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POLICYBRIEF
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From Rubble to Resource: Minimising Unrecoverable Inorganic Construction and Demolition Waste

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Highlights

1. Over 60% of buildings are yet to be constructed by 2050, amplifying the building sector's environmental impact. Currently, construction already consumes 45.3 billion tons of raw materials annually, making it the largest resource consumer and waste producer.

2. Current policies do not promote the implementation of a circular building sector

3. Minimizing unrecoverable inorganic construction & demolition waste can be achieved by maximising functionality and operational time

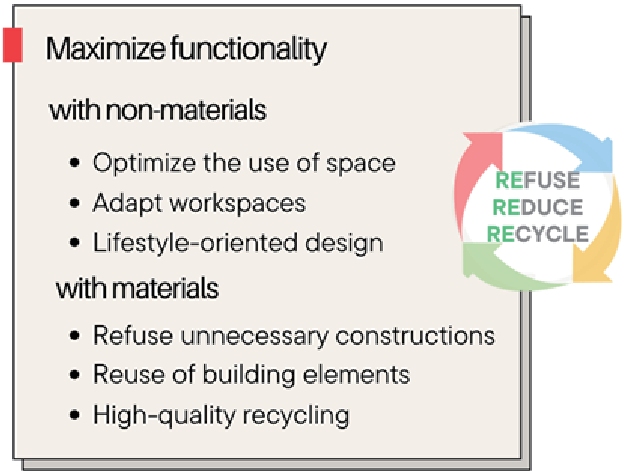
4. (Re-)design space-sufficient buildings for 100+ year lifespans while enabling future reconfiguration and high-quality material recovery, supported by integrated circularity and carbon footprint assessments

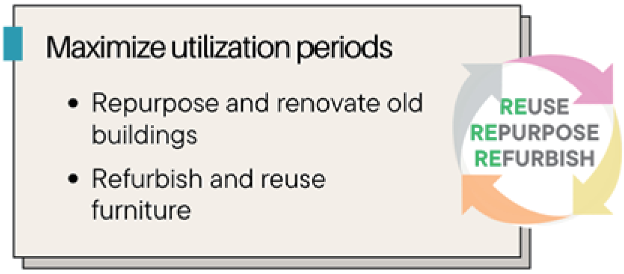
Introduction

The construction industry is the most resource-consuming and, at the same time, the largest producer of waste among all sectors. Sand, gravel, and clay, which are primarily used in construction, are the most consumed materials on Earth. The extraction of these materials increased significantly, rising from 9.6 billion tons in 1970 to 45.3 billion tons in 2020 (United Nations Environment Programme, 2024). In Germany, construction and demolition waste accounted for 63% of the total national waste in 2021 (Statistisches Bundesamt (Destatis), 2023).

By 2050, the global population is projected to reach approximately 9.7 billion, leading to increased housing demand due to accelerated urbanisation (UN DESA, 2022). It is estimated that around 60% of the buildings projected to exist by that year have yet to be constructed, primarily in Asia and Africa (United Nations Environment Programme & Global Alliance for Buildings and Construction, 2024).

Therefore, it is evident that resource scarcity and waste generation are significant challenges to a sustainable economy. The Circular Economy (CE) model offers a strategy to maintain the value of materials for as long as





possible, working toward closing the material loop. In contrast to the traditional linear economy, based on a "Take-Make-Use-Waste" model, the CE prioritises minimising unrecoverable waste, enabling materials to re-enter the cycle and retain value. In line with (Hatzfeld et al., 2022), mitigating unrecoverable inorganic waste can be achieved by maximising the functionality of buildings, structures or materials over utilisation periods.

CE is not limited to recycling alone; it incorporates strategies to preserve functionality and extend material lifecycles. The 9R circularity model, developed by UNEP (United Nations Environment Programme, 2019), emphasises reducing materials, especially raw materials, from the earliest design stages. It offers a structured approach to actions within a hierarchy of priorities. Among the promoted actions, It is encouraged to Refuse unnecessary constructions; Reduce and Reuse to conserve resources; Refurbish to extend product lifespans; and Repurpose and Recycle to reintegrate materials into production systems.

Circularity

In accordance with Hatzfeld et al. (2022), unrecoverable waste is understood as the notion of no longer retaining a function. A CE necessitates the expansion of existing solutions as well as the development of creative solutions that avoid unrecoverable waste. Hence, any measures to upkeep functionality minimise this unrecoverable waste. These may be measures to serve the original function, e.g. by reuse, refurbishing, or measures where a new function is achieved, e.g. by repurposing or recycling (up-, re- or downcycling). Losses of functionality within the scope of circular strategies are still commonplace today, especially in material recycling and are called "downcycling" in our context. The given policy recommendations follow this logic, prioritising circularity strategies that retain the highest functionality over an operational time and disfavouring circularity strategies that lead to heavy downcycling.

To increase building functionality, it is crucial to consider the longevity, adaptability and circularity of materials at the design stage. By incorporating durable materials (like textile-reinforced concrete) and flexible design, the building is adaptable to enhanced functions, which makes it useable for longer periods and reduces the need for demolition and new construction.

Minimising Inorganic Material Waste

Sustainable construction should be rooted in locally relevant approaches that emphasise resource efficiency, traditional knowledge, and regenerative practices. Many communities have long-standing traditions of material reuse and low-waste construction that can serve as models for reducing inorganic material waste (Natori et al., 2023).

In cases where building is unavoidable, easy disassembly and reuse of materials—such as in modular construction—allow for the repurposing of components with minimal structural or functional degradation. Additionally, prioritising high-quality recycling helps preserve material value while preventing downcycling, which can reduce functionality and overall quality. To track and improve these practices, (Parchomenko et al., 2019) recommend using CE metrics like recycling efficiency, which measures how well waste materials are converted into usable materials and how much of the recycled material is reintegrated into the production process.

Material Recycling Regulations

Regulatory frameworks vary significantly across regions due to the economic conditions, cultural practices and resources availability in each region. However, they

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commonly share the emphasis on promoting a circular economy, minimising adverse environmental impact, and optimising resource efficiency (Armistead & Babaahmadi, 2024). For instance, in the European Union, several legal frameworks and policies are mandating the recycling and reuse of CDW to promote sustainability and circular economy practices. In North America, policies primarily emphasise market-based mechanisms and voluntary certifications such as LEED to encourage recycling initiatives (Hoareau & Tam, 2024). Nevertheless, there are limitations to unlocking the full potential of circularity: according to many building standards, concrete producers are restricted to using no more than a specific ratio of recycled concrete aggregate — 45% maximum, for example under German standards. There is no scientific basis for imposing such limits. However, this is in addition to the cultural acceptance of the utilisation of recycled building materials or the reuse of existing buildings.

Resource Nexus Perspective

Construction relies on multiple interdependent resources — raw materials, energy, water, land, and the atmosphere — interconnected through material extraction, processing, construction, and waste management

- Circular strategies like high-quality recycling, material reuse, and adaptive building design can extend resource value and reduce waste but may also introduce new demands, such as increased energy consumption and higher processing costs;
- Rather than addressing resources in isolation, the Resource Nexus approach integrates sustainability efforts to prevent unintended trade-offs across interconnected systems

Minimising Space Waste

Space waste refers to inefficiencies in using non-physical resources. It includes issues such as underused areas, poor design choices, or lost functionality in how buildings or systems operate. Reduction of per capita residential floor area and commercial floor area would reduce environmental impacts of the built environment immensely (Malik et al., 2024). The world is, in contrast, moving further away at an increasing speed from space sufficiency (United Nations Environment Programme, 2024). Per capita spatial requirements are growing globally (Ellsworth-Krebs, 2020). In Germany, for example, residential floor space rose from an average of 19 m^2 per capita in 1960 to 47 m^2 per capita in 2020 (Noll & Weick, 2014; Statistisches Bundesamt, 2015).

Although many of these space increases are crucial to meet human needs, some can also be identified as wasteful. One may call the waste of functionality through unused space non-material, but it is highly connected to material waste, as adequate strategies may prevent new building in the first place (Refuse) or prevent oversizing of buildings (Reduce).

The Resource Nexus Perspective

The resource nexus approach helps to understand the interlinkages, synergies and trade-offs between the environmental resources. Understanding this relationship is crucial to develop strategies for waste minimisation and to optimise resource consumption (Hatzfeld et al., 2022). By designing multiuse or hybrid space buildings, no space is wasted. This approach can better help policymakers to make informed decisions.

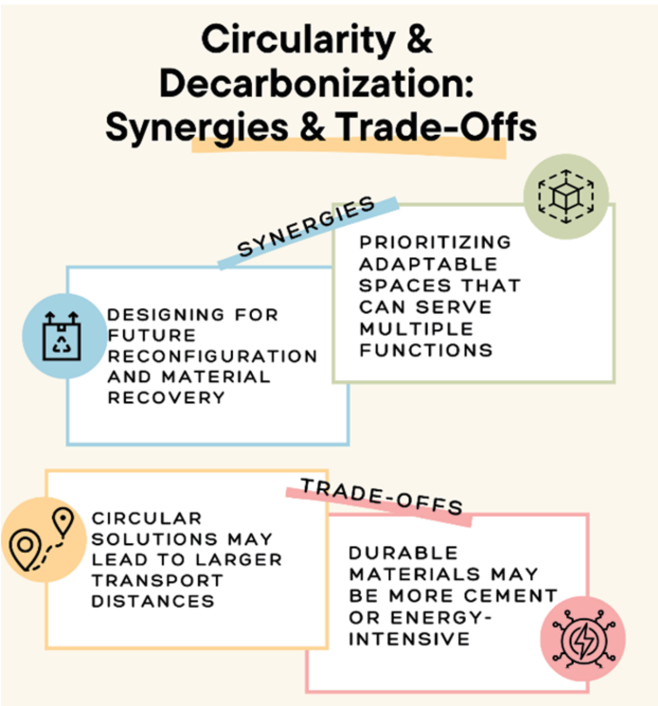
Circularity and Decarbonization: Synergies and Trade-Offs

The building sector represents a critical arena for decarbonisation efforts, being responsible for 34% of the global energy demand, as well as 37% of global energy-related CO2 emissions, with their construction at 10%, and their use at 27% in 2022 (United Nations Environment Program & Global Alliance for Buildings and Construction, 2024). In 2022, Cement alone was responsible for 4% of global CO2 emissions (Friedlingstein et al., 2023). Thus, transformative strategies are essential to mitigate environmental impact and accelerate sustainable development.

Decarbonisation can be in synergy with CE measures, especially when space waste is minimised. Extending building lifespans emerges as a powerful decarbonisation strategy, effectively reducing the need for new construction materials and spreading embodied carbon across longer periods (Arenas & Shafique, 2024). This approach minimises demolition and reconstruction emissions while supporting a more sustainable built environment. By prioritising materials with extended utility and designing for adaptability, the construction sector can significantly reduce its carbon footprint (Arenas, N. A., Shafique, M., 2024).

For material waste, there can also be trade-offs, for example, when recycling concrete aggregate is used instead of natural aggregate and the transport distance of the recyclate is longer. Also, circularity often encourages higher-quality materials that may also be more energy- or clinker-intensive and thus lead to more GHG emissions in the production phase. Many circularity metrics blend circularity together with impacts like toxicity, carbon footprint, etc., in a single value, that hides possible synergies and trade-offs. Circularity should thus be measured in an integrated manner with carbon footprint assessments (and/or other environmental impact assessments).

For example, the Circular Transition Indicators (CTI) framework offers a sophisticated approach to measuring and implementing decarbonisation. (WBCSD, 2024). By comprehensively tracking material inflow and outflow, evaluating design potential, and assessing material recovery, this methodology provides stakeholders with actionable insights. The framework enables organisations to make data-driven decisions that optimise resource efficiency and directly impact carbon dioxide equivalent emissions.



Material innovation plays a crucial role in decarbonisation efforts. Selecting materials with long service lives, low embodied carbon, and high recyclability can dramatically reduce environmental impact. Technologies like Carbon Reinforced Concrete, with potential 100-year lifespans, demonstrate how material science can support carbon reduction goals. Many building codes still target rather short lifespans considering possible actual building lifetimes with implemented circularity strategies. The Egyptian building code for example targets 70 years, the Eurocode is based on a design life of 50 years (Salem & S.E. Ismaeel, 2016; Standard, 2002).

Decarbonisation can be amplified by integrating technology to minimise carbon-intensive replacements and optimising resource deployment through:

- Smart building technologies
- Real-time space utilisation tracking
- Predictive maintenance systems

Policy Recommendations

To generate better circularity strategies, national statistics should measure:

I. Recycling rates with quality differentiation: Assess downcycling qualitatively (stating new application) or quantitatively (economic value, mechanical performance indicators). Differentiating high- and low-quality recycling preserves material value and prevents resource degradation.

II. Housing vacancies: Identifying vacant spaces promotes efficient space utilisation and reduces the need for unnecessary new construction.

III. Reasons for building demolition: Identifying whether demolitions are driven by economic or regulatory factors rather than structural necessity enables targeted policies for refurbishment, reuse, and waste reduction.

IV. Circularity in an integrated manner with carbon footprint and/or other environmental impact: To ensure the strategies align circularity efforts with climate goals and ecosystem health, rather than only material reuse.

Further: the following policy recommendations are proposed:

V. Allow higher recycling rates in construction materials while retaining high quality, e.g., the use of 100% recycling aggregate in concrete mixtures.

VI. Favor planning for building lifespans for 100 years or longer to encourage the use of different innovative materials.

VII. Encourage designing for future reconfiguration and material recovery and enable material reuse across different product systems.

VIII. Municipalities advise citizens on better use of residential space, space-sufficiency-oriented home exchange.

IX. Include space-sufficient communal living in legislation like tenant protection or favour it with tax cuts.

X. Provide incentives for smart building technologies, real-time space utilisation tracking, and predictive maintenance systems.

XI. Restructure building codes, appliance standards and tax policies to encourage space reductions (e.g., progressive tax on space needs higher than 35 m^2 per capita).

XII. Integrate sufficiency initiatives in decarbonisation agendas.

Action Points

1. Avoid unnecessary construction, minimise material use, maximise material reuse, repurposing, refurbishment, and high-quality recycling.
2. Promote planning for 100+ year building lifespans and favour the use of novel materials with high recyclability
3. Track recycling quality by measuring downcycling grades, economic value, and performance indicators. Favour integrated circularity assessments with environmental impact evaluations.
4. Support adaptive reuse, multi-functional spaces, and modular designs to reduce resource consumption and prioritise space sufficiency.

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