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Reframing Net-Zero Building Delivery Through Life-Cycle Thinking, Material Circularity, and Context-Sensitive Design: An Integrated Research Perspective for Sustainable Construction Transition

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ABSTRACT

Background: The transition toward net-zero and nearly net-zero buildings has become one of the defining priorities of contemporary construction policy, climate governance, and sustainable design research. Yet the concept of "net-zero" remains vulnerable to simplification when it is treated as an operational energy target alone. The references provided for this study indicate that a meaningful transition requires a broader perspective integrating carbon emissions, life-cycle assessment, material selection, circular construction, rural and regional adaptation, certification systems, policy alignment, and implementation pathways.

Objective: This article develops an integrated research framework for understanding how net-zero building strategies can move beyond isolated performance metrics toward a whole-life, resilient, and context-responsive model of sustainable construction. The study aims to synthesize the provided literature into a publication-ready argument concerning the relationship between net-zero goals, embodied impacts, design-stage decisions, material recovery, and governance conditions.

Methodology: A qualitative integrative review design was adopted using only the references supplied. The literature was organized into six analytical themes: climate-policy and sectoral urgency; net-zero building definitions and contextual adaptation; life-cycle assessment and visualization; sustainability rating systems and design-stage decision support; circular material flows and construction-demolition waste valorisation; and implementation challenges in developing, historical, and rural contexts. A comparative thematic synthesis was then used to develop a unified interpretive framework.

Results: The literature indicates that net-zero building discourse is evolving from an energy-centered paradigm toward a more comprehensive whole-life sustainability model. The most robust studies emphasize that operational efficiency, embodied carbon reduction, material reuse, and resilient local adaptation must be addressed simultaneously. Life-cycle assessment emerges as a pivotal bridging method, while circular use of waste-derived and alkali-activated materials demonstrates the practical value of integrating demolition recovery into new construction and remediation. Certification schemes, BIM-enabled sustainability tools, and public-private partnership strategies offer enabling mechanisms, but their effectiveness depends on contextual fit rather than universal transferability.

Conclusion: The study argues that net-zero buildings should be understood not as isolated technical products but as socio-material systems shaped by early design choices, policy environments, local resource conditions, and end-of-life recovery strategies. Future progress depends on shifting from operational net-zero rhetoric toward a circular, whole-life, and regionally grounded construction paradigm.

Keywords: Net-zero buildings, life-cycle assessment, circular construction, embodied carbon, sustainable materials, building sustainability, construction transition.

INTRODUCTION

The built environment has become central to global climate mitigation because buildings and construction are not peripheral emitters but structural contributors to environmental degradation, resource depletion, and long-term carbon lock-in. Reports devoted to the global status of buildings and construction have repeatedly emphasized the urgency of reducing emissions while improving efficiency and resilience across the sector (Abergel et al., 2017; Dean et al., 2016). This urgency has intensified as climate governance frameworks have increasingly converged around decarbonization pathways, national commitments, and transition targets linked to the Paris Agreement and broader energy transition narratives (UNFCCC, 2025; IEA, 2023; Den Elzen et al., 2019). In this context, net-zero buildings have emerged as a powerful idea. They promise a building stock that consumes less, emits less, and aligns more closely with long-term climate objectives. Yet the very popularity of the term "net-zero" has created conceptual risks. When a concept becomes politically attractive, technically fashionable, and symbolically powerful, it can also become diluted.

One major problem is that net-zero buildings are often interpreted too narrowly. In many policy and design conversations, the phrase is used as if it refers primarily to operational energy balancing: reduce consumption, add on-site renewables, and offset remaining demand. That approach has undeniable importance, and the literature on net-zero energy buildings demonstrates the gains that can be made through improved efficiency, photovoltaic integration, and climate-responsive strategies (Feng et al., 2019; El Hassani et al., 2023; Badr & Umar, 2024). However, the references provided for this article suggest that such an interpretation is no longer sufficient. A building can appear operationally efficient while still embodying significant carbon in its materials, causing substantial emissions during construction, relying on unsustainable supply chains, or generating avoidable waste at the end of life (Hong et al., 2014; Barbhuiya & Das, 2023; Khan et al., 2023). In other words, operational net-zero is not the same as whole-life sustainability.

This distinction matters because the built environment is not only an energy-consuming system but a material system. It extracts, processes, assembles, maintains, renovates, demolishes, and discards matter at scale. Once this is recognized, the discussion must move beyond building energy use alone toward a whole-life framework that includes life-cycle impacts, material circularity, demolition recovery, certification systems, and design-stage decision support. Several of the references in the corpus directly reinforce this shift. Reviews of life-cycle assessment in buildings show that sustainability cannot be judged only at the operational phase, especially when embodied impacts are significant and front-loaded in the construction process (Soust-Verdaguer et al., 2016; Hollberg et al., 2021; Barbhuiya & Das, 2023). Studies on early-stage building material selection and BIM-integrated life-cycle sustainability tools further indicate that the most consequential sustainability decisions often occur before construction begins (Soust-Verdaguer et al., 2023). This means that the net-zero challenge is not merely about running buildings more efficiently. It is about designing differently from the start.

Another reason a broader framework is needed is that the path to net-zero is not uniform across geographies, economies, and building contexts. The reference set includes work on hot and humid climates, rural bio-based houses, developing countries, Mediterranean certification practices, and historical remediation contexts (Feng et al., 2019; El Hassani et al., 2023; Badr & Umar, 2024; Pushkar, 2024; Capasso et al., 2023). These studies imply that any meaningful theory of net-zero buildings must account for climate, material availability, local traditions, infrastructure capacity, and social constraints. A model that works well in a highly industrialized urban context may be poorly suited to a rural, resource-constrained, or historically sensitive environment. This is particularly important for developing countries, where the desire for rapid modernization may collide with affordability, technical capacity, and the need for locally appropriate strategies (Badr & Umar, 2024). It is also important in historic remediation, where sustainability cannot simply mean replacement and new construction, but often requires valorisation of waste streams, adaptive reuse, and compatible materials (Capasso et al., 2023; D'Angelo, 2022).

The literature also shows that net-zero building discourse is increasingly entangled with broader governance and transition questions. Nationally determined contributions, decarbonization timelines, and the progress of major economies shape the policy environment within which buildings are designed and regulated (Den Elzen et al., 2019; UNFCCC, 2025). At the same time, sectoral transformation depends on mechanisms such as public-private partnerships, industry guidance, certification systems, and standards that make abstract goals operational (Akomea-Frimpong et al., 2022; BSI Group, 2025; Ferreira et al., 2023). This governance dimension is often underestimated in purely technical studies. A net-zero target is not self-executing. It depends on institutional coordination, access to expertise, implementation incentives, material supply chains, and practical tools. As a result, the transition to net-zero buildings is not only a design challenge or an engineering challenge. It is a systems challenge.

The present article is motivated by the need to integrate these dimensions into a single research perspective. The references provided by the user are diverse, but they are united by a common concern: how the building sector can move from sustainability rhetoric to materially grounded, life-cycle-informed, and context-sensitive transformation. Some sources provide macro-level sectoral framing through global status reporting, emissions tracking, and policy alignment (Abergel et al., 2017; Dean et al., 2016; IEA, 2023). Others address performance and contextual adaptation in net-zero or nearly net-zero buildings (Badr & Umar, 2024; El Hassani et al., 2023; Feng et al., 2019). Others focus on life-cycle thinking, visualization, and certification comparison (Ferreira et al., 2023; Hollberg et al., 2021; Soust-Verdaguer et al., 2016). Still others emphasize circular construction and the transformation of waste into resources through gypsum innovation, geopolymers, alkali-activated materials, and building remediation (Capasso & Iucolano, 2020; D'Angelo et al., 2021; Liguori et al., 2017; Villoria Sáez et al., 2019). Read together, these sources offer more than isolated insights. They provide the basis for a whole-life interpretation of net-zero construction.

The problem statement of the article can therefore be expressed clearly. Current discourse on net-zero buildings often privileges operational energy performance and headline carbon targets while underemphasizing embodied impacts, circular material strategies, regional adaptation, and design-stage decision processes. This creates a gap between the symbolic ambition of net-zero and the practical requirements of genuine whole-life sustainability. The literature indicates that this gap is especially significant in four areas. First, embodied carbon and construction-phase emissions remain insufficiently integrated into mainstream net-zero thinking (Hong et al., 2014; Khan et al., 2023). Second, the role of life-cycle assessment in informing early design choices is recognized but not yet fully normalized across practice (Soust-Verdaguer et al., 2016; Hollberg et al., 2021; Soust-Verdaguer et al., 2023). Third, circular material reuse and waste valorisation are highly promising but often remain at the edge rather than the center of mainstream net-zero strategies (D'Angelo et al., 2021; D'Angelo, 2022; Capasso et al., 2023). Fourth, context-specific pathways for developing, rural, and historically sensitive settings require more attention than one-size-fits-all models allow (Badr & Umar, 2024; El Hassani et al., 2023).

The literature gap, then, is not simply the absence of individual studies. It is the absence of an integrated conceptual framework that connects operational net-zero targets with life-cycle assessment, embodied carbon, circular construction, certification mechanisms, regional adaptation, and material innovation. Existing references contribute valuable insights within their own domains, but the field benefits from a synthesis that shows how these dimensions reinforce one another. Without such a synthesis, there is a risk that net-zero buildings will be pursued as technically efficient but materially incomplete objects. That would be a serious limitation for sustainability research and practice.

The objective of this article is to generate a publication-ready original research study based strictly on the supplied references and to develop an integrated framework for understanding net-zero building transitions as whole-life socio-material processes. More specifically, the study aims to answer five research questions. First, how do the provided references collectively redefine the meaning of net-zero buildings beyond operational energy balance? Second, what role does life-cycle assessment play in linking early design decisions to long-term environmental outcomes? Third, how does circular material valorisation challenge conventional linear construction models? Fourth, what contextual and governance conditions shape the feasibility of net-zero transitions across different settings? Fifth, what kind of integrated research perspective can support more credible and resilient sustainable construction pathways?

The significance of the article is both theoretical and practical. Theoretically, it contributes to the evolution of net-zero discourse by arguing that the future of sustainable buildings lies in a convergence of operational efficiency, embodied carbon awareness, circular material systems, and context-sensitive implementation. Practically, it highlights actionable domains: design-stage decision support, certification critique, waste valorisation, and policy-linked transition mechanisms. The article does not claim to provide a universal formula for all buildings. Rather, it argues that the most robust sustainability pathway is one that treats buildings as dynamic entities situated within resource systems, policy systems, climate systems, and local socio-material cultures.

Methodology

This study adopts a qualitative integrative review methodology based strictly on the reference set provided in the prompt. The purpose of the methodology is not to generate new quantitative findings, conduct a formal meta-analysis, or test a numerical hypothesis, but to produce a coherent and publication-ready research article through structured synthesis of heterogeneous sources. The references include sectoral reports, journal articles, conference papers, edited-book chapters, institutional guidance documents, and practice-oriented contributions. Because of this diversity, an interpretive integrative method is more appropriate than a statistical aggregation method. The goal is to identify recurring concepts, align them thematically, and develop a theoretically grounded framework for whole-life net-zero building transitions.

The first stage of the methodology involved corpus delimitation. Only the references supplied by the user were used. No external sources were added, even when additional contextual material might have been useful. This strict boundary ensures fidelity to the task and makes the resulting analysis a direct synthesis of the provided literature rather than a general review of all net-zero building research. It also means that the conceptual architecture of the article had to emerge from the internal diversity of the supplied corpus.

The second stage involved classification of the literature into six analytical themes. The first theme was sectoral urgency and climate-governance context. This theme included global building-sector reports, emissions tracking, and policy alignment documents that establish the macro-level need for transformation (Abergel et al., 2017; Dean et al., 2016; IEA, 2023; UNFCCC, 2025; Den Elzen et al., 2019). These references were treated as framing sources because they clarify why net-zero buildings matter in relation to sector-wide emissions, climate commitments, and broader energy transition trajectories.

The second theme was net-zero and nearly net-zero building performance in context. This theme included studies examining net-zero strategies in hot and humid climates, rural bio-based housing, and developing-country conditions, as well as institutional guidance on net-zero energy buildings (Badr & Umar, 2024; El Hassani et al., 2023; Feng et al., 2019; BSI Group, 2025). These works were analyzed for how they define performance, contextual adaptation, and implementation constraints. Rather than treating net-zero as a fixed universal formula, these references suggest that the pathway is climate-specific, socio-economic, and highly dependent on local material and energy conditions.

The third theme was life-cycle assessment and whole-life carbon thinking. This theme included work on energy consumption and greenhouse gas emissions during construction, reviews of LCA simplification for single-family houses, visualisation of LCA results in design, and broader methodological reflections on construction material life-cycle assessment (Hong et al., 2014; Soust-Verdaguer et al., 2016; Hollberg et al., 2021; Barbhuiya & Das, 2023). These studies were central because they shift analysis from the operational phase of a building to a whole-life perspective, covering construction, material selection, visualization, and decision support.

The fourth theme was certification systems and design-stage sustainability tools. This included critical analysis of LEED, BREEAM, and DGNB for retail buildings, comparative analysis of LEED-certified interior projects, and BIM-integrated tools for automatic material selection using life-cycle sustainability assessment (Ferreira et al., 2023; Pushkar, 2024; Soust-Verdaguer et al., 2023). These references were examined to understand how sustainability frameworks become operationalized in practice and how assessment systems can either support or constrain meaningful whole-life performance.

The fifth theme was circular materials, waste valorisation, and eco-innovative construction products. This theme was particularly substantial in the corpus. It included works on geopolymerization, crushed brick valorisation, tuff and brick waste activation, lightweight gypsum using vegetal protein, gypsum composites with glass waste, sustainable binding materials, and demolition-to-reuse pathways (Capasso & Iucolano, 2020; Capasso et al., 2023; Caputo et al., 2020; D'Angelo, 2022; D'Angelo et al., 2021; Liguori et al., 2017; Villoria Sáez et al., 2019). These sources were interpreted as evidence that net-zero transitions are materially inseparable from circular construction and construction-demolition waste recovery.

The sixth theme was implementation pathways, public-private partnerships, and regional/historical contexts. This theme included work on public-private partnerships for net-zero targets, historical building remediation, naturalistic engineering, and perceptual or territorial recovery methodologies (Akomea-Frimpong et al., 2022; Capasso et al., 2023; D'Angelo et al., 2021; D'Angelo et al., 2021). While some of these references are not framed explicitly as net-zero studies, they were included because they show how sustainability goals must be mediated by regional practices, governance arrangements, and existing building stocks.

The third methodological stage involved thematic coding. Each source was coded for its primary emphasis, its scale of intervention, and its implied theory of sustainable transition. Coding categories included operational energy focus, embodied carbon relevance, material circularity, design-stage influence, governance relevance, context sensitivity, and implementation mechanism. For example, a study on photovoltaic integration into bio-based rural housing was coded not only as a net-zero performance paper but also as a context-sensitive adaptation paper because it links energy strategies to local building typologies and regional realities (El Hassani et al., 2023). Similarly, a review of LCA visualization was coded not simply as a methodological study but as a design-process intervention because it addresses how environmental knowledge becomes usable for architects and decision makers (Hollberg et al., 2021).

The fourth stage involved cross-theme synthesis. This was the key analytical step. The question was not merely what each paper said in isolation, but what larger framework emerged when the papers were read together. Through this process, several recurring conceptual bridges became evident. The first was the bridge between operational efficiency and embodied impact. The second was the bridge between life-cycle assessment and early design decision making. The third was the bridge between circular materials and net-zero credibility. The fourth was the bridge between rating systems and actual sustainability depth. The fifth was the bridge between global targets and local implementation realities. These bridges became the scaffolding for the article's central argument.

The fifth stage involved interpretive consolidation into an IMRaD-compatible narrative. Because the user requested a continuous, publication-ready article rather than a fragmented review, the coded insights were reorganized into a unified argument: that net-zero building transition should be understood as a whole-life socio-material process rather than an operational energy exercise. This argument was then elaborated through results and discussion sections that preserve the distinction between what the literature directly supports and what the article infers from comparative synthesis.

This methodology has clear strengths. It is well suited to heterogeneous literature. It allows strict adherence to the provided references while still generating an original conceptual contribution. It also enables a systems perspective that would be difficult to obtain from a narrow empirical study. However, the method also has limitations. Because the corpus is user-provided, the analysis reflects the strengths and biases of that selection. Some references are highly technical and others more policy-oriented. Some provide complete bibliographic detail, while others function more as practice-oriented or institutional documents. The article therefore does not claim exhaustive coverage of all net-zero building research. Its conclusions are interpretive and framework-building rather than statistically generalizable. Even so, given the objective of generating a publication-ready synthesis grounded strictly in the supplied material, the methodology is appropriate and defensible.

Results

The synthesis of the supplied literature yielded a series of integrated findings that collectively challenge narrow interpretations of net-zero buildings and support a broader whole-life construction paradigm.

The first major finding is that the concept of net-zero buildings is undergoing a clear expansion from an operational energy target to a multi-dimensional sustainability agenda. Sectoral reports on zero-emission and resilient buildings establish that the construction sector's transition cannot be reduced to the installation of efficient technologies alone (Abergel et al., 2017; Dean et al., 2016). Likewise, emissions-focused reporting and climate policy references show that building-sector decarbonization is embedded in larger national and global commitments rather than isolated technical performance goals (IEA, 2023; UNFCCC, 2025; Den Elzen et al., 2019). The literature therefore suggests that net-zero should be interpreted not as a narrow building label but as part of a transition logic spanning climate governance, energy systems, design methods, and material practices.

The second finding is that operational net-zero strategies remain essential but are highly context dependent. The review of net-zero energy buildings in hot and humid climates shows that climatic conditions significantly shape design choices, energy performance strategies, and lessons learned from case studies (Feng et al., 2019). The rural Morocco case demonstrates that net-zero pathways can be meaningfully rooted in bio-based earth housing and photovoltaic integration rather than imported as purely high-tech models (El Hassani et al., 2023). The developing-country perspective further reinforces that nearly net-zero buildings must respond to real conflicts involving affordability, infrastructure gaps, and local constraints (Badr & Umar, 2024). Together, these studies produce a consistent insight: there is no singular universal route to net-zero performance. Effective strategies emerge from alignment between climate, materials, economics, and social context.

The third finding is that whole-life carbon thinking is no longer optional if net-zero claims are to remain credible. The literature on construction-phase energy consumption and greenhouse gas emissions already made clear that substantial impacts occur before a building even begins operation (Hong et al., 2014). Later critical reflections on the carbon footprint of net-zero buildings reinforce the idea that operational success can conceal significant embodied emissions if materials, construction methods, and life-cycle boundaries are ignored (Khan et al., 2023). This is one of the most consequential findings across the corpus. It means that a building may be celebrated as net-zero while still contributing significantly to climate burdens through its materials and construction processes. Once whole-life carbon is considered, the apparent simplicity of net-zero narratives disappears, and sustainability becomes a matter of temporal distribution as well as total reduction.

The fourth finding is that life-cycle assessment functions as a bridging methodology between design intention and environmental reality. Reviews of LCA simplification for single-family houses show that the field has been seeking ways to make life-cycle analysis more practical and accessible for decision makers, rather than reserving it for post hoc academic evaluation (Soust-Verdaguer et al., 2016). Work on visualising LCA results demonstrates that information format matters because design professionals need interpretable tools if environmental knowledge is to influence decisions in real time (Hollberg et al., 2021). The methodological review of construction material LCA further supports the idea that sustainable decision making requires structured evaluation of impacts across material life cycles rather than reliance on generic assumptions (Barbhuiya & Das, 2023). These studies jointly indicate that LCA is not simply a calculation tool. It is an epistemic infrastructure for making environmental consequences visible early enough to matter.

The fifth finding is that early design stages are decisive leverage points for sustainability transition. The BIM-integrated automatic tool for building material selection shows how life-cycle sustainability assessment can be embedded in design-stage workflows rather than added retrospectively (Soust-Verdaguer et al., 2023). This is highly significant because many environmental burdens are effectively locked in during concept development and material specification. Once a project advances beyond early design, opportunities for major impact reduction often shrink. The literature therefore supports the conclusion that the path to meaningful net-zero performance begins not with late-stage technological add-ons but with early-stage systemic design choices.

The sixth finding is that certification systems provide useful structure but do not automatically guarantee whole-life sustainability depth. Comparative analysis of LEED, BREEAM, and DGNB for retail buildings shows that sustainability assessment frameworks differ in emphasis and applicability (Ferreira et al., 2023). Pushkar's comparative work on LEED-certified commercial interiors likewise indicates that certification outcomes must be interpreted in relation to regional contexts and specific project types rather than assumed to be universally comparable (Pushkar, 2024). This suggests that rating systems are helpful governance tools, but they can become reductive if used as substitutes for deeper environmental understanding. The literature does not reject certification. Instead, it implies that certification should be treated as one layer of sustainability governance, not the final proof of holistic performance.

The seventh finding is that material circularity is indispensable to a credible net-zero construction agenda. The corpus provides extensive evidence that construction and demolition waste can be transformed into valuable inputs for new materials and remediation strategies. Studies on crushed bricks as geopolymer feedstock, valorisation of tuff and brick waste, and the broader transition from demolition to reuse all illustrate how materials previously understood as waste can be repositioned within circular building systems (D'Angelo et al., 2021; Capasso et al., 2023; D'Angelo, 2022). This finding is especially important because it shifts the net-zero conversation away from the idea that sustainability lies primarily in better new products. Instead, it suggests that sustainability may also lie in refusing the linearity of extraction, use, and disposal.

The eighth finding is that alkali-activated and geopolymeric approaches occupy a particularly promising position within the circular materials literature. Solubility testing of natural and secondary raw materials in alkaline media demonstrates the technical potential for geopolymerization pathways (Liguori et al., 2017). Studies on crushed bricks and historical building remediation further reveal that such approaches are not only theoretically interesting but relevant to real construction challenges, including restoration contexts and waste valorisation (D'Angelo et al., 2021; Capasso et al., 2023). This matters because geopolymers and alkali-activated materials address multiple sustainability concerns at once: reduction of virgin material dependence, potential carbon reduction, waste recovery, and compatibility with certain local resource conditions.

The ninth finding is that lightweight and waste-enhanced gypsum research broadens the scope of eco-innovative material systems beyond geopolymers alone. The use of vegetal protein as a foaming agent in lightweight gypsum and the viability of gypsum composites with glass waste indicate that circular and lower-impact innovation can take diverse forms, including performance modification of familiar construction materials (Capasso & Iucolano, 2020; Villoria Sáez et al., 2019). This is a valuable reminder that sustainable materials transition is not dependent on a single material family. It can emerge through multiple, context-specific trajectories that improve performance while lowering environmental burden.

The tenth finding is that local and territorial dimensions matter more than generalized net-zero discourse often acknowledges. The literature on rural net-zero housing, historical remediation, naturalistic engineering, and recovery methodologies for minor centers indicates that buildings are not isolated technical shells but elements of cultural landscapes and territorial systems (El Hassani et al., 2023; D'Angelo et al., 2021; D'Angelo et al., 2021). This suggests that sustainability cannot be fully assessed without considering how buildings relate to place, heritage, available materials, and local forms of habitation. Such insight is especially relevant for regions where vernacular knowledge, landscape constraints, or cultural value are central to the meaning of the built environment.

The eleventh finding is that governance and implementation structures are crucial to scaling net-zero ambition. The critical review of public-private partnerships in reaching net-zero targets by 2050 indicates that construction transition depends on institutional collaboration, financing arrangements, and coordinated action beyond the project scale (Akomea-Frimpong et al., 2022). Guidance documents from standard-setting bodies further show that technical clarity and implementation guidance remain necessary for diffusion of better practice (BSI Group, 2025). The literature therefore supports the conclusion that the sustainability transition of the built environment is not only a technical redesign problem. It is also a governance challenge.

The twelfth and most integrative finding is that the strongest model emerging from the corpus is not “net-zero building” in the narrow sense, but whole-life circular net-zero transition. In this model, operational efficiency, embodied carbon reduction, material reuse, certification critique, policy alignment, and local adaptation are not separate agendas. They are mutually reinforcing dimensions of one transition framework. The references collectively point toward a building paradigm in which environmental credibility depends on what happens before construction, during construction, in operation, in renovation, and at end of life. That temporal breadth is the defining result of the present synthesis.

Discussion

The results of this study suggest that the future of net-zero building research lies in moving decisively beyond an operational-energy-centered paradigm toward a whole-life, circular, and context-responsive construction framework. This shift is not simply semantic. It changes what counts as success, what kinds of knowledge matter, and what kinds of interventions deserve priority.

The first implication is conceptual. If net-zero buildings are defined mainly by operational energy balance, then the design process may optimize what is easiest to meter while ignoring what is most consequential over the full life of the building. The references on embodied impacts and life-cycle assessment make clear that this would be a serious mistake (Hong et al., 2014; Soust-Verdaguer et al., 2016; Khan et al., 2023). Materials, construction methods, transport burdens, demolition pathways, and replacement cycles all shape environmental outcomes. Therefore, the very meaning of “zero” becomes unstable if system boundaries are drawn too narrowly. A building might reach operational net-zero while still depending on carbon-intensive materials or wasteful practices. This suggests that future research and policy should distinguish more carefully between operational net-zero, carbon-neutral claims, and whole-life net-zero pathways.

A second implication concerns timing. The literature strongly indicates that environmental performance is largely designed in at the beginning. This is especially evident in work integrating life-cycle sustainability into BIM-based material selection and in broader reflections on the need to visualize LCA results during the design process rather than after the fact (Hollberg et al., 2021; Soust-Verdaguer et al., 2023). In practice, this means that sustainability should not be treated as a compliance layer added near project completion. It must be embedded from the conceptual stage. This has consequences for professional education, procurement processes, software workflows, and interdisciplinary collaboration. If early decisions matter most, then the institutions that shape early decisions become strategically important.

A third implication is that context is not a complication to be managed after a universal solution is defined. It is the foundation of solution quality. The review of net-zero buildings in hot and humid climates, the rural Morocco case, and the developing-country perspective all undermine the idea that one performance model can be exported unchanged across regions (Feng et al., 2019; El Hassani et al., 2023; Badr & Umar, 2024). Context here means climate, yes, but also local construction traditions, economic feasibility, material availability, social acceptance, and infrastructure conditions. This is especially important for developing countries, where imported sustainability models may create new dependencies or ignore proven local building logics. A context-sensitive net-zero model is not a weaker model. It is a more realistic and equitable one.

This context sensitivity also reshapes the evaluation of certification systems. LEED, BREEAM, and DGNB can support standardization, comparability, and market signaling, which are valuable functions (Ferreira et al., 2023). However, the literature suggests that certification systems can only partially capture the depth of sustainability needed for whole-life transition. They may privilege measurable criteria that fit assessment structures, while undervaluing local resource loops, vernacular suitability, or culturally embedded building practices. Pushkar’s comparative analysis of LEED-certified office interiors across Mediterranean contexts reinforces that certification outcomes are not culturally or climatically neutral (Pushkar, 2024). This does not mean certification systems lack value. It means they should be treated critically and supplemented by deeper life-cycle and contextual analysis.

A fourth implication concerns circularity. Much of mainstream building sustainability discourse still privileges operational efficiency technologies such as better insulation, HVAC optimization, and renewable integration. The literature in the current corpus does not reject these strategies, but it shows that material circularity deserves equal prominence. Work on geopolymers, alkali-activated materials, gypsum innovation, and reuse of demolition waste demonstrates that the building sector’s decarbonization potential is materially grounded (Capasso & Iucolano, 2020; D’Angelo et al., 2021; Liguori et al., 2017; Villoria Sáez et al., 2019). A building that uses recovered or reactivated materials can avoid some of the environmental burdens associated with extraction and virgin production. Moreover, circularity addresses not only carbon but waste management, landfill pressure, regional resource efficiency, and industrial symbiosis.

This is why the transition from demolition to reuse described in the corpus is so important (D'Angelo, 2022). It challenges a deeply ingrained logic of linear construction, where old buildings or components are treated as burdens to be removed rather than repositories of future value. Once demolition waste is viewed as a potential raw material, the sector's relationship to time changes. End-of-life becomes a beginning rather than an end. This temporal reframing aligns strongly with whole-life sustainability thinking and strengthens the credibility of net-zero discourse. A building sector that ignores demolition waste while celebrating operational net-zero is only partially decarbonized in any meaningful sense.

The historical building remediation literature adds another important dimension. Sustainable transition is often narrated as if it concerns only new buildings. But many regions, especially those with rich built heritage or constrained land availability, must work largely with existing stocks. The references on valorisation of tuff and brick waste for historical remediation, naturalistic engineering, and methodologies of territorial recovery suggest that sustainability in such contexts depends on compatible materials, careful adaptation, and place-aware strategies (Capasso et al., 2023; D'Angelo et al., 2021; D'Angelo et al., 2021). This is a powerful counterpoint to the assumption that sustainability always requires technological replacement. In many cases, sustainable transition may depend more on intelligent reuse than on complete rebuilding.

A fifth implication concerns governance. Global reports and Paris Agreement references make clear that the building sector is under pressure to align with larger climate commitments (Abergel et al., 2017; IEA, 2023; UNFCCC, 2025). However, alignment with climate ambition does not automatically translate into implementation capacity. The public-private partnership literature suggests that the pathway to 2050 targets depends on cooperation structures, financing mechanisms, and institutional coordination rather than technical feasibility alone (Akomea-Frimpong et al., 2022). This is particularly important because the construction sector is fragmented, with many actors making small but cumulative decisions. Architects, developers, contractors, regulators, material suppliers, and owners all influence outcomes. Net-zero transition therefore requires governance arrangements capable of distributing responsibility without dissolving accountability.

The BSI guidance reference reinforces the need for translation between high-level sustainability goals and usable practice frameworks (BSI Group, 2025). Standards, guidance, and structured methodologies help reduce ambiguity, but they must remain adaptable enough to respond to different building types and regional realities. A rigid framework can be as limiting as no framework at all. This again points to the importance of balance: enough structure to guide implementation, enough flexibility to preserve contextual relevance.

The discussion also reveals a tension between simplification and depth. Life-cycle assessment simplification is important because overly complex tools may prevent widespread uptake (Soust-Verdaguer et al., 2016). Yet excessive simplification can obscure burdens or mislead decisions. The same applies to net-zero narratives more generally. Simplicity has communicative power, but sustainability requires depth. A useful future direction, therefore, lies not in rejecting simplification altogether but in designing layered tools: simple enough for practical use, deep enough to preserve material truth. Visualization research is particularly valuable here because it suggests that the challenge is not only what information is available, but how it is communicated to designers and stakeholders (Hollberg et al., 2021).

Several limitations of the present study should be acknowledged. First, the article is bounded by the supplied reference set and does not claim to represent the entire net-zero building literature. Second, the corpus includes sources of varying type and granularity, from broad sectoral reports to technical materials studies and conference contributions. As a result, the analysis emphasizes conceptual integration rather than direct comparison of empirical findings. Third, some references are clearly embedded in Mediterranean and Italian contexts, especially those related to circular materials and remediation. This enriches the discussion but also means that some themes are more regionally detailed than others. Even so, these limitations do not weaken the article's core contribution, which is to show that operational net-zero discourse becomes stronger, not weaker, when reinterpreted through whole-life, circular, and contextual lenses.

Future research should build on several directions that emerge from the synthesis. One direction is the development of integrated whole-life net-zero assessment models that combine operational energy, embodied carbon, waste recovery potential, and regional material availability. Another is the strengthening of design-stage digital tools that allow life-cycle consequences to shape material and form decisions in real time. A third is further investigation into circular material systems, especially those derived from construction and demolition waste, in order to connect laboratory innovation with industrial implementation. A fourth is closer examination of certification systems to determine how they might evolve beyond checklist logic toward genuinely whole-life performance governance. A fifth is stronger comparative research across regions, especially developing countries, rural territories, and historical urban contexts where sustainability pathways differ significantly from dominant high-tech narratives.

Ultimately, the discussion leads to a strong conclusion: net-zero buildings should not be treated as isolated technical achievements but as nodes in a much larger construction transition. Their environmental value depends on how they are designed, what they are made from, how their impacts are assessed, how they relate to local conditions, and what happens to their materials over time. The most credible future for sustainable construction will emerge not from narrowing the meaning of net-zero, but from broadening it responsibly.

Conclusion

This article has developed a publication-ready integrative research study based strictly on the supplied references and argued that net-zero building transition must be reinterpreted through a whole-life, circular, and context-sensitive lens. The literature shows that while operational energy performance remains important, it is no longer sufficient as the dominant or sole indicator of sustainable building success. Buildings are not only consumers of energy during use; they are assemblies of materials, carriers of embodied carbon, participants in waste streams, and elements of wider socio-environmental systems.

The reference set makes four broad conclusions possible. First, the climate and policy context establishes that the building sector must decarbonize rapidly and credibly if wider mitigation goals are to be achieved (Abergel et al., 2017; IEA, 2023; UNFCCC, 2025). Second, net-zero performance is highly context dependent, requiring adaptation to climate, local materials, socio-economic realities, and regional building traditions (Badr & Umar, 2024; El Hassani et al., 2023; Feng et al., 2019). Third, life-cycle assessment and embodied carbon thinking are essential if net-zero claims are to reflect real environmental performance rather than partial accounting (Hong et al., 2014; Hollberg et al., 2021; Soust-Verdaguer et al., 2016). Fourth, circular material strategies and demolition-waste valorisation are not peripheral supplements to sustainability but core pathways for reducing impacts and strengthening resilience in the construction sector (Capasso & Iucolano, 2020; D'Angelo et al., 2021; Liguori et al., 2017; Villoria Sáez et al., 2019).

The article therefore proposes that the most meaningful model for the future is not operational net-zero in isolation, but whole-life circular net-zero transition. In that model, operational energy reduction, embodied impact minimization, design-stage decision support, certification critique, and material reuse are integrated rather than separated. Such a model also requires governance mechanisms capable of translating global ambition into local implementation, including partnerships, standards, and practical guidance systems (Akomea-Frimpong et al., 2022; BSI Group, 2025).

A final and especially important conclusion is that sustainable construction transition must remain sensitive to place. Rural settlements, historical buildings, developing-country contexts, and culturally significant landscapes cannot simply receive standardized net-zero formulas. They require pathways rooted in local materials, local capacities, and local meanings. This does not weaken sustainability; it makes it more durable and more just.

In sum, the future of net-zero buildings depends on whether the field is willing to move beyond the narrow comfort of operational metrics toward the more demanding but more truthful terrain of whole-life sustainability. The literature supplied for this study strongly supports that move. A net-zero building worthy of the name is not just efficient in operation. It is carefully designed, materially responsible, circular in logic, regionally responsive, and accountable across its entire life cycle.

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