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REVIEW

# Circular Retrofit Approaches: Linking Building Renovation, Resource Efficiency, and Environmental Sustainability

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## ABSTRACT

Circular retrofit practices are now being more firmly placed as a tool to reshape building renovation to be resource efficient and environmentally sustainable by adding life to assets, minimizing material throughput, and minimizing waste without compromising or impairing building performance. This report summarizes theoretical underpinnings, lifecycle plans, evaluation procedures, and implementation terms to describe the circular retrofits, as opposed to traditional energy-focused renovation. We explain the workings of circular retrofit thinking, with the focus on adaptability and reversibility, as well as value retention as internal design logic by the material, component, building, and district loop levels. Our next approach involves strategies in the pre-retrofit diagnostics, circular design and digital documentation, procurement and contracting, selective deconstruction, and operational practices that support the sustainability of performance and extend the service life of the components. The review assesses impact assessment methods, such as whole-life life cycle assessment, dynamic carbon accounting, material flow analysis, circularity indicators, and life cycle costing, which are vulnerable to system boundaries, baselines, service-life assumptions, and end-of-life allocation. Lastly, we examine barriers and enablers by policy, markets, business models, digital governance, and skills, and determine conditions for pathways that can be taken during the transition of pilot projects to mainstream practice. Future studies ought to focus on common typologies and accountability, longitudinal execution indicators, and composite evaluation systems that are unified in terms of carbon, resources, expense, and resilience.

***Keywords:*** Circular Retrofit; Building Renovation; Resource Efficiency; Whole-Life Carbon; Construction and Demolition Waste

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# 1. Introduction

The construction industry is at the crossroads of two critical issues of the twenty-first century: the pressing necessity to cut greenhouse gas emissions, and the no less pressing necessity to limit the sphere of resource extraction and the generation of waste [1,2]. Constructions are energy-consuming when in operation, yet they are also resource-consuming artifacts; the building, operation, and processing of their end-of-life consume a lot of upstream effects in mining, manufacturing, transport, and disposal. In most areas, most of the 2050 building stock already in place today implies that the highest near- and medium-term sustainability benefits will be attained not only through the creation of more improved new buildings, but through the enhancement of the already existing buildings. Renovation and retrofit are in a strategic position: they can be used to improve the performance of operations, increase the life span of services, and maintain the embodied value of old structures and elements [3]. However, traditional retrofit practice has conventionally been understood vaguely - as mainly an energy saving intervention - without systematically dealing with the material and circularity aspect, which is becoming more and more defining of the whole-life environmental performance.

It is particularly consequential that this new gap has been created since the paradigm of energy retrofit, as vital as it is, can inadvertently cause the transfer of the burden of operating energy to embodied effects [4]. The deep energy retrofits often imply significant material supplements (insulation, new facades, glazing, equipment), complicated assemblies, and early substitution of serviceable elements. Such near-term climate benefits can be compromised or can create periods of long payback in the carbon-intensive supply chain through the accumulation of resource costs and added embodied emissions. In addition, renovations produce enormous amounts of construction and demolition waste, most of which is downcycled or discarded in landfills because of contamination, composite materials, and low reverse logistics. The retrofit approaches should begin to change as the policy and industry focus on operational energy shifts to whole-life carbon and other wider resource effects. This has driven the focus towards circular approaches to retrofit, cutting-edge techniques which explicitly connect renovation of buildings to resource-efficiency and environmental sustainability using concepts of life extension, design to be adaptable and be disassembled, re-use of components, refurbishment, remanufacturing, and high-quality recycling [5].

Circular retrofit strategies can be conceptualized as the adaptation of circular economy principles to the renovation life-cycle by trying to maintain the functional and material value of the already existing building mass but providing a performance upgrade in line with climate, health, and resilience objectives [6]. Instead of perceiving a building as a disposable system of products, circular thinking describes it as a temporary store of materials and components, an urban mine, and focuses on ways to slow, narrow, and close material cycles. Slowing loops entails the stretching out of building and piece life with durability, maintainability, and flexibility. Narrowing loops will minimize the volume of material moving, through dematerialization, interventions to right-size, and focus on high-impact upgrades. Closing loops aims at maintaining materials in circulation using reuse, refurbishment, remanufacture, and recycling routes that save on value and reduce the environmental burden. These strategies can be used to enhance energy and carbon targets when they are applied to renovation decisions, to deal with other areas of sustainability like waste prevention, toxicity reduction, extraction pressure on biodiversity, and supply-chain vulnerabilities.

Notably, circular retrofit is not a solitary method, but a collection of tools spread throughout the process of renovation [7,8]. At initial project phases, it might include increased building diagnostics, assessment of material stocks, and selective deconstruction planning to find the elements that can be salvaged. In the case of design, it may denote the utilization of modular, layered assemblies, reversible connections, and specifications that aid in maintaining and reconfiguring later in the design. The circularity in procurement can be supported by performance-oriented specifications, take-backs, and contracting models, which embrace longevity and recoverability. Under the construction, the strategy could focus on the selective deconstruction, on-site sorting, and reclaimed components quality assurance. Circular retrofit is operational based on monitoring, planned maintenance, and the ability to improve systems gradually without inducing a wholesale response. Lastly, it also plans the future renovation by registering materials and components (e.g., material passports) and making sure that the materials that are added today can be taken apart and reclaimed tomorrow. This view of the lifecycle points out the fact that circularity is a challenge of organization and information, as much as it is a technological problem.

Irrespective of the increasing momentum, adopting the concepts of a circular retrofit approach is still difficult [7,9]. The current buildings are heterogeneous, and their documentation is often inadequate; the legacy hazards and contamination may complicate reuse, and the viability of component preservation is based on labor, time, and logistics. Secondary products have regulatory, liability, and warranty obstacles, and secondary product markets are skewed and piecemeal. There can be no standard metrics and decision tools in the design teams to compare the circular options with the conventional solutions, especially in situations where trade-offs occur between operational energy savings and embodied impacts. The limitations of data (particularly in the reuse of components, refurbishment, and end-of-life condition) can create uncertainty in the life cycle assessment, and pessimize bold interventions. In addition, a multi-actor system of owners, tenants, financiers, designers, contractors, regulators, insurers, and suppliers makes the circular retrofit decision-making process embedded in such a way that long-term value capture is not possible because of misaligned incentives. This leads to the fact that circular retrofit is usually presented by pilots other than mainstream at scale, and the evidence concerning its ecological outcomes and cost-related aspects is usually spread across different disciplines.

Literature that exists is abundant but disjointed. The studies of energy retrofit have come up with effective methods of operational modeling, measurement, and verification as well as the evaluation of policies. Research on the circular economy has also developed ideas of design to disassemble, product-service system, and material passport, frequently on a new-construction or new-product design basis as opposed to renovation. Construction and demolition waste studies indicate that there are technical and market obstacles to high-value recovery, but often the renovation process is seen as a waste-generation event and not a value-retention opportunity. Whole-life carbon is being increasingly considered in life cycle assessment research, although comparability has been weak due to inconsistent system boundaries, functional units, and assumptions regarding service life, replacement cycles, and end-of-life processing. The streams should be looked at in parallel rather than in reality; the renovation decisions made in the real world need integrated energy performance, material strategies, circular value retention, indoor environmental quality, and economic viability. To be able to back the progress of the research and the application of the research in practice, a regular review synthesizing these areas into a logical framework is required [6,8,10].

The current review article meets this demand by evaluating the concept of circular retrofit as a systems field that is connected to building renovation, resource efficiency, and environmental sustainability. The main assumption is that the modernization of the old buildings may be reconceived not as an energy-focused intervention only, but as a comprehensive sustainability plan, one that addresses the operational and embodied effects and minimizes the resource flows and waste. To operationalize this premise, the review poses four related questions: (i) How are the concepts of circular retrofitting specified and contextualized throughout the whole building lifecycle and at various loop levels (materials, components, buildings, districts)? (ii) How can renovation be made circular with the use of strategies, technologies, and project delivery practices? At what point do they have the biggest impact? (iii) What does environmental and resource-efficiency outcomes measurement entail, and what is the methodological assistance that leads to a degree of heterogeneity reporting beneficial outcomes and trade-offs? (iv) How do policy, market, digital, and organizational obstacles and facilitators influence adoption, and what is the most promising way of increasing the scale of the circulative retrofit practices [11–14]?

To address these questions, the review integrates evidence in a variety of methodological traditions, such as life cycle assessment (LCA), material flow analysis (MFA), building energy modeling, and development of the circularity indicators and empirical case studies of renovation projects and deconstruction supply chains [15,16]. The combination of operational and embodied effects within whole-life frameworks is given specific focus, as this is where the approaches of the circular retrofit stand the most in contrast to the traditional practice. Other dimensions that are often regarded as secondary but are of primary importance to adoption are also addressed in the review: life cycle costing and distributing risk; regulatory restrictions and quality assurance of reused components; and the contribution of digital tools (Building Information Modeling (BIM), digital twins, traceability technologies) to facilitating material inventories, documentation, and recoverability in the future. Since the choice of renovation depends on the context, the review points to the importance of building typology, climate zone, market maturity of secondary materials, and policy regimes to determine the viability and efficiency of circular strategies.

The second part of the article is structured in the following way. Section 2 provides conceptual background and suggests a systematic perception of circular retrofit in terms of loop level, lifecycle phases, and decision situations. Section 3 examines circular retrofit plans and enabling technologies in the fields of diagnosis, design, procurement, construction/deconstruction, operation, and next-use planning. Section 4 consolidates evaluation techniques and measures of resource performance and environmental sustainability, where the whole-life carbon, circularity indicators, and uncertainty management are highlighted. Section 5 analyses policy and market barriers and enablers, business model barriers and facilitators, and digital infrastructure barriers and facilitators, and concludes with a research agenda to enhance comparability, evidence standards, and scalability. Section 6 overviews the essential lessons to be learnt and provides practical implications for researchers, practitioners, and policymakers interested in streamlining the practice of renovation to be in line with circular and climate objectives.

It is by synthesizing these points of view that the current review will shed light on the meaning of such practices as the circular retrofit, where they are proven to contribute value, and what needs to be altered methodologically, institutionally, and technologically in order to be converted into a commonplace practice in building renovation. It is not meant to supersede the priority of energy retrofit, but to expand it: to make sure that when the existing buildings are changed to be decarbonised, they also reduce the amount of material extracted, avoid waste, and enhance the overall environmental performance of the constructed environment through its lifecycle[17,18].

# 2. Conceptual Foundations and Frameworks for Circular Retrofits

## 2.1. From Energy Retrofits to Circular Retrofits: Scope and Definitions

Circular retrofit methods are based on the expansion of the traditional renovation, with the existing building stock being considered both a performance-enhancing and a resource-saving asset[19]. Since the traditional aim of energy retrofits is the minimization of operational energy demand by envelope upgrades and system replacements, the typical circular retrofits combine these goals with a strategy that keeps values of materials, components, and assemblies intact throughout their lifespan. In order to achieve conceptual clarity and coherence across the disciplines, the approach used to carry out this review is to embrace a series of working definitions, which we consider to be used to draw the difference between the approaches of circular retrofitting and the traditional energy-driven renovation approaches (**Table 1**). Within this framing, the building is not just an energy-consuming system but also a long-term store of products and materials with the impacts they embodied already being in the bank and can be held with life extending and value retaining. Circular retrofit can then be characterized as a renovation intervention that intentionally tries to reduce, tighten, and close material loops that fulfil functional needs, including safety, comfort, and service supply. Slowing loops underlines the need to increase the service life of structures and components of a building by means of durability, maintainability, and adaptability. Narrowing loops aims at trying to lessen the amount of new material input needed to meet performance goals by using sufficiency-oriented design and intelligent intervention intensity. The strategy of closing loops aims at recovering value by means of reuse, refurbishment, remanufacture, and high-quality recycling routes that do not lead to downcycling and minimize disposal.

**Table 1.** Core terminology and conceptual scope of circular retrofit approaches used in this review.

| Term/Concept | Working Definition in This Review | Typical Unit of Analysis | Practical Implications for Renovation |
|---|---|---|---|
| Circular retrofit | Renovation that improves performance while retaining and recovering material/component value across time (slowing, narrowing, closing loops) | Building + components + materials | Shifts design focus from "replace" to "retain, adapt, recover" |
| Slowing loops | Extending service life of buildings/components through durability, repair, maintenance, adaptability | Service life (years), replacement frequency | Prioritize life extension and upgradeability over premature replacement |

**Table 1.** *Cont.*

| Term/Concept | Working Definition in This Review | Typical Unit of Analysis | Practical Implications for Renovation |
|---|---|---|---|
| Narrowing loops | Reducing material/energy throughput needed to deliver function | Material inflow (kg/m$^2$), intervention intensity | Prefer sufficiency and optimized scope to avoid over-renovation |
| Closing loops | Keeping materials in circulation via reuse, refurbishment, remanufacture, high-quality recycling | Recovery rate, reuse share, recycling quality | Requires selective deconstruction, sorting, and secondary markets |
| Value retention | Preserving functional and/or economic value of existing elements and new additions for future cycles | Residual value, functional performance | Encourages reversible assemblies and documentation (passports/logbooks) |
| Design for disassembly | Designing assemblies so layers/components can be separated without damage | Assembly/component level | Enables future upgrades and high-value recovery rather than downcycling |

One prominent conceptual difference is that the idea of circular retrofit is not characterized simply by the utilization of the characterization of circular or recycled material contents, but rather by the planning and organization of the retrofit process over time[20]. Two projects can use the same insulation or mechanical equipment, but be radically different in circularity, be based on the premature disposal of existing elements, be based on reversible assemblies, be based on choices of components that can be upgraded later, and have documentation that supports recovery in the future. Circular retrofit is also contrasted to generalized sustainability renovation because it preempts resource efficiency and material loop solutions as the primary design variables, and co-benefits. This point is especially significant in situations where operational decarbonization is achieved by grid electrification and renewable energy, which puts embodied impacts, material scarcity, and waste generation as an increasing proportion of the whole-life burdens. **Figure 1** shows conceptual framing, as it puts the strategies of circular retrofit in context to consider them within the scope of a lifecycle that connects the decision to renovation and its impact on the environment throughout the whole of its life.

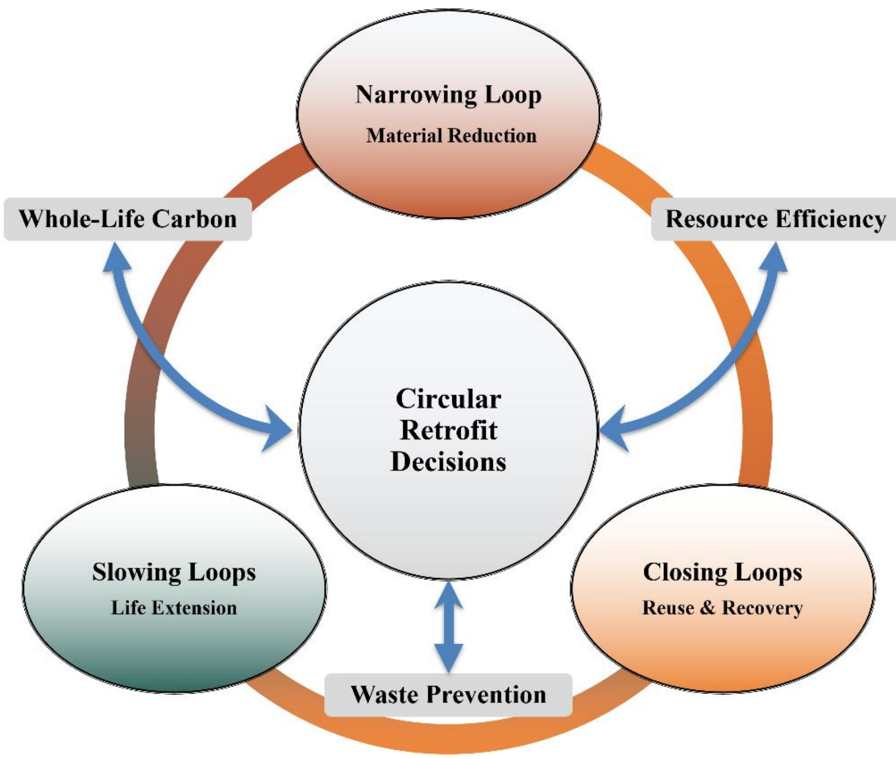


**Figure 1.** Conceptual framework linking circular retrofit strategies (slowing, narrowing, closing loops) with renovation decisions and whole-life sustainability outcomes.

## 2.2. System Boundaries and "Loop Levels" in Circular Retrofit Thinking

The conceptualization of interventions and the level of conceptualization are very reliant on the conceptualization of the system and its boundaries [11,21]. Circularity can be defined on a material level by material selection, i.e., recycled materials, bio-based alternatives, or low-impact binders, or by restricting the number of hazardous additives that make recovery more difficult. On a component level, circular retrofit prioritizes retaining, reusing, or refurbishing discrete building parts, such as façade panels, structural members, doors, raised floor, luminaires, or mechanical components, in the event of technical performance and compliance that may be guaranteed. This tier is tightly connected with the issues of standardization, testing, liability, and quality control, as the components should be able to meet the functional and safety standards in their second life.

Circular retrofit, at the building level, extends beyond the replacement of its components to also encompass life reforming by structural conservation, spatial reorganization, and adaptive re-use [7,22]. In this case, circularity is manifested by maintaining the core and shell in service, eliminating the necessity of a new building and preventing the embodied effects of the replacement. The building typology, heritage restrictions, occupancy requirements, and the malleability of the structural grid and service areas have a great effect on interventions at this level. Circular retrofit is integrated into wider infrastructures of exchange, logistics, and governance at the district or urban level. Re-use marketplaces, material banks, consolidated sorting facilities, and common aspects of energy systems can allow recovery and re-use of material across single project boundaries. Network effects also come out at this level as the feasibility of reuse and refurbishment of the projects will increase as more projects will be involved, stabilize supply chains of the secondary materials, and give confidence as the practice will be done in the same way.

The boundary is also not a spatial problem but a temporal one [23]. The decisions made at retrofitting change the pathway in the future since they determine the ease with which a building can be maintained, reconfigured, or dismantled in future cycles. Circular retrofit thinking thus needs to take time horizons, future renovation probability, and uncertainty with regard to climate adaptation, technology development, and evolving user demand. A small project centered on a single renovation activity is prone to maximizing short-term results while minimizing long-term recoverability. On the other hand, a lifecycle limit with design decisions taking into account successive interventions can explain apparently suboptimal design decisions in the short term, but enhance adaptation and reduce the aggregate impact across decades.

## 2.3. Circular Retrofit Principles as Design Logic: Adaptability, Reversibility, and Value Retention

Several design principles have been replicated in circular retrofit scholarship and practice since they directly affect the ability of a building to maintain value in response to its adaptive performance needs. Adaptability is the capability of a construction to suit new functions, layouts, and services with minimal disturbance to the material [24,25]. Adaptability is usually sought in the context of retrofit projects in terms of the flexible partitions, accessible service routes, and space configurations where invasive demolition is unlikely to occur due to changes in the future. Reversibility is pretty related, but it focuses on the technical ability to partition assemblies into recoverable components. Reversible relationships, modularization, and layered design allow replacement of short-lived layers selectively and without destruction of long-lived layers like the structural frame.

These principles are associated with environmental outcomes that are connected to value retention as a key goal. Retaining value refers to the conservation of functional performance and embedded investment of current materials and parts, hence lessening the need for fresh production and subsequent effects [26]. The value retention in retrofits may occur as structural systems preservation, mechanical equipment refurbishment and recommissioning, or re-use of interior components whose performance can be confirmed. The same applies to the materials that are brought in during the renovation process and should be chosen and put together in a manner that would allow them to be useful in the future. This is a focus on the overall lifecycle performance of the building and its elements instead of focusing on the instant project result.

The real-life application of these principles is based on the availability of information and coordination. Mechanisms such as material passports and building logbooks have often been suggested as a way of recording what is there, what has been incorporated, and how the elements are brought together, hence facilitating reuse and deconstruction management in the future. Such documentation can be supported by digital modeling environments, especially BIM, although the success of each depends on the uniform nature of data standards, responsibility delegation, and permanent archiving of records. In the absence of credible information, circularity strategies can be opportunistic, as opposed to systematic, based on salvageable objects easy to recognize, as opposed to systematic decision-making [27].

## 2.4. Decision Frameworks and Hierarchies for Circular Retrofit Prioritization

The process of making circular retrofit decisions entails several, and at times competing targets, which must be prioritized. The modification of the hierarchies of the circular economy to the context of renovation and avoiding unnecessary intervention is one of the most popular conceptual tools, which is followed by a reduction in material inputs, reusing or refurbishing old buildings, and only then by recycling or disposal. This, in practice, means that the question of retrofit planning is not what to substitute, but what can be left and improved by maintenance, repair, and optimization. This design has been based on the identification that the factor that can be used most efficiently in terms of resource requirement is the one that is already available, as long as it can address safety, comfort, and performance requirements [19,28].

Nevertheless, the implementation of hierarchies is to be interpreted rather carefully in the case of retrofit since buildings should also meet the energy performance requirements, indoor environmental quality requirements, and regulatory demands [29]. An example of this is keeping an old facade to maintain embodied value that limits operational decarbonization in the event that it does not allow an acceptable level of thermal performance or comfort, especially in future hotter climates. An increased use of hierarchical logic with multi-criteria assessment in decision frameworks is therefore the best way of balancing carbon, resources, cost, health, resilience, and risk. It is the integration of such criteria that forms the core of the idea of circular retrofit, since it avoids the idea of circularity being addressed as an isolated goal. Rather, a circularity becomes a dimension (one) at which the performance envelope becomes more transparent in terms of trade-off assumptions and scenario analysis.

The multi-criteria decision analysis is also often referred to as a way of justifying these trade-offs, especially where quantitative measures are not complete or unpredictable [30,31]. Sequencing and path dependency are also relevant in the decision-making in renovation projects because early decisions concerning structural preservation, routing of services, and envelope strategy determine the possibilities of future decisions. Structures that include some form of staging and gradual upgrades may be particularly useful, allowing buildings to enhance functionality and still stay in use, and minimize inconvenience. Circularity can also be driven through this staged method of reducing the replacement in advance and a more even allocation of material inputs over time as performance needs dynamically change.

## 2.5. Operationalizing Circular Retrofit in Research: Typologies and Comparability

The ongoing problem in the literature is that the concept of circular retrofit involves a wide variety of terminology, scales and outcome measures, preventing the comparison of the results of the studies. Circularity is also defined by some work with the main labeling of the material choices, some with the labeling of the practices of deconstruction and reuse, some with the adaptive reuse and life extension [32–34]. A more comparative approach would require a typological method that differentiates the types of interventions based on the loop strategy, lifecycle stage and level of action. The loop strategies may be defined in terms of the aim to slow, narrow or close the loop, whereas the differences in lifecycle stage explain the use of circularity obtained by early-stage diagnostics, design-reversible, circular procurement, selective deconstruction, or operational maintenance. The level of action differentiates between interventions, which have an overall effect on materials, components, entire buildings or larger urban systems.

Intervention-environmental outcome linkage can also be better made through such typologies [19]. As an example, the life extension at the building level can bring about such huge avoided impacts through demolition and replacement but this will depend on the counterfactual and assumed service life that has been extended. Reusing components can lower the embodied impacts compared to new products, although outcomes are determined by transport distances, refurbishment steps, and performance equivalence. Substitution of materials can decrease the impacts per unit material but overall effects are determined by the amount used, as well as whether substitution brings in new problematic areas like toxicity or end-of-life incompatibility. There cannot be typologies and clear reporting, and it becomes hard to identify which circular retrofit strategies are most efficient in what situations and under what conditions.

One of the associated conceptual problems is that of counterfactuals and baselines. The nature of the circular retrofit results is always comparative due to the fact that, in most cases, the benefits are achieved through prevention of production, prevention of waste, or prevention of demolition [35]. Baseline selection thus can have a serious impact on the results reported and may cause variations in conclusions drawn across studies. Besides, the time aspect of the circular retrofit raises the questions about the time when the effects take place and what valuation is required. Maintaining an existing component does not incur immediate embodied emissions, but might incur increased operational energy in the short term (because the performance is lower than a replacement choice), as well as leaving flexibility for an upgrade in the future. Their timing effects are better captured by research structures that explicitly capture such timing effects than by snapshots that are static.

## 2.6. Integrating Circular Retrofit with Whole-Life Sustainability Outcomes

The conceptual rationale of circular retrofit eventually follows the fact that it could lead to better whole-life performance because it can regulate the operational and embodied effects and decrease the throughput of resources [36]. This must involve a comprehensive understanding of the effects of retrofit options on various dimensions of sustainability at the same time. Operational energy and carbon are still key, particularly in those cases where buildings are still being heated using fossil fuels or in those cases where comfort and even health are being undermined by poor thermal performance. Meanwhile, embodied effects become comparatively more important as emissions in operations are reduced by the process of grid decarbonization and electrification. Circular retrofit frameworks react to this changing balance by focusing on interventions that will provide operational gains without excessive material turnover, and by making even the newly added material recoverable.

Circular retrofit overlaps with indoor ecology and resiliency, besides carbon and energy [37]. Ventilating, moisture, and envelope airtightness changes can be used to enhance health outcomes, although they present dangers unless combined with sufficient ventilation and commissioning. Likewise, climate adaptation retrofit strategies, including shading or cool roofs or flood-resistant assemblies, can also have the consequence of extending service life and minimizing future repair cycles, which in turn promote circularity. Such relations imply that circular retrofit cannot be conceptualized as a concomitant agenda that will be competing with energy retrofit, but as a coherent strategy that will expand the performance narrative to encompass the value of material retention, waste prevention, and long-term flexibility.

In short, the conceptual bases of circular retrofit integrate the principles of the circular economy with the conditions of renovation: heterogeneity of the old buildings, changing performance requirements, and a multi-actor decision system. This discipline is joined together by the focus on lifecycle thinking, retention of value, and the deliberate creation of assemblies and processes that can be recovered in the future. To translate circular retrofit between aspirational idea and coherent practice and to foster the support of strong evaluation in a variety of contexts, it is important to set the boundaries of the system, typologies, and integrated decision frameworks [21,38].

## 2.7. Typology-Based Differentiation of Circular Retrofit Approaches

Circular retrofit strategies are not uniformly applicable across building types. Historic buildings face stringent preservation regulations that limit envelope modifications and material substitutions; circularity here focuses on reversible interventions, maintenance of original fabric, and documentation of existing materials rather than deep energy retrofits. High-rise residential involves complex ownership structures (mixed private/social landlords), phased occupancy during renovation, and logistical constraints for material handling at height; circular priorities include standardized component reuse (windows, fixtures) and centralized deconstruction planning. Commercial stock typically offers clearer ownership and faster depreciation cycles, enabling business models such as product-service systems and leasing of facade or Mechanical, Electrical, and Plumbing (MEP) components; however, shorter tenant turnover periods may conflict with long-term value retention strategies [39].

# 3. Circular Retrofit Strategies and Technologies across the Renovation Lifecycle

## 3.1. Pre-Retrofit Diagnostics and the Identification of Circular Potential

Circular retrofit projects have an extended diagnostic phase that contains both a typical energy examine to systematic evaluation of the existing building as a component and material inventory [28]. This stage is generally a time of combining building condition surveys, documentation inspection, and more concrete questions regarding what is possible to hold on to, what needs to be upgraded, and what can be reused. The fact that existing buildings are, in most cases, associated with incomplete or outdated documentation makes the process of circular diagnostics often depend on a variety of evidence sources, such as on-site inspection, selective dismantling of assemblies, and selective sampling to identify the composition of materials and the existence of substances that can pose a risk to the safety of people. The goal is to develop a stable performance and recoverability baseline, such as structural integrity, envelope condition, and mechanical system serviceability, and the possibility of a selective dismantling.

Diagnostic practices are becoming more and more digital in capture in order to enhance the material and component information resolution and traceability. When there are no drawings, laser scanning and photogrammetry can be used to aid geometric reconstruction and as a foundation of digital modeling. The process of identifying the materials can rely on visual inspection, product marking, and laboratory testing, particularly in situations where reuse requires confirmation of mechanical properties or compliance tests. When retrofitting circular buildings, logistical concerns that are typically addressed as construction planning problems (accessibility, occupancy-based phasing, temporary storage of salvaged materials, and local availability of refurbishment services or secondary markets) also form part of the diagnostic stage in the case of circular retrofit. In this regard, circular potential cannot be considered merely a material property, but rather the socio-technical situation that is defined by the ecosystem of buffering infrastructure and regulatory demands surrounding it [40].

## 3.2. Design Strategies for Retention, Adaptability, and Reversibility

The design phase is the phase in which the intent of the retrofit in circles is converted into technical and organizational decisions that determine the material footprint of the project and future adaptability [32,41]. The retention-oriented design starts with the identification of those elements that can be preserved and that have high environmental and economic benefits, especially the structural frame, foundations, and any other long-lasting elements. By conserving these aspects, a significant amount of impact could be avoided since it would decrease the demolition and replacement, which also decreases the construction period and minimizes dislocation. Retention is not, however, a default behavior; frequently, design ingenuity is needed to accommodate new performance requirements and new constraints. Herein involves balancing thermal and moisture performance requirements with the current facades, integrating new services within small spatial areas, and accommodating upgrades in structure without involving large quantities of replaced materials.

Flexibility is sought through the design of spaces and construction systems that can be changed in the future with the least demolition. Practically, this can mean re-examination of partitions, routing of services, and spatial zoning in such a way that modifications are implemented by reversible interventions as opposed to invasive reconstruction. Layered design strategies, in which short-lived elements like finishes and equipment are isolated with long-lived structural and envelope layers, can be used to enhance both maintainability and circularity, since it allows replacement only selectively. The entrenchment of reversibility is achieved by the use of modular assemblies, standard dimensions, and interconnection features that can be disassembled to avoid harm to other materials. The design phase is thus the core issue in avoiding the formation of future locked-in composite assemblies that work quite well at the beginning but are inaccessible at the subsequent renovation step [42].

The choice of material in circular retrofit design is frequently presented as a priority that follows the line of preference towards reusing the already existing components and using the reclaimed products where possible[43]. Circular design focuses on more recoverable and less toxic materials when new materials are required, e.g., by avoiding problematic additives or composites that are difficult to separate. The idea of design to allow for the next retrofit is particularly relevant when deep retrofits are concerned, and elaborate envelope systems, airtightness layers, and integrated facade solutions can be very facilitating or hindering concerning future upgrades. The design of retrofit circles thus has a way of giving preference to those assemblies that do not give preference to performance and instead emphasize legibility and separability, and documentation practices that reveal the hidden layers to future actors.

### 3.3. Digital Tools and Information Workflows Enabling Circular Design

Digitalization has a unique contribution to the concept of circular retrofit since it helps in making current decisions and recovering in the future. Building information modeling is becoming a tool of coordination as well as storing material and component information that may be used in inventorying, specification, and subsequent recovery planning[44]. In renovation, the BIM models are usually started as a geometry/systems representation. Circular retrofit workflows aim to add to these models with qualities that can be considered to be relevant to the concept of circularity, including material composition, sequence of dismantling, anticipated service life, and possible reuse pathways. This enrichment of the data can help the scenario analysis, which will be able to compare alternative intervention strategies based on embodied impacts, operational performance, and maintenance requirements.

It has been suggested that materials passports and building logbooks are mechanisms that could formalize this information and make it available throughout the building lifecycle[45]. They rely on standardization, control, and allocation of accountability to update data as renovation changes soon turn data into a non-functional state. These tools can be supplemented digitally with twins and sensor-based monitoring that allows tracking performance throughout the time, aids commissioning, and detects maintenance requirements that increase component life. The combination of design models and active data is especially useful in circular retrofit, since it facilitates the feedback loops, which provide information that the desired performance and value-retention results are realized in practice. Simultaneously, the application of these tools poses interoperability, data ownership and other long-term stewardship questions, particularly when the ownership or facility management role shifts.

### 3.4. Circular Procurement and Project Delivery Mechanisms

The ambitions of circular retrofit are often limited or facilitated through procurement decisions and the contract regulations. Traditional procurement tends to focus on low initial price and standardized commodities and may lead to replacement instead of retention, and may not welcome reclaimed components, which are viewed as riskier. Circular procurement aims to modulate these incentives by defining the functional requirements and not the prescriptive product decisions so that the designers and the contractors can offer retention, refurbishment, and reuse solutions[46]. However, the performance-based specifications may open some roads to other avenues, but this should be accompanied by well-defined ways of verifying them to ensure safety and quality.

Circular outcomes can also be contributed to through contractual arrangements that assign roles of performance and recovery. Take-back clauses and extended producer responsibility arrangements could help to motivate manufacturers and suppliers to make components recoverable and offer reverse logistics. Product-service systems, where the elements of building are leased and not purchased, are occasionally suggested to get incentives to provide durability and maintenance, but their practicality on the retrofit is dependent on the maturity of the market and the capability of such models to fit in the existing ownership frames. Circular retrofit may especially be helped by integrated project delivery as well as early contractor involvement, since constructability and deconstruction considerations can have an impact on design before critical decisions are made. In the case of circularity based on the selective deconstruction, reuse logistics, and sequencing, in early cooperation, the uncertainty can be minimized, and the chances of the implementation increased[47].

### 3.5. Deconstruction, Site Practices, and Recovery Logistics

At implementation, circular retrofit will have to struggle with practical limitations associated with time, labor, safety, and coordination [48,49]. One of the cornerstone practices that distinguishes between the concepts of circular retrofit and the concept of demolition-oriented renovation is selective deconstruction. Selective deconstruction is used in preference to fast sorting out assemblies with limited sorting because it aims to save the integrity of components and material quality by careful disassembly and segregation. This method may support high-value reuse, however, it is site-constrained, project-sensitive, and may demand special skills and training. Selective deconstruction is highly dependent upon the original design of the building and whether or not the assemblies are attached mechanically instead of bonded or cast in place.

Sorting and handling practices in the field are essential since contamination and damage may quickly negatively affect the worth of the recovered materials [50]. The logistics planning should consider the storage, transportation, and the coordination with the downstream consumers, e.g., refurbishes, reuse markets, or recycling centers. Circular retrofit, in most instances, needs bridging of time gaps between material availability and its usability, and this may necessitate buffer storage or soft supply. Prefabrication can be utilized offsite in addition to circular retrofit to minimize waste, and enhance quality assurance, particularly of modular envelope retrofit or mechanical service skids. Readymade retrofit systems can help speed up on-site construction and minimize disturbance; however, they should be developed in such a way that the resulting system is not overly integrated to be challenging to dismantle in the future.

The management of hazardous materials is an issue of recurrent limitation in renovation, and is of specific interest to circularity [10,51]. Asbestos, lead-based paints, and other pollutants may make re-use impossible or may cost a lot to be removed, with consequences that alter the environmental and economic balance of recovery. The problem of circular retrofit strategies thus tends to incorporate the concept of early hazard detection and a risk-based approach to define the aspects that can be safely retrieved. It may result in pragmatic compromise of retention, selective replacement, material recovery, understanding that circularity is never a given state of affairs but a change of priorities within the safe and compliant range.

### 3.6. Operational Strategies, Commissioning, and Maintaining Circular Value

The results of circular retrofit are not guaranteed when the project is completed, but rather on the practices of operations that maintain the performance and the life of the components [12,19]. The reason why commissioning is especially important is that retrofits may introduce complicated interactions between airtightness, ventilation, moisture behavior, and occupant use. Inadequate commissioning may result in poor performance, comfort, or indoor air quality and consequently cause early changes or reversal of retrofit interventions, which counteract an energy objective and a circularity objective. The intensive use of monitoring and verification can be used to guide the realization of operational savings objectives and ensure that systems are functioning as intended.

The key to slowing material loops is maintenance strategies that put an immediate focus on planned maintenance and upgradability [52]. Facility managers can deal with faults without causing tremendous demolition when the components are designed and installed such that they can be accessed and replaced. Circular retrofit, then, must make the design intent and facility management capacity align, not only in terms of documentation, spare parts, and service contract availability, but also in terms of supporting repair over replacement. The occupant engagement is also important since the behavior of the users affects the operational energy, ventilation performance, and component wear. The expectations of user acceptance and comfort in a building that is in the process of renovation during occupancy may determine whether the retrofit strategies are maintained or adjusted in regard to long-term results.

### 3.7. End-of-Life Planning and Designing for the Next Renovation Cycle

Circular retrofit is characterized by the fact that it foresees further cycles of change. In this case, end-of-life planning is not the conclusion of the life of the building, but the replacement of specific layers, systems, or components [53]. Future disassembly design and recording as-built records and material passports make it more likely that the materials that are put in place today can be reclaimed in the future with high value. This prospective viewpoint is of particular interest as the level of performance is getting more dynamic, and the capacity to adapt to climate is rising, which provokes the possibility of consecutive retrofit waves.

This planning requires reverse logistics and secondary markets to achieve the advantages. Documentation is not sufficient to close loops without the need for recovered components. Circular retrofit methods thus more and more refer to the creation of reuse markets, material banks, and reuse hubs that can take up, reprocess, and reuse recovered materials[54]. In those areas where such infrastructures are still in their infancy, circular retrofit can give life extension and on-site re-use as more immediate measures, but insist on wider ecosystem development as a scaling pre-condition. This logic is embodied in the concept of designing renovation to renovate: the choices made to carry out the retrofit must not only address the current performance issues, but must also maintain an open future, minimize disruption to it, and avoid the formation of waste and non-recyclable assemblies. **Figure 2** illustrates how circular retrofit strategies are distributed across the renovation lifecycle, highlighting critical decision gates and information handovers.

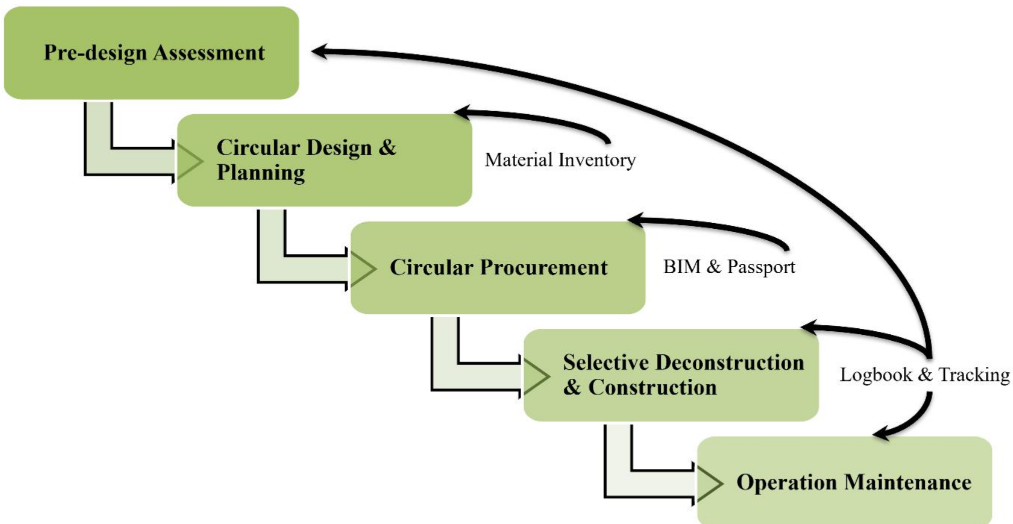


**Figure 2.** Lifecycle process map illustrating decision points, information flows, and circular strategies across circular retrofit delivery.

Circular retrofit strategies and technologies are not connected to a particular intervention across the renovation lifecycle, but through the combination of decisions made by the different stages[21]. Pre-retrofit diagnostics is an aspect that influences what can be maintained or salvaged, design is factoring in flexibility and dismantling ability, procurement is balancing incentives and risk mitigation, site usage is maintaining material quality, and operation is maintaining performance and lengthy replacement intervals. Circular retrofit thus depends on the ability to coordinate actors and phases, with information continuity, and with the market able to absorb secondary flows to make it effective. This lifecycle integration is what makes circular retrofit unique from piecemeal reuse or recycling efforts and offers the foundation to create a systematic connection of renovation efforts to resource efficiency and environmental sustainability results. Circular retrofit outcomes in the renovation lifecycle are a result of strategies applied in the various phases of it, such as the initial diagnostics and the planning of the next cycle, and not the result of individual interventions (**Table 2**).

**Table 2.** Circular retrofit strategies and enabling conditions across the renovation lifecycle.

| Lifecycle Stage | Primary Circular Objective | Representative Strategies (Descriptive) | Key Enabling Conditions | Common Constraints/Risks |
|---|---|---|---|---|
| Diagnosis/pre-design | Identify retainable and recoverable value | Condition surveys, material inventories, hazard screening, reuse feasibility | Access to records, testing capacity, early stakeholder alignment | Unknown conditions, contamination, time limitations |

**Table 2.** *Cont.*

| Lifecycle Stage | Primary Circular Objective | Representative Strategies (Descriptive) | Key Enabling Conditions | Common Constraints/Risks |
|---|---|---|---|---|
| Design | Embed adaptability and reversibility | Layered assemblies, modularity, reversible connections, future access to services | Integrated design process, compatible details, clear performance targets | Performance trade-offs, complexity, legacy constraints |
| Procurement | Align incentives and manage risk | Performance-based specs, circular criteria, take-back clauses, early contractor involvement | Supplier network, quality assurance, contractual clarity | Liability concerns, warranties, limited secondary supply |
| Construction/deconstruction | Preserve material quality | Selective deconstruction, segregation, controlled handling, off-site refurbishment | Skilled labor, space/logistics planning, recovery partners | Schedule pressure, damage, storage/transport costs |
| Operation | Extend life and maintain performance | Commissioning, monitoring, repair-oriented maintenance, planned upgrades | Facility management capacity, documentation continuity | Performance gaps, occupant behavior, maintenance underfunding |
| Next-cycle planning | Enable future recovery and upgrade | As-built logbooks, material passports, disassembly guidance, tracking | Data governance, standardized formats, long-term stewardship | Data loss across ownership change, platform incompatibility |

# 4. Assessing Impacts: Resource Efficiency and Environmental Sustainability Metrics

## 4.1. The Role of Assessment in Circular Retrofit Decision-Making

Assessment methods offer the analytical basis upon which the utility of strategies of circular retrofit is determined to be achieving meaningful reductions in resource productivity as well as environmental sustainability, and to explain trade-offs that would otherwise be hidden in single-objective decision criteria [17]. Within the practice of renovation, decisions that seem advantageous in one respect may have unintended side effects in another, especially where the reduction of operational energy needs more material, where a reuse route leads to a transport or refurbishment overhead, or where the choice to selectively deconstruct leads to an increment in labor and time. debunking benefits is thus the central point of impact assessment in circular retrofits, which involve not only other possible benefits, but extends the advice on decision-making when there is uncertainty by describing which interventions can be robustly beneficial across multiple outcomes and which are sensitive to both boundary choices and assumptions or contextual issues such as grid carbon intensity and the state of the supply-chain.

Since circular retrofits work at cross-lifecycle levels and loops, evaluation should take into consideration the short-term and long-term consequences of the project associated with service life, flexibility to renovate in the future, and prevented production [55]. This adds complexity to their methodology in comparison to traditional retrofit evaluation that commonly pays too much attention to operating energy and short-term economic payback. Baselines must also be treated carefully by circles retrofit assessment since most benefits come about due to avoided burdens, which can be avoided demolition, avoided production of replacement goods, or avoided landfill. This, in turn, has an implication on the credibility and utility of assessment as contingent upon the clear reporting of functional units, system boundaries, counterfactual scenarios, and how time is treated.

## 4.2. Life Cycle Assessment Approaches for Renovation Contexts

The concept of life cycle assessment has gained popularity to measure the environmental impacts of the production, use, and end-of-life operations of building elements and systems, and it has become a focal point for the assessment of the whole-life performance in the course of retrofit work [15,56]. Applied to circular retrofit, LCA should reflect both the effects due to additives of materials and processes caused by renovation and those due to non-retention, or reuse of recovered elements. This involves a keen specification of the functional unit, which in renovation studies is frequently fueled by floor area and service life; however, it can also be articulated in terms of building functionality delivered, e.g., thermal comfort or indoor air quality within a particular period. The fact that functional units incorporate service life is especially critical, since one of the aims of circular retrofit plans is oftentimes to increase the lifespan of the building, and it is impossible to gauge per-square-meter options without taking into consideration how much longer the building will offer service.

LCA methodological decisions can have significant impacts on the outcomes reported. Attributional LCA is typically applied in building studies to assign an average impact of production and disposal processes to a product system, whilst consequential LCA attempts to model marginal changes in the larger system which take place as a result of a choice, such as the effect that increased demand has on the technologies used in production or the effect that waste has on recycling markets. The consequential perspectives may apply to circular retrofit since reuse and recycling interventions may affect markets and supply chains, but are more information-intensive and unpredictable. Consequently, most studies take a hybrid method with attributional inventory that is combined with sensitivity testing on scenarios to estimate the marginal effects. No matter the method used, the renovation LCAs are obligated to disclose assumptions regarding replacement cycles, maintenance loads, and performance similarity between new and reused parts, as this has a strong influence on the embodied impact estimates [57].

Another issue is that end-of-life paths are represented, and notably, in the case of circular retrofit, disassembly and documentation are designed to enhance recoverability in the future [58]. Standard versions of building LCAs tend to employ simplified end-of-life assumptions, e.g., an unchanging recycling rate or a generic form of landfill disposal, which is not always reflective of the value-retention strategies that are presented by circular retrofits. Further developed solutions simulate other end-of-life solutions, such as selective deconstruction, component reuse, and high-quality recycling, and explicitly represent collection, sorting, and processing. The distribution of recycling or reuse benefits is another controversial decision whose popular strategies consist of cut-off strategies, substitution credits, and allocation of recycled content. Such decisions may be very different in their results, and cross-studies may not be easily compared unless some ways are harmonized or at least properly documented.

### 4.3. Dynamic Perspectives and the Timing of Carbon and Resource Impacts

The effects of timings that are often obscured by the static LCA representations are common to circular retrofit decisions. Embodied impacts are mainly realized in the initial stages of producing and installing the materials, and the operational savings would be a long-term process [59]. Moreover, numerous circular approaches are advantageous because they are not about direct substitution, and thus, the embodied effects of the creation are postponed. Dynamic LCA and time-dependent carbon accounting models also seek to capture such time-dependent profiles directly, allowing answering such questions as the speed with which a retrofit will pay back the improperly embodied emissions it introduces, the justification of upfront material investments based upon the projected building service life, building grid decarbonization trends desiring tree-serve countries on shorter-range climate goals focused on near-term emission control, etc.

The time dependence is particularly crucial when determining deep retrofit, which involves a significant input of materials and incremental or staged methods that spread interventions over time [60]. Monitored approach can minimize direct embodied emissions and offer flexibility; however, it could postpone operational power savings. On the other hand, a retrofit that involves an intensive and one-time retrofit may provide quick operational cuts at the expense of a hefty initial embodied cost. This choice will depend on the intensity of carbon in the energy supply, the rate at which the grid is likely to decarbonize, and the urgency of the emission cut in definite climate policy horizons. The impact of service life extension can also be expressed in the form of dynamic approaches, whereby the advantages of building or component maintenance can be viewed by maintaining buildings and components longer and longer without rebuilding or replacement. Such advantages, however, are conditional in the realms of realistic assumptions concerning the length of use of the building and the possibility of its upgrades in the future, which is why scenario analysis should be considered, but no single-point calculations are important.

## 4.4. Material Flow Analysis and Quantifying Resource Efficiency

Material flow analysis is a complement to LCA since it is much more concerned with the quantities, stocks, and paths of materials in the built environment [61,62]. MFA can also be applied in circular retrofit situations to quantify the material stock contained in the existing buildings, estimate what could be recovered by means of urban mining, and when and where the recoverable material would be found after renovation or deconstruction. In contrast to LCA, which represents flows into environmental impacts, MFA focuses on mass balances and flow structures, which is why it is a useful model for analyzing the resource efficiency strategy, including retention, reuse, and recovery logistics.

MFA can be used on a building scale to distinguish between interventions that mainly decrease the contribution of new material to the building and those that enhance the recovery of outputs. As an illustration, maintenance of an older structural frame will lower inflows and outflows through reduction of demolition and replacement, but selective deconstruction will not necessarily diminish inflows but may enhance quality and destination of outflows, thereby enhancing the probability of materials being kept in valuable loops. On the urban level, MFA can aid the recovery infrastructure planning by estimating the volumes of particular materials, finding the periods of their maximum availability, and connecting them with the demand in renovation markets. Such a view is essential to the scalability of circular retrofits since reuse and refurbishment will be feasible not only based on project-specific choices but also due to the presence of stable flows necessitating investments in sorting facilities, storage, and refurbishment capacity [63,64].

MFA also brings out the quality of materials and contamination, which are mostly discussed qualitatively in general discourse on the circular economy. In many building materials, retention of value is associated with purity and integrity. Mixed waste from demolition can theoretically be recycled, but in reality, it leads to low-value aggregate (or landfill). Circular retrofits, which focus on selective deconstruction and reuse of components, can hence be viewed as an approach to safeguarding the quality of materials, which can be represented by MFA in terms of differentiated flow categories instead of considering all recovered mass as identical [65].

## 4.5. Circularity Indicators and the Challenge of Measuring Value Retention

Various circularity indicators have been suggested to measure the degree of circularity of a building or a retrofit intervention, and have often been defined in terms of the proportion of recycled material, reuse levels, recoverability, and waste diversion [66]. These indicators are appealing in circular retrofit assessment since they can properly reflect the dimensions not fully covered by traditional environmental impact categories, e.g., the extent to which materials are kept in high-value loops. But indicator-based assessment also has conceptual issues, especially regarding what is being measured and its relationship with environmental outcomes.

The mass-based indicators, like reused or recycled materials, are relatively easy to calculate, yet they may be untrue relative to the environmental importance since not all materials have equal impacts per unit mass. A minor quantity of high-impact material avoided by means of reuse could be more important than a large quantity of low-impact material dealt with by recycling. Markers that are made based on potential recoverability or design-to-be-disassembled qualities might be more indicative of future circular potential, but they presuppose future behavior, market conditions, and enforcement of deconstruction practices. Value-retention indicators seek to respond to this by using not just mass but also the functional or economic value retained (in reuse and refurbishment), but they demand such data unavailable or context-specific [67].

In the evaluation of circular retrofit, indicators that most likely connect circular strategies with decision-relevant outcomes and can be interpreted together with LCA and MFA results would be most useful. Instead of attempting to find one measure of circularity, numerous evaluations have an advantage with a dashboard system where the mass-based measures, the value-retention measures, and the environmental effects are shared. Such an integrated representation can avoid circularity washing in which high recycled content is touted as a circular success, even when the assemblies are unrecoverable. In fact, it is currently waste diversion that is being celebrated in the face of downcycling pathways that essentially do very little to reduce primary extraction [68,69].

### 4.6. Integrating Operational and Embodied Impacts in Whole-Life Frameworks

Whole-life assessment in retrofit situations is an attempt to reconcile the operational energy and other related emissions with the embodied effects of buildings and construction[36]. This integration is necessary in circular retrofit projects since most of the circular strategies directly change embodied impacts, whereas operational performance is a key cause of climate performance. Whole-life models need clear assumptions regarding energy usage, occupancy of the building, system use, and replacement times, and regarding grid emissions variables in the long run. Since retrofits can significantly alter energy demand and the carbon intensity of the energy supplied by means of electrification, whole-life results may be very sensitive to assumptions in scenarios.

One of the key central questions of analysis is the relationship between the intensity of retrofit and embodied burden[66]. Deep envelope retrofits can also save a lot of heating and cooling loads, although they demand more material, the embodied impacts of which can be substantial. On the other hand, the less intensive measures might provide less material burden but provide fewer operational benefits, particularly when there is high heating or cooling demand. Rather than resolving this tension, circular retrofit strategies seek to choose actions that provide high operational value per unit embodied impact, focus on retention of serviceable items, and make sure that the added materials and systems are fitted in a manner that minimizes future replacement. This usually necessitates the comparison of a variety of design scenarios under a set of constant conditions, such as a business-as-usual renovation or minimum compliance. It also demands the modeling of rebound and interaction effects, like occupant behavior change, ventilation rate, or indoor temperature setpoint change post-retrofit, that can affect operational savings achieved.

Whole-life models are growing to embrace more than carbon to encompass other environmental types and performance issues[70]. Renovation may affect indoor air quality, thermal comfort, acoustics, and moisture behavior, and indirect sustainability impacts may be that they determine occupancy satisfaction, maintenance requirements, and future intervention probability. Equally, extreme event repair and replacement can be prevented by climate resilience practices, building up avoided material and other energy benefits that are usually not reflected in the standard whole-life carbon processor. These larger effects are still methodologically hard to incorporate, but are necessary to have a realistic picture of the performance of circular retrofits in changing climate and use conditions. Because no single method captures all relevant dimensions of circular retrofit performance, complementary assessment approaches are often required, each addressing different decision questions and sources of uncertainty (**Table 3**).

### 4.7. Economic Assessment and the Coupling of Cost with Environmental Performance

The economic evaluation techniques, particularly the life cycle costing and total cost of ownership techniques, are key in knowing the potential of the circular retrofit strategies adoption. Nature Selective deconstruction, refurbishment of components, and improved documentation are among many such circular practices that may add upfront costs or need non-standard procurement and coordination. But they can also be cost-saving (in the long run) by increasing component life, saving on the cost of waste disposal, enhancing maintainability, and decreasing the frequency of future major interventions. Life cycle costing has the ability to reflect these dynamics since it is able to reflect capital costs, operating costs, maintenance, replacement costs, and end-of-life costs over a specified time[53,71].

It is significant to couple economic evaluation with environmental evaluation since decisions are never made depending on environmental grounds. Multi-objective analyses may indicate dominated options, i.e., those worse in terms of cost and environmental performance, as well as options that are trade-offs, such as those better in terms of environmental performance at a higher cost or the reverse. Market maturity of the secondary material and services, the regulatory compliance channels, and the risk valuation all depend on the market maturity of circles retrofit, and such trade-offs are usually determined according to the market maturity of the secondary material and services. As an illustration, insufficient certainty on warranties on re-used parts may translate into a higher risk premium, which will supersede the savings on a new purchase. Circular retrofit feasibility is particularly subject to economic assessment, including risk and uncertainty, and not deterministic costs only[72].

**Table 3.** Comparison of assessment methods used to evaluate environmental, resource, and economic performance of circular retrofits.

| Method | Primary Question Answered | Strengths of Circular Retrofit | Typical Blind Spots | When Most Useful |
|---|---|---|---|---|
| Whole-life LCA | What are total environmental impacts across life cycle? | Captures embodied + operational impacts; supports scenario comparison | Sensitive to boundaries/allocations; limited future-market realism | Comparing retrofit design options and materials/assemblies |
| Dynamic carbon accounting/dynamic LCA | When do emissions occur and how fast do benefits accrue? | Reveals timing effects and near-term vs. long-term trade-offs | Requires assumptions on grid trajectories and service lives | Evaluating deep vs. staged retrofits and "carbon payback" |
| Material Flow Analysis (MFA) | How much material enters/leaves and where does it go? | Quantifies stocks, urban mining potential, recovery quantities | Does not translate directly into environmental impacts | Planning reuse/recovery infrastructure and project material planning |
| Circularity indicators | How circular is the intervention in terms of loops/value retention? | Makes recoverability, reuse, and design intent visible | Can decouple from actual environmental benefit if used alone | Tracking circular performance alongside LCA/MFA |
| Life Cycle Costing (LCC)/Total Cost of Ownership (TCO) | What are costs over time (Capital Expenditure (CAPEX)/Operational Expenditure (OPEX)/maintenance/replacement)? | Addresses adoption feasibility and long-term value | Hard to capture risk premiums and non-market benefits | Choosing feasible circular options; procurement/business-case building |
| Monitoring, Reporting, and Verification (MRV)/performance verification | Does the building achieve intended operational performance? | Limits performance gap; supports durability of outcomes | Often excludes embodied and end-of-life impacts | Post-retrofit commissioning and operational optimization |

## 4.8. Uncertainty, Data Quality, and Comparability across Studies

There is uncertainty everywhere in the circular retrofit assessment since renovation projects have incomplete knowledge regarding the current states, changing construction process, and circumstances-dependent end-of-life results. Information on refurbished parts, processing of secondary materials, and selective deconstruction is not often extensive, and the environmental product statements are usually of new items and not used products. Uncertainty regarding occupant behavior, quality of commissioning, and discrepancies between the design and the actual operation are also present in operational energy modeling in retrofits. Because of this, the results of assessment can be highly variable even with similar interventions, and point estimates can be inaccurate when they are not accompanied by ranges or sensitivity analysis [28].

Strong practice of assessment thus puts into focus transparency and uncertainty management. Sensitivity analysis will help to define the assumptions that are the most significant in terms of results, including the service life extension, refurbishment intensity, transport distances, grid decarbonization rates, and end-of-life allocation tactics [36,53]. Instead of basing a scenario analysis on the assumption of a single path into the future, plausible futures may be compared, a process that is vital to circular retrofit since future recoverability and reuse markets are uncertain and may shift over time with the changing policy and industry. Uncertainty can also be modeled using Monte Carlo simulation and probabilistic techniques but it requires data that is not always accessible. Also, the reportable range of assumptions is structured and enhances interpretability, although probabilistic methods are not possible.

The lack of comparability across studies is still a problem due to discrepant boundaries, units of function, and reporting conventions. Research might vary regarding the construction process, maintenance, replacement, or other types, and they might also vary with product stages, by either allocating or not allocating the benefits of reuse. Setting the more consistent reporting standards for retrofit and circularity assessment would, therefore, further consolidate evidence synthesis and afford more credible advice to practice. At least, the baseline scenario, the supposed service life, the way existing embodied impacts have been treated, and the method of the end-of-life modeling should be explicitly mentioned in the studies, as these factors are the basis of the interpretation of the reported benefits [73].

### 4.9. Toward Integrated Evaluation Frameworks for Circular Retrofit Performance

A complementary approach to evaluation should be applied to the scene of a circular retrofit to be integrated with the advantages of the complementary approaches, but still be applicable to decision-making at work. LCA gives characterization of the environmental impact, MFA gives understanding of stocks and flow structures, value-retention attributes are captured through the circularity indicators, and feasibility and adoption potential are assessed through economic assessment [74]. The difficulty lies in bringing these viewpoints together without creating such a cumbersome analytical load that renders it unattractive to use in the design and delivery of projects.

An actionable point of view is to coordinate approaches towards common situations and consistent system boundaries in such a way that they can be read side by side. As an example, a cluster of retrofit design scenarios may be considered in terms of whole-life carbon, material inflow and outflow masses, reuse and recoverability indicators, and life cycle costs, with uncertain ranges indicating major assumptions. The integrated approach facilitates clear trade-offs, and it assists in finding the strategies that are effective in all the dimensions, like maintenance of structural systems, giving priority to repairable and upgradable assemblies, and creating new components to be added in the future and to be disassembled. In the long run, once the quality of data and the digital representation of documentation become more common, the post hoc evaluation tools may develop into real-time decision support to drive the circular retrofit decisions all the way back to the initial design phase through the operation [75].

## 5. Enablers, Barriers, and Implementation Pathways

### 5.1. Policy and Regulatory Conditions Shaping Circular Retrofits

The policy and regulation have a powerful impact on the ability to implement a scale of circular retrofit approaches, as they dictate what can be done, what is encouraged, and what is deemed as evidence of safety and performance [11]. The building codes and product standards in numerous jurisdictions are authored based on new products that have well-established certification routes. This may pose a strain on the reuse of components, even where the elements may be shown to perform well, as documentation, labelling, and traceability requirements may prove to be hard to meet in case of reclaimed components. It can also limit innovation by the processes of permitting, where authorities insist on prescriptive compliance as opposed to performance-based demonstrations. This leads to the fact that circular retrofit activities tend to go through an individually negotiated process as opposed to systematic routes, which increases transaction costs and makes replication difficult.

The management of waste and materials can either facilitate or hinder circularity based on the way it characterizes recovered materials and whether it helps to recover high-value products [76,77]. The definition of waste, end-of-waste, and responsibilities concerning the management of potentially contaminated materials influence the possibility of the recovered elements being sold as products. In those jurisdictions where the regulatory standards consider the recovered materials to be waste until final processing is done, reuse becomes harder and costlier. On the other hand, unambiguous directives that draw a line between those elements that can be reused and those that cannot be, and give realistic quality assurance specifications can help to minimize uncertainty and promote the evolution of the market. Policy is also relevant to specify the way renovation demand is set by energy performance requirements, whole-life carbon reporting, and whole-government renovation targets. In the event that regulations focus on the operational energy per se, they can inadvertently promote replacement-heavy interventions. Once they add in the whole-life rationale and resource-effectiveness, they develop more of a reason as to why retention, deferrals, and recoverability should be upgraded.

The issue of incentive structures plays a critical role in reshaping the decisions to be taken in the renovation process [78]. The energy efficiency measures, which have historically been the target of subsidies and financing mechanisms, can expedite the adoption of retrofit but do not reward the circular strategies of selective deconstruction, component refurbishment or improved documentation. Circular approaches will be economically efficient with increased incentives to cover embodied carbon reversal, waste avoidance, and certified reuse. Public procurement can also serve as a market-shaping tool in that it imposes a circular requirement on renovation tenders, thus triggering the supply chain of reused parts and refurbishing services. With time, standardized and regular demand signaling can stabilize the practice of circular retrofit and reduce its costs due to standardization and learning processes.

### 5.2. Market Maturity and the Development of Secondary Material Ecosystems

Circular retrofits rely on market and logistical systems that can absorb recovered materials and provide secondary components with predictable quality and supply. Circular strategies in situations where reuse marketplaces, salvage yards, refurbishment hubs, and material brokers are not yet well developed can be confined to on-site retention or small-scale reuse. Supply can also be intermittent even in demand areas since recovered elements are not always available and heavily depend on the project schedule, demolition, and site restrictions. This has been one of the most long-term structural impediments to circularity in renovation due to this temporal mismatch between supply and demand [10,51].

The focus of market maturation is quality assurance and standardization. The uncertainty about the performance, warranty, and compliance documents is one of the reasons why designers and contractors are reluctant to request reclaimed components. This uncertainty can be mitigated through the secondary markets, which can create grading systems, testing procedures and traceability regimes that render the quality of products readable to the purchasers and regulators. Nevertheless, this kind of systems can be created only in terms of coordinated investment and long-term demand. Logistics is also an important decisive point since, in most cases, the recovered materials need to be sorted, cleaned, stored and transported, and such services may threaten to surpass the savings of not buying anything new without an effective organization. Circular retrofit economics are thus enhanced when recovery infrastructure is geographically close to one another, when travel costs are not very long, and when storage capacity and inventory control minimize waste and damage [19].

Virgin material and the relative cost of disposal are also determining factors in market development. In regions where landfill and burning are still inexpensive, and the cost of virgin material is not subject to environmental externalities, circular solutions have structural headwinds [10]. On the other hand, the economic balance can be changed to recovery and reuse through increased disposal charges, landfill prohibitions, and taxes on materials. However, the cost signals are not always enough; market development needs trust, visibility, and effective transaction mechanisms. The list of reclaimed products on digital platforms, standardized documentation and certification systems can lower the search costs and lead to more confidence; however, it requires physical infrastructure and professional networks to coordinate the complicated transactions.

### 5.3. Business Models and Contracting Structures That Align Incentives

The distribution of value and risk among the stakeholders is a strong factor that determines the implementation of circular retrofit [10]. The traditional contracting practice frequently rewards short-term cost reduction and schedules that may deter the practice of labor-intensive systems like selective deconstruction and the detailed inventorying process. Furthermore, numerous advantages of circularity, like diminished future replacement, reduced lifecycle expenditures, and enhanced adaptability, flow to the building owners or users over time and not to the contractors that provide the project. Such a lack of alignment may lead to a failure to invest in the strategies whose returns are uncertain and long-term.

Another type of business model aims at aligning the incentives through linking the providers to performance and recoverability in the long term [55]. A partial template is performance contracting, which is common in energy retrofit and involves compensating for the reductions in operations that have been verified. Application of this reasoning to embodied effects and circularity outcomes is conceptually attractive but challenging to implement due to the greater complexity of circular performance measurement and validation, as well as the fact that future phenomena, such as future renovation or post-use recovery, affect outcomes. Durability and take-back can be promoted by product-service systems and leasing models in which manufacturers retain ownership of components and offer them as services, but these models need contractual and legal structures that can be accommodated in building ownership and financing models. Their viability is frequently dependent on the component type, with greater viability of standardized parts like lighting, flooring, or facade modules than custom assemblies.

Risk management is one of the primary obstacles. The issue of liability with regard to the reuse of components can also result in risk-averse behavior towards new products, especially in safety-related sectors. The warranty expectations and the practice of insurance tend to be structured around novel products with an evident responsibility of the manufacturer. In order to facilitate the concept of circular retrofit, the contracting structures might have to include the direct responsibility chains, testing and certification demands, and joint risk provisions that can render reuse acceptable to insurers and regulators. These risks can be mitigated through integrated project delivery and early contractor involvement, as it allows feasibility and compliance considerations to inform a design decision before procurement to prevent late-stage substitutions and delays [47,79].

## 5.4. Digital Infrastructure, Data Standards, and Information Governance

The continuity of information is also a key enabler of the concept of circular retrofit since the ability to retain, remake, and recover materials and components in the future is based on understanding what materials and components are present, how they are put together, and how they work [55]. This implies in practice the digital infrastructure capable of storing and supporting building information through changes in ownership and operations. Solutions such as BIM models, building logbooks, and material passports are frequently proposed to work, but the effect is to be realized based on adoption, interoperability, and governance. The actual usefulness of digital documentation may be restricted under unsafe software ecosystems, less than hopeful availability of common attribute arrangement plans, and unresolved accountability for the support of data.

Standards of data are important since circular retrofit needs information that goes beyond the normal design coordination, such as the composition of materials, disassembly sequence, a record of maintenance, anticipated service life, and environmental characteristics [80,81]. In the absence of standard forms of representation and communication of this information, documentation is project-driven and hard to reuse across actors or platforms. Interoperability, in particular, is necessary when circularity is dependent on secondary markets, as buyers and regulators should have an opportunity to receive credible information that could be verified. This can be facilitated by the use of traceability technologies like QR codes or RFID, which need to be connected to long-term databases and governance frameworks that can make information available across decades.

There are also questions that exist in relation to ownership, privacy, and access as brought about by information governance [82]. The construction data might be of a commercially sensitive character, and the facility managers might not be driven or even have the resources to keep detailed records. When the circular retrofit practices rely on documentation as the way to recover in the future, then the long-term stewardship will be the problem of collective action. It can be assisted by the public policies and procurement requirements to have building logbooks or whole-life carbon reporting, so that it establishes institutional reasons to keep the data. Governance can also be backed up with industry-led efforts that define the roles of data custodianship and develop trusted repositories that persist beyond projects and firms.

## 5.5. Skills, Organizational Capacity, and Stakeholder Coordination

The implementation of circular retrofit demands some capabilities that are not routine in most renovation markets. Screen grabbing, grading, refurbishment planning, and circular procurement require specific expertise and a change in professional practice [83]. Design teams should have the capability to incorporate the principles of disassembly and adaptability without impairing performance. Contractors will also have to develop the competencies of attentive removal, sorting, and manipulation of materials, as well as concur with lower-end participants like refurbishers and reuse marketplaces. To be able to assess reused components and performance-based compliance demonstrations, inspectors and regulators should be guided and trained. Facility managers should have systems and competencies that can ensure documentation and adopt repair-oriented maintenance strategies that can slow down the replacement cycle.

The issue of organizational capacity is especially important to renovation projects since they have complicated constraints, such as occupancy, phasing, and unknown existing conditions [84]. Circular retrofit will introduce more layers of coordination, such as inventorying, reuse, salvage logistics, and quality assurance of reused items. The requirements may be hard to incorporate into the traditional project schedules and procurement models, and only through the involvement of the stakeholders at an early stage and the allocation of roles and duties. The approaches to collaboration in its delivery can contribute by creating common goals and allowing iterative decision-making when the unknown conditions are revealed in the process of construction.

The other stakeholder coordination is to align the occupant needs and expectations with the circular strategies. The choice of renovation depends not only on the technical performance, but also on the comfort of the user and the perceived quality, and the tolerance to disruption [84]. Reused elements can be stigmatized aesthetically or questioned in terms of reliability, and staged retrofit strategies can necessitate reinterventions that impact the occupants over time. Communication, participatory design, and performance demonstration can become a foundation of acceptance and the possibility of further alterations that negatively impact the circular results. Circular retrofit in this sense is a technical and social change, which necessitates modifications in norms regarding the definition of what a high-quality renovation is and how value is perceived.

### 5.6. Implementation Pathways: From Pilots to Scalable Practice

Scaling circular retrofit from pilot projects to mainstream practice requires coordinated change across multiple socio-technical domains, as summarized in **Figure 3**. To proceed with bigger projects such as circular retrofit, it is necessary to shift the individually-based demonstration projects to routinized practices that are anchored by standards, markets, and institutional capacity. One of the avenues is the standardization of the processes related to the building material inventory and pre-demolition audits, which can render reuse planning more predictable and less uncertain. The other one is to establish component-based reuse pathways with precise testing and certification processes, and focus on those categories where reuse can be most practical and most effective [43,85]. The lighting systems, interior partitions, raised floors and some facade components can be recognized as potentially successful starting points due to the modularity and the ability to be tested more easily than custom structural elements, though the opportunities will vary depending on the situation.

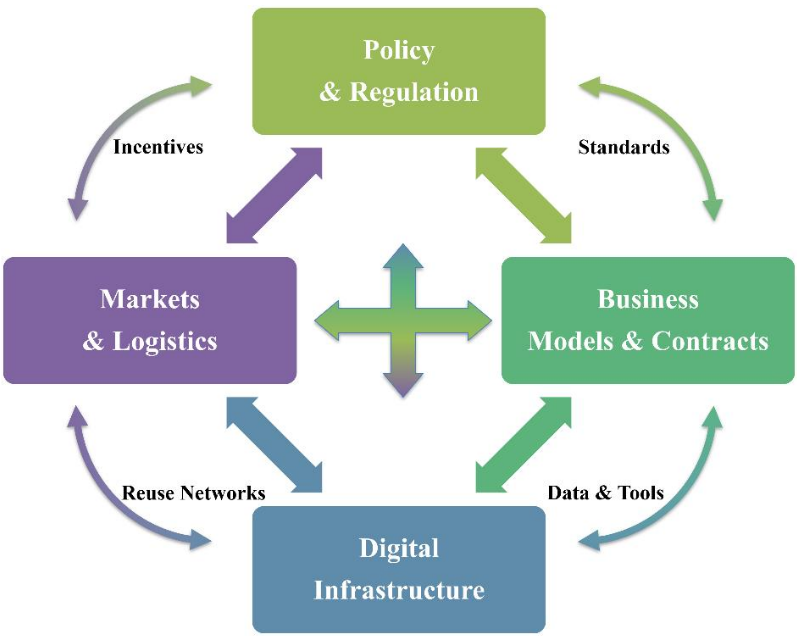


**Figure 3.** Socio-technical system influencing the scaling of circular retrofit practices, showing interactions among policy, markets, business models, digital infrastructure, and skills.

Another scaling pathway achieved through alignment with the principles of circularity is that of industrialization and prefabrication [86]. Modular retrofit systems are capable of waste reduction and better-quality control, and they can facilitate future circularity if they are designed to be disassembled. Nonetheless, the industrialized solutions should be considered with caution, not to form closely connected assemblies that make recovery subsequent difficult. Design principles suitable for scalability need the inclusion of reversibility and strata-service life logic into prefabricated systems, and are achieved through documentation practices that may be read and comprehended over time.

Such policy-led ways involve integration of circular requirements with renovation subsidies, the compulsion of the whole-life carbon disclosures, and the public procurement of creating consistent demand for circular practices and secondary materials. The market-based channels are the expansion of professional networks in deconstruction and salvage, investment in refurbishment centers, and creation of reliable digital platforms in the secondary exchange of parts. Notably, these are dependent pathways. Markets require policy support as a way of reducing risk and generating demand; they also require policy operational tools and standards to be implementable and skills and capacity-building to be instated. A systemic approach towards regulation, finance, digital infrastructure, and professional practice is hence more responsive to the scalable success of circular retrofit adoption as opposed to single initiatives [19,87].

## 5.7. Research Gaps and a Forward Agenda for Implementation and Evaluation

There are a number of gaps limiting the development of mainstream circular retrofits. To begin with, there has been very little empirical research on the long-term performance of reused and refurbished components operating in the service environment, such as durability, maintenance requirements, and acceptance by tenants. Second, there should be more harmonization of assessment methods in order to facilitate comparison between projects and regions, especially the modeling of baselines, service life extension, and end-of-life recovery. Third, the economics of the circular retrofit are not well comprehended at the various levels of market maturity, particularly when taking into consideration the transaction cost, risk premium, and learning effects with time.

There is also a need to conduct further research on governance and institutional design. There are still questions regarding who should be the custodian of building material data, how material passports may be preserved during the change of ownership, and how the regulators may be able to provide safety and reuse at the same time. The creation of testing, certification, and documentation standards for reclaimed components is a very essential field where interdisciplinary effort can yield practical results. Lastly, equity needs to be taken into consideration. The policies of renovation and circularity may influence the affordability, burden of disruption, and the benefits distribution among social groups. To make the circular retrofit pathways a part of just transitions instead of accelerated unfair investment trends is the key to achieving approach legitimacy and sustainability [88].

Comprehensively, it can be stated that propagating circular retrofit on an amateur scale demands indexed development within the policies, markets, business model, and digital infrastructure, as well as in professional practice [89]. The change does not merely involve switching to new materials and tools, but restructuring renovation systems to have retention, reuse, flexibility, and recoverability as the expected state of affairs, as opposed to exceptional actions. The practicability of scaling circular retrofit practices hinges on addressing a combination of interconnected regulatory, market, contractual, and organizational hindrances, as well as focused measures that support them (**Table 4**).

**Table 4.** Barriers and enabling actions for scaling circular retrofit practices across policy, market, and organizational domains.

| Domain | Typical Barriers | Practical Enabling Actions | Main Actors | Expected Effect on Scaling |
|---|---|---|---|---|
| Codes and compliance | Reuse pathways unclear; prescriptive approval processes | Performance-based compliance guidance; standardized testing/certification routes | Regulators, standards bodies, labs | Reduces transaction cost and approval uncertainty |
| Liability and warranties | Insurance and warranty norms favor new products | Shared-risk contracts; verified grading/testing; warranty innovations | Owners, insurers, suppliers, contractors | Increases confidence to specify reused components |
| Markets and logistics | Fragmented secondary supply; timing mismatch; lack of storage | Regional recovery hubs, marketplaces, storage solutions, reverse logistics | Reuse operators, municipalities, industry | Stabilizes supply and reduces cost of recovery |
| Procurement and delivery | Lowest-bid incentives; late contractor involvement | Circular criteria in tenders; integrated delivery; early deconstruction planning | Public/private clients, procurement teams | Shifts incentives toward retention and recovery |

**Table 4.** *Cont.*

| Domain | Typical Barriers | Practical Enabling Actions | Main Actors | Expected Effect on Scaling |
|---|---|---|---|---|
| Data and documentation | Missing as-builts; poor interoperability; data decay over time | Building logbooks/material passports; governance for updates; open standards | Owners, facility managers, software ecosystem | Enables systematic circular planning across cycles |
| Skills and culture | Limited experience with selective deconstruction and reuse | Training, accreditation, demonstration projects, guidance templates | Professional bodies, contractors, academia | Improves execution quality and normalizes practice |

# 6. Conclusion

Circular retrofit practices can provide a viable channel of relating building renovation with resource efficiency and environmental sustainability by redefining renovation as a whole-life value-retention problem, but not as a one-off upgrade process. In the literature reviewed, one message stands out clearly: operational energy cannot be used as a measure or an optimization strategy for environmental performance in renovation. Since the intensity of operations in many areas is increasingly decarbonized through electrification and grid decarbonization, the embodied impacts, material throughput, and waste generation are making all the difference between whether renovation will bring actual improvement in sustainability benefits. Circular retrofit is a reaction to this reversed balance, which responds to the need to save old structures and elements, to reduce the needless material turnover, and guarantee that new additions can be reused to save the environment through flexibility, reversibility, and strong documentation.

The review notes that circular retrofit can be viewed as a lifecycle approach in diagnosis, design, procurement, construction, and deconstruction practices, operations, and planning of the subsequent intervention cycle. Determining whether the vision of the circle is achieved is a combination of pre-retrofit diagnostics to comprehend recoverable, design solutions to isolate layers, to allow disassembly and derive, acquire, and contract procurement, and on-site practices that safeguard the environmental quality of materials. Digital tools, such as BIM-capable inventories, building logbooks, and material passports, are significant enablers as they offer continuity of information and uncertainty reduction, although they cannot work without interoperability and long-term governance, but not alone with technology adoption. Similarly, market infrastructure for reuse and refurbishment, such as logistics, storage, certification, and trusted marketplaces, seems to be a repeatable situation of scaling, lacking which circular retrofit is confined to opportunistic reuse or retention within the project constraints.

The evaluation techniques play a core role in the development of research and practice, but the review also indicates that outcomes are extremely sensitive to methods. The variations in units of functionality, baselines, assumptions on service-life, reuse and recycling allocation, and the management of time-dependent carbon effects can lead to different inferences even on similar interventions. Strong assessment thus involves clear reporting and, where possible, scenario-based and uncertainty-sensitive methods which express the comparative and future-dependent nature of the benefits of the outcome of circular retrofit. A combination of complementary approaches, including whole-life LCA of environmental effects, MFA of material stocks and flows, and the metric of circularity of value retention attributes, and life cycle costing of feasibility, provides the most insightful foundation for decision-making, but only when these approaches are aligned on like values and premises.

Regarding implementation, the review recommends that the main obstacles to scaling circular retrofits are systemic, as opposed to technical ones. There can be a disparity in regulatory frameworks and product standards in reuse practices, liability, and warranty norms, and procurement models tend to underestimate long-term benefits, including maintainability and adaptability. The lack of skills and coordination issues among the stakeholders also restricts uptake, particularly in occupied renovations, where timing, time constraints, and uncertainty are exaggerated. All these obstacles must be tackled through concerted effort: policy that pays off whole-life results and scales back risk of uncertainty on reuse; market development, in which the salvage and refurbishment activities are professionalized; contracting and insuring, in which such risks are regulated; and digital governance, in which these risks are kept within custodianship over decades.

Several research priorities and standard-setting will emerge in the future. A more uniform typology of circular retrofit interventions is first of all required to enhance the comparability of the studies and to better understand what strategies work best in what building types, climates, and market conditions. Second, more empirical research is needed on the long-term performance and reliability of reused and refurbished components, and real projects should be monitored to determine the performance gap and durability issues. Third, coordinated assessment protocols are to be formulated where the baselines, service life expansion, end-of-life situation, and time-related carbon issues are explicitly mentioned. Lastly, equity and distributional impacts are to be considered among the foundational considerations as renovation pathways determine affordability, disruption burdens, and access to healthy indoor environments.

To conclude, the circular retrofit strategies do not substitute the traditional energy retrofit; they widen and enhance it by keeping in mind that operational enhancement should be requested in addition to material value preservation and waste avoidance. Circular retrofits can be used to lower the entire life environmental impact when set against a consistent lifecycle plan and backed by coherence in policy, market infrastructure, and assessment practices, and would help to maintain the usefulness and dynamism of older buildings. The next step towards this direction involves shifting towards demonstrations that are not isolated but rather standardized, repeatable models of delivery, and institutional structures that would make circularity a commonplace expectation in renovation, and thus bring the transformation of the built environment in line with climate objectives and institutional resource management.

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## Institutional Review Board Statement

Not applicable.

## Informed Consent Statement

Not applicable.

## Data Availability Statement

No new data were created or generated in this study. As this is a review, it is based on data and information from previously published sources, which are cited in the reference list.

## Conflicts of Interest

The authors declare no conflict of interest.

## AI Use Statement

The authors declare that no artificial intelligence (AI) tools were used in the preparation of this manuscript.

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