse building blocks: this study introduces a novel grouping of reuse levers into ten building blocks, providing a structured framework for addressing recurring challenges at the project level. The only exception is Share the story (Section 4.10), which phrasing is adopted from the Design for Reuse Primer (Public Architecture, 2010) due to its clarity and relevance.

2. Actionable Insights

- From considerations to actions: unlike the literature reviewed by Ashrafi et al. (2025), which lists considerations (the *what*), this research provides actionable levers (the *how*) derived from in-depth case studies. For instance, instead of stating "Determine recovery techniques" (ibid.), we propose specific actions to do so, such as engaging deconstruction teams (Section 4.4.2) or conducting small-scale processing tests (Section 4.5.2);
- Planning and logistics: while these aspects were only partially addressed in prior literature, *Build on local tools, spaces and skills* (Section 4.8) and *Ensure for smart planning* (Section 4.9) discuss specific examples of how to organize reuse planning and logistics;
- Façade-specific levers: while some levers have been mentioned in previous literature, this study contributes additional insights and examples that are particularly relevant to façades. These include *Façade audits and workshops* (Section 4.5.1),

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Experimental 1:1 mock-ups (Section 4.5.3), and *Versatile and flexible design* (Section 4.7.1), the latter being related to building applications where the façade image plays a significant role;

- Multi-component products: for complex products such as windows or insulated glazing, this study highlights the added value of involving remanufacturing intermediaries (Section 4.6.1).

3. Empirical Contributions

Original case study documentation (Supplementary Material S3): While the particular mapping of timelines added procedural insights to all case studies, three projects were already extensively documented in books - MU (Ooms, 2022), K118 (Stricker et al., 2022) and BKB (Ruby and Vaner, 2023). The seven other projects (US, CP, BP, NS, CB, SF, ESB) are original contributions to the reuse case study documentation in literature.

5 Conclusion

By analyzing ten pioneering façade renovation projects, this study addresses a critical research gap on how project teams can overcome recurring challenges to the reuse of façade products. The outcome is a set of 30 actionable levers, organized into ten reuse building blocks that together form a structured yet flexible framework for architects, engineers, and clients aiming to integrate reuse into façade renovation projects.

In addition to this framework, the research contributes actionable insights that extend beyond existing reuse considerations and levers in literature. These include strategies for planning and logistics, façade-specific levers such as façade audits and mock-up programs, as well as approaches for multi-component products involving remanufacturing intermediaries.

Finally, the empirical contribution lies in the documentation of ten real-life projects. The project sheets (Supplementary Material S3) provide detailed accounts of study and execution phases, offering practitioners concrete examples and inspiration. They also showcase aspects inherent to reuse processes (such as locality and craftsmanship) and can positively influence perceptions of the feasibility of reusing façade products in large-scale renovation projects. Ultimately, this research contributes to a growing body of knowledge that seeks to redefine façade renovation from a tabula rasa approach to one that values the existing.

5.1 Future research

Future research should focus on contextual validation, in-depth analyses and translating the research findings into non-academic formats for practitioners. First, it should examine the contextual dependency of reuse levers through empirical validation. This could be achieved *via* pilot façade renovation projects (i.e., action research) or comparative case studies across diverse geographical regions and on different façade typologies. Such investigations are required to understand how local regulations, market dynamics, and cultural practices shape the feasibility and effectiveness of particular reuse levers.

Second, additional in-depth case studies should zoom in on particular aspects, such as:

- Specific façade products: detailed mapping of reuse strategies, including reconditioning processes and the associated actors, assets and skills. The project sheets could serve as a foundation, supplemented by additional cases. For instance, the five glass cases (US, BP, CP, SF, ESB) could be expanded with five additional glass cases, applying different reuse operations;
- Off-site reuse cases: investigation into different material scouting strategies and actions, involving both intermediary resellers and project-to-project exchanges. This research should also identify particular approaches to building application procedures enabling off-site reuse of image-defining façade products;
- Quantitative analyses on reuse operations: evaluating the environmental gains, local job creation, timing, costs, *etc.*, of the reuse operations of façade products, compared to using new products;
- Technical performance testing: large-sample tests on reclaimed products, such as the insulation performance of insulated glazing units.
- Business model studies: detailed Value Network Mapping (Galle and Matti, 2022) on emerging intermediary roles which offer remanufacturing and refurbishing services for multi-component products, such as windows and glazing. The Betsy Perk case illustrates how glass remanufacturing companies can reduce complexity and uncertainty, signaling promising directions for new intermediary roles.

Third, future research could translate the research findings into practice through actionable documentation (e.g., illustrated booklets), linking the reuse levers to project timelines. Iterative validation *via* practitioner interviews, workshops, or pilot implementations (i.e., action research) should ensure relevance and usability.

Data availability statement

The original contributions presented in the study are included in the article/Supplementary Material, further inquiries can be directed to the corresponding author.

Ethics statement

Written informed consent was obtained from the individual(s) for the publication of any potentially identifiable images or data included in this article.

Author contributions

RV: Conceptualization, Data curation, Formal Analysis, Investigation, Methodology, Validation, Visualization, Writing – original draft, Writing – review and editing. EG:

Conceptualization, Data curation, Formal Analysis, Investigation, Methodology, Visualization, Writing – original draft, Writing – review and editing. WG: Conceptualization, Funding acquisition, Resources, Supervision, Writing – review and editing.

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Conflict of interest

Author RV were employed by Bureau Bouwtechniek.

The remaining author(s) declared that this work was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fbuil.2025.1727219/full#supplementary-material

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