Activating Territorial Circular Ecosystems for Material Reuse in Construction: Enabling Conditions Across Six European Contexts and Transferability to Italy

sustainability

MDPI

Article

Activating Territorial Circular Ecosystems for Material Reuse in Construction: Enabling Conditions Across Six European Contexts and Transferability to Italy

Alessandro Barra * and **Guido Callegari ***

Dipartimento di Architettura e Design, Politecnico di Torino, 10125 Turin, Italy
* Correspondence: alessandro.barra@polito.it (A.B.); guido.callegari@polito.it (G.C.)

Abstract

The construction sector generates over one-third of all waste in Europe, yet the reuse of building components remains marginal compared to recycling, and circular strategies are rarely aligned on the territorial scale at which materials, stakeholders and infrastructure operate. This paper investigates the regulatory, institutional, infrastructural and operational conditions under which reuse to become a systemic practice. A desk-based comparative analysis of six European contexts (Belgium, the Netherlands, Switzerland, Germany, France, Denmark) was conducted on 282 documents, using a framework of seven dimensions grouped into three macro-families drawn from the literature on territorial circular ecosystems. The findings show that these conditions form a dependency chain of five ordered links: legal recognition of the non-waste status; a standardized pre-demolition audit; preparation and storage physical hubs, in parallel with research infrastructures, absorbing technical uncertainty; a guarantee system covering performance, liability and insurability; and a demand-side activation. The guarantee link is a constraint and a key element in demand activation. Regulation is necessary but not sufficient, since binding instruments target recycling or auditing while reuse remains voluntary in all six contexts. The chain yields a typology of ecosystem configurations and a replicable diagnostic instrument, whose transferability is assessed on the Italian case.

Keywords: building component reuse; construction and demolition waste; design for reuse; circular economy; circular territorial ecosystem; pre-demolition audit; urban mining; design from availability

Check for updates

Academic Editors: Jacopo Gaspari and Lia Marchi

Received: 17 July 2026
Revised: 11 August 2026
Accepted: 14 August 2026
Published: 17 August 2026

1. Introduction

The European construction sector is one of the priority areas for the circular transition in Europe, as it remains a key contributor to the climate crisis due to the CO_2 emissions it generates (approximately 34% of global emissions), its use and consumption of resources, and its waste generation [1]. Construction and demolition waste (CDW) is the largest waste stream by mass, accounting for approximately 40% of the waste generated in Europe and more than one-third of total EU waste [2–4]. This type of waste, which is characterized by high recovery rates (88%) [5], is used for low-value applications (downcycling), such as road fill and subbase material [2]. The New Circular Economy Action Plan identifies the construction sector as one of the sectors with the greatest potential within the circular economy and outlines a package of measures focused on design, durability, reuse, recycling, material traceability, and the recovery of construction and demolition waste [6].

To classify the various circular strategies, the literature commonly uses the "R" framework, which consists of ten strategies (R0 refuse, R1 rethink, R2 reduce, R3 reuse, R4 repair, R5 refurbish, R6 remanufacture, R7 repurpose, R8 recycle, R9 recover) arranged hierarchically according to the principle of value conservation [7,8]. As shown in Figure 1, the position of each strategy within the hierarchy reflects its degree of circularity: the shorter the cycle, the greater proportion of value, impact, and embodied energy that is preserved [7,9].

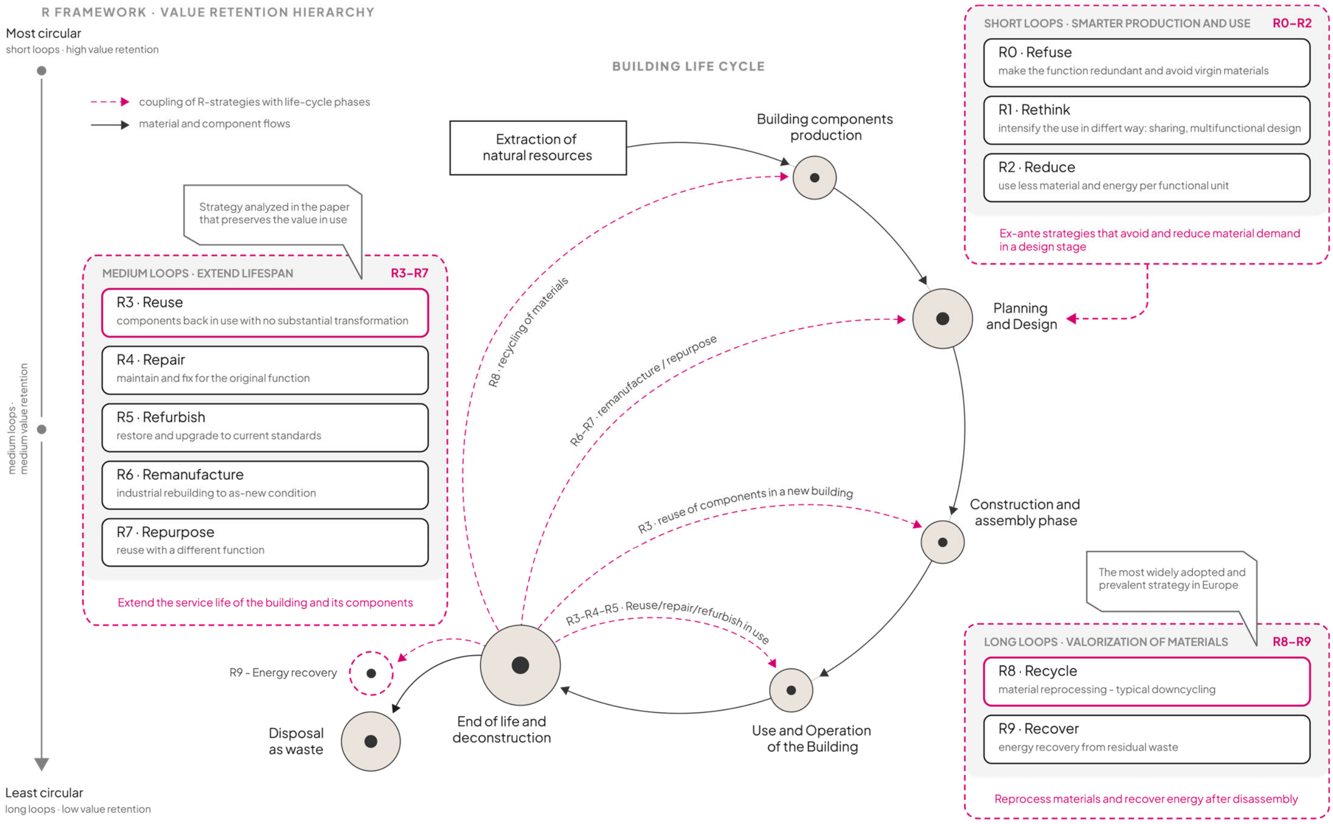

Figure 1. The R Framework, loop length and its coupling with the building life cycle. Authors' own elaboration. The R-strategy hierarchy is based on Potting J., Hekkert M., Worrell E. and Hanemaaijer A. (2016), Circular Economy: Measuring innovation in product chains, PBL Netherlands Environmental Assessment Agency, The Hague [7].

Within this framework, the distinction between recycling and reuse becomes clear: recycling (R8) is a long-cycle option, in which the material is put back into use only after reprocessing that typically involves a reduction in its functional value (downcycling); reuse (R3), on the other hand, operates on a shorter cycle, reintroducing components and elements without substantial transformation, thereby preserving their use value [8]. The difference is not merely conceptual because, for example, for the same function, the reuse of steel structural elements can reduce greenhouse gas emissions by 60–83% compared to recycling [10]. A similar benefit is seen with concrete, where reusing it reduces the material's environmental impact by about 75% compared to construction using new materials [11]. As Reike et al. (2018) note, high levels of circularity have already been achieved in recycling and recovery, while the greatest potential for progress today lies in the shift toward short-loop strategies [8].

This study addresses three gaps identified in a review of the current state of research. The first gap is empirical. The literature documents individual reuse projects and the tools that support them, it offers no systematic, comparable characterisation of the territorial conditions that make those projects possible. Consequently, it remains unclear whether successful cases share a common set of conditions or merely a common outcome. The second gap is analytical. Territorial conditions are treated as a list of independent enabling factors without considering whether they are in a relationship of precedence or substitution. This leaves practitioners without a basis for prioritising among them. The third gap is operational. Findings are transferred from advanced contexts to less advanced ones by identifying missing elements rather than the point in a sequence at which a given context is blocked. Addressing these gaps requires a framework that is applied uniformly across contexts and is explicit about the relationships among the conditions it identifies. This paper, therefore, addresses the following research questions:

RQ1—"What regulatory, institutional, infrastructural and operational conditions and what recurring patterns emerge from cases across Europe to facilitate the development of circular practices such as the reuse of building materials and components?"
RQ2—"How have these enabling conditions translated into effective reuse practices across the selected European contexts, and what does this transferability imply for contexts such as Italy?"

Starting with a review of the literature, this paper examines the territorial conditions (regulatory, institutional, infrastructural and operational) that have received even less attention than practices, digital tools, and case studies [12,13], even though they are recognized as key factors in the adoption and spread of circular practices at the regional and local levels [14–17].

In these studies, the discussion tends to remain at the theoretical level or to focus on individual cases [16], without, however, developing a systematic and comparable characterization of the territorial factors that enable reuse processes. This study addresses this knowledge gap, between the description of case studies and the analysis of the conditions that make them possible, by highlighting how reuse practices lead to an understanding of the local circular ecosystem. The proposed comparative approach involves exploring six European contexts that are more advanced in these practices, with the aim of deriving insights applicable to other contexts such as Italy, where practices for the reuse of building components are still at an early stage of structuring. Despite being among the most exemplary European contexts in the field of the circular economy [18,19] there is still a limited number of practices that best preserve the value of materials, such as reuse.

This analysis was carried out with the aim of supporting the development and implementation of the ECO3R Ecosystem, launched in 2021 by the Politecnico di Torino across an area comprising 19 municipalities within the Metropolitan City of Turin. The initiative includes the establishment, in 2027, of a research infrastructure funded under the INFRA+ call promoted by the Piedmont Region. This infrastructure will serve as the material and knowledge-based hub of a territorial circular ecosystem, for which this contribution seeks to identify possible models and implementation strategies.

The construction sector continues to show a persistent resistance to innovation in established practices, driven by conservatism, the fragmentation of the supply chain, and a regulatory framework geared more toward recycling than reuse [20,21].

The context analysis is structured along a line of reasoning that, starting from the conceptual framework, progressively leads to the definition of operational implications. The paper is structured as follows (Figure 2). Section 2 establishes the theoretical framework of the study, clarifying the adoption of the circular economy in the construction sector and the distinction between the reuse of materials and components and recycling. The text builds on this framework to define the concept of a circular territorial ecosystem and outline its main components, linking them to the macro-families and dimensions underlying the analytical framework. Section 3 provides a comprehensive overview of the approach adopted, the criteria for selecting European contexts, the framework's structure, and the sources utilized for the analysis. Section 4 applies the framework to the six contexts analyzed, highlighting recurring patterns for each macro-family. Section 5 explores these findings in relation to the tensions between the dimensions of the framework, the enabling conditions that arise from them, the transferability of the results, the implications for Italy, and the limitations of the study. Finally, the conclusions address the research questions, clarifying the framework's contribution, its possible applications, and potential future developments.

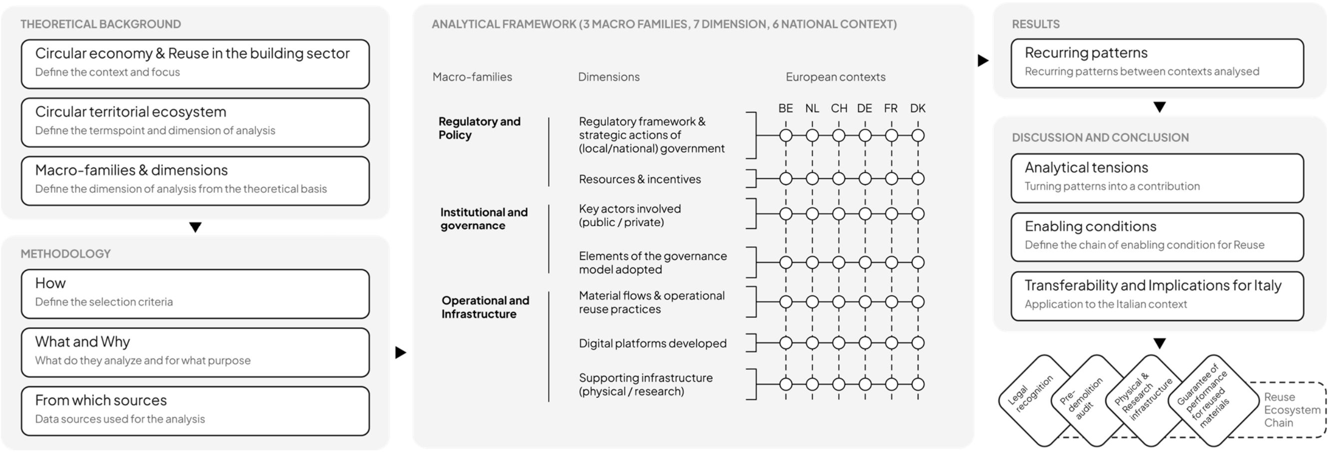

Figure 2. Overall structure of the study. From the theoretical background and comparative methodology, through an analytical framework of three macro-families and seven dimensions applied to six European contexts (BE, NL, CH, DE, FR, DK), to the recurring cross-context patterns and their discussion as enabling conditions and implications for transferability in Italy. The reuse ecosystem chain (bottom right) links legal recognition, pre-demolition audit, physical and research infrastructure, and guarantee of performance for reused materials.

2. Background

2.1. The Circular Economy in the Construction Industry and the Reuse of Components

The construction sector is a key area in the transition to the circular economy (CE). This is primarily due to the ongoing application of the linear 'take-make-dispose' model, in which the resources utilized diminish in value upon completion of their useful life [22]. Additionally, the materials managed within this sector are inherently more substantial in weight compared to other categories of waste. According to the latest estimates by the United Nations Environment Programme (UNEP), the building and construction sector is responsible for approximately 37% of global CO2 emissions and consumes nearly half of the world's raw materials [23]. Notably, this sector generates the largest volume of waste in the European Union, accounting for about one-third of the total [2]. In contrast to industrial products, which are typically straightforward and short-lived, buildings are complex, long-lasting systems composed of elements with different life cycles. This characteristic renders their circularity a systemic and multiscale challenge [24].

2.1.1. The Circular Economy Principles: Classification of Cycles by Length and Retained Value

In this context, the application of EC principles to the built environment aims to maintain materials, components, and buildings in use at their maximum value for as long as possible, through strategies of regeneration, reduction, slowing down, and closing resource cycles [25]. These strategies can be structured according to the length of the cycles and the value retained: Reike et al. (2018) distinguish between short cycles, in which products and components remain close to their original function with minimal intervention;

medium cycles, which involve repair or rework; long cycles, in which materials lose their identity and are reintroduced as secondary raw materials [8]. This framework corresponds to the priority scale for R strategies formulated by Potting et al. (2017), which ranks the options based on the value that each one helps preserve [7]. The R Framework [7,8] clarifies its strategic importance because, unlike recycling (long-loop) where reprocessing diminishes the material's potential value, reuse falls under medium-loop strategies, which are closer to short-loop strategies. The latter maintain materials and components at a higher level of utility while conserving the energy and materials they contain [8]. Shorter cycles have been shown to retain a greater share of the value and to avoid impacts [7,8]. Reuse is both a catalyst and a priority objective for the gradual adoption of more sustainable and circular practices.

2.1.2. Position of Reuse of Building Components and Recycling

Building component reuse denotes the reintroduction into use of a discrete element that retains its form, its assembly logic and its function, such as a beam, a window or a facade panel, and it is the object of this paper. Material reuse is only used where the material is in bulk and retains its properties, but not its form. An example of this would be reclaimed timber sections that have been resawn to a different size. Recycling is reserved for processes that destroy the identity of the element.

The recycling of CDW is the most heavily regulated and well-established practice in Europe, with an estimated recovery rate of around 89% in the EU-27 [26–28]. However, it is important to interpret this apparent circular maturity of the sector correctly. As demonstrated by analyses conducted by the European Environment Agency and the Joint Research Centre, this significant figure is predominantly attributable to backfilling operations and low-value applications (downcycling), including the utilization of recycled aggregates in road subbases [2,27].

In terms of circularity, the recycling of CDW thus constitutes a long-range link within the R framework [7], because the material is usually crushed and reprocessed through a process of downcycling. This process involves energy consumption that results in the loss of a significant portion of the carbon embedded in the material during this operation. Reuse practices, on the other hand, refer to a short- to medium-term cycle. In this cycle, materials and components are put back into use while retaining their form, performance and embedded value [8,29]. A study by Rakhshan et al. (2020) found that the main advantages of implementing component reuse strategies in the construction sector are economic, including a reduction in consumption and emissions [12]. Despite this potential, however, reuse remains an occasional rather than systematic practice, hampered by recurring economic, informational, and regulatory barriers [12,20,27,30], which only rarely takes the form of an established practice at the local level. The sector therefore has potential for enhancement not in the intensification of recycling, a practice that is already well established and widely used, but rather in the transition to short- to medium-term practices such as reuse. These are the only practices capable of leading to significant reductions in emissions and an increase in the sector's actual circularity. These practices are currently in the development stage, despite being less frequently cited among European best practices.

In this context, building components reuse is playing an increasingly significant role in the scientific literature of the sector and in grey literature [20,30,31]. Furthermore, in recent years, reuse processes have been increasingly common in experiments with circular practices at the European level. When considering the adoption of reuse practices, it is important to recognize that these practices may be subject to conditions that deviate from a standard or "ordinary context". These conditions may include, but are not limited to, uncertain availability, technical specifications (i.e., data on the material and components), balancing supply and demand, and effective material flow management (i.e., procurement). In this instance, the focus is on the context of the reuse process. In order to guide action along the trajectory of the recovery process, it is necessary to track, organize and interpret the information flows associated with the various components and systems. However, this requirement is not a given in existing processes, where the availability and interoperability of information are often limited. From this perspective, the path toward circularity faces its first obstacle precisely in the management of the information needed to support recovery.

2.2. From a Fragmented Practice to the System: Circular Regional Ecosystems

As outlined in the previous paragraph, the evidence indicates that the primary barrier to the widespread adoption of reuse is not technical. This is because procedures for selective demolition, material classification and the reuse of components are now available and proven [12,20,31]. The "barrier to entry" for widespread adoption is a set of systemic conditions involving regulatory frameworks geared towards recycling rather than reuse, economic and market barriers, a lack of intermediary channels and reverse logistics, and a lack of information on the reliability and availability of components [5,12,20] and the lack of models to serve as a reference for economic development. In this regard, it is evident that adopting reuse practices in the construction sector requires comprehensive organisational restructuring across the entire supply chain. This encompasses investments in logistics, the generation, management, and dissemination of information, and the redesign of processes [32]. The emergence of such conditions, through hubs and material banks, signifies an intermediate step [33] towards the establishment of a regional ecosystem. The conditions analysed are inherently local in nature [15] and lead to the concept of a circular territorial ecosystem. This concept, used as an analytical framework, provides the basis for the dimensions of analysis used to examine the case studies in the following paragraphs.

The concept of a circular territorial ecosystem is still approached in a variety of ways, which has gradually broadened its scope without establishing a single, unambiguous definition. Pietrulla (2022) [34] describes it as "[. . .] *a system of mutually dependent relationships in which the whole functions as a unit and maintains a vital relationship with its environment, where the complementarity and heterogeneity of the actors involved are fundamental to achieving a shared value*.". In this configuration, there is no rigid hierarchy, but rather a network of complementary roles coordinated by a key figure, the Orchestrator, who is responsible for governance and strategic alignment [34]. Aarikka-Stenroos et al. (2021) define circular economy ecosystems as heterogeneous communities of actors—hierarchically independent yet interdependent—that are oriented toward a sustainable ecosystem outcome [35]. Trevisan et al. (2022) highlight its dynamic and co-evolutionary nature, in which actors integrate resources and co-create circular value flows through mutual interaction [36,37]. Aarikka-Stenroos et al. (2021) further define them as multi-actor entities oriented toward the joint creation of economic and environmental value, structured across multiple levels (micro, meso, and macro), and introduce a taxonomy comprising three categories of flows (material flow-based, knowledge flow-based, and economic value flow-based) and five main types (industrial, urban, entrepreneurial, knowledge-based, and innovation-based) [35].

Despite their differing approaches, these contributions converge on a common vision: a circular ecosystem emerges from the integration of industrial ecology and the circular economy, taking on a territorial configuration in which various stakeholders (businesses, public entities, citizens, universities, and civil society organizations) collaborate to close resource cycles and generate shared value.

However, the literature also points to some unresolved issues: there is a lack of unambiguous definitions, established models, and configurations for circular territorial ecosystems, as well as common operational methodologies for their identification and implementation. On the defining elements, however, the most recent studies agree: governance with clear roles and responsibilities and a coordinating entity; transparency of information flows; complementarity and interdependence among stakeholders; and the building of trust and a shared vision [34,37,38].

Based on the definitions analyzed [34,35,37–39], a circular territorial ecosystem can be defined as "an integrated territorial system, consisting of a diverse community of interconnected public and private actors—hierarchically independent yet interdependent—who cooperate by sharing flows of materials, economic value, and knowledge to regenerate resources and create shared value. These actors, coordinated by a facilitator, operate within defined (local) territorial boundaries, triggering processes of symbiosis and innovation that foster resilience and the transition toward circular economy models" [40].

This differs from a network of actors in kind. A network is constituted by the relationships between its nodes. For example, designers, deconstruction contractors and dealers who exchange information or materials on a project-by-project basis form a network, which dissolves once the project ends. Following emerging conceptualizations of circular territorial ecosystems [41,42], four features distinguish the two. First, an ecosystem presupposes a coordinating actor with an explicit governance mandate; a network, however, may have no center. Second, the members of an ecosystem are functionally complementary, jointly covering the building life cycle so that the output of one member becomes the input of another. This is in contrast to a network, where the members are homogeneous and mutually substitutable. Third, it is stabilized by shared assets, such as inventories, platforms, storage hubs and protocols, that persist beyond individual transactions and reduce the cost of subsequent ones. In contrast, a network stores no value between interactions [42]. Fourth, it is oriented towards a system-level outcome: a functioning reuse market that no single member could deliver, as opposed to the sum of bilateral exchanges. The Belgian case is illustrative: Rotor, Rotor DC, Opalis and the Buildwise audit framework constitute an ecosystem because a designer who has never dealt with a given supplier can still specify reclaimed elements through Opalis and source them from an operator working to a shared protocol [43]. Without a platform, hub and protocol, the same actors would remain a network capable of delivering individual projects, but not a replicable practice. A network delivers projects while an ecosystem delivers practices.

As a multidimensional, dynamic, open, and complex construct, the circular territorial ecosystem can be broken down into several recurring structural components, which can be identified through an analysis of the literature:

the actors and the network of relationships among them;
the organizational and governance model that sets it apart;
the processes and flows (resources, information, knowledge, economic) that characterize them;
the supporting physical and digital infrastructure (circular hubs, digital platforms, and databases).

It should be noted that these four structural dimensions alone do not provide a complete picture of a real territorial ecosystem. To understand how it functions, it is also necessary to consider the regulatory and financial dimensions that enable or hinder its implementation. The regulatory aspect establishes the legal preconditions within which reuse practices can operate, while the financial aspect defines the conditions under which reuse practices become competitive and economically sustainable.

https://doi.org/10.3390/su18168401

2.3. Toward a Framework for Comparative Analysis: From Ecosystem Components to Dimensions of Analysis

The ecosystemic components analysed in the previous section describe a circular territorial ecosystem. They specify what such an ecosystem must contain, but not how the presence, or absence, of each element can be observed within a given national context. Moving from conceptualisation to comparison, therefore, requires an operationalisation step, in which each component is translated into a dimension of analysis, understood as an observable lens through which regulatory instruments, economic incentives, actor constellations, governance arrangements, material practices, and enabling infrastructures can be systematically examined across heterogeneous contexts. The purpose of this translation is twofold: first, to ground the comparison in the ecosystemic perspective developed earlier; second, to ensure that the same set of questions is posed for each context, a fundamental prerequisite for a structured comparison aligned with the paper's objective. Table 1 summarises the resulting framework, linking each ecosystemic component to its analytical counterpart and to the main sources in the literature.

Table 1. Systemic components, analysis dimensions and key references in the literature.

N°	Ecosystemic Component	Analysis Dimension	Main Sources
1	Regulatory	Regulatory framework and strategic actions of (local/national) government	[14,15,20]
2	Economic Flows	Resources and incentives	[14]
3	Actors	Key actors involved (public/private)	[34,35,37,39,44,45]
4	Governance	Elements of the governance model adopted	[14,34,37,46,47]
5	Material Flows and Processes	Material flows and operational reuse practices	[12,48–51]
6	Infrastructure (Digital, physical and research)	Digital platforms	[13,52–54]
7		Supporting infrastructure (physical/research)	[33,55–59]

The correspondence between components and dimensions is close to one-to-one, with one deliberate exception: the infrastructure component is disaggregated into two distinct dimensions, digital platforms and supporting infrastructure (physical/research), since the two have different configurations and bodies of literature due to their nature (digital and physical), even though they are linked in some cases. Merging them would obscure the contribution each makes, which the comparison aims to capture.

The methodological procedure through which these dimensions are applied to the selected European contexts is detailed in the following section.

Two considerations motivate this deliberate exception. From an analytical perspective, digital and physical/research infrastructures perform non-substitutable functions: the former reduce information asymmetry (i.e., what exists, where it is located and what condition it is in), while the latter reduce transactional and performance uncertainty (i.e., where material is stored and prepared for reuse and who validates its technical suitability). For example, a platform cannot store a beam, and a warehouse cannot make its contents visible to a designer two hundred kilometres away. Empirically, the two types of infrastructure are unevenly distributed across the six contexts: some have a dense population of platforms over a thin layer of physical hubs, while others have the reverse. Therefore, a single aggregate category would average out precisely the asymmetry that accounts for divergent outcomes. Keeping the dimensions separate allows the framework to discriminate between contexts rather than merely rank them. This approach is also consistent with two partially overlapping bodies of literature (see Table 1).

Since the framework is this paper's main contribution, it is important to state explicitly the basis on which it should be judged. It is an analytical and descriptive observation grid which specifies the questions asked of each context. It does not measure a latent construct, produce a score or predict an outcome. Its adequacy is therefore not established through expert scoring or a Delphi procedure, which would test the plausibility of the categories with a panel rather than their ability to organise evidence. Instead, its adequacy rests on three properties that the reader can assess directly. The first property is source validity: every dimension derives from a structural component identified in the literature on circular territorial ecosystems. Table 1 makes each correspondence and its sources explicit so that no dimension has been introduced ad hoc. Second, in terms of completeness relative to the existing literature: Table A1 in Appendix A shows that all components identified by existing conceptualisations are represented here. The regulatory and financial preconditions have been added because they are implicit in a general theory of ecosystems. Thirdly, in terms of discriminant capacity, when applied to six contexts, the framework distinguishes between them rather than assigning uniformly high values and reveals asymmetries (such as the divergence between digital and physical infrastructure) that a coarser grid would conceal.

Table A1 also clarifies what is new. While existing frameworks are designed to define what a circular ecosystem is, this one is designed to determine whether a given territory has one, and if not, which component is missing. This shift in purpose requires the additional dimensions and the disaggregation of infrastructure. However, the same design has its limitations because it does not weight the dimensions, nor does it establish that the conditions it identifies are sufficient (Section 5.5). The empirical validation of the dependency chain against primary data, in the form of interviews with stakeholders and experts in the six contexts, as well as its application to the Metropolitan City of Turin (Section 6), is underway and is reported here as a limitation rather than an achievement of this paper.

3. Methods

The purpose of this section is to describe the methodology used for the comparative analysis of European contexts, in form intended to be reproducible. This includes the case studies selection criteria, the dimensions of analysis employed and the main sources used. This is intended to make the methodology understandable and reproducible for future similar research.

3.1. Research Design

This paper was developed using a qualitative research approach based on a desk-based multiple-case comparative analysis (documentary analysis of secondary sources). The decision to take a qualitative approach is rooted in the nature of the research question, which does not aim to quantify the prevalence of reuse but rather to understand which enabling conditions foster its adoption at the territorial level, its various configurations, ecosystem models, and the system of relationships among the actors. As Yin (2018) [60] contends, case study analysis is the most suitable approach when research addresses "how" questions related to contemporary phenomena embedded in their real-world context. These phenomena cannot be isolated and are beyond the researcher's control [60]. The use of multiple cases, rather than a single case, allows for an approach based on replication rather than statistical sampling. In this approach, each context serves as independent evidence of the relationships between conditions and the development of reuse. This approach strengthens the robustness and analytical generalizability of the results obtained.

The analysis is based on secondary documentary sources. This choice aligns with the selected subject of analysis (the territorial context), whose enabling conditions (regulatory frameworks, governance models, networks of actors, management of material flows, platforms, and infrastructure) are primarily codified in publicly accessible online documentation, such as national regulations and policy guidelines, reports on European projects, guidelines and technical documentation on digital platforms, and gray and scientific literature. The principle of multiple sources of evidence [60] is achieved here through the analysis of diverse types of documents [61], which are publicly available and their convergence is verified for each case. Applying the same analytical framework, with its eight dimensions, to all contexts ensures cross-case comparability. The limitations associated with the lack of primary data are discussed in Section 5.4 on Limitations.

3.2. Case Selection

The selection process was conducted in two phases. In the initial phase, a survey was conducted of best practices in the reuse of building materials and components developed at the European level. The aim was to identify the regional contexts where such practices are most advanced and well-documented. The survey was conducted using keyword searches (“building component reuse,” “reclaimed materials,” “urban mining,” “circular construction,” “material reuse hub”) across a range of sources: European project portals, such as Interreg Europe, Circular Cities and Regions Initiative (CCRI), and Circular Construction in Regenerative Cities (CIRCuIT), are valuable resources for this sector. Databases of digital platforms and marketplaces for reclaimed components are also useful tools. In addition, scientific and grey literature in this field can provide valuable insights.

The inclusion criteria were the recurrence of the context in the sources examined, the advanced state of research and experimentation on the reuse of building components, active participation in dedicated European projects (FCRBE, Facilitating the Circulation of Reclaimed Building Elements; PREUSE, Public Responses to Enable the Use of Salvaged building Elements; CIRCuIT; CCRI, etc.), in which collaboration between public and private actors has produced operational guidelines, networks for the exchange of knowledge and materials, and digital platforms. The application of these criteria resulted in the identification of six national contexts: Belgium (BE), the Netherlands (NL), Switzerland (CH), Germany (DE), France (FR) and Denmark (DK).

The selection is a purposive sample, not a probabilistic one. It is focused on cases that provide a wealth of information about the phenomenon under investigation. It is not focused on statistical representativeness [62,63]. The six contexts were deliberately chosen as advanced cases, capable of highlighting the enabling conditions for reuse on a territorial scale.

To ensure auditability, the selection criteria were applied sequentially rather than holistically. A context entered the candidate pool if at least two independent European sources referenced it as a site of building component reuse, and was retained only if it met all three inclusion criteria:

(i) documented reuse practice extending beyond a single demonstrator project;
(ii) participation in at least one dedicated European project on reuse, which guarantees the existence of publicly accessible documentation produced to a common template and therefore comparable across contexts;
(iii) at least one operating physical or digital infrastructure dedicated to reuse, which distinguishes a structured practice from a policy declaration.

Two exclusion criteria were applied: documented activity concerning recycling or recovery only, and reuse confined to furniture and objects without a construction stream. Table A2, reported in Appendix A, reports the assessment of the candidate pool.

The retained set was checked for variation along the two axes identified in the literature as most likely to differentiate outcomes. This ensured that the sample would not comprise six instances of the same model. The six contexts differ in the origin of the process: law-led (FR); publicly mandated within a waste management system (DK); and operator- and standards-driven (BE, NL, CH, DE). The contexts also differ in the legal status of the material, which is resolved in two cases and unresolved in four. The limitations of this design, particularly the exclusion of less advanced contexts, are discussed in Section 5.5.

3.3. Analytical Framework Based on 7 Dimensions and 3 Macro-Families

To understand the contextual conditions that accompanied the development of circular practices, we defined several dimensions of analysis. These dimensions highlighted not only the operational practices but also the factors that characterize the relevant national context and the systemic mechanisms that foster their development. Seven dimensions were selected to facilitate exploration of the identified European contexts through complementary lenses:

The regulatory framework encompasses the strategic measures adopted by local governments.
Existing resources and incentives.
The key stakeholders involved are from both the public and private sectors.
The organizational and governance model that has been adopted for the implementation of these practices is as follows:
Material flows and reuse practices adopted.
The digital platforms were developed in their respective contexts.
The territory is supported by a distributed infrastructure, which is divided into two categories: physical infrastructure and research infrastructure.

The first dimension relates to the regulatory context, which demonstrates how policies and the regulatory framework can influence outcomes and how they may be related to the driver or an obstacle to promoting circular practices [14,15,20]. Indeed, each national and local context possesses its own unique cultural, legislative, and market-specific characteristics, which collectively influence its feasibility.

To assess the extent to which these practices are supported, it is important to consider the resources and incentives dedicated to providing financial support (tax incentives, public funds, European programs) for these circular practices. This aspect is a crucial factor in the adoption and diffusion of such practices. It is linked to the concept of a policy mix for the circular transition [14].

The third dimension consists of the key stakeholders involved, based on a multi-stakeholder ecosystem approach that includes government entities, businesses, designers, research centers, and civil society organizations. The socio-technical transition perspective underscores the pivotal role of stakeholders and networks in propelling sustainable innovation processes [34,35,37,39,44,45].

An analysis of the organizational and governance model helps clarify the decision-making and coordination mechanisms (public or private) that influence the scalability and sustainability of these practices. Research on collaborative governance indicates that it plays a pivotal role in ensuring the stability of circular ecosystems [46,47]. Effective governance fosters interdependence, integration, and complementarity among stakeholders. The overarching objective of this approach is to extend the useful lifespan of materials and optimize their value before they are regenerated or recovered [14,34,37].

Studying a regional context also requires analyzing material flows and the processes used for their reuse. A comprehensive understanding of circularity entails a thorough examination of how these flows are managed in various countries and how they are mapped [12,48–51]. This encompasses a wide range of aspects, from logistics to the primary stages of the recovery and reuse of building materials and components.

The sixth section provides an in-depth analysis of the role of digital platforms in supporting these practices. Technologies such as digital databases, circular knowledge and network platform, Building Information Modeling (BIM), Geographic Information Systems (GIS) and marketplaces serve as enabling infrastructure for the tracking, transparency, and exchange of recovered materials [13,52–55,64]. Their role is emphasized by prominent stakeholder platforms for the European and national circular economy (ECESP and ICESP), as well as by specialized platforms dedicated to promoting processes and expertise related to the reuse of building materials, products, and components (Opalis, Rotor DC, Restado, Madaster, etc.) [55].

Another element of analysis is supporting infrastructure, which has been subdivided into physical and knowledge-based infrastructure. The presence of specific locations dedicated to facilitating these practices is essential throughout the territory. These can take various forms. In this study, "physical" refers to locations that facilitate the logistical aspects of reuse ecosystems, including material storage warehouses, collection and reuse centers, hubs, artisan workshops and Repair Cafés [33,55,56,59]. Those designated as "research" serve as spaces for research and experimentation that support the development of circular practices (circular hubs, research laboratories, etc.). These initiatives foster collaboration among universities, research centers, businesses, and local institutions, with the aim of serving as a key hub for promoting technical experimentation and the scientific validation of solutions developed in theory [33,55,57]. This aspect is also relevant for assessing the extent of knowledge transfer between research and practice.

The seven dimensions presented can be grouped into three macro-families (Regulatory & Policy, Institutional & Governance, and Operational & Infrastructural) as illustrated in Figure 3. These macro-families categorize the characteristics of the dimensions based on the layer of the territorial system to which they belong. The family of regulatory conditions encompasses the conditions defined at the national level, including the regulatory context, resources, and incentives. It serves as the outer boundary condition, since it determines the material's legal status and the availability of financial resources, thereby defining the space within which the other two families can act at all. The family of institutional and governance conditions encompasses the stakeholders involved, as well as the organizational and governance models that coordinate their actions. It operates as the transmission layer converting that regulatory space into coordinated action by assigning roles, designating an orchestrator and aligning public and private interests, and without it a permissive regulatory framework produces no observable practice. The category of operational and infrastructure conditions encompasses the elements that make reuse practically feasible, through audits, flows, platforms and hubs. These elements include operational workflows and practices, digital platforms, and supporting infrastructure distributed throughout the territory. It is also the family that generates the feedback that eventually reshapes the other two, as when a voluntary technical protocol developed by operators is subsequently adopted as a standard.

Reading the framework in this direction, the macro-families are related by enablement downwards and by feedback upwards, and it is the interruption of either direction, rather than the weakness of any single dimension, that accounts for the divergences observed in Section 4.

https://doi.org/10.3390/su18168401

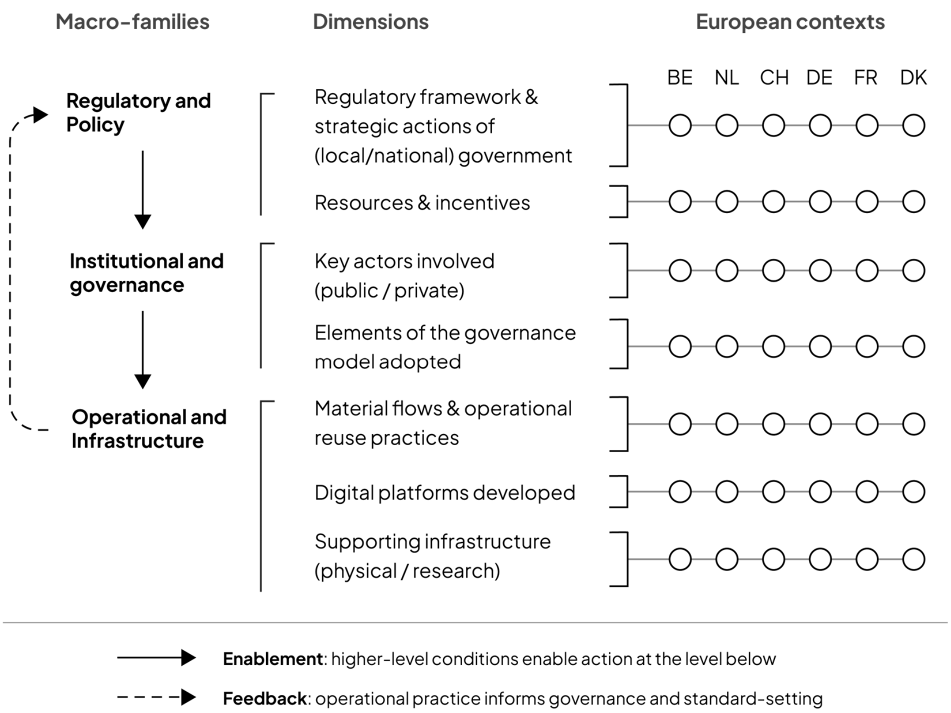

Figure 3. Analytical framework based on 3 macro-families, 7 dimensions and 6 national contexts and the relations between the three macro-families.

3.4. Data Sources and Analysis

The source corpus was assembled through a structured search protocol applied consistently across contexts and documented here to enable reproduction. Table 2 reports the search strings, the repositories consulted, the inclusion and exclusion criteria and the outcome of screening.

Table 2. Search and screening protocol.

Element	Specification
Search strings (English)	("building component reuse" OR "component reuse" OR "reclaimed building elements" OR "salvaged building materials" OR "urban mining" OR "circular construction" OR "material reuse hub" OR "pre-demolition audit" OR "design for disassembly") AND (name of country or region)
Search strings (national languages)	BE and NL: "hergebruik bouwmaterialen", "materialenpaspoort"; FR: "réemploi matériaux construction"; DE: "Bauteilwiederverwendung", "Rückbau"; DK: "genbrug byggematerialer", "selektiv nedrivning"; IT: "riuso componenti edilizi", "demolizione selettiva"
Repositories consulted	European project portals (Interreg Europe, Interreg North-West Europe, CCRI, CIRCuIT, FCRBE, PREUSE); national and regional legislative databases (Legifrance, Retsinformation, Gesetze im Internet, Fedlex); agency repositories (ADEME, OVAM, FOEN/UFAM, ISPRA); Scopus and Web of Science for peer-reviewed literature; documentation pages and reports of the platforms and infrastructures identified.

Table 2. *Cont.*

Element	Specification
Inclusion criteria	The document refers to one of the six contexts or to Italy; it addresses the reuse of building materials or components, or a condition enabling it (regulatory status, audit procedure, incentive, actor, governance arrangement, platform, infrastructure); it was published or in force between 2015 and July 2026; it is publicly accessible; its language is English, French, German, Italian, Danish or Dutch.
Exclusion criteria	Documents addressing recycling only, with no reuse content; documents concerning the reuse of furniture or objects with no construction stream; press articles and blog posts without an identifiable institutional or corporate source; duplicate versions of the same document; documents superseded by a later official version.
Screening procedure	Three stages. (1) Identification: 455 records retrieved. (2) Screening on title, issuing body and abstract or summary against the inclusion and exclusion criteria: 359 records retained. (3) Full-text assessment for relevance to at least one analytical dimension, with removal of duplicates and superseded versions: 282 records retained and coded. Records excluded at stage 3 were logged with the reason for exclusion.

For each national context, a diverse corpus of documents was compiled, divided into five types of sources and presented in Table 3:

regulatory documents and national and/or regional policy guidelines;
deliverables and materials produced by European projects focused on reuse, often developed through collaboration among various European contexts analyzed;
documentation available on web platforms dedicated to promoting and facilitating circular reuse practices or serving as marketplaces for recycled components;
research literature;
grey literature (institutional, industry and other reports);
websites of the key players identified.

Table 3. Quantitative summary of sources by type and context *.

Sources Type	Belgium	Netherland	Switzerland	Germany	France	Denmark	TOT
Normative/governative actions	16	10	13	11	13	10	73
EU projects	6	1	0	0	0	3	10
Digital platforms	15	13	22	12	21	12	95
Research literature	0	4	4	0	0	2	10
Grey literature	15	19	6	10	14	12	76
Web sources	4	4	2	2	1	5	18
TOT	56	51	47	35	49	44	282

* The counts reflect the SIZE of the collected corpus, not the maturity of the context.

The corpus of 282 sources was analyzed using document analysis [61], applying the same framework of analytical dimensions to all cases (Section 2.3). In the first phase, the documentation for each context underwent a qualitative interpretive review to populate the dimensions with comparable evidence. In the second phase, a cross-case comparative analysis was conducted to identify the enabling conditions and recurring patterns present across the national contexts analyzed. In accordance with the purposive design based on information-rich cases [62,63], the objective of the comparison is to provide a descriptive and characterizing analysis of the various causes of the spread of reuse, rather than an explanatory one.

The coding procedure was as follows. A codebook, derived from the definitions of the seven dimensions given in Section 3.3, was prepared before coding commenced. For each dimension, it specified the question to be answered, the type of evidence required for a cell to be populated, and the boundary with adjacent dimensions where confusion was foreseeable. These boundary rules proved to be the operative part of the codebook (Table A3, in Appendix A), since most ambiguous cases concerned the attribution of an item to one dimension rather than to a neighboring one. Coding proceeded context by context rather than dimension by dimension. Each context was therefore read as a whole before being decomposed. Every populated cell recorded the sources supporting it, which makes the resulting matrix (Table S1) traceable item by item. This procedure is consensus coding with an auditable trail. The first author coded the corpus and the second verified each cell against the recorded sources, resolving disagreements by returning to the documents. This approach is appropriate for an interpretive design in which the analytical categories are theoretically derived rather than emergent. The corresponding limitation is that the coding was not replicated by a coder external to the research team, as stated in Section 5.5. Cell-level traceability in Table S1 is the compensating safeguard, since it allows a reader to assess any individual attribution independently.

Since the design is desk-based, the reliability of each finding depends on the authority and verifiability of the underlying documentation, which varies systematically across dimensions and contexts. Every source in the corpus was assigned an evidence level on a three-point ordinal scale defined by the status of the document, not its length, recency or accessibility:

- E1—binding or official documentation, comprising national and regional regulations, legal instruments, technical standards and official implementing acts (e.g., the French AGEC Law [65] and Art. L541-4-4 of the Code de l'environnement [66], Décret No. 2021-821 [67], BEK 496/2024 [68], DIN SPEC 91484 [69], D.Lgs. 36/2023 [70]). A finding at this level is directly verifiable against a public normative text.
- E2—institutional and technical documentation, comprising deliverables and guidelines of EU-funded projects (Interreg NWE FCRBE, PREUSE, CIRCuIT, CCRI), reports of public agencies (ADEME, Agence de la Transition Écologique; OVAM, Openbare Vlaamse Afvalstoffenmaatschappij; FOEN/UFAM, Federal Office for the Environment), peer-reviewed literature and technical protocols issued by recognized bodies (Buildwise; CSTB, Centre Scientifique et Technique du Bâtiment; CTICM, Centre Technique Industriel de la Construction Métallique). A finding at this level is documented and traceable, but reflects the perspective of a specific institution.
- E3—declarative or self-reported documentation, comprising other grey literature, platform documentation and the websites of the actors themselves. Such sources establish intentions, claims or self-declared activities; they were used only to establish the existence of actors, platforms and infrastructures, and never as the sole basis for a comparative statement.

Each cell of the analytical matrix was assigned the highest available evidence level for each dimension–context pair. This was done based on the principle that a cell is verifiable at the level of its strongest source. The resulting distribution is reported in Table A4 in Appendix A. Two decision rules governed the cross-case analysis. First, no recurring pattern is reported in Section 4 unless supported by at least one E1 or E2 source in a majority of the contexts in which it was observed. Second, statements predominantly based on E3 sources are formulated as claims about the documented presence of a configuration and not about its scale, throughput, or performance.

As shown in Table A4, the evidentiary basis of the framework is not uniform. The regulatory dimension relies entirely on E1 sources in all six contexts and can therefore be compared with confidence. The same holds for material flows and operational practices in the three contexts where pre-demolition auditing is mandated by law or technical standard, which rest mostly on E2 sources. The dimensions concerning actors, digital platforms and supporting infrastructure rely more heavily on E3 sources. The reason is structural: the existence and operational status of a hub or a marketplace are usually documented by its own operator. This asymmetry directly affects how the results should be interpreted. The comparative claims in Sections 4.2 and 4.3 concern the documented presence and configuration of institutional and infrastructural arrangements, not their volume or effectiveness. No independent verification of the latter was available. Since this asymmetry stems from the nature of the subject rather than uneven coverage of any single case, it affects the same dimensions in all six contexts.

The limitations on traceability stem from the depth and nature of the sources, which vary significantly across contexts. In some cases, the documentation is produced directly by the actors involved and is therefore operational in nature, covering projects, platforms, hubs and infrastructure. In other cases, it is primarily programmatic or informational, comprising national programmes, project deliverables and scientific papers. This aspect introduces limitations in terms of the traceability and comparability of the evidence, as part of the documentation describes intentions or strategies rather than practices verified in the field. This topic is further discussed in Section 5.

4. Results

This section begins with a presentation of the analytical framework used, which is structured into 7 rows (dimensions of analysis) and 6 columns (European contexts). The complete matrix is included in the Supplementary Materials (Table S1) and provides a summary of the key findings for each context in relation to the ecosystem dimensions explored.

A cross-case analysis reveals recurring patterns, which are presented in the following paragraphs organized by reference macro-family, as illustrated in the previous section (Section 3.3), thereby partially addressing RQ1. The tensions and enabling conditions that emerge from this comparison are presented and discussed in Section 5, which is dedicated to the Discussion.

4.1. Regulatory and Policy Conditions

In all cases, reuse practices are accompanied by some form of regulatory framework, albeit of varying nature and scope. The following examples illustrate this point: regional frameworks in Belgium (Circular Flanders [71], Circular Wallonia [72], Be Circular [73]; the PREC program [74]), national strategies in the Netherlands (National Circular Economy Program 2023–2030 [75], CE 2050 goal [76]), enabling legislation in France (Anti-Gaspillage pour une Économie Circulaire or AGEC Law [65]), technical standards in Germany (DIN SPEC 91484 [69]), cantonal regulations in Switzerland (Waste Ordinance OLTRif/VVEA [77], guidelines from the Federal Office for the Environment—FOEN/UFAM [78]), and national strategies in Denmark (National Strategy for the Circular Economy and national waste management plans [79], as well as the 2024 measures dedicated to the reuse of deconstruction materials [68]). These framework initiatives are supported by a range of operational tools, including reuse clauses in procurement contracts, standardized pre-demolition audit systems, quality and material certification protocols, roadmaps with circular economy objectives, and public pilot projects.

The analysis indicates that the regulatory dimension functions on two levels. The first level is the regulatory framework level, which consists of laws and strategies that define the status and objectives of reuse. An example of this is the AGEC Law in France. The second level is the instrumental level, which consists of technical standards and procedures that translate the principles defined at the previous level into operational practices. An example of this is the DIN SPEC 91484 standard [69] in Germany. The six contexts are distributed evenly across the two levels. Some have a robust regulatory framework but operational tools that are still being defined, while others have well-established technical procedures despite the absence of a legislative framework dedicated to reuse.

4.1.1. Misalignment Observed Between Contexts

An analysis of recurring patterns reveals an imbalance and misalignment between the framework and the tools, in two opposite directions. In no context are the framework's ambitions and the specific binding instruments on reuse aligned. In four cases, the framework is very advanced, but the instruments are underdeveloped. In the Netherlands, the situation is the reverse: the instruments are mature but oriented toward recycling. Regulatory requirements are almost entirely focused on recycling, while reuse remains voluntary. In situations where a binding instrument exists, it generally measures the material footprint or mandates material recovery, rather than the reuse of components. For instance, the Mantelverordnung (DE) and the requirement for recycled concrete, as well as the Betonakkoord (NL), provide guidelines for recycling, but do not address reuse. A digital tool developed in Belgium called TOTEM (BE), for instance, measures a building's material footprint but does not mandate reuse.

The only two contexts with binding tools dedicated to reuse are France (AGEC Law [65]; PEMD, Produits, Équipements, Matériaux, Déchets [80]; REP, Responsabilité Élargie du Producteur [81]; ReQPR, Reconnaissance Qualité des Processus de Reconditionnement [82]) and Denmark (selective demolition, Affaldsbekendtgørelsen [83], BEK 496/2024 [68]). There is a clear distinction between four contexts with recycling requirements and two that are beginning to introduce reuse regulations. Therefore, recycling is considered a mandatory requirement, while reuse is considered a voluntary measure.

4.1.2. France and Germany: Two Contexts with Binding Instruments Dedicated to Reuse

The French and German cases demonstrate how these two levels operate and how the same outcome can be achieved through different approaches. In France, the AGEC Law operates through secondary instruments rather than the law itself. Decree No. 2021-821, effective 1 July 2023, converted the former pre-demolition waste diagnostic into the PEMD diagnostic. Mandatory for projects with more than 1000 m^2 of cumulative floor area, it requires the diagnosticians to distinguish products intended for reuse from waste streams. Both the report and the post-works completion form are filed with the national platform managed by the CSTB, which aggregates project-level obligations into a centralized record of forthcoming availability. Since 1 January 2023, the REP PMCB scheme has included financing. Four approved eco-organizations, funded by an eco-contribution levied on construction products, are bound by reuse and reusability targets expressed as a percentage of the estimated waste stock. Art. L541-4-4 completes the sequence by allowing elements selected on-site by a qualified operator to leave the demolition site without acquiring waste status. The diagnostic obligation, dedicated financing and legal status are all in place, however, ADEME recorded a reuse rate below 1% in 2025.

Germany produces the same artefact without a dedicated legislative mandate, through a technical standard. DIN SPEC 91484 [69] establishes a process for documenting the assessment of building products for high-quality reuse before demolition. The process involves splitting the audit into preliminary and detailed inspections, specifying who is authorized to perform them, and determining the minimum product and building data to be recorded. This data is recorded in a format designed to generate digital material passports. Adoption is voluntary and demand-driven. It is invoked against the circularity criteria of the EU Taxonomy and is operationalized by private intermediaries, such as Concular. It is also increasingly required in the tender documentation of institutional clients.

The convergence is on the artefact, not the mechanism that produces it. This is the practical outcome of the top-down/bottom-up tension discussed in Section 5.1 and what makes the two pathways unequally transferable.

The pre-demolition audit and selective deconstruction constitute ae the emerging converging operational lever. This is the type of tool used as a concrete starting point for reuse. The Diagnostic PEMD (Produits, Équipements, Matériaux, Déchets) establishes a threshold for projects over 1000 m^2 for the application of this procedure (FR, mandatory). BEK 496/2024 [68] (Bekendtgørelse om håndtering af affald og materialer fra bygge- og nedrivningsarbejde) mandates selective demolition for projects with removal areas of at least 250 m^2 (DK, mandatory). DIN SPEC 91484 standardizes the steps to follow for conducting a pre-demolition audit (DE, voluntary). Buildwise defines a four-phase framework to follow (BE, voluntary, bottom-up). The requirements for separating construction and demolition waste established by the Besluit bouwwerken leefomgeving or Bbl (NL, mandatory) facilitate the adoption of a pre-demolition audit. This indicates that the process of reuse commences when a building is decommissioned.

Two less common patterns also emerge. The first is the removal of "waste" status as a legal precondition for reuse. This has been explicitly codified in only two contexts: in France, where the AGEC Law stipulates that products from demolition intended for reuse do not acquire "waste" status, and in Denmark, where the Miljøbeskyt-telsesloven permits the use of selected, uncontaminated C&D fractions without specific authorization. The legal resolution of waste status appears to be a prerequisite for the other instruments. In its absence, reuse remains in a regulatory gray area, and adherence to the available instruments can only remain voluntary. The second pattern pertains to the EU's role as a regulatory driver in contexts where national legislation is less robust. This is evident in Germany, where DIN SPEC 91484 is aligned with the European taxonomy, and in Belgium, where the Buildwise operational framework was developed under the Interreg NWE FCRBE project.

Financial support for reuse practices comes primarily from public resources, while private capital plays a complementary rather than a substitute role, driven by specific interests. Often, the identified funds or incentives are allocated broadly to circular practices in a general sense and are not specific to reuse practices. Public funding is often multi-level or derived from European funds, as seen in Belgium (EU projects and regional funds), Germany (EU, federal, and Länder), and Switzerland (federal, cantons, and municipalities). In instances where funding is not public, it typically takes three identified forms:

the extended producer responsibility mechanism applied to the construction sector, which channels private capital toward preparation for reuse (France, through eco-organizations); funding provided by digital platforms and private intermediaries connecting supply and demand (Germany, Concular and affiliated companies).
philanthropic capital and corporate self-financing (Denmark, Realdania, and waste management operators).

4.2. Institutional and Governance Conditions

The analysis reveals two main categories of actors: public and private. Public actors are often regional or cantonal in nature, and typically involve public agencies responsible for environmental sustainability and waste management. Research institutions are responsible for generating the knowledge and providing the framework that enables cooperation among different actors, based on EU projects (Interreg NWE FCRBE, PREUSE, CIRCuIT, etc.).

In the private sector, reuse is driven by architectural decisions involving designers, architects, and engineers. These stakeholders are present in all contexts, demonstrating that such practices are driven from the bottom up and by design choices. The infrastructure for reuse is always in place, facilitating the operational and logistical aspects of reuse practices.

In certain contexts, such as the Netherlands and Germany, certification bodies play a substantial role in regulating reuse processes and practices.

A closer look at the governance model adopted reveals that the primary levels of action are municipal/regional (in terms of implementation) and national (as a framework). The enabling actors influencing governance are mostly private entities: consultants or designers (Rotor, Superuse Studio, Baubüro in situ, Bellastock, Lendager) who apply reuse practices in the early stages of a building's life cycle, and actors operating in the final stages of selective demolition and materials management (Rotor DC, Restado, Tscherning).

A legally binding mechanism to implement reuse, derived from legislation, is generally still lacking, except in France, where the AGEC Law, through the PEMD and REP PMC, gives priority to réemploi. The key instruments vary widely, but in four out of six cases, digital platforms emerge as enablers of the process (for the market, networks of stakeholders, and the dissemination of knowledge). Finally, the dominant form of coordination consists of developing a network of public and private stakeholders who define actions aimed at facilitating and implementing the reuse market.

4.3. Operational and Infrastructure Conditions

An analysis of European contexts does not reveal comparable data on the reuse of materials and components. This is because such data is not calculated, and only in one context (France) do figures appear very low compared to recycling rates. What emerges, however, is a standard process that generally follows the same phases, with some variations noted in each context. The six main stages of the reuse process identified are: (1) audit/inventory, (2) selective deconstruction, (3) storage/qualification, (4) recertification/testing, (5) preparation for reuse, and (6) reintroduction to the market (sale or direct reintroduction to the same construction site).

A high density of marketplaces has been identified in nearly all the contexts analyzed, particularly in the context of digital infrastructure. In the absence of effective coordination from either the market (DE) or the state (FR), regional networks are being established to provide this coordination. Matchmaking platforms between stakeholders define systems in which the flow (shops for materials and components) is prioritized over the stock (dynamic matching of supply and demand). Knowledge platforms are frequently linked to those that provide stakeholder mapping. Databases of circular material passports are becoming more widespread in various contexts; however, Madaster remains the most widely used to date.

When comparing supporting infrastructures, however, physical infrastructures often outnumber research infrastructures. This type of infrastructure stems primarily from two recurring models—linked to the social economy and public waste management—rather than from a commercial perspective. These infrastructures are managed by public cooperatives that prioritize social inclusion (Buurman, BatiTerre, Bau-teilbörse, Ressourcerie, RéaVie) or are integrated into a public waste recovery and management network (De

HER, Utrecht Trechterweide, PlusByg, Aarhus & Copenhagen material exchange centers). Purely commercial dealers are in the minority (Rotor DC, Restado, Genbyg). The density of knowledge-based infrastructure is correlated with the presence of a leading technical university that drives it (TU Delft, ETH, SUPSI). It has been noted that the majority of physical infrastructures (Aarhus, Copenhagen, Circulairwarenhuis, the Reallabor markets) are predominantly connected to the reuse of furniture and objects, with the construction sector serving as a secondary stream. Hybrid infrastructures (both physical and knowledge-based) fall into two categories:

living labs or academic demonstrators (ActLab, Green Village), where the connection between research and practice is more direct but more fragile due to their often limited duration;
social enterprises that integrate training into their market operations (RéaVie/Solid-R, Buurman), combining knowledge dissemination and logistics management in a sustainable manner, as they are supported by a social revenue base.

4.4. Synoptic Comparison of Enabling Conditions Across the Six Contexts

Each entry records an observed configuration and its status, rather than a score. A weak or absent entry denotes missing documentation, not a negative judgment. Read column by column, the table characterizes each context. Read row by row, and it reveals the distribution of each condition.

Three patterns emerge, which are discussed in Section 5. First, the rows are unevenly populated. Dimensions 3, 6, and 7a recur in almost every context. In contrast, the legal resolution of non-waste status (dimension A) and the guarantee of technical performance (dimension B) appear in no more than two contexts. Second, the two least populated rows are the initial and final links of the sequence set out in Section 5.2, which provides the empirical basis for interpreting the conditions as a chain rather than a list. Third, no column is uniformly consolidated. Not even France, the only context to have closed the transversal condition, possesses the territorial infrastructure required to operate at scale.

5. Discussion

5.1. Analytical Tensions Among the Dimensions Analysed

An examination of the six European contexts, through the proposed framework, reveals certain analytical tensions that distinguish European models and shape the comparison with the Italian case. Viewed through this lens, it becomes clear why seemingly similar conditions produce different results in different contexts. Each tension identifies an axis along which each analyzed case is positioned differently, and their convergence indicates where the decisive constraint operates. The identified tensions are presented below.

Top-down regulation vs. bottom-up experimentation. This difference concerns the origin of the process of reusing building materials and components. In some cases, regional or national public entities standardize processes or procedures to facilitate the practice (FR). In other cases, it is more effective to involve private actors who directly experiment with processes and procedures to find the best way to adopt such practices, thereby generating the standard (BE, CH, DE, DK). These are two paths toward the same outcome with opposite implications for transferability.

Material as Waste vs. as a Resource. The legal status of demolition material must be established as a fundamental prerequisite: is it waste output or input for new cycles? As the French case illustrates, this issue has been addressed by distinguishing between "réemploi" and "reutilization", which define an intermediate stage when the material or component leaves the demolition site (AGEC Law, 2020) [65]. During this stage, materials selected by a qualified operator on-site are not classified as waste (Art. L541-4-4 of the Code de l'environnement, implementing the AGEC Law, 2020) [66]. However, this provision included in the legislation has yet to yield any tangible results. The 2025 ADEME report indicates that less than 1% of construction materials and products are reused [84]. Therefore, legal recognition of "non-rejection" is a necessary but not sufficient condition. Regulatory reclassification alone is insufficient to stimulate the market. This is precisely the gap that the CSTB is attempting to fill with ReQPR [82]. Belgium, Switzerland and Germany, on the other hand, take a more practical approach, while Italy, the Netherlands and Denmark primarily manage these flows as waste [27,28].

Project Circularity vs. Local Ecosystem. Circularity can only be replicated when individual projects contribute to a broader ecosystem [11–13]. This is where "design from availability" comes into play. In this approach, actual availability only feeds back into the design if the ecosystem makes it transparent and reliable. uropean case studies demonstrate that circularity is only replicable when each project contributes to a broader ecosystem. This ecosystem consists of databases (e.g., Madaster and Immobilien Basel-Stadt), digital platforms (e.g., Opalis and Zirkular), protocols (e.g., DIN SPEC 91484 and Interreg NWE FCRBE guidelines), and supporting infrastructure (e.g., BatiTerre, Bauteilbörse, Ressourcerie, De HER, and Aarhus and Copenhagen material exchange centers). These elements each makes a specific contribution to a broader system, consistent with the literature on the territorial dimension of the circular economy [15–17] and on hubs as an intermediate step in the transition [33]. "Design from Availability" embodies this concept by relating to the actual availability of local materials, actors, tools, and procedures, thereby influencing design choices, but only if the local ecosystem is clear and reliable.

Environmental Ambition vs. Economic Sustainability. Reuse is rarely motivated solely by environmental value. It is also essential to consider the economic sustainability of the adopted strategy, which is currently supported by public and philanthropic incentives. Economic competitiveness is the fundamental prerequisite for a market operating in parallel with the market for new goods. Advanced contexts demonstrate that reuse is rarely driven solely by environmental value; rather, it is supported by subsidies and incentives, such as Interreg projects, OVAM, Milieulijst, and Innovation Fund Denmark, as well as private philanthropic funds such as Realdania. The challenge remains to ensure that reused products are environmentally sound and economically competitive, which is necessary for a parallel market.

An enabling factor overlaying these tensions is the technical assurance of reused materials. The presence or absence of this assurance explains why even advanced regulatory frameworks do not necessarily lead to reuse. Uncertainty about the performance, liability, and insurability of reused materials is a gap that hinders the development of these practices. In emerging contexts (FR and DE), this trust is built through regulation and the establishment of guarantees [9,85], but above all, through collaboration among various actors, in line with the regulatory inconsistencies already noted in the literature on reuse [20] and with the barriers systematized by Rakhshan et al. (2020) [12]. This aspect is largely absent in the six contexts analyzed, even though it is a fundamental step in enabling the practice of reuse. France's most recent implementation of this approach is ReQPR, a voluntary third-party quality certification program for refurbishment centers. The CSTB launched ReQPR in collaboration with the Métropole du Grand Paris on November 25, 2025 [82] and with the Centre Technique Industriel de la Construction Métallique (CTICM), which has developed a guide of professional recommendations for the reuse of steel components. The C2P Commission (Commission Prévention Produits) recognizes these recommendations as compliant with the principle of "technique courante", that is, as established construction practice and therefore insurable under standard conditions.

Table A6 in Appendix A summarizes the position of each context across the four tensions and the technical guarantee transversal factor (TF). The positions are qualitative and are derived from the analytical matrix (Table S1). They indicate the dominant orientation of each context rather than the absence of the opposite pole. When read comparatively, two patterns emerge. First, no context occupies the enabling pole on all five axes. France and Belgium, at opposite ends of T1 and T3, nonetheless converge on comparable operational outcomes. Second, France is the only context that clearly separates from the others on TF, a distribution consistent with the reading proposed in Section 5.2, where technical guarantee operates not as one tension among others, but as a constraint that becomes binding once the preceding four are resolved.

5.2. An Enabling-Conditions Framework for Building Component Reuse

The enabling conditions identified in the comparative analysis are not a list of independent factors, but rather an ordered sequence of dependent relationships (Figure 4). Interpreted together, the patterns outlined in the results actually form a sequential chain. Legal recognition of non-rejection is a prerequisite for the standardized audit, which depends on two independent and parallel processes. One process involves channelling material flows toward physical management and storage hubs, while the other involves the activities of research infrastructures that experiment with innovative valorization practices aimed at subsequent standardization into regulated processes. On this foundation, building materials and components are reused, supported by a guarantee system that fosters trust in their reuse [85–87].

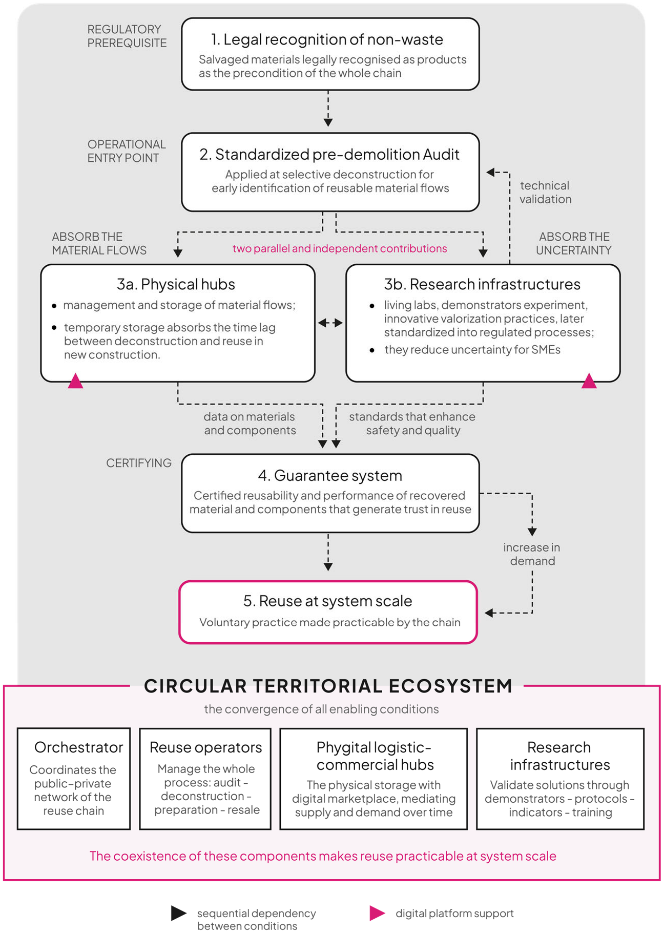

Figure 4. The enabling conditions for the reuse of building components in the sequential chain of dependencies that converge into the circular ecosystem.

From a regulatory standpoint, national legislation alone is not enough, because it creates the necessary, but not sufficient, conditions for the implementation of reuse practices. None of the analyzed contexts mandate reuse, and the absence of such a requirement implies that this practice is voluntary. Other enabling conditions include clearly defining the reuse potential of materials from selective demolition sites and establishing a standardized process to certify the reusability of materials. The focus of the policy shifts to the assurance function of the existence of an entity and a procedure that certifies the suitability of the reused material or component. Recent studies converge on this issue, even though they originate from different contexts, identifying design standards and certification protocols as the primary lever for industry confidence in reuse [30], while others show how the difficulty in defining new frameworks of responsibility discourages the adoption of reused materials and components [88]. Therefore, regulation becomes effective only when translated into operational tools, such as clauses in public procurement contracts, standardized pre-demolition auditing procedures [87], quality protocols for reused materials and pilot projects.

In terms of financial resources, the most comprehensive incentive systems are associated with two recurring conditions: a multilevel public financing framework aligned between the European, national, and regional levels, and at least one dedicated instrument (e.g., a fiscal instrument, as in the Netherlands, or a fund earmarked for reuse, as in France under the AGEC law) that distinguishes targeted support from general circular financing.

At the institutional level, the enabling condition is the territorial coexistence of actors that cover the entire life cycle of a building. These actors range from designers, who promote reuse through their design choices, to deconstruction and materials management operators, who close the supply chain, to regional public agencies and research institutes, which facilitate cooperation. At the governance level, this translates into a multilevel framework, such as a national strategic framework adopted at the regional or municipal level, operationalized by an intermediary actor that connects design, deconstruction, and the market (the orchestrator). In the absence of binding mechanisms, coordination among public and private actors supported by digital platforms constitutes the primary mechanism for structuring the reuse market (digital marketplaces).

From an operational standpoint, the pre-demolition audit and selective deconstruction serve as the starting point for a transparent and documented process for reusing recovered materials, components, and products [87]. All of the contexts analyzed are based, albeit in different ways, on the early identification of reusable streams.

Digital platforms play an enabling role in circularity, a fact that is widely recognized in the literature [52–54]. However, they are only effective if they are connected to a network of local actors, which allows the entire system to scale up. A comparison of the analyzed platforms demonstrates their potential when integrated with the following:

technical documentation that provides reliable data on the quantity and quality of materials (Madaster);
geographic mapping of reuse stakeholders and the regional availability of materials (Ressources, Opalis, Harvest Map Oogstkaart, Cirkla, Cycle Zero, etc.);
the matching of supply and demand among designers and businesses (Rotor DC, Restado, Salza, etc.);
public procurement processes that facilitate reuse by providing supporting tools (Immobilien Basel-Stadt).

A key insight emerges: a digital platform does not generate circularity if it is isolated from reliable documentation, mapping, the market, and public demand. Its effectiveness depends on its integration into a broader regional ecosystem consisting of a coordinated network of stakeholders, physical hubs, standardized procedures, performance verification tools, and resource geolocation systems, not merely on its existence.

Physical infrastructure enables the reuse chain to function. In fact, analysis shows that reuse requires spaces to prepare, repair, and store items. The most organized systems have warehouses, temporary storage areas, living labs, and demonstration projects, as well as reuse and collection centers that accommodate these functions. Examples include Matériuum's Ressourcerie in Geneva, Denmark's PlusByg public hubs, and Rotor DC's warehouses in Brussels. The transition from waste management to reuse requires a network of local infrastructure that can bridge the time gap between deconstructing a building and using its recovered materials in new construction. Hubs dedicated to reuse and temporary storage act as intermediaries between supply and demand. However, the literature interprets them as an intermediate step, rather than a definitive one, in the circular transition [33].

Rather than playing a secondary role, research infrastructures (i.e., circular hubs and living labs) provide technical validation to SMEs, reducing the performance uncertainty identified in the literature as a critical barrier to reuse [12] and attributed to the ability to provide guarantees in more recent research [88]. In line with the literature on open innovation, which attributes this function to living labs [89] and transition intermediaries [90], these entities produce technical validation of innovative solutions, circular design protocols and procedures, circularity indicators, knowledge for professional training, and coordination among stakeholders. These elements recur in the examined contexts (BE, NL, CH, DE, and DK), where experimentation enables operational processes and the development of shared standards. The French case demonstrates the outcome of a fully realized chain with institutionalization in formalized guarantee mechanisms (ReQPR and CSTB/CTICM).

Together, these conditions shape the circular territorial ecosystem (Figure 4), which consists of a coordinator who oversees the network, operators who manage the entire reuse process, logistics and commercial hubs with both physical and digital components, and research infrastructure that validates solutions through demonstrators. The coexistence of these components, rather than the isolated presence of a few, makes reuse feasible at a systemic scale.

Figure 4 should be read as a flow diagram rather than a list. Each link is necessary, but not sufficient, for the next one. The absence of a link prevents the next one from taking effect. Physical hubs and research infrastructures appear as parallel branches because they process the same input different ways, the former absorbs the material flow released by the audit and the latter absorbs the technical uncertainty that flow carries. Both converge on the guarantee system, where a reused element becomes specifiable by a designer and acceptable to a client. The reading is diagnostic: the analyst should identify the first interrupted link, since intervention is required there rather than where activity is most visible.

Interactions, Substitutions and a Typology of Ecosystem Configurations

Presenting the enabling conditions as an ordered chain raises the question of how the links interact: whether strength in one compensates for weakness in another, and whether some combinations are more productive than others. Three observations follow from the comparison.

First, the links are not equally substitutable. Legal recognition of non-waste status and guarantee of technical performance discharge functions that no other condition can perform. What admits partial substitutes is not the function itself, but rather the entity that carries it out. In countries where the legal status of the material remains unresolved, such as Belgium, Switzerland, and Germany, a professional protocol combined with a reputable, qualified intermediary operates as a de facto substitute. This transfers liability to an operator whose competence is recognized by the market, even if not by the law. The substitution works, but it does not scale. It binds the practice to the reputation of a small number of firms, and it collapses if those firms leave the market. Conversely, a research infrastructure can temporarily carry a missing guarantee by validating elements on a case-by-case basis, as has been observed in the Netherlands and Switzerland. This solution is also limited. Case-by-case validation carries a fixed cost per element that does not fall as volume rises. A declining unit cost at higher volume is precisely what an institutional guarantee scheme provides.

Second, certain combinations are subject to trade-offs rather than complementarities. A strongly top-down regulatory pathway can ensure the swift establishment of the first link, but it tends to crowd out the bottom-up experimentation that fosters operational expertise. The obligation then arrives before the capacity to discharge it. The French reuse rate, still below 1% five years after the enactment of the AGEC Law, illustrates this outcome. A market-led pathway shows the inverse profile: operational capacity accumulates, but the unresolved legal status caps the practice at the volume that reputational trust can carry. A further trade-off exists between recycling and reuse infrastructure. Where the reuse chain is grafted onto an efficient public waste management network, as in the Netherlands and Denmark, logistical capacity is immediately available. However, the operating logic of that network, calibrated on mass recovery, tends to divert flows towards recycling at the first point of friction.

Third, these regularities can be organized into a typology of configurations (Table 4), defined by which links are present and which are interrupted. The typology is intended as a practical instrument. It allows a context to be positioned and its priority intervention to be identified. That intervention varies by configuration and is not necessarily the next link in the sequence.

Table 4. Typology of territorial reuse ecosystem configurations, with characteristic failure mode and priority intervention.

Configuration	Contexts	Links Consolidated	Interrupted Link	Characteristic Failure Mode	Priority Intervention
A. Regulation-led	FR	Legal status; standardized audit; dedicated financing; emerging guarantee	Territorial layer of hubs and preparation capacity	Circularity remains on paper: obligations are discharged documentarily while volumes remain marginal	Build preparation and storage capacity, and convert the PEMD inventory into an operational supply tool
B. Practice-led/market-led	BE, DE	Standardized audit protocols; operators; platforms; commercial intermediation	Legal status of the material; institutional guarantee	Institutional ceiling: the practice does not scale beyond the firms that vouch for it	Codify the derogation into a legal status and institutionalize third-party qualification
C. Infrastructure-led/public service	DK, NL	Logistics and collection network; binding deconstruction or separation rules; data infrastructure	Qualification of the individual element; incentives specific to reuse; guarantee	Dislocation effect: mature recycling channels capture flows that could have been reused	Introduce reuse-specific targets and pricing that differentiate preparation for reuse from recovery
D. Knowledge-led	CH	Research infrastructures; demonstrators; municipal public demand	National regulatory framework; guarantee	Demonstrator dependence: excellence remains confined to exemplary projects	Transfer validation from academic testing to a repeatable certification procedure
E. Latent	IT	Green procurement architecture; aggregate marketplace; collection centre network	Legal status; standardized audit; guarantee; preparation hubs	Procurement instruments address a supply that does not legally or technically exist, which results in inoperative demand.	Legal recognition of the status of non-waste and then act on the intermediate links (audit, hubs, guarantee)

5.3. Transferability and Implications for the Italian Context

As mentioned in Paragraph 1, Italy is a leader in the circular economy and recycling practices. However, it lags behind in other circular practices, such as reuse. Regarding the Italian construction sector, the national framework already includes a top-down mechanism characterized by CAMs and green procurement. The Italian Procurement Code (D. Lgs. 36/2023) [70] makes it mandatory to include the minimum environmental criteria in project and bidding documentation (Art. 57, comma 2). The circular dimension is first and minimally recognized in Annex I.7 (Section II, Article 11), which requires, albeit with reference to the specific project type and subject to the Project Manager's discretion, the identification of processes that promote the reuse of primary and secondary materials (subparagraph d) and the definition of measures that reduce external procurement through reuse within the project (subparagraph f). This signals an evolving regulatory trend that remains at the programmatic level without establishing an enabling, binding, and verifiable criterion for reusing building components. Furthermore, a structured network of collection centers managed by waste management operators exists, but it is geared toward recycling, proper disposal, and municipal waste management. The existence of a marketplace for aggregates (Market Inerti) represents progress in adopting digital platforms that serve as an interregional meeting point for supply and demand. However, these platforms are still weakly connected to the operational infrastructure at the regional level, including collection centers, reuse centers, and networks of demolition and deconstruction contractors.

Three features of the Italian regulatory architecture explain why these provisions fall short of an enabling condition for reuse.

The first concerns the object of the mandatory element. Art. 57(2) of D. Lgs. 36/2023 obliges contracting authorities to incorporate the minimum environmental criteria into tender and design documents, so the Code's binding force is wholly derivative of the CAM decrees. These criteria are based on thresholds for recycled and recovered content expressed as a percentage of weight. A crushed and reprocessed aggregate meets these criteria as easily as a reclaimed element, and typically more cheaply. Therefore, the obligation can be discharged entirely through recycling. The revised CAM for buildings (D.M. 24 November 2025, applicable from 2 February 2026, replacing D.M. 256/2022) refines rather than displaces this logic: it adds a plan for the future disassemblability of the work and requires that at least 70% by weight of the components used be directly reusable or amenable to disassembly and selective deconstruction at the end of life. This is a design-for-disassembly requirement; it acts on the supply of reusable elements one building generation from now, while no requirement, and no verification procedure attaches to the specification of already reclaimed components in the work being procured today.

The second concerns normative force. Annex I.7, Section II, Art. 11 lists among the contents of the technical–economic feasibility document the identification of processes promoting the reuse of primary and secondary materials (letter d) and measures reducing external supply through in-project reuse (letter f), but subordinates both to the nature of the intervention and to the assessment of the Responsabile Unico del Progetto (RUP). The results is a documentary obligation rather than a performance requirement: no threshold, no verification method, no non-compliance regime, and a feasibility document recording the absence of reuse opportunities is fully compliant.

The third lies upstream of the Code and is decisive. Material arising from demolition remains special waste by default under D. Lgs. 152/2006, and no national end-of-waste criterion or on-site declassification procedure comparable to Art. L541-4-4 of the French Code de l'environnement applies to reclaimed building components. A contracting authority that chooses to specify them therefore faces a supply that is legally waste, technically undocumented absent a standardised audit, and uninsurable absent a guarantee scheme.

The Code's provisions are thus less insufficient in ambition than inoperative in their preconditions. They sit at the demand end of a chain whose first three links, as defined in Section 5.2, are missing. This places Italy in configuration E of Table 4, and explains why the priority does not lie with the most visibly available instrument, public procurement itself.

In this case, the critical issue is not the absence of regulations, but rather whether they align with current objectives and can be translated into operational procedures and practices that help build a circular construction value chain. Compared to what has been identified at the European level, certain aspects could be incorporated from the Italian level that are still missing:

1. Classifying materials, components, or products from selective demolition sites as reusable resources, with or without further processing, rather than as special waste by default, following a careful assessment by expert operators. This first step can trigger the activation of the others. It is a necessary but not sufficient condition.
2. A standardized, regional, pre-demolition audit procedure that serves as a tool for design and reporting and that can foster a market for materials and urban mining practices.
3. A specific guarantee system, as France demonstrates, can prevent the spread of these practices even where the law is progressive.
4. Support infrastructure for research, which is currently lacking, to serve as a bridge between innovation and SMEs. The aim is to promote experimentation with innovative circular approaches and the training of specialized professionals.
5. Establish regional hubs to prepare materials for reuse and temporary storage. These hubs can serve as temporary logistics centers for construction materials and components. With the help of digital platforms, they can facilitate connections between supply and demand. In the absence of shared protocols for material certification, specific insurance systems, and public demand capable of guiding the market, the current digital marketplace, Market Inerti (an Italian digital platform designed to facilitate the matching of supply and demand for aggregate materials), would remain underutilized and risk generating uncompensated costs.

The same seven-dimension framework used for the six European contexts is applied to Italy, grounding the diagnosis in comparison rather than assertion. For each dimension, Table A7 (Appendix A) reports the enabling configuration recurring in the European cases, the Italian situation and the resulting gap. These gaps are interdependent, and their resolution follows the dependency chain rather than the order of institutional convenience. Table A8 (Appendix A) and Figure 5 translate them into a phased roadmap, specifying for each phase the required action, the actor with the mandate to lead it, the supporting actors, the barrier that has so far prevented it, and a verifiable indicator of completion. Phases overlap, and the indicative horizons refer to elapsed time from the start of the sequence, not to fixed dates.

Figure 5 presents the roadmap as a temporal sequence, providing insights that the tabular form cannot convey. The phases overlap across the sixty-month span rather than following one another. Several can proceed in parallel, and phase 4 accelerates phase 2 rather than conditioning it. Sequentiality, therefore, governs when each phase becomes capable of producing an effect, not the order in which the work is performed.

https://doi.org/10.3390/su18168401

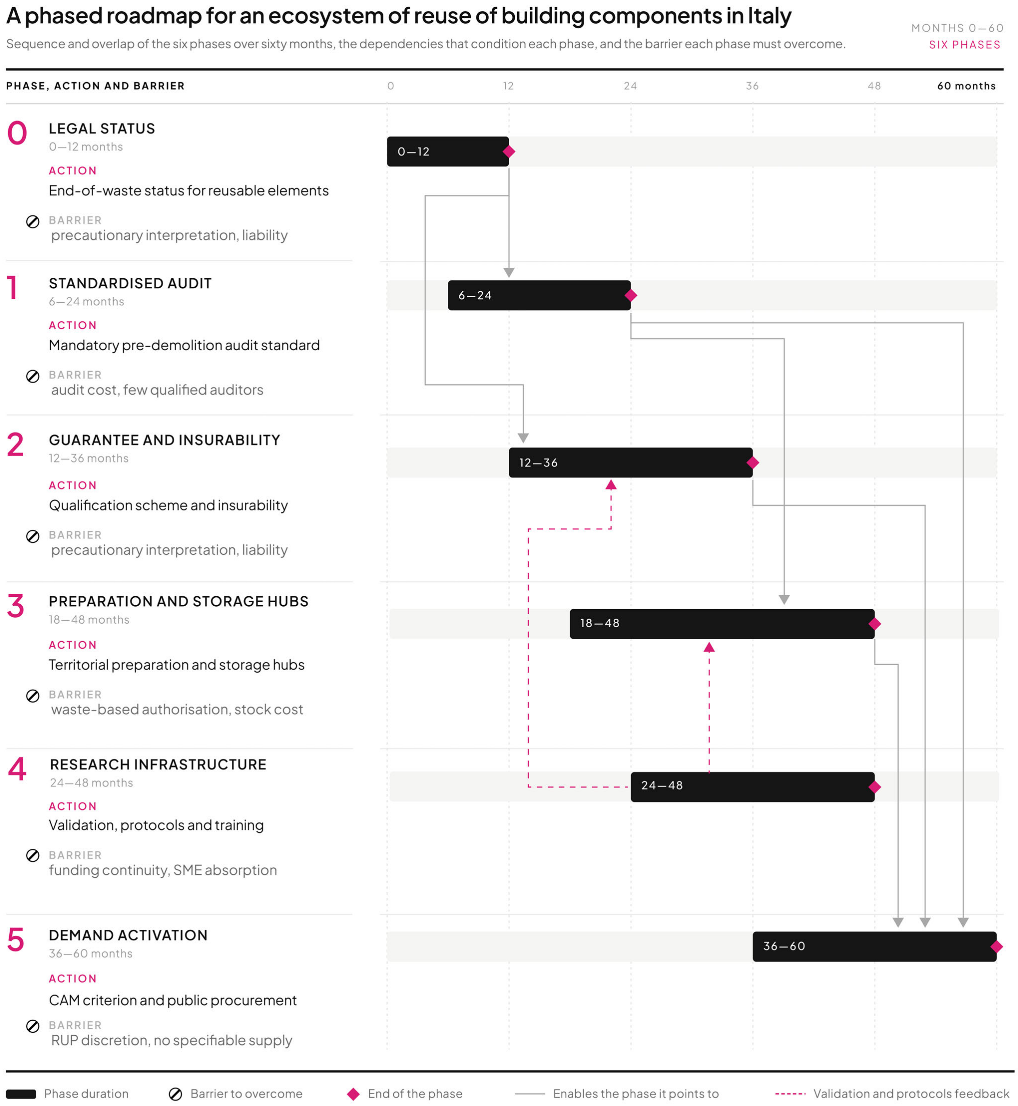

Figure 5. Implementation roadmap for the activation of a territorial reuse ecosystem in Italy and phases dependencies.

The dependencies manifest in three distinct forms. First, phase 0 enables phases 1 and 2. This is because an audit mandate or qualification scheme cannot be built on material whose legal classification is unresolved. Phase 0 is the only phase that cannot be deferred without arresting the sequence. Second, phases 1, 2 and 3 converge on phase 5. This records why demand-side instruments fail when they are introduced before a supply that is legally specifiable, technically documented, insurable and physically available. Phase 3 operates on horizons shorter than the time a hub needs to reach steady-state throughput. Consequently, in the interim, the hub carries stock without a demand able to absorb it. Phase 5 is designed to address this gap, but the fiscal instrument that would fund it (an equivalent of the earmarked eco-contribution revenue under the French REP PMCB) presupposes an extended producer responsibility scheme for construction products that Italy has not established. This absence is a further missing link, not an implementation detail. Third, phase 4 returns validation protocols and technical documentation to phases 2 and 3 along a dashed path. This is the only relation that runs backwards in the sequence while running forwards in time. Its subordination is functional rather than chronological. The first year of phase 2 is institutional, whereas the technical content on which insurers price risk arrives from month 24. Without it, the guarantee would depend on the case-by-case validation identified above as non-scalable. Therefore, the continuity of its funding is not an administrative but a structural concern.

Leadership is shared between public and private actors, with none holding it twice consecutively. The sequence requires five handoffs between institutions neither mandate nor budget, and no coordinator is currently designated. Establishing one is a precondition of the roadmap rather than one of its phases.

5.4. Positioning of the Findings in Relation to the Literature

The results engage four strands of literature, and the relation to each is one of qualification rather than confirmation.

With regard to the literature on the circular economy in the built environment, the findings confirm the established diagnosis that the sector's apparent circular maturity is an artefact of measurement: It is important to note that EU recovery rates of around 88–89% are not comparable across Member States. This is due to divergent definitions of backfilling which inflate reported performance [28], and the recovered fraction is overwhelmingly low-grade aggregate [91]. The comparison provides an explanation for why the shift to short loops has not followed. Research indicates that the literature attributes the gap to barriers understood as independent obstacles to be removed [12,92,93]. The evidence presented here indicates that the obstacles are organised in a specific order, and that removing them in the wrong order has no effect. The French case, where an advanced legal and financial architecture (AGEC Law, the PEMD diagnostic, the PMCB extended producer responsibility scheme) coexists with reuse volumes still short of the 2% target set for 2024 [94], is difficult to interpret within a barrier framework and straightforward within a sequential one [95].

With regard to the literature on the reuse of building materials and components, the barriers identified by Rakhshan et al. (2020) are all present in the six contexts, but the comparison reorders them [12]. The economic, social and regulatory barriers that the study identifies as the most significant are able to be addressed effectively once the intermediate links are in place, since platforms and hubs address them directly. The qualification of the individual element remains binding in five of the six contexts. The argument that this barrier is institutional rather than technical is well established.

The techniques for assessing reclaimed elements are well established and increasingly codified [11]. However, there is a lack of a body authorised to certify these techniques and an insurer willing to accept the certification [95,96].

With respect to territorial governance and transition research, the findings support the importance attributed to intermediaries [90] and specify that function more narrowly. The orchestrator's role, as observed in the consolidated cases, is not primarily that of a convenor or vision-builder, but rather that of an entity that converts a project-level obligation into a territorial signal. This is exemplified by CSTB's approach, which involves the aggregation of PEMD diagnostics into a public inventory. In contrast, in a more fragmented Swiss configuration, where an orchestrator merely convenes, coordination is documented, but the practice does not scale. However, the findings presented in this study differ from those reported by Van Uden et al. (2025), who suggested that circular building hubs act as a transitional phase that will eventually experience a decline in size once digital matching mechanisms effectively balance supply and demand [33]. This reading is based on practitioners' expectations; however, the six configurations observed here suggest that hubs are a permanent requirement of a reuse chain. This is because the time gap between deconstruction and reincorporation is a structural feature of construction, rather than an inefficiency to be eliminated. As such, hub siting is governed by a persistent spatial and temporal mismatch between secondary supply and construction demand [59,97].

With regard to the literature on digital material passports and platforms, the results are highly divergent. Research indicates that passports and marketplaces have a significant enabling role [25,98]. The analysis shows that they are present in almost every context, even those where reuse remains limited. Consequently, their presence is not a strong discriminator. A platform can only contribute when it is coupled with a documented inventory upstream, a physical hub that can hold stock, and a public demand that can absorb it. Without these couplings, the platform displays an availability that cannot be acted upon. This supports the more cautious recent position that digital instruments remain largely conceptual and disconnected from the needs of the actors expected to use them [99,100], with a direct implication for Italy, where the platform is the element most readily available and the one whose isolated development would be least productive.

5.5. Limitations

Based on the approach and topics discussed in this paper, the scope of the findings is constrained by three limitations.

The first limitation concerns the evidence base. The analysis is desk-based and relies on secondary documentation whose availability and granularity vary across contexts; informal and tacit dynamics remain beyond its reach, and cross-checking sources against one another mitigates this only in part. The coding is likewise interpretive, and the field is moving quickly: initiatives such as ReQPR (November 2025) are too recent for their effectiveness and durability to be assessed.

The second limitation concerns case selection. The six contexts were selected precisely because reuse is comparatively advanced in them. While consistent with an information-rich design, this approach observes a single type of outcome: it can establish which conditions are present where reuse occurs, but not whether they are sufficient, since contexts sharing those conditions without developing reuse remain unobserved. Therefore, the framework should be read as identifying necessary and jointly enabling conditions, and the dependency chain as an ordering of preconditions rather than a causal model with identified effects. The same choice fixes where the chain begins. Had less advanced settings been included, Southern and Eastern European contexts where CDW management is dominated by landfill and cost-driven recycling would have revealed further upstream conditions: effective enforcement of waste-tracking obligations, a formalized and technically equipped demolition sector, and landfill pricing high enough to make recovery economically viable. In the six cases, these are taken for granted because they are already in place. Whether the sequence remains unchanged or lengthens as contextual maturity falls can only be established by a systematic extension to a contrasting sample. In its current form, the framework is better suited to diagnosing why an advanced context has stalled than to prioritizing interventions where the preconditions are absent. The hypothetical application to Italy (Section 5.3) only partially offsets this bias, since Italy shares the regulatory and enforcement baseline of the six cases but is itself a less advanced context for reuse.

The third limitation is a validity boundary. The conditions are formulated in functional terms; their institutional carriers are not. The analysis relies on the EU acquis, specifically the end-of-waste architecture of the Waste Framework Directive. For that reason, the comparative sample was not extended beyond Europe. The six contexts are comparable precisely because the dimension identified here as decisive, the legal status of demolition material, is governed by the same supranational framework in all of them. Applying different analytical categories outside this framework would distort the comparison rather than expand it. The framework is therefore proposed as transferable within that architecture, and its extension beyond it is a matter of research design rather than a claim made here.

https://doi.org/10.3390/su18168401

These limitations converge on a single methodological requirement, the triangulation of desk-based findings with primary empirical evidence. Comparative and design-oriented research in construction management addresses this through a two-stage sequence, in which a documentary or model-based stage establishes what is formally in place and a subsequent empirical stage establishes whether it operates as documented [101,102]. Read against this template, the findings reported here have mixed status: the presence and configuration of the individual links are documented, but their ordering into a dependency chain is yet to be proven. Interviews with actors and experts in the six contexts have already been initiated and are intended for subsequent contribution. They are designed to verify whether those operating within the contexts recognise the ordering of the links. The application to the Metropolitan City of Turin, described in Section 6, provides a setting in which the chain can be observed as it is assembled, rather than being reconstructed after the event. The proposition can be corroborated in a specific sense: the ordering would be supported if actors operating in contexts where a given link is absent described the subsequent links as inoperative rather than merely weak. Conversely, it would require revision if reuse were found to operate at a volume where an earlier link is missing, or if practitioners consistently identified a binding aspect that the framework lacks.

6. Conclusions

The objective of this paper is to investigate the conditions under which the reuse of building materials and components can become a structured territorial practice, rather than a set of episodic experiences. Regarding RQ1, a comparison of six European contexts reveals that these conditions do not operate as independent factors, but rather as a chain ordered by relations of dependency. Legal recognition of the non-waste status constitutes the precondition, the standardized pre-demolition audit is the operational point of attachment, and physical hubs and research infrastructures are the devices that absorb, respectively, the material flows and the technical uncertainty. This sequence is further constrained by the guarantee of the performance of reused materials. The absence of this constraint explains why even advanced regulatory frameworks do not, by themselves, produce effective reuse. In none of the contexts does bindingness attach to reuse as such: where an obligation exists, it concerns the audit or selective deconstruction, while the practice itself remains voluntary.

Regarding RQ2, the transition from conditions to practices is observed only where these components coexist within a territorial ecosystem coordinated by an orchestrating actor. This ecosystem includes logistical and commercial poles that combine physical and digital components, as well as research infrastructures that validate solutions. It is their coexistence, rather than the isolated presence of individual dimensions, that makes reuse viable at the system scale. The interaction analysis further validates this outcome: the extreme links of the chain are functionally irreplaceable, whereas the intermediate ones allow partial, non-scalable substitutes. This explains why contexts that appear equally advanced diverge as the volume increases. For Italy, this yields a precise indication regarding transferability. The instruments the country already possesses sit at the two ends of the chain: a demand-side regulatory apparatus calibrated on recycled content and an operating digital marketplace. However, neither becomes productive on its own. The legal reclassification of the material is necessary to regulate it at a different level than the current one. This reclassification would allow for a standardized audit procedure, the establishment of territorial hubs for preparation for reuse and for research, and the implementation of a system of technical and insurance guarantees.

The contribution of this work lies in the framework of seven dimensions and three macro-families, which offers a replicable grid for reading, in comparable terms, the territorial enabling conditions of a reuse ecosystem, thereby addressing the gap identified in the literature between the description of individual cases and the systematic representation of the conditions that make them possible. When applied to contexts of varying maturity, the framework enables analysts to identify the present and absent links of the chain, as well as the most opportune sequence for action. The typology of configurations proposed in Section Interactions, Substitutions and a Typology of Ecosystem Configurations converts this diagnosis into a decision rule, since the priority intervention differs by configuration and does not coincide with the next link in the sequence.

At the policy level, the results show that regulatory effectiveness depends less on the framework's ambition and more on its translation into operational instruments. This dependency chain implies both a priority order and a choice of instrument type at each stage. The initial link, the legal status of the material, allows only for a regulatory instrument because no incentive or information campaign can resolve a matter of legal classification. It is also, in budgetary terms, the least costly intervention and the one that conditions the productivity of every subsequent measure. The second link, the standardised audit, is best served by a hybrid of regulatory and informational instruments: a technical standard defining procedure and data structure, made binding above a threshold in public works and accompanied by professional qualification schemes. This is because when a mandatory audit is conducted without the involvement of qualified auditors, the result is compliance documents rather than usable inventories. The third link comprises two parallel capacities. Preparation and storage capacity is where economic instruments become decisive, because the hub absorbs the cost of the time gap between deconstruction and reuse, a cost that no regulatory obligation can eliminate and that determines whether the flow is diverted to recycling; capital support, differentiated authorisation regimes and pricing that separates preparation for reuse from generic recovery act here. Research infrastructure, its parallel, calls for an instrument of a different type again, namely sustained public funding of validation and demonstration capacity, since its output is neither a rule nor a subsidy but the technical evidence on which the following link depends. The fourth link, the guarantee, requires an institutional instrument in the strict sense (a third-party qualification body and the recognition of qualified reuse as ordinary construction practice) since what is at stake is the allocation of liability rather than the provision of an incentive. Demand-side instruments, including reuse clauses in public procurement, belong at the end of this sequence and not at its beginning: introduced earlier, they address a supply that is neither legally nor technically specifiable, and they generate documentary compliance without material effect. For practice, it follows that designers, deconstruction operators and public bodies cannot act in isolation, because they are components of an ecosystem and generate value only when integrated.

Three limitations of this study define its immediate future research agenda. First, the chain of conditions has been reconstructed from documentary sources and requires validation with primary data: interviews with practitioners and experts in the six contexts have already begun and will be the subject of a subsequent contribution. Second, several of the instruments observed, the ReQPR certification in particular, are too recent for their effectiveness to be assessed, so the framework will require longitudinal monitoring of the observed contexts and periodic updating. Third, the framework has been derived from contexts of comparatively high institutional maturity, all operating within the same European regulatory architecture. Its operational value will be tested through application to a territorial ecosystem in the Metropolitan City of Turin, within the ECO3R project (Politecnico di Torino with the Consorzio Chierese Servizi, under the Piedmont Region's INFRA+ call). In this context, the Circular Design PoliTo Lab serves as a testbed for implementing the strategies currently adopted within the ECO3R territorial ecosystem and for applying and testing the enabling conditions identified through the comparative analysis, with the aim of supporting the structuring and scaling up of reuse practices. Within this project, the roadmap phases related to physical and research infrastructure are currently at an early stage of implementation and initial monitoring. The research infrastructure, in particular, is being developed within a three-year programme launched in 2025, while the upstream phases remain under national and regional jurisdiction.

Three further extensions would establish the framework's scope conditions rather than its internal validity. Extending the comparison to contexts of lower institutional maturity would test whether the first link shifts upstream as the regulatory baseline weakens. Extending it beyond the European regulatory architecture would test whether the same functions can be discharged by different institutional carriers. Extending it to sectors where reuse is already industrialized would establish whether the guarantee link is specific to construction, where each element is incorporated into a unique load-bearing assembly, or a general property of markets for reused durable goods. Taken together, these extensions would move the framework from one documented on advanced European cases to one whose limits of application are known.

Supplementary Materials: The following supporting information can be downloaded at https://www.mdpi.com/article/10.3390/su18168401/s1, Table S1: Cross-national context analysis matrix of ecosystem dimensions for material and component reuse in the building sector (Belgium, the Netherlands, Switzerland, Germany, France and Denmark).

Author Contributions: Conceptualization, A.B. and G.C.; methodology, A.B. and G.C.; software, A.B.; validation, A.B. and G.C.; formal analysis, A.B. and G.C.; investigation, A.B. and G.C.; resources, A.B. and G.C.; data curation, A.B.; writing—original draft preparation, A.B.; writing—review and editing, A.B. and G.C.; visualization, A.B.; supervision, G.C.; project administration, G.C.; funding acquisition, G.C. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the European Union—NextGenerationEU through the Italian Ministry of University and Research (MUR), under the National Recovery and Resilience Plan (PNRR), Mission 4, Component 2, Investment 3.3, Ministerial Decree No. 117/2023—CUP E14D23001940004. The doctoral scholarship was co-financed by Vico S.r.l. The paper reports only the authors' viewpoints; neither the European Union nor the European Commission are responsible for them.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The data presented in this study are derived from publicly available sources, including EU project deliverables, national and regional regulatory documents, technical reports from public agencies, and peer-reviewed literature, as cited throughout the article and detailed in the source-tracking tables (Tables S1, 1, 3, A1 and A4). The comparative coding matrix developed by the authors is available from the corresponding author on request.

Acknowledgments: The authors gratefully acknowledge Vico S.r.l. for their active collaboration in the research project and for co-founding it. During the preparation of this work the authors used AI for proofreading (Grammarly v.1.2.274.1916, Deepl). After using this tool/service, the authors reviewed and edited the content as needed and take full responsibility for the publication's content.

Conflicts of Interest: The authors declare no conflicts of interest.

Abbreviations

The following abbreviations are used in this manuscript:

BE	Belgium
NL	The Netherlands
CH	Switzerland

DE	Germany
FR	France
DK	Denmark
RQ1	Research question 1
RQ2	Research question 2
ReQPR	Reconnaissance Qualité des Processus de Reconditionnement
CSTB	Centre Scientifique et Technique du Bâtiment
CTICM	Centre Technique Industriel de la Construction Métallique
PEMD	Produits, Équipements, Matériaux, Déchets
CAM	Criteri Ambientali Minimi
AGEC	Anti-Gaspillage pour une Économie Circulaire
CE	Circular Economy
UNEP	United Nations Environment Programme
CDW	Construction and Demolition Waste
CCRI	Circular Cities and Regions Initiative
CIRCuIT	Circular Construction in Regenerative Cities
FCRBE	Facilitating the Circulation of Reclaimed Building Elements
PREUSE	Public Responses to Enable the Use of Salvaged building Elements
OVAM	Openbare Vlaamse Afvalstoffenmaatschappij
ADEME	Agence de la Transition Écologique
FOEN/UFAM	Federal Office for the Environment
ISPRA	Istituto Superiore per la Protezione e la Ricerca Ambientale
REP	Responsabilité Élargie du Producteur

Appendix A

Table A1. Positioning of the proposed framework with respect to existing conceptualisations of circular ecosystems.

Reference Framework	Unit of Analysis	Components Identified	Territorial Scale	Operationalized for Comparison	Relation to the Present Framework
Pietrulla (2022)—circular ecosystem [34]	Circular ecosystems classified by geographic reach and industry scope (review with proposed classification)	Four categories from two variables (local/global; intra/cross-industrial); four success factors: governance with an orchestrator, processes, clear complementarity, customer orientation	Geographic reach is one of the two classification variables	Partially: a classification of ecosystem set-ups, not an observation grid	Source of dimension 4, the orchestrator being retained as the core of the governance dimension, and of the territorial delimitation adopted here; the local, cross-industrial category is the closest antecedent of our object, but it classifies ecosystems that already exist rather than diagnosing whether one can form, which is the shift this framework makes.
Aarikka-Stenroos et al. (2021)—CE ecosystems [35]	Multi-actor entity across micro, meso and macro levels	Material, knowledge and economic value flows; five ecosystem types	Multi-level, not specifically territorial	Partially: a taxonomy of types, not an observation grid	Source of dimension 5 and of the tripartite flow logic; the taxonomy is used to interpret contexts rather than to classify them.
Trevisan et al. (2022)—circular value ecosystems [37]	Systematic review consolidating the construct	Value proposition and value cycles; actor roles; governance through orchestration, non-hierarchical and collaborative	Not specified	No: review, no comparative instrument	Source of dimension 4: orchestration as a non-hierarchical coordination mechanism is retained as the core of the governance dimension. The emphasis on value cycles informs the treatment of the conditions as a sequence rather than a checklist.
Present framework	National or regional context as an enabling environment for building component reuse	7 dimensions in 3 macro-families, including regulatory and financial preconditions and the disaggregation of infrastructure	National context with regional articulation	Yes: applied identically to six contexts and to Italy	-

Table A2. Assessment of candidate contexts against the inclusion criteria (C1: reuse practice beyond a single demonstrator; C2: participation in a dedicated European project; C3: operating reuse infrastructure).

Candidate Context	C1	C2	C3	Decision and Reason
Belgium (BE)	Yes	Yes	Yes	Included—densest documented configuration; reference case for the bottom-up pathway
The Netherlands (NL)	Yes	Yes	Yes	Included—data-centred configuration; national programme with mature instruments
Switzerland (CH)	Yes	Partial	Yes	Included—non-EU member, retained deliberately to test whether the conditions depend on the EU acquis
Germany (DE)	Yes	Yes	Yes	Included—standard-led pathway without a legislative anchor
France (FR)	Yes	Yes	Yes	Included—the only fully law-led pathway; necessary contrast case
Denmark (DK)	Yes	Yes	Yes	Included—binding selective deconstruction within a public waste-management system
United Kingdom	Partial	Partial	Yes	Excluded—post-Brexit divergence of the regulatory framework makes the comparison non-homogeneous on the dimension identified as the first link
Sweden, Norway, Finland	Partial	Partial	Yes	Excluded—activity documented mainly for furniture and interior fit-out, with the construction stream secondary
Austria	Partial	No	Yes	Excluded—practice documented at the level of individual projects, without a territorial configuration
Spain, Portugal	No	Partial	Partial	Excluded—documented activity concerns recycling and recovery of construction and demolition waste rather than component reuse
Italy (IT)	No	Partial	Partial	Not included among the comparison cases; treated separately in Section 5.3 as the target context of the transferability analysis

Table A3. Coding rules and boundaries between adjacent dimensions.

Dimension	Coding Question	Evidence Required	Boundary Rule
1. Regulatory framework	Which instruments define the legal status of the material and the obligations bearing on reuse?	Legal or regulatory document, technical standard, or official strategy document in force.	Instruments creating a financial obligation or entitlement are coded under dimension 2, even where established by the same document.
2. Resources and incentives	Which financial instruments support reuse? Are they specific to it?	Funding programme, fiscal measure or financing mechanism with an identifiable scope.	Coded as reuse-specific only where the instrument distinguishes reuse from circularity in general; otherwise, recorded as generic.
3. Key actors involved	Which actors are documented as operating in the reuse chain and at which stage?	Documented operational activity, not membership of a network or a declaration of intent.	An actor operating an infrastructure is coded here and, separately, under dimension 7; the two entries are not treated as independent evidence.
4. Governance model	How is action among these actors coordinated?	Documented coordination arrangement, formalised partnership	The existence of actors belongs to dimension 3; the relationship connecting them belongs to dimension 4.
5. Material flows and reuse practices	Through which stages does material pass, and what is the documented operational process?	Procedure, protocol or documented process description.	The obligation to carry out a procedure belongs to dimension 1; the procedure and the steps to be followed to carry it out fall under Dimension 5.
6. Digital platforms	Which digital platforms are operating, and which function does each perform?	Operating platform with accessible documentation; function classified as inventory, mapping, marketplace, matchmaking, knowledge, networking.	A platform operated by a physical hub is coded here for its digital function and under dimension 7 for its physical function.
7. Supporting infrastructure	Which physical and research infrastructures exist, and what do they do?	Operating site with a documented address or programme, classified as physical, research or hybrid.	Infrastructure that has only been conceived or designed but never built are excluded. Classified as research only when experimentation or training is documented; reprocessing, storage and resale alone are classified as physical.

Table A4. Highest evidence level available for each analytical dimension and national context (E1 = binding or official documentation; E2 = institutional and technical documentation; E3 = declarative or self-reported documentation).

Dimension	BE	NL	CH	DE	FR	DK
1. Regulatory framework	E1	E1	E1	E1	E1	E1
2. Resources and incentives	E2	E1	E2	E2	E1	E2
3. Key actors involved	E2	E2	E3	E3	E2	E3
4. Governance model	E2	E2	E2	E2	E2	E2
5. Material flows and reuse practices	E2	E2	E2	E1	E1	E2
6. Digital platforms	E3	E3	E3	E3	E3	E3
7. Supporting infrastructure	E3	E2	E2	E3	E2	E3

Table A5. Synoptic comparison of enabling conditions across the six European contexts (● present and consolidated; ◐ present but partial or voluntary; ○ absent or not documented).

Dimension	BE	NL	CH	DE	FR	DK
1. Regulatory framework dedicated to reuse	◐ Regional strategies; no reuse-specific obligation	◐ National programme; instruments oriented to recycling	◐ Cantonal ordinances; no national frame	◐ Technical standard, voluntary	● AGEC Law, PEMD, REP PMCB	● BEK 496/2024, selective deconstruction
A. Non-waste status legally resolved	○ via qualified operators	○ Absent	○ Absent, if not for some types of recyclable waste	○ Define case by case	● Art. L541-4-4	● Selected uncontaminated fractions
2. Reuse-specific financial instrument	◐ EU projects and regional funds	● Fiscal instruments (MIA/Vamil, Milieulijst)	◐ Multi-level, not reuse-specific	◐ Private intermediation	● Eco-contribution under REP PMCB	◐ Philanthropic and corporate
3. Actors' coverage of the reuse processes	● Designers, dealers, deconstruction operators	● Broad, data-oriented	◐ Concentrated in a few cities	● Intermediaries and platforms	● Including eco-organisations	● Public operators and contractors
4. Orchestration function	● Public agencies and Buildwise	● National programme and certification bodies	○ Fragmented across cantons	◐ Private intermediaries	● CSTB and public agencies	● Municipalities and public operators
5. Standardized pre-demolition audit	◐ Buildwise framework, voluntary	◐ Separation obligation under Bbl	○ Not standardized	◐ DIN SPEC 91484, voluntary	● Diagnostic PEMD, mandatory above 1000 m^2	● Mandatory above 250 m^2
6. Digital platforms	● Opalis, Rotor DC	● Madaster (material passports)	● Zirkular, Salza, Cirkla	● Concular, Restado	● PEMD platform, marketplaces	● Genbyg, Circue
7a. Physical infrastructure	● Rotor DC, Bauteilbörse	● De HER, Utrecht Trechterweide	● Ressourcerie, BatiTerre	◐ Reallabor markets, dealers	◐ Ressourceries, on the growth	● PlusByg, municipal centres
7b. Research infrastructure	● Buildwise, living labs	● TU Delft, Green Village	● ETH, SUPSI, ActLab	○ Only research project, never realized	● CSTB, CTICM	◐ Project-based (CIRCuIT)
B. Guarantee of technical performance	○ Professional protocols only	○ Oriented to recycled content	○ Case-by-case validation	◐ in development by companies	● ReQPR, C2P recognition	○ Not addressed

Table A6. Position of the six European contexts along the analytical tensions and the transversal factor of technical guarantee.

Tension	BE	NL	CH	DE	FR	DK
T1. Origin of the process (top-down regulation or bottom-up experimentation)	Bottom-up: operators and Buildwise generate the protocol; regional strategies frame but do not prescribe	Mixed: strong national programme, but instruments generated by sectoral agreements (for recycling, Betonakkoord)	Mixed: cantonal fragmentation, but some of them provide a digital database in public tenders. Practice driven by designers and technical universities	Bottom-up: standard-led (DIN SPEC) with market adoption, no legislative anchor	Top-down: law-led sequence (AGEC Law, PEMD, REP PMCB, ReQPR)	Top-down: binding selective demolition (BEK 496/2024) with public implementation
T2. Legal status of the material (waste or resource)	Waste: effective derogation through qualified operators	Waste: flows are managed within the waste regime	Waste: cantonal ordinances oriented to recovery	Waste: declassification handled case by case	Resource: explicitly codified (Art. L541-4-4)	Resource: for selected uncontaminated fractions (Miljøbeskyt-telsesloven)
T3. Locus of circularity (project or local ecosystem)	Ecosystem: densest configuration (Rotor DC, Opalis, hubs, protocol)	Ecosystem, but organized around data (Madaster)	Ecosystem at city/cantonal scale (Basel, Geneva); weak national integration	Ecosystem in formation, driven by private intermediaries (Concular, Restado)	Project-centred: obligations attach to the individual site; the territorial layer is still thin	Ecosystem embedded in the public waste-management network (PlusByg, municipal centers). Project-led by specific private designer and decommissioning companies
T4. Driver of viability (environmental ambition or economic sustainability)	Mixed: EU project funding plus social-economy revenue base	Economic: fiscal instruments (MIA/Vamil, Milieulijst) internalize the incentive	Environmental: public and institutional demand, limited dedicated funding	Economic: private intermediation and platform-based business models	Economic through EPR: eco-contribution earmarked for preparation for reuse	Philanthropic and corporate (Realdania, waste operators) rather than fiscal
TF. Technical guarantee of reused elements (absent or institutionalised)	Partial: professional protocols, no insurance scheme	Weak: certification bodies are active, but oriented to recycled content	Weak: validation takes place through demonstrators and academic testing	Under construction: standard covers the audit, and a private company, Concular, is building it in cooperation with insurance companies	Institutionalized: ReQPR and CSTB/CTICM recognized as a technique courante	Weak: regulation covers deconstruction, not the qualification of the element

Table A7. Application of the analytical framework to the Italian context, against the configuration recurring in the six European cases.

Dimension	Recurring European Configuration	Italian Situation	Gap
1. Regulatory framework	Legal status of the reclaimed element resolved (FR, DK) or derogated through qualified operators (BE, CH, DE); reuse addressed by a dedicated instrument in 2 of 6 cases.	CAM mandatory through Art. 57 D. Lgs. 36/2023; reuse mentioned in Annex I.7 without threshold or verification; demolition material remains special waste under D. Lgs. 152/2006.	No end-of-waste route for building components (only for aggregates); no binding instrument on the specification of reclaimed components
2. Resources and incentives	Multilevel public funding plus at least one dedicated instrument (fiscal in NL, EPR-financed fund in FR).	PNRR and regional circular-economy funding, allocated to circularity in general; no line earmarked for preparation for reuse or specific to reuse strategy.	Absence of an instrument that distinguishes reuse from generic circular investment
3. Key actors involved	Full life-cycle coverage: designers, deconstruction operators, dealers, regional agencies, research institutes.	Designers and demolition contractors present; near-absence of dealers in reclaimed components and of a preparation-for-reuse operator category.	Missing intermediary link between deconstruction and the market.

Table A7. *Cont.*

Dimension	Recurring European Configuration	Italian Situation	Gap
4. Governance model	National frame implemented regionally, operationalised by an orchestrator connecting design, deconstruction and market.	Regional competence over waste; no designated orchestrator for reuse; coordination project-based.	No reuse orchestration function.
5. Material flows and reuse practices	Pre-demolition audit as the entry point, mandatory (FR, DK, NL) or standardized and voluntary (DE, BE).	Pre-demolition audit not standardized for reuse; selective demolition practised for waste-management compliance, not for reuse potential.	Absence of a standardized audit procedure for reuse; the reuse potential has never been assessed before demolition.
6. Digital platforms	Platforms connected to documentation, actor mapping, market and public demand (Madaster, Opalis, Rotor DC, Immobilien Basel-Stadt).	Market Inerti operating as an interregional marketplace for aggregates; material passports are not diffused.	Platform layer disconnected from audits, hubs and procurement; scope limited to aggregates.
7. Supporting infrastructure	Network of preparation and storage hubs (Rotor DC, Ressourcerie, PlusByg) with research infrastructures anchored to technical universities	Dense network of collection centres oriented to waste and recycling; no reuse preparation hubs; no dedicated research infrastructure (ECO3R under implementation)	Both the physical and the research infrastructure layers oriented to the reuse of building and material components are missing

Table A8. Implementation roadmap for the activation of a territorial reuse ecosystem in Italy: sequence, actors, barriers and indicators.

Phase	Action	Lead Actor	Supporting Actors	Barrier to Overcome	Indicator of Completion
0. Legal status (0–12 months)	Establish an end-of-waste route or an on-site declassification procedure for building elements selected for reuse by a qualified operator, on the model of Art. L541-4-4 (FR)	MASE, with ISPRA technical support	Regions; SNPA; professional bodies	Precautionary administrative interpretation and unallocated liability for the declassified element	Ministerial decree in force; procedure applicable in at least three Regions
1. Standardized audit (6–24 months)	Adopt a national pre-demolition audit standard defining stages, auditor qualification and a machine-readable data structure, on the model of DIN SPEC 91484; make it mandatory in public works above a floor-area threshold	UNI, in coordination with MASE	Regions; professional orders (CNI, CNAPPC); universities; demolition and waste management companies	Cost of the audit borne by the client without a corresponding benefit; shortage of qualified auditors or of a professional figure entitled to perform it	Published UNI standard; audit required in public tenders above the threshold; auditor training scheme active
2. Guarantee and insurability (12–36 months)	Establish a third-party qualification scheme for preparation-for-reuse processes and a technical framework enabling insurers to treat qualified reused elements as ordinary construction practice, on the model of ReQPR and the CSTB/CTICM recommendations	Accredia and ANIA, with ITC-CNR and UNI	Insurance companies; CNI/CNAPPC; building product companies	Absence of harmonised technical specifications and unresolved interaction with CPR marking for reused products	Operational certification scheme; at least one insurance product covering qualified reused elements
3. Preparation and storage hubs (18–48 months)	Convert and extend the existing collection-centre network into territorial hubs for preparation for reuse and temporary storage, with an authorisation regime distinct from waste storage	Regions and metropolitan cities	Municipal waste operators; social-economy cooperatives; consortia	Authorisation regime designed for waste, land availability and the cost of holding stock over the time gap between deconstruction and reuse	At least one operating hub per Metropolitan City; measured throughput of prepared elements
4. Research infrastructure (24–48 months)	Establish research infrastructures providing technical validation, protocol development and specialised training, bridging innovation and SMEs	Universities and research centres (ECO3R, Circular Design PoliTo Lab)	Regions (INFRA+ and equivalent instruments); industry associations; SMEs	Continuity of funding beyond the project cycle and weak absorptive capacity of SMEs	Infrastructure operating beyond initial funding; validation protocols transferred to at least one standard
5. Demand activation (36–60 months)	Introduce into the CAM a verifiable criterion on the specification of reclaimed components, distinct from recycled content and from future disassemblability; extend Market Inerti from aggregates to qualified components and connect it to audit outputs; develop a public procurement digital platform to facilitate reuse in public tenders	MASE, with regional authorities	Contracting authorities; building company operators; ANCE and professional orders (CNI, CNAPPC); platforms	Discretion of the RUP under Annex I.7; absence of a supply that is legally and technically specifiable, which the preceding phases resolve	Reuse criterion in force with a verification method; share of public works specifying qualified reused elements measured annually

References

1. UNEP. *Global Status Report for Buildings and Construction 2024/2025*; United Nations Environment Programme: Nairobi, Kenya, 2025; ISBN 9789280742152.
2. European Environment Agency. *Construction and Demolition Waste: Challenges and Opportunities in a Circular Economy*; European Environment Agency: Copenhagen, Denmark, 2020.
3. Vermeulen, J. *EU Construction & Demolition Waste Management Protocol*; European Commission: Brussels, Belgium, 2016.
4. Dodd, N.; Donatello, S. *Level(s) Indicator 2.2: Construction and Demolition Waste and Materials User Manual: Overview, Guidance and Instructions (Publication Version 1.0)*; JRC: Nakano-ku, Japan, 2020.
5. García, C.; Caro, J.; Foster, G.; Pristerà, G.; Gallo, G.; Tonini, F. *Techno-Economic and Environmental Assessment of Construction and Demolition Waste Management in the European Union Status Quo and Prospective Potential*; Publications Office of the European Union: Luxembourg, 2024.
6. European Commission. *COM(2020) 98—A New Circular Economy Action Plan for a Cleaner and More Competitive Europe*; European Commission: Brussels, Belgium, 2020.
7. Potting, J.; Hekkert, M.; Worrell, E.; Hanemaaijer, A. *Circular Economy: Measuring Innovation in the Product Chain*; PBL Netherlands Environmental Assessment Agency: The Hague, The Netherlands, 2017.
8. Reike, D.; Vermeulen, W.J.V.; Witjes, S. The Circular Economy: New or Refurbished as CE 3.0?—Exploring Controversies in the Conceptualization of the Circular Economy through a Focus on History and Resource Value Retention Options. *Resour. Conserv. Recycl.* **2018**, *135*, 246–264. [CrossRef]
9. Wehner, B.; Campanella, D.; Martin, K. *Reclaimed Construction Material Insurance (RCMI)*; Concular GmbH: Stuttgart, Germany, 2024.
10. Berglund-Brown, J.; Ochsendorf, J. Reusing Heavy-Section Steel in Buildings: Carbon Reduction Potential and Material Availability. *J. Archit. Eng.* **2025**, *31*, 04025020. [CrossRef]
11. Küpfer, C.; Bastien-Masse, M.; Fivet, C. Reuse of Concrete Components in New Construction Projects: Critical Review of 77 Circular Precedents. *J. Clean. Prod.* **2023**, *383*, 135235. [CrossRef]
12. Rakhshan, K.; Morel, J.-C.; Alaka, H.; Charef, R. Components Reuse in the Building Sector—A Systematic Review. *Waste Manag. Res. J. Sustain. Circ. Econ.* **2020**, *38*, 347–370. [CrossRef] [PubMed]
13. Byers, B.S.; Raghu, D.; Olumo, A.; De Wolf, C.; Haas, C. From Research to Practice: A Review on Technologies for Addressing the Information Gap for Building Material Reuse in Circular Construction. *Sustain. Prod. Consum.* **2024**, *45*, 177–191. [CrossRef]
14. OECD. *The Circular Economy in Cities and Regions*; OECD Urban Studies; OECD Publishing: Paris, France, 2020; ISBN 9789264642959.
15. Tapia, C.; Bianchi, M.; Pallaske, G.; Bassi, A.M. Towards a Territorial Definition of a Circular Economy: Exploring the Role of Territorial Factors in Closed-Loop Systems. *Eur. Plan. Stud.* **2021**, *29*, 1438–1457. [CrossRef]
16. Bianchi, M.; Cordella, M.; Menger, P. Regional Monitoring Frameworks for the Circular Economy: Implications from a Territorial Perspective. *Eur. Plan. Stud.* **2023**, *31*, 36–54. [CrossRef]
17. Caceres Ruiz, A.M.; Sanches Pereira, A.; Zaman, A. Regionalising the Circular Economy: A Three-Step Integrative Review and Gap Analysis. *Clean. Environ. Syst.* **2025**, *19*, 100371. [CrossRef]
18. Ronchi, E.; Leoni, S.; Vigni, F.; Cancelli, D.; Galli, L.; Di Mario, V.; Brunori, C.; Beltrani, T.; Cellamare, C.M.; Chiavetta, C.; et al. *Rapporto Sull'Economia Circolare in Italia 2026*; Fondazione per lo Sviluppo Sostenibile—Circular Economy Network: Roma, Italy, 2026.
19. ISPRA. *Tasso di Uso Circolare dei Materiali—Indicatori Ambientali 2025*; ISPRA: Roma, Italy, 2025.
20. Condotta, M.; Zatta, E. Reuse of Building Elements in the Architectural Practice and the European Regulatory Context: Inconsistencies and Possible Improvements. *J. Clean. Prod.* **2021**, *318*, 128413. [CrossRef]
21. Giorgi, S.; Lavagna, M.; Campioli, A. Circolare e Sostenibile: Verso l'ottimizzazione Dei Flussi Materici Nei Processi Di Riqualificazione Edilizia in Italia. *Ing. Ambiente* **2019**, *6*, 151–163.
22. Benachio, G.L.F.; Freitas, M.d.C.D.; Tavares, S.F. Circular Economy in the Construction Industry: A Systematic Literature Review. *J. Clean. Prod.* **2020**, *260*, 121046. [CrossRef]
23. UNEP Building Fast. *Falling Short. As Climate Risks Rise and Cities Grow, We Must Rethink How We Build to Create Better Lives for All—Global Status Report for Buildings and Construction 2025/26*; United Nations Environment Programme: Nairobi, Kenya, 2026; ISBN 9789280742831.
24. Pomponi, F.; Moncaster, A. Circular Economy for the Built Environment: A Research Framework. *J. Clean. Prod.* **2017**, *143*, 710–718. [CrossRef]
25. Çetin, S.; De Wolf, C.; Bocken, N. Circular Digital Built Environment: An Emerging Framework. *Sustainability* **2021**, *13*, 6348. [CrossRef]
26. European Parliament; Council of the European Union. *DIRECTIVE 2008/98/EC of the Council of 19 November 2008 on Waste and Repealing Certain Directives*; Official Journal of the European Union: Luxembourg, 2008.

27. Caro, D.; Lodato, C.; Damgaard, A.; Cristóbal, J.; Foster, G.; Flachenecker, F.; Tonini, D. Environmental and Socio-Economic Effects of Construction and Demolition Waste Recycling in the European Union. *Sci. Total Environ.* **2024**, *908*, 168295. [CrossRef] [PubMed]
28. Moschen-Schimek, J.; Kasper, T.; Huber-Humer, M. Critical Review of the Recovery Rates of Construction and Demolition Waste in the European Union—An Analysis of Influencing Factors in Selected EU Countries. *Waste Manag.* **2023**, *167*, 150–164. [CrossRef] [PubMed]
29. MacArthur Foundation, E. *Towards the Circular Economy Vol. 1: Economic and Business Rationale for an Accelerated Transition*; Ellen MacArthur Foundation: Isle of Wight, UK, 2013.
30. Corsini, L. A Systems Approach the Circular Economy: Policy Recommendations to Increase Building Components Reuse. *Sustain. Prod. Consum.* **2025**, *57*, 292–305. [CrossRef]
31. Geerts, G.; Ghyoot, M.; Naval, S.; Godon, B.; Topalov, H.; Billet, M.; Thibault, F.; Vanel, V. *Procurement Strategies: Integrating Reuse in Large-Scale Projects and Public Procurement*; Interreg NEW FCRBE: Brussels, Belgium, 2022.
32. Huuhka, S.; Aarikka-Stenroos, L.; Lahdensivu, J.; Jonker-Hoffrén, P.; Arnold, V.; Stenberg, E.; Blok, R.; Gudmundsson, K.; Teuffel, P.; Mettke, A. Recreating the Construction Sector for Circularity. In *The Routledge Handbook of Catalysts for a Sustainable Circular Economy*; Routledge: London, UK, 2023; pp. 42–66.
33. Van Uden, M.; Wamelink, H.; Van Bueren, E.; Heurkens, E. Circular Building Hubs as Intermediate Step for the Transition towards a Circular Economy. *Constr. Manag. Econ.* **2025**, *43*, 446–464. [CrossRef]
34. Pietrulla, F. Circular Ecosystems: A Review. *Clean. Circ. Bioecon.* **2022**, *3*, 100031. [CrossRef]
35. Aarikka-Stenroos, L.; Paavo, R.; Llewellyn, D.W.T. *Research Handbook of Sustainability Agency—Chapter 17—Circular Economy Ecosystems: A Typology, Definitions, and Implications*; Edward Elgar Publishing Ltd.: Lansdown Road, UK, 2021; ISBN 9781789906035.
36. Aminoff, A.; Valkokari, K.; Antikainen, M.; Kettunen, O. Exploring Disruptive Business Model Innovation for the Circular Economy. In *Proceedings of the Sustainable Design and Manufacturing 2017*; Campana, G., Howlett, R., Setchi, R., Cimatti, B., Eds.; Smart Innovation, Systems and Technologies, Vol. 68; Springer: Cham, Switzerland, 2017; pp. 525–536. [CrossRef]
37. Hofmann Trevisan, A.; Gonçalves Castro, C.; Gomes, L.A.V.; Mascarenhas, J. Unlocking the Circular Ecosystem Concept: Evolution, Current Research, and Future Directions. *Sustain. Prod. Consum.* **2022**, *29*, 286–298. [CrossRef]
38. Asgari, A.; Asgari, R. Designing Circular Innovation Ecosystems: Insights from Stakeholders, Values, and Investment Policies. *Front. Sustain.* **2023**, *4*, 1197688. [CrossRef]
39. Hofmann Trevisan, A.; Gonçalves Castro, C.; Augusto De Vasconcelos Gomes, L.; Mascarenhas, J. Circular Ecosystem Structure and Orchestration: Outlining Actions to Innovate, Integrate, and Invest. In *Proceedings of the Design Society*; Cambridge University Press: Cambridge, UK, 2023; Volume 3, pp. 897–906.
40. Barra, A.; Callegari, G.; Monteu Cotto, T.U.; Ricciardi, G. ACT-FLOW Framework: A Multi-Level Approach to Enabling Local Territorial Circular Processes in the Construction Sector Through Actor Networks and Material Flows. *Architecture* **2026**, *6*, 107. [CrossRef]
41. Torre, A.; Bourdin, S. The Territorial Circular Ecosystem: Foundations for a Systemic and Place-Based Approach to Circular Economy. *J. Circ. Econ.* **2026**, *4*, 27–43. [CrossRef]
42. De Salvo, V.; Carraro, M.; Bianchini, M. Validare le Pratiche Collaborative per l'economia Circolare: Il Punto di Vista del Design. *TECHNE J. Technol. Archit. Environ.* **2021**, *22*, 122–130. [CrossRef]
43. Ghyoot, M.; Topalov, H.; Bottani-Dechaud, L.; Rejai, E. *Facilitating the Circulation of Reclaimed Building Elements: A Review of 5 Years of Methods and Experiments in North-West Europe*; Rotor: Brussels, Belgium, 2023.
44. Barquete, S.; Shimozono, A.H.; Hofmann Trevisan, A.; Gonçalves Castro, C.; de Vasconcelos Gomes, L.A.; Mascarenhas, J. Exploring the Dynamic of a Circular Ecosystem: A Case Study about Drivers and Barriers. *Sustainability* **2022**, *14*, 7875. [CrossRef]
45. Klapper, L.; Spindler, D.; Hoeborn, G.; Boos, W. Circular Ecosystem Development: A Process Framework and Practical Application. In *Proceedings of the 10th International Conference on New Business Models NBM*; University of Iceland: Reykjavík, Iceland, 2025.
46. Ansell, C.; Gash, A. Collaborative Governance in Theory and Practice. *J. Public Adm. Res. Theory* **2008**, *18*, 543–571. [CrossRef]
47. Ostrom, E. Beyond Markets and States: Polycentric Governance of Complex Economic Systems. *Transnatl. Corp. Rev.* **2010**, *2*, 1–12. [CrossRef]
48. Furlan, C.; Wandl, A.; Geldermans, B.; Sileryte, R. A Refined Waste Flow Mapping Method. *Contesti Città Territ. Progett.* **2020**, *14*, 74–89. [CrossRef]
49. Furlan, C.; Wandl, A.; Cavalieri, C.; Unceta, P.M. Territorialising Circularity. In *GeoJournal Library*; Springer Science and Business Media B.V.: Berlin/Heidelberg, Germany, 2022; Volume 128, pp. 31–49.
50. Brunner, P.H.; Rechberger, H. *Handbook of Material Flow Analysis*; CRC Press: Boca Raton, FL, USA, 2016; ISBN 9781315313443.
51. Meglin, R.; Kytzia, S.; Habert, G. Regional Circular Economy of Building Materials: Environmental and Economic Assessment Combining Material Flow Analysis, Input-Output Analyses, and Life Cycle Assessment. *J. Ind. Ecol.* **2022**, *26*, 562–576. [CrossRef]

52. Aral, D.; Kayaçetin, N.C.; Durmuş Arsan, Z. Circular Economy in the Built Environment: A Systematic Literature Review on the Role of Digital Technologies across Regional Contexts. In *Proceedings of the IOP Conference Series: Earth and Environmental Science*; IOP Publishing: Montreal, QC, Canada, 2024; Volume 1363, pp. 1–15.
53. Vrijders, J.; Deweerdt, M.; De Roissart, E.; Denis, F.; De Back, T. *Digital Tools for Reuse Linking Reuse and Contemporary Trends in the Construction Industry*; Interreg NWE FCRBE: Brussels, Belgium, 2022.
54. Massari, G.F.; Nacchiero, R.; Giannoccaro, I. Digital Technologies for Resource Loop Redesign in Circular Supply Chains: A Systematic Literature Review. *Resour. Conserv. Recycl. Adv.* **2023**, *20*, 200189. [CrossRef]
55. De Wolf, C.; Çetin, S.; Bocken, N. *Circular Economy and Sustainability A Circular Built Environment in the Digital Age*; De Wolf, C., Çetin, S., Bocken, N., Eds.; Springer: Cham, Switzerland, 2024; ISBN 978-3-031-39675-5.
56. Callegari, G.; Ricciardi, G.; Roccasalva, G.; Simeone, P. Territorial Ecosystem for Circular Economies: Eco3R Research Project. In *Proceedings of the 5th International Conference: The Value of Buildings Materials in the Ecological Transition of the Construction Sector*; Baratta, A.F.L., Calacagnini, L., Magarò, A., Eds.; Anteferma Edizion Srl: Conegliano, Italy, 2023; pp. 174–183.
57. CIRCuIT. Circular Construction in Regenerative Cities—Insights from the CIRCuIT Project. 2023. Available online: https://report.circuit-project.eu/assets/circuit-final-report_full_report.pdf (accessed on 14 June 2026).
58. European Commission Designing a Circular Economy Hub in Riga. Available online: https://green-forum.ec.europa.eu/green-business/green-public-procurement/good-practice-library/designing-circular-economy-hub-riga_en (accessed on 14 June 2026).
59. Tsui, T.; Furlan, C.; Wandl, A.; van Timmeren, A. Spatial Parameters for Circular Construction Hubs: Location Criteria for a Circular Built Environment. *Circ. Econ. Sustain.* **2024**, *4*, 317–338. [CrossRef]
60. Yin, R.K. *Case Study Research and Applications*, 6th ed.; SAGE Publications: Thousand Oaks, CA, USA, 2018.
61. Bowen, G.A. Document Analysis as a Qualitative Research Method. *Qual. Res. J.* **2009**, *9*, 27–40. [CrossRef]
62. Patton, M.Q. *Qualitative Research & Evaluation Methods: Integrating Theory and Practice*; SAGE Publications, Inc.: Thousand Oaks, CA, USA, 2015; ISBN 1483301451.
63. Ahmad, M.; Wilkins, S. Purposive Sampling in Qualitative Research: A Framework for the Entire Journey. *Qual. Quant.* **2025**, *59*, 1461–1479. [CrossRef]
64. Chauhan, C.; Parida, V.; Dhir, A. Linking Circular Economy and Digitalisation Technologies: A Systematic Literature Review of Past Achievements and Future Promises. *Technol. Forecast. Soc. Change* **2022**, *177*, 121508. [CrossRef]
65. République Française Loi N° 2020-105 du 10 Février 2020 Relative à la Lutte Contre le Gaspillage et à L'économie Circulaire (Loi AGEC). Journal Officiel de la République Française. 2020. Available online: https://www.legifrance.gouv.fr/jorf/id/JORFTEXT000041553759/ (accessed on 18 June 2026).
66. Code de L'environnement Article L541-4-4, Loi n° 2020-105 of 10 February 2020, Art. 54. 2020. Available online: https://www.legifrance.gouv.fr/codes/article_lc/LEGIARTI000041561313 (accessed on 18 June 2026).
67. République Française. Décret n° 2021-821 du 25 Juin 2021 Relatif au Diagnostic Portant sur la Gestion des Produits, Équipements, Matériaux et des Déchets Issus de la Démolition ou de la Rénovation Significative de Bâtiments. Journal Officiel de la République Française, 27 June 2021. Available online: https://www.legifrance.gouv.fr/jorf/id/JORFTEXT000043704853 (accessed on 10 June 2026).
68. Danish Ministry of Environment (Miljøministeriet). *Bekendtgørelse Om Håndtering af Affald og Materialer fra Bygge- og Nedrivningsarbejde [Statutory Order on the Management of Waste and Materials from Construction and Demolition Works], BEK Nr. 496 of 21 May 2024*; Ministry of Environment: Copenhagen, Denmark, 2024. Available online: https://www.retsinformation.dk/eli/lta/2024/496 (accessed on 14 July 2026).
69. DIN Deutsches Institut für Normung. DIN SPEC 91484: Procedure to Record Building Materials as a Base to Evaluate the Potential for a High-Quality Reutilization Prior to Demolition and Renovation Work; Berlin, 2023. Available online: https://www.dinmedia.de/en/technical-rule/din-spec-91484/371235753 (accessed on 20 February 2026).
70. Governo Italiano. *D.Lgs. 31 Marzo 2023, n. 36; Codice dei Contratti Pubblici in Attuazione dell'Articolo 1 della Legge 21 Giugno 2022, n. 78*; Governo Italiano: Roma, Italia, 2023.
71. Vlaanderen Circulair. Available online: https://vlaanderen-circulair.be/en (accessed on 20 June 2026).
72. Circular Wallonia. Available online: https://economiecirculaire.wallonie.be/home (accessed on 20 June 2026).
73. Be Circular. Available online: https://be-circular.com/ (accessed on 20 June 2026).
74. Bruxelles Environnement. *Programme Régional en Economie Circulaire 2016–2020: Mobiliser les Ressources et Minimiser les Richesses Perdues: Pour une Économie Régionale Innovante*; Bruxelles Environnement: Bruxelles, Belgique, 2016. Available online: https://document.environnement.brussels/opac_css/elecfile/PROG_160308_PREC_DEF_FR.pdf (accessed on 10 March 2026).
75. Ministerie van Infrastructuur en Waterstaat. *Nationaal Programma Circulaire Economie 2023–2030 [National Circular Economy Programme 2023–2030]*; Ministerie van Infrastructuur en Waterstaat: The Hague, The Netherlands, 2023. Available online: https://www.rijksoverheid.nl/documenten/2023/02/03/nationaal-programma-circulaire-economie-2023-2030 (accessed on 2 July 2026).

76. Ministerie van Infrastructuur en Milieu; Ministerie van Economische Zaken. *Nederland Circulair in 2050: Rijksbreed Programma Circulaire Economie [A Circular Economy in the Netherlands by 2050]*; Ministerie van Infrastructuur en Milieu: The Hague, The Netherlands, 2016. Available online: https://open.overheid.nl/documenten/ronl-a6ce8220-07e8-4b64-9f3d-e69bb4ed2f9c/pdf (accessed on 2 July 2026).
77. Swiss Federal Council. *Ordinance of 4 December 2015 on the Avoidance and the Disposal of Waste (Waste Ordinance, ADWO/OLED/VVEA), SR 814.600*; Swiss Federal Council: Bern, Switzerland, 2015. Available online: https://www.fedlex.admin.ch/eli/cc/2015/891/en (accessed on 25 June 2026).
78. Federal Office for the Environment (FOEN). Circular Economy. Available online: https://www.bafu.admin.ch/en/circular-economy (accessed on 25 June 2026).
79. Danish Government. *Strategy for Circular Economy—More Value Creation and Better Environment Through Design, Consumption and Recycling*; Ministry of Environment and Food and Ministry of Industry, Business and Financial Affairs: Copenhagen, Denmark, 2018. Available online: https://mim.dk/publikationer/2018/strategy-for-circular-economy (accessed on 10 July 2026).
80. Ministères Transition Écologique, Aménagement du Territoire, Transports, Ville et Logement. Le Diagnostic «Produits, Équipements, Matériaux et Déchets» (PEMD). 2024. Available online: https://www.ecologie.gouv.fr/politiques-publiques/diagnostic-produits-equipements-materiaux-dechets-pemd (accessed on 6 June 2026).
81. Direction de l'Information Légale et Administrative (Premier Ministre). *Filières à Responsabilité Élargie du Producteur (REP)*; Service Public Entreprendre: Paris, France, 2025. Available online: https://entreprendre.service-public.gouv.fr/vosdroits/F37937 (accessed on 10 June 2026).
82. CSTB. Référentiel Technique ReQPR. 2025. Available online: https://www.cstb.fr/getmedia/14e7b394-a8f3-44eb-80fb-09a5129cf115/Referentiel_technique_ReQPR_V1.pdf (accessed on 10 July 2026).
83. Ministry of Environment and Gender Equality. *Bekendtgørelse om Affald (Affaldsbekendtgørelsen) [Statutory Order on Waste], BEK Nr. 1749 of 30 December 2024*; Ministry of Environment and Gender Equality: Copenhagen, Denmark, 2024. Available online: https://www.retsinformation.dk/eli/lta/2024/1749 (accessed on 14 July 2026).
84. Nicolas, J.; Lenaïg, L. *Building Construction Products and Materials—2024 Data. Annual Report*; Raediviva: Angers, France, 2025. Available online: https://librairie.ademe.fr/economie-circulaire-et-dechets/9405-11204-building-construction-products-and-materials-2024-data-9791029726996.html#/44-type_de_produit-format_electronique (accessed on 18 June 2026).
85. ARUP. *The Reuse Playbook—A Whole-Industry Guide to Construction Material Reuse*; ARUP: London, UK, 2026. Available online: https://www.arup.com/en-us/insights/the-reuse-playbook/ (accessed on 10 July 2026).
86. Costa, A.R.; Hoolahan, R.; Charef, R. Eight Recommendations to Adopt Materials Passports and Accelerate Material Reuse in Construction: Insights from Academia and Practice. *npj Mater. Sustain.* **2025**, *3*, 33. [CrossRef]
87. Räsänen, A.; Lahdensivu, J. Quality Assurance Process for Reuse of Building Components. In *Life-Cycle of Structures and Infrastructure Systems*; CRC Press: London, UK, 2023; pp. 142–148.
88. Ericsson, F. Swedish Clients' Views on Certification of Reused Building Products and Reuse Actors. *J. Phys. Conf. Ser.* **2025**, *3140*, 162001. [CrossRef]
89. Leminen, S.; Westerlund, M.; Nyström, A.-G. Living Labs as Open-Innovation Networks. *Technol. Innov. Manag. Rev.* **2012**, *2*, 6–11. [CrossRef] [PubMed]
90. Kivimaa, P.; Boon, W.; Hyysalo, S.; Klerkx, L. Towards a Typology of Intermediaries in Sustainability Transitions: A Systematic Review and a Research Agenda. *Res. Policy* **2019**, *48*, 1062–1075. [CrossRef]
91. Di Maria, A.; Eyckmans, J.; Van Acker, K. Downcycling versus Recycling of Construction and Demolition Waste: Combining LCA and LCC to Support Sustainable Policy Making. *Waste Manag.* **2018**, *75*, 3–21. [CrossRef] [PubMed]
92. Charef, R.; Morel, J.C.; Rakhshan, K. Barriers to Implementing the Circular Economy in the Construction Industry: A Critical Review. *Sustainability* **2021**, *13*, 12989. [CrossRef]
93. Hart, J.; Adams, K.; Giesekam, J.; Tingley, D.D.; Pomponi, F. Barriers and Drivers in a Circular Economy: The Case of the Built Environment. *Procedia CIRP* **2019**, *80*, 619–624. [CrossRef]
94. European Topic Centre on Circular Economy and Resource Use. *Circular Economy Country Profile 2024—France*; European Environment Agency: Copenhagen, Denmark, 2024.
95. Nicolas, J.; Sébastien, B. Barriers to Reuse in the Construction Sector: A Circular Value Chain Perspective. *Bus. Strategy Environ.* **2026**, 1–18. [CrossRef]
96. Iacovidou, E.; Purnell, P. Mining the Physical Infrastructure: Opportunities, Barriers and Interventions in Promoting Structural Components Reuse. *Sci. Total Environ.* **2016**, *557–558*, 791–807. [CrossRef] [PubMed]
97. Tsui, T.; Venverloo, T.; Benson, T.; Duarte, F. Spatial Optimization of Circular Timber Hubs. *npj Urban Sustain.* **2024**, *4*, 13. [CrossRef]
98. Honic, M.; Kovacic, I.; Rechberger, H. Improving the Recycling Potential of Buildings through Material Passports (MP): An Austrian Case Study. *J. Clean. Prod.* **2019**, *217*, 787–797. [CrossRef]

99. Çetin, S.; Raghu, D.; Honic, M.; Straub, A.; Gruis, V. Data Requirements and Availabilities for Material Passports: A Digitally Enabled Framework for Improving the Circularity of Existing Buildings. *Sustain. Prod. Consum.* **2023**, *40*, 422–437. [CrossRef]
100. Çetin, S.; Gruis, V.; Straub, A. Digitalization for a Circular Economy in the Building Industry: Multiple-Case Study of Dutch Social Housing Organizations. *Resour. Conserv. Recycl. Adv.* **2022**, *15*, 200110. [CrossRef]
101. Dubois, A.; Gadde, L.E. Systematic Combining: An Abductive Approach to Case Research. *J. Bus. Res.* **2002**, *55*, 553–560. [CrossRef]
102. Ketokivi, M.; Choi, T. Renaissance of Case Research as a Scientific Method. *J. Oper. Manag.* **2014**, *32*, 232–240. [CrossRef]