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A New Framework for Circular Refurbishment of Buildings to Operationalize Circular Economy Policies

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Abstract: The current policies aimed at promoting the decarbonization of existing buildings under the principles of the circular economy are in need of practical measures tailored to local conditions to increase their effectiveness. The lack of standard practices for assessing buildings' refurbishment strategies toward energy efficiency and CE principles reflects this reality. To tackle this issue, a new framework for refurbishing circular buildings, is proposed in this paper, based on circular procurement and incorporating a lifecycle perspective. This framework articulates a dialogue between local authorities and private stakeholders through a set of steps that encompass building mapping, selective disassembly, (re)design, and (re)build practices, providing opportunities to implement policy-based incentives. The application of the framework within the Portuguese context demonstrates the potential to identify critical moments within the refurbishment process that can materialize in a new set of CE policy actions to be implemented at the building level. These policies are aligned with local construction permitting procedures and take advantage of the resources and incentives offered by the local administration, such as tax incentives.

Keywords: circular economy; Circular Refurbishment Framework; buildings refurbishment; circular design; policy-based incentives

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1. Introduction

The existing building stock has a significant impact on achieving European Union (EU) carbon neutrality goals in 2050 [1], as buildings account for 40% of the EU's final energy consumption and 36% of greenhouse gas (GHG) emissions [2], 85% of which were built before 2001 and approximately 90% of which will still exist in 2050 [2].

Buildings are responsible for over 35% of the EU's total waste generation and 50% of extracted materials. It is estimated that 5–12% of total national GHG emissions are associated with material extraction, construction product manufacturing, and buildings' construction and refurbishment [3]. Consequently, buildings' embodied energy should be considered when conceptualizing refurbishment strategies [4], particularly as greater material efficiency could save up to 80% of total national buildings' embodied GHG emissions [3]. The EU Renovation Wave [2] also acknowledges this, assuming that operational energy reduction will not be sufficient to achieve carbon neutrality.

However, most of the scientific literature focuses on reducing operational energy consumption in buildings while disregarding embodied energy and the application of Circular Economy (CE) principles to the existing building stock. Additionally, although the obstacles to implementing CE principles in buildings have been identified, only a limited number of scientific papers are focused on building refurbishment and provide concrete strategies for its adoption. This is also reflected at the EU policy level, where there is a need for tangible actions to integrate CE in building refurbishment.

Given these limitations, this paper addresses the challenges and strategies in adopting CE principles in building refurbishment by conducting a critical analysis of existing frameworks, relevant regulations, and EU policies and incentives, and provides a new framework for the circular refurbishment of existing buildings, based on circular procurement and a lifecycle perspective, to operationalize EU policies.

The framework outlines the refurbishment stages from a CE perspective, highlighting critical steps for collaboration between local authorities and private stakeholders and providing opportunities to implement policy-based incentives. The potential implementation of the framework has been tested in the Portuguese context and can be adopted in the refurbishment practices of any EU member country.

This paper is organized into five sections, including this introduction. Section 2 describes the methodology, Section 4 identifies the state-of-the-art and existing policies towards CE adoption, and Section 4 describes the proposed framework for CE refurbishment and identifies critical steps to promote CE incentive-based policies. The framework is applied to the case study of Portugal in Section 5, and discussion and conclusions are presented in Section 6.

2. Methods

In order to achieve the research objectives, the background on the main challenges and potential strategic solutions for implementing CE principles in building refurbishment was provided by an expensive literature review on this topic [5]. A literature review of published research articles, reports, and grey literature using a combination of the keywords "circular design", "CE buildings framework", "CE buildings refurbishment framework", "CE procurement phases in construction", "circular economy regulation", "design methodology for CE," and "EU policy for CE in construction" was conducted. A total of 118 papers were initially screened, and 54 papers were selected for final analysis, categorization, and characterization into two streams: the design process for CE refurbishment (16 papers) and EU Regulation and Policy (38 papers). A critical analysis was performed per stream to identify the state-of-the-art in European-driven initiatives related to CE adoption in the building sector and existing frameworks for CE refurbishment. The analysis revealed a knowledge gap in the operationalization of CE policies in building refurbishment in the EU, which led to the development of a six-stage framework for CE in building refurbishment. This framework is based on the three pillars of CE [6] and incorporates circular procurement, lifecycles, and refurbishment, articulating six stages of design with building lifecycles and circular processes (maintenance, repair, reuse, recovery, and recycling). Selected challenges and corresponding solutions for CE adoption in building refurbishment, identified in the literature review, were linked to relevant EU regulation and policy and each stage of the framework to analyze to what extent previously identified challenges and solutions have been addressed. Finally, this was applied to a specific case study, which reviews the current regulations for building refurbishment and related policy-based incentives for the Portuguese context. This research identified steps of collaboration between local authorities and private stakeholders to promote actions for policy-based incentives, which were explored and discussed in the Portuguese case-study analysis.

Figure 1 provides an overview of the methodology.

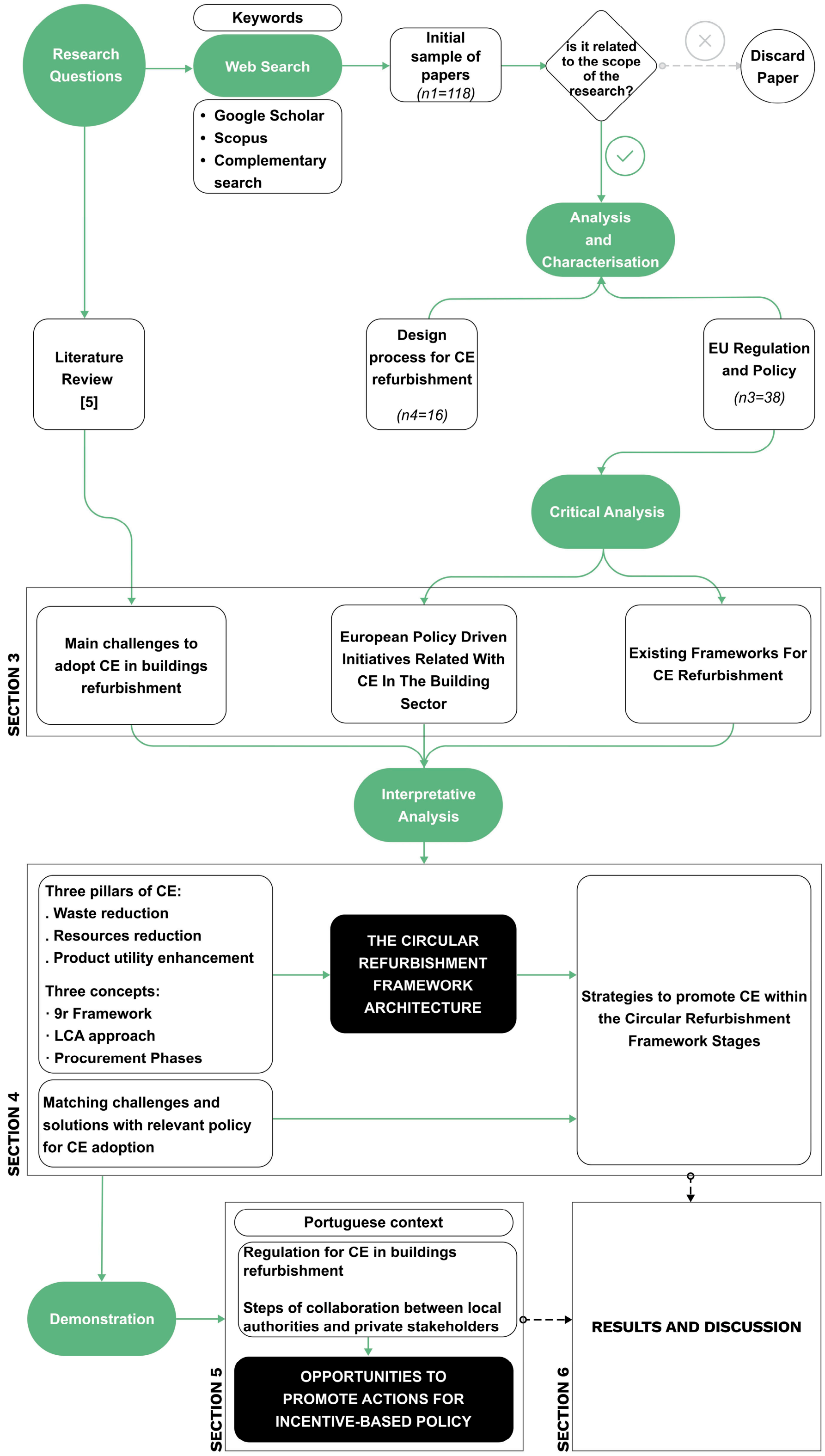

Figure 1. Schematic representation of the research methodology.

3. Background

CE practices in the built environment are just emerging, and although a policy context is already defined as part of a global strategy to achieve carbon neutrality by 2050 [1], there are still a multitude of challenges and research gaps to be tackled.

3.1. Main Challenges to Adopting CE in Building Refurbishment

The major challenges and research gaps towards CE adoption in the existing building stock were studied and organized by the authors [5] in six dimensions, as presented in Table 1, to facilitate a more effective definition of strategies to tackle the existing barriers.

Table 1. Challenges to adopting CE in construction (built from [5]).

Dimensions	Challenges	
Economic	E1	Lack of platforms and storage facilities for reclaimed products
	E2	Lack of platforms for CE professionals and CE jobs
	E3	Estimation challenges; short-term blinkers
	E4	Lack of strategies and infrastructures for new CE materials production
	E5	Lack of CE business models
Social	S1	Lack of trust and lack of CE vision for the building sector
	S2	Lack of platforms for CE professionals and CE jobs
	S3	Lack of collaboration between stakeholders (silo mentality)
	S4	Willingness to go around the law
Organizational	O1	Lack of platforms and storage facilities for reclaimed products
	O2	Lack of standard practices for End-of-Life (EOL) and Construction and Demolition Waste (CDW) management (pre design stage)
	O3	Collaboration and management issues
	O4	Issues with manufacturers' responsibility and approaches
	O5	Constraints for EOL processes implementation on site
	O6	Lack of methodology and standard practices for CE design
	O7	Lack of training skills
Technical	T1	Building-related barriers
	T2	Lack of materials knowledge and technical challenges for CE
	T3	Challenges to EOL implementation
	T4	Production related barriers (materials and technology)
	T5	Barriers to apply new CE oriented design
Environmental	EN1	Toxic materials removal
	EN2	Lack of awareness of CE impact in climate change
	EN3	Lack of awareness of transportation impact in CE in construction
	EN4	Low of energy efficiency at operation stage
	EN5	Lack of methodology of CE evaluation towards climate change mitigation
Policy	P1	Lack of platforms and infrastructures for reclaimed materials, components and products
	P2	CDW related barriers
	P3	Lack of consistent regulatory framework for CE
	P4	Reclaimed materials related barriers
	P5	Lack of knowledge among stakeholders
	P6	CE business related barriers

It is concluded [5] that the majority of organizational and technical challenges (83%) are predominantly EOL-related, reflecting buildings' linearity. This is mainly because building systems, elements, and materials are interconnected and cannot be separated for partial recovery or disassembly, leading to little or no parts being reused or recycled. This can only be altered by acting in the design stage, which is crucial in defining CE refurbishment strategies [7]. This stage should combine organizational, technical, and environmental strategies such as utilizing existing components, extending buildings use stages to the maximum, and focusing on the EOL stage from the beginning.

Current transversal barriers to the adoption of CE in buildings are mainly economic, social, and policy-related [5], where policy constraints do include the lack of promotion/requirement of platforms and infrastructures for reclaimed materials, components, and products, CDW-related barriers, as well as the lack of a consistent regulatory framework for CE, barriers related to reclaimed materials, a lack of knowledge among stakeholders, and barriers related to CE businesses.

In summary, the state of the art of CE for the existing building stock identifies the inability to adapt and calls for better planning for refurbishment from economic and environmental perspectives when compared to new construction [8–10]. As a consequence, transversal and multidimensional strategies are critical to support the implementation of specific solutions for CE building refurbishment and to tackle the identified barriers to CE adoption [11]. This requires the combination of several initiatives to reduce embodied GHG [12], with a focus on CE building design and construction strategies such as reusing existing buildings, components, and materials; selecting materials correctly; and enabling future reuse, recycling, and/or energy recovery options for materials.

Public authorities play a crucial role in supporting this process by creating engagement with stakeholders and promoting CE incentive-based policies that encourage CE adoption. The next section provides an overview of existing EU policies for the building sector.

3.2. European Policy-Driven Initiatives Related to CE in the Building Sector

From a top-down approach, the EU recognizes the significance of incorporating CE principles in building refurbishment, assuming that increasing deep refurbishments is crucial to achieve full decarbonization by 2050 [13], as it leads to a potential decrease of buildings' embodied carbon emissions by 60–80% [14].

The EU has taken several initiatives to support and increase building refurbishments, such as the Recommendation (EU) 2019/786 on building renovation [15] and the EU Renovation Wave [2], which included the European Green Deal [1], both of which align with the Circular Economy Action Plan (CEAP) published in 2020 [16]. The CEAP aims to adopt a comprehensive approach to existing building stock, including multiple CE indicators from product level to building design, digital logbooks, public procurement, sustainable finance, and soil sealing reduction [3].

Although some circularity indicators have been suggested, there is still no standardized methodology for measuring circularity and monitoring CE adoption in existing building stock. Some CE principles have been included in broader sustainability evaluation methodologies such as the EN17680 Standard [17] and the Level(s) Framework [18]. The information gathered from the CE assessment will potentially be used to monitor the existing building stock through digital building logbooks [3], the EU building stock observatory (BSO), and national energy performance certificates (EPC) databases. The CE adoption in building refurbishment may also be partially supported by the recovery and resilience facility (RRF), which was created to mitigate the impact of the COVID-19 pandemic and move toward a climate-neutral economy [19].

In practical terms, CE recommendations developed in European programs [20,21] are being transposed to country-level legislation [22–25], while the manufacture of new construction products must also follow CE principles [26]. The Eco-Design Directive [27] already sets mandatory minimum standards for product efficiency.

In conclusion, the strategies for CE adoption in building refurbishment [5] are broadly covered by EU policy, such as to analyze circularity and establish guidelines for material identification, reuse, and recycling, building disassembly, and building design, with a focus on the technical, environmental, and organizational dimensions of CE at the EOL (mapping and selective disassembly) and (re)design stages.

3.3. Existing Frameworks for CE Refurbishment

The implementation of CE principles in building refurbishment is particularly challenging from a practice perspective, as each building has unique characteristics and a one-size-fits-all design approach is not feasible. This complicates the systematic application of CE principles in the refurbishment process.

In the past, various sustainability assessment frameworks have been attempted, but they are not specifically designed to promote CE and often apply to both new and existing buildings. These frameworks typically make use of life cycle assessment (LCA) methods [28] and have been adapted by some authors [29] to include reuse practices and determine operational and embodied environmental impacts [8] or to perform integrated life cycle sustainability assessments based on circular building phases by overlaying procurement phases [30].

However, a few authors have developed specific frameworks for adaptive reuse of heritage buildings. Specifically, G. Foster [31] proposes a 5-phase circular economy framework for the adaptive reuse of cultural heritage buildings and three circular strategies connecting the building life-cycle phases. Furthermore, A. Hedieh et al. [32] developed a conceptual 10-step model as a basis for the adaptive reuse of heritage buildings. These frameworks identify existing buildings as sources of materials for refurbishment projects and follow a process that includes design, execution, use, maintenance, and monitoring. The objective of these frameworks is to extend the lifespan of the building and continuously meet the needs of its occupants. In this context, A. Hedieh et al. [32] emphasize the importance of "mapping level of significance" to determine the adaptive reuse potential of existing buildings, as it influences subsequent steps of the model.

The absence of a widely recognized CE assessment framework for the built environment [33] highlights the need for a holistic and systematic CE approach in building refurbishment [34], and this provides the motivation for the development of a new framework that is discussed in Section 4, which is aimed at ensuring that CE principles are properly integrated into the refurbishment process.

4. A New Framework for CE in Building Refurbishment

The novel framework addresses the difficulties outlined in the previous section by mapping the phases of building refurbishment and their interconnections to determine points of communication among stakeholders. As such, the establishment of a new framework for building refurbishment is crucial for effectively organizing processes and determining steps to overcome the previously recognized challenges, leading to the practical implementation of CE policy.

The methodology for the creation of this Circular Refurbishment Framework is based on the three pillars of CE [6] (waste reduction, resource reduction, and product utility enhancement) and combines three concepts:

- The 9R framework [35];
- The LCA approach [28];
- The Procurement Phases [36].

The 9R framework [35] prioritizes waste avoidance, and the first steps correspond to the pre-use phase (smarter product creation and use), including refuse, rethink, and reduce strategies, while extending the lifetime of products includes reuse, repair, refurbish, remanufacture, and repurpose strategies. The post-use phase includes recycling and recovering. When applied to building refurbishment, the end-of-life of the building is considered when it no longer serves its inhabitants' needs and requires refurbishment. The other steps of the 9R framework can be applied to building components.

The LCA approach consists of four stages: product stage, construction process, use stage, and end-of-life., and considers the reuse, recovery, and recycling potential. When considering a CE refurbishment context, mapping of the existing building condition is usually the first stage in refurbishment strategies for existing buildings [30,37,38] and is also considered when making decisions about refurbishment options using LCA methodology [39]. After mapping, setting refurbishment options that align with CE is essential to prevent waste and optimize resources.

The procurement phases, as defined in the RIBA Plan of Work [36], are similar to a cradle-to-gate system boundary [28] and include: strategic definition; preparation and briefing; concept design; spatial coordination; technical design; manufacturing and construction; handover; and use.

It should be noted that practices for refurbishing heritage buildings, which are more restrictive regarding demolition and CDW generation, can serve as inspiration for CE refurbishment. It considers the following basic principles: minimum intervention; preservation of the existing historical value and adoption of a compatible technological innovation; compatibility of new materials used in restoration; reversibility of the interventions; distinction of the additions; enhancement of the existing structures [40]. Existing characteristics, protection motives, and enhancement opportunities are also three of the five aspects of sustainable urban heritage management and conservation identified in [41] research. Adopting a tailored approach is also recommended when the refurbishment of historic buildings aims at lowering energy demand and greenhouse emissions [40].

In addition to the inspiration for the refurbishing heritage buildings analysis, the analysis of the overlap of the three concepts identified before, as illustrated in Table 2, was important to the development of the Circular Refurbishment Framework proposed here, which is discussed in the next subsection.

Table 2. Overlap of the three concepts in the Circular Refurbishment Framework methodology.

9R Framework	LCA Approach	Procurement Phases
Refuse		Strategic definition
Rethink		Preparation and briefing
Reduce		Concept design
		Spatial coordination
		Technical design
	Product Stage (A1–A3)/ Construction Process (A4–A5)	Manufacturing and construction
		Handover
Reuse	Use Stage (B1–B7)	Use
Repair		
Refurbish	End-of-Life (C1–C4)/Module D	
Remanufacture		
Repurpose		

4.1. *The Circular Refurbishment Framework Architecture*

The new framework offered in this paper comprises six stages, as illustrated in Figure 2, and is intended to facilitate CE adoption in building refurbishment. Following the findings above, mapping is the first EOL stage and is dedicated to characterizing the existing building. Setting the refurbishment strategy and preparing the next stage: selective disassembly/demolition, is the subsequent phase, which is followed by the conceptual and detailed designs for construction, which take place at the third stage: (re)design. Stage 4 comprises the (new) products that will be used in Stage 5: (re)construction. Operation is the last stage of the framework, related to the use of the building. The Circular Refurbishment Framework also outlines the necessary actions to close product and material loops by considering maintenance, repair, reuse, recovery, and recycling.

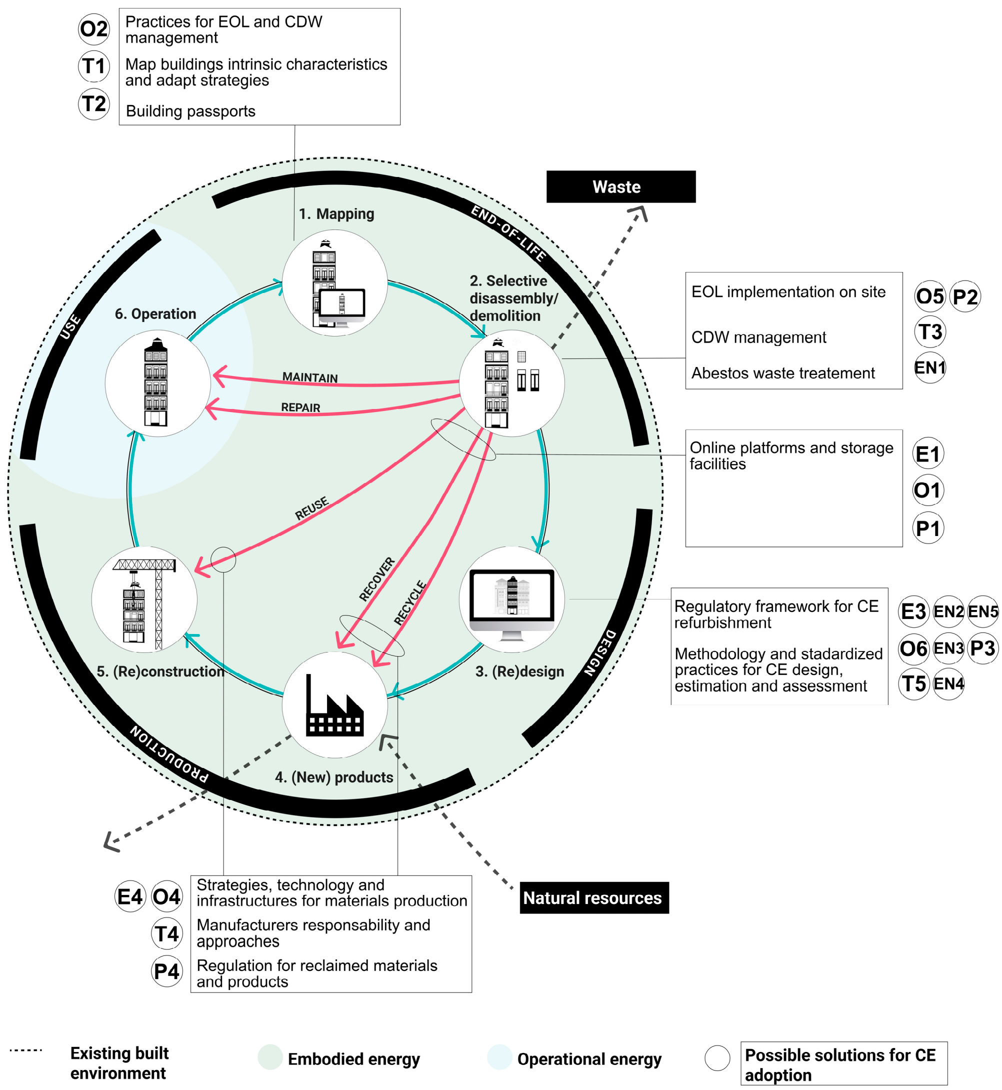

Figure 2. Stage-specific solutions offered in the context of the Circular Refurbishment Framework.

4.2. Strategies to Promote CE within the Circular Refurbishment Framework Stages

The Circular Refurbishment Framework was designed to mitigate CE challenges by framing refurbishment activities. Its goal is to ensure stage-specific compliance with previously defined strategies for CE adoption in building refurbishment [5], supported by EU policies. Accordingly, the stage-specific solutions, combined with selected transversal strategies, which are elaborated in the next paragraphs, are adopted within the Circular Refurbishment Framework (Figure 2) to operationalize EU policy towards CE adoption, enabling tangible actions.

4.2.1. Mapping Stage

Mapping, the first stage, is critical to overcoming building characterization gaps and EOL pre-design practices (O2, T1, T2, in Table 1). This stage consists of characterizing the existing situation, setting refurbishment options, and preparing the selective disassembly/demolition stage. The design team surveys the building's geometry, quality, function, past uses, thermal performance, degradation state, and construction system and materials.

This survey forms a snapshot of the existing building. To facilitate CE practices, surveys must include maintenance disassembly guidelines, reuse potential, recovery potential, and recycling potential. This information is afterwards converted into digital datasets and forms the building passports or material passports [20,42–44], providing CE information on building materials, components, and products.

Given the complexity of the information involved, the adoption of a building information modeling (BIM)-supported methodology is recommended [45]. For instance, methodologies like Historic BIM (HBIM) [46] comprise data collection and processing from laser scanning/photogrammetry and BIM models with historical parametric components. Furthermore, certification systems like GBC Historic Building Certification from Leadership in Energy and Environmental Design (LEED) have protocols to evaluate sustainable heritage renovation, with on-site study and diagnostic investigations to be inserted in a BIM-model and a building passport (historic building identity card). Knowing existing building construction systems is also an issue in the mapping stage, which can be overcome with archetype-based information [47,48] and a building automated characterization methodology [49]. Mapping is an important stage to provide data on construction age and building materials [50], the state of conservation, and the roof (area and orientation), which are usually not available. Materials passports could be produced by BIM models providing data describing pre-defined characteristics of materials in products, which may facilitate their use for recovery and reuse during deconstruction projects.

Building from existing EU policies, energy performance certificates (EPCs), which constitute the basis for assessing the minimum energy performance standards for existing buildings [2], could be coupled with building passports to tackle the challenges of a lack of standard practices for EOL and CDW management at the pre-design stage, a lack of material knowledge and related technical challenges for CE and building-related barriers (O2, T1, T2, Table 1), and map the building's intrinsic characteristics. Moreover, building passports could also support refurbishment strategies by serving as baseline information for the building renovation passports and building digital logbooks included in the renovation wave [2]. In parallel, guidelines for building passports, adapted to national contexts, should be developed to enable CE adoption in subsequent stages, namely: implementing EOL on site; forwarding materials for reuse, recovery, or recycling (E1, O1, P1, Table 1); performing CE and Level(s) Framework assessments [18]; and conducting material flow analysis at urban scale. Environmental Product Declarations (EPD) should also be generalized for all construction products and contain circularity data.

4.2.2. Selective Disassembly/Demolition Stage

After mapping, a briefing with the client may be used to validate the strategic definition of future refurbishment design and circularity potential, and this constitutes the second stage—selective disassembly/demolition. Here, disassembly and selective demolition criteria are defined, constraints are identified, and plans for on-site implementation are developed. These plans include setting up CDW management, polluted material sorting and removal, onsite collection, inventory, and storage, according to previously set CE strategies. Elements to be maintained and repaired should be kept in the building, while elements to be reused should be listed, recovered, and stored. Furthermore, inventory, selective collection, and transportation for reclaimed storage facilities are also necessary for recycling, recovery, and reuse of products if not integrated into the future design. These procedures aim to tackle O5, T3, and EN1 constraints (Table 1). During disassembly works, any unexpected challenges must be reflected in multi-level updated information and strategies: the building passport, the BIM model, and the refurbishment design, involving all stakeholders (S3, Table 1).

However, some conditions related to the policy dimension need to be met first: new guidelines towards CE for EOL implementation on site, CDW management, and asbestos waste treatment could be developed, eventually by adapting waste regulation [51] to CE prerequisites [35], together with permits, controlling, and monitoring mechanisms

(O5, T3, EN1, P2, Table 1). These actions should be complemented with training and raising awareness among construction workers about the reduction of CDW and selective collection of products (O7, S2, Table 1). In addition, online platforms and storage facilities for reclaimed products should be created and updated to enable materials' reuse, recovery, or recycling (E1, O1, P1, Table 1). In the latter case, the global vision for CE in construction goes beyond these infrastructures with the definition of new vision strategies for CE material production (S1, E4, Table 1).

4.2.3. (Re)design Stage

After selective disassembly, the existing building is a "blank page" for the new conceptual design, spatial coordination, and technical design. The (re)design stage emerges, whose key actions are methodological, standardized practices, and assessment for circular refurbishment design, involving all stakeholders. Providing clients with cost estimation and long-term CE benefits regarding costs, GHG emission reductions (E3, Table 1), and assuring a good design using reused, recovered, and recycled materials is essential for their agreement on CE adoption. Design decisions could be supported by multi-objective optimization (clients' specifications, multiple uses during a building's lifespan, CE principles, climate change impact, etc.) (T5, Table 1). Defining principles and a methodology for CE refurbishment design includes keeping as much as possible from the existing building, designing for adaptability and flexibility, improving standardization and modularity, designing for disassembly, designing with reclaimed products, ensuring sustainable management of end-of-life waste, and promoting energy efficiency at the use stage (O6, T5, EN4, Table 1). Establishing a BIM-based quantitative assessment for CE is indispensable to assess refurbishment design and project delivery, namely by defining indicators based on the above-mentioned principles, including transportation and lifecycle climate change impacts. Additionally, developing a material hierarchy based on the GHG emissions and circularity indicators might be useful when selecting the best design options (O6, T5, EN2, EN3, Table 1). Technical guidance and specific training should be provided to practitioners for CE refurbishment design (O7, Table 1).

At the policy level, the definition of a regulatory framework for CE refurbishment, together with the definition of a methodology and standardized practices for CE design, estimation, and assessment, will be essential to tackle challenges E3, O6, T5, EN2, EN3, EN4, EN5, and P3 (Table 1). LCA methodology [52] should be used more consistently and adopted for assessing buildings and construction environmental impacts, making use of BIM technologies, although new developments can be made with the wide adoption of the Level(s) Framework and the upcoming strategy within CEAP [16]. Solutions to CE adoption must be transposed, at this stage, to national regulation, as there is country-specific regulation to be considered.

4.2.4. (New) Products Stage

The development of a new concept of endogenous material use occurs in parallel with design and on-site practices for CE refurbishment. Exploring the local or regional capacity on material supply through anthropogenic stock is the first step to reduce transportation and identify gaps that lead to potential business opportunities. This stage calls for the use of eco-design principles by optimizing material use, reducing/eliminating hazardous materials and raw materials, increasing products' lifespan, designing for disassembly, designing for standardization, using secondary materials and recovered components, and selecting bio-based materials, all of which are in line with CE. Furthermore, these principles should be complemented with standards, requirements, and deliverable specifications for CE products and materials, with implications for the durability and reparability of materials and products. Developing new specific insurance products for CE products should help to avoid over-specification and over-design (E4, O4, T4, P4, Table 1).

At a policy level, the European Commission has a key role in promoting standardization and sustainability in industrial production, including CE principles of reuse, recovery, and recycling of waste, which will help to tackle E4, O4, T4, and P4 challenges (Table 1).

4.2.5. (Re)construction Stage

(Re)construction, the fifth stage, should consider the implementation of CE refurbishment design in the building, keeping in mind CE principles and tracking the challenges that might occur, making design adjustments. Training skills for CE among construction workers and control offices is necessary, and the design team should follow building refurbishment works until completion.

4.2.6. Operation Stage

Operation is the sixth stage after (re)construction and the last stage of the framework, which implies the use of the building and its maintenance plan so that its lifespan can be extended to the maximum.

At the supply chain level, the information available from digital building logbooks, integrating building renovation passports, smart readiness indicators, level(s) framework assessments, and EPCs should be accessible and updated across a building's lifecycle and to all stakeholders to enable collaboration and their adequate management and to set guidelines and reclaimed products platforms (S3, O3, P5, Table 1). These transversal solutions also include training initiatives (O7, P5, and Table 1) through Cohesion Policy Funds and the Just Transition Fund [2], and reinforced technical assistance and adequate financing and funding through the RRF [2], to complement the European Local Energy Assistance as this is a priority for national recovery plans.

In conclusion, the newly developed Circular Refurbishment Framework presented here enables the creation of a collection of feasible solutions by identifying points of This framework connects building mapping, selective disassembly practices, (re)design, and (re)construction processes and presents opportunities for policy-based incentive implementation. Although it has the potential for broad application in EU refurbishment procedures, the Circular Refurbishment Framework can also be adapted to fit the specific context of individual countries, as demonstrated in the case study outlined in Section 5.

5. Case Study: Application to the Portuguese Context

Identifying critical moments and corresponding actions for a CE incentive-based policy requires a joint analysis of public policy, regulation, and the new Circular Refurbishment Framework, as the macro-level policy affects the micro-level management of environmental impacts of existing building refurbishments [5,53]. As it becomes more evident if applied to a specific case study, the Portuguese policy context is explored and discussed in this section.

5.1. Regulation for CE in Buildings Refurbishment

Although there is no specific regulation for CE adoption in the Portuguese building sector, CE principles are implicit in some legal frameworks, such as those governing waste [51] and building refurbishment [54]. Although a CDW prevention and management plan is only mandatory for public works, Decree-Law 95/2019 establishes guidelines for mitigating environmental impact by minimizing resource extraction, waste production, and harmful gases, prioritizing reuse and recycling; reducing GHG emissions; improving energy efficiency; reducing energy needs (including embodied energy); and designing for EOL.

More specific guidelines for practitioners, although not mandatory, were developed within the Portuguese Long-Term Strategy for Buildings Refurbishment ELPRE [55] context to support the National Building Rehabilitation Fund (FNRE) on the design of residential refurbishments for leasing [56], but they only apply to the buildings associated with the Fund. It includes good practices and some of the strategies mentioned in Section 4.2.:

- At the mapping stage: adopting an Inspection and Diagnosis Report (IDR), a pre-demolition audit, and a strategic intervention plan, following CE-based recommendations;
- At the selective disassembly/demolition stage: adopting CDW prevention and management plans in all refurbishments is a good practice;
- At the (re)design stage: adopting lifecycle sustainable and cost-optimal criteria to select design, assessing environmental sustainability through EN15798 [28], and using certification methods (also in subsequent stages).

In this context, CDW policy will remain ineffective, and many refurbishment works might remain unknown, as it is not mandatory to provide this information to city halls. Furthermore, by linking incentives mainly to urban renewal policies, many existing buildings will be excluded, conflicting with the long-term strategy to refurbish almost all existing building stock by 2050. Specific strategies to adopt CE as a current practice could be transposed from EU policy to the Portuguese context within the revision of ELPRE [55] into a national building renovation plan by 2024 [57].

5.2. New CE Refurbishment Steps for an Incentive-Based Policy

In order to promote CE in building refurbishment, critical moments were identified, making use of the new Circular Refurbishment Framework for Portugal (Figure 3), to adopt the solutions articulated with specific policy guidelines discussed in Section 4.2. This will materialize in a new set of CE policy actions discussed in this section, to be implemented at the building scale and coordinated with the Portuguese Legal Framework for Urban Development and Construction Works (RJUE) [58]. The proposed approach aims to facilitate dialogue between public authorities (city halls) and private stakeholders (building owners and design teams) to promote CE principles in building refurbishment.

To address the lack of information on existing buildings and adopt CE principles in refurbishment strategies, it is suggested to adopt mapping as the first step for CE refurbishment, as the characterization of the existing building stock constitutes the baseline scenario for deconstruction and selective disassembly strategies, implementing databases and stock and flow analysis of resources and materials, conducting a circularity assessment, and defining future design options. Public authorities should provide guidelines for building passports and selective disassembly while developing platforms and storage facilities for reclaimed products, which will be useful for subsequent steps. The stepwise approach proposed is discussed in the next few paragraphs.

Step 1: Communication for construction works/pre-project delivery for approval

The mapping stage would be prior to the first existing control moment in RJUE: communication for construction works when a construction permit is not mandatory. For refurbishments subject to a construction permit, a new control point is to be created after the mapping stage (pre-project delivery for approval), which will facilitate the process of obtaining the construction permit afterward. In this stage, the mandatory deliverables include the building passport, either new or updated, and a selective disassembly plan. The building passport is a more comprehensive version of the material passport, which contains circularity information and is based on a circularity assessment. This document can use information technologies like BIM to provide an additional layer of information beyond the current legal requirement of an EPC. Building passports are an important step in addressing the knowledge gap associated with the use of materials from existing building stock in construction systems. More detailed information at the material level could be provided by material passports [59], which are, however, complex to implement due to the lack of an established model for presenting the necessary information for material recovery and reuse in the construction sector. A reduced VAT tax for construction works would be the incentive for this control step, based on circularity indicators and other assessment criteria to be defined (the Level(s) Framework [18] can be an option).

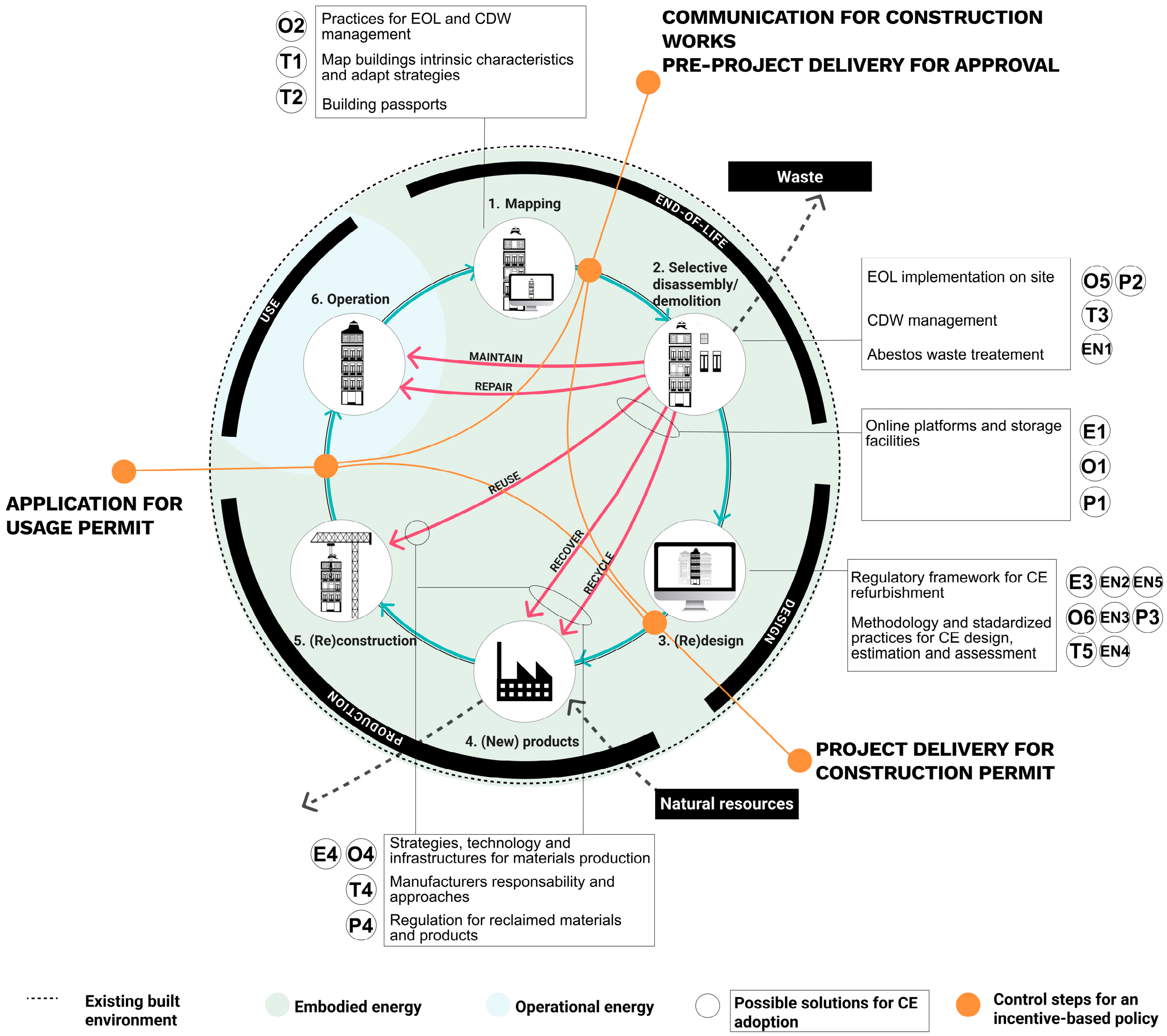

Figure 3. Circular Refurbishment Framework for Portugal.

Step 2: Project delivery for construction permit

At the design stage, public authorities should provide guidelines for CE refurbishment design. Priority in project analysis and construction permit delivery will be given if evidence that the design complies with CE principles is delivered when submitting the project for approval.

Step 3: Application for usage permit

Currently, when refurbishment works are completed, promoters apply for a usage permit, in the case of refurbishments subject to a construction permit, or for an inspection when they apply for tax benefits. In the latter case, it is suggested that the inspection be replaced or complemented with a simplified report of the refurbishment as built. In both cases, evidence should be provided that the refurbishment meets the minimum assessment criteria for CE so that property tax exemption could be granted. Property tax should be progressively updated after exemption to not incentivize the willingness to go around the law.

Despite introducing little change in the existing incentive scheme, the incentives suggested in this section would be conceded according to CE criteria, combined with energy efficiency, and would have a significant impact on achieving the 2050 goal of decarbonizing existing building stock. This requires a great and continuous effort from public authorities to provide guidelines, quantitative assessment indexes, and incentives for CE adoption in building refurbishment. Additionally, a CE-accomplishment scale could be defined to provide different degrees of incentives. To tackle the financing issue, also stressed in ELPRE, it is suggested that the interest rate for refurbishments be linked to CE criteria, like the choice of recovered, recycled, or bio-based materials.

Figure 4 summarizes the critical steps and strategies for an incentive-based policy.

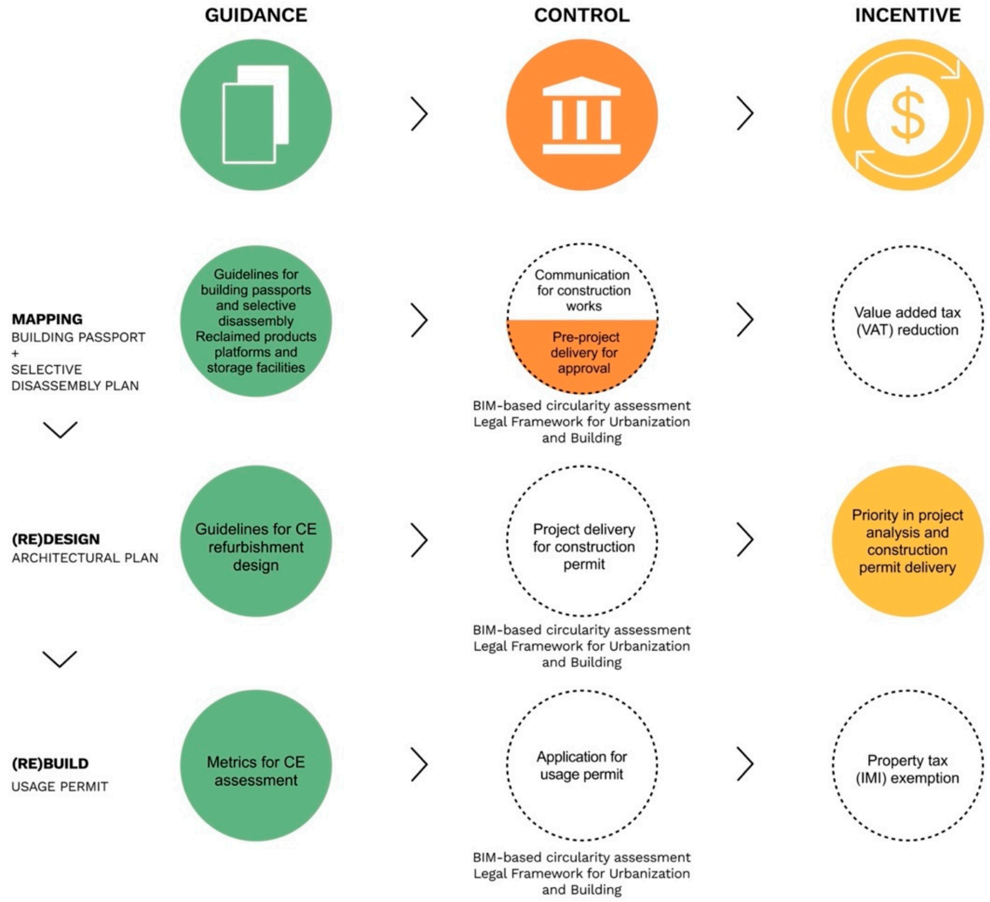

Figure 4. Steps and strategies for an incentive-based policy.

As mentioned by [60], further research should focus on identifying or developing CE indicators that reflect not only environmental but also social, economic, and governance aspects to ensure that the framework includes indicators able to capture aspects relevant to the four pillars of sustainable development.

As an example, possible criteria for a BIM-based circularity assessment would be to establish a set of indicators, including a building circularity indicator, an overall system circularity indicator, an average system circularity indicator, an overall product circularity indicator, an average product circularity indicator, an overall disassembly potential, an average disassembly potential, origin material (virgin material/reused/recycled/bio-based), an overall embodied carbon, an overall embodied energy, and an EOL strategy (reuse/recycle/unrecoverable waste). Other criteria, based on the 9R framework [35], within four dimensions are: reduce/flexibility of space (number of possible combinations of different spaces); reuse (number of elements that will be reused from other buildings; number of elements that will be reused within the building); recover (number of components that will be recovered); recycle (number of elements for recycling).

6. Discussion and Conclusions

This paper contributes a new framework for promoting CE practices in existing building refurbishment design, with practical implications. The analysis of different case studies allowed for inferring specific policy actions aimed at promoting CE adoption at the design stage and throughout the building's life cycle, with a focus on refurbishment but with ample application in an international context.

In particular, the framework developed highlights the importance of involving public and private stakeholders from the early design stages, as demonstrated in a case study of Taiwan, where the lack of government incentives hindered CE implementation in the construction sector [61]. To this end, the implementation of the Circular Refurbishment Framework in a Portuguese context resulted in effective recommendations for CE adoption in specific refurbishment stages through the definition of three steps of guidance/control points/incentives. This framework contributes to a more regulated and coordinated dialogue between local authorities and private stakeholders, bridging existing building mapping, selective disassembly practices, (re)design, and (re)build, and providing opportunities to implement actions for policy-based incentives.

The Circular Refurbishment Framework introduces a critical first step in circular procurement, "mapping," which emphasizes the importance of characterizing existing building stock as the foundation for the CE approach. The building passport is created (or updated) in this phase, making use of existing quantities of materials that might be available as anthropogenic stocks and providing input for local authorities to manage construction material flows, preparing the basis for selective demolition and building (re)design. This is the first of a six-step framework (mapping, selective disassembly, (re)design, (new) products, (re)construction, and operation) that identifies steps or control moments where the promoter or the design team interacts with local authorities.

To facilitate CE adoption in building refurbishment, a set of policy actions is proposed along the steps identified, which are interconnected with the construction permit process and utilize existing city hall organization skills and the government tax system. It is concluded that, to provide consistent incentives, it is necessary to first assess and quantify circularity. Time-based incentives, such as priority in project analysis and faster construction permit delivery, are cost-free and only have implications for the organization of local administration services. Moreover, these might be the most valuable incentives, as the process of applying for a construction permit is often very slow. However, tax-based incentives should only be granted to refurbishment projects that have adopted CE principles. Additionally, support actions such as the creation of online platforms for reclaimed materials, proximity storage facilities, training, standardized practices, and a quantitative index for circularity assessment are crucial for the successful implementation of the framework and should be prioritized.

The adoption of this framework would constitute a breakthrough in the promotion of CE in buildings and thus contribute to both resource use efficiency and climate change mitigation.

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