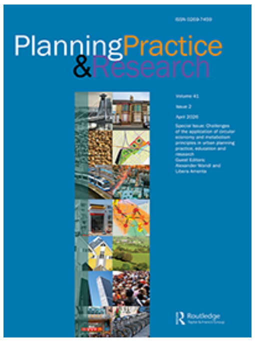

Planning Practice & Research

ISSN: 0269-7459 (Print) 1360-0583 (Online) Journal homepage: www.tandfonline.com/journals/cppr20

The Delft scales to aspects circular built environment model: the result of two years of interdisciplinary discussions

A. Wandl, O. Ioannou, V. Gruis, D. Peck, A. Jenkins, B. Geldermans, K. van den Berghe, F. Bucci-Ancapi, T. Tsui, M. van Uden, T. Egger, M. Dabrowski, P. Medici & T. Klein

To cite this article: A. Wandl, O. Ioannou, V. Gruis, D. Peck, A. Jenkins, B. Geldermans, K. van den Berghe, F. Bucci-Ancapi, T. Tsui, M. van Uden, T. Egger, M. Dabrowski, P. Medici & T. Klein (2026) The Delft scales to aspects circular built environment model: the result of two years of interdisciplinary discussions, Planning Practice & Research, 41:2, 317-338, DOI: 10.1080/02697459.2025.2589890

To link to this article: https://doi.org/10.1080/02697459.2025.2589890

PLANNING PRACTICE & RESEARCH
2026, VOL. 41, NO. 2, 317–338
https://doi.org/10.1080/02697459.2025.2589890

Routledge
Taylor & Francis Group

PRACTICE REVIEW

The Delft scales to aspects circular built environment model: the result of two years of interdisciplinary discussions

A. Wandl[a], O. Ioannou[b], V. Gruis[c], D. Peck[b], A. Jenkins[d], B. Geldermans[e], K. van den Berghe[c,f], F. Bucci-Ancapi[c], T. Tsui[a*], M. van Uden[c], T. Egger[a], M. Dabrowski[a], P. Medici[g] and T. Klein[b]

[a]Department of Urbanism, Delft University of Technology, Delft, Netherlands; [b]Department of Architectural Engineering and Technology, Delft University of Technology, Delft, Netherlands; [c]Department of Management in the Built Environment, Delft University of Technology, Delft, Netherlands; [d]School of Natural and Built Environment, University of Salford, UK; [e]Department of Design Sciences, University of Antwerp, Antwerp, Belgium; [f]Department of Management in the Built Environment, Faculty of Architecture and the Built Environment, Delft University of Technology, Delft, Netherlands; [g]Faculty of Social and Behavioural Sciences, Delft University of Technology, Delft, Netherlands

ABSTRACT

This paper presents the findings of an interdisciplinary academic exchange exploring the transition towards a circular built environment (CBE), developed over two years of collaborative work at Delft University of Technology's Circular Built Environment Hub. A key outcome of this work is developing a comprehensive definition of the CBE and the related Scales to Aspects model, which connects the multi-scalar and cross-disciplinary nature of circularity, ranging from materials and components to buildings, neighbourhoods, cities, and regions. It highlights critical tensions, such as the lack of integration between circular strategies and other global challenges.

ARTICLE HISTORY
Received 6 July 2025
Accepted 10 November 2025

KEYWORDS
Circular built environment; circular economy; scales to aspects

Introduction

As one of Europe's leading architecture schools in circular design, the Faculty of Architecture and the Built Environment at TU Delft has spent the last decade investigating how the circular economy (CE) reshapes the built environment. We see this paper as a means of assuming our responsibility to engage other architecture, urbanism, spatial planning, and broader socialscience communities to take an active role in the circular transition, specifically its spatial dimension. There were many reasons for doing this. The most important being that the research outputs of the CBE Hub group could be used to inform education in our and others' bachelor's and master's programmes and multiple lifelong learning outcomes. Circularity spans professional and inter-sectoral boundaries; no single discipline can deliver it alone. Building social capital and professional capacity for co-creation is therefore a central task for universities and their partners.

CONTACT A. Wandl a.wandl@tudelft.nl
*Present address: Faculty of Science, Institute of Environmental Sciences, Leiden University

Building a shared narrative also enhances our communication with a broader audience of institutional and industry partners with whom we collaborate regularly.

In 2017, the faculty established the Circular Built Environment (CBE) Hub, bringing together researchers from architecture, real estate development, materials science, urbanism, public policy, and management. Acknowledging the central position of academia in the broad spectrum of societal stakeholders and its close ties with partners from all sectors, the CBE Hub members set out to create a comprehensive understanding of the field of circularity in the built environment. Working with municipalities, ministries, housing associations, and industry consortia, the Hub seeks systemic answers rather than sector-specific fixes.

Early meetings revealed that our disciplines were using the term *circular* in divergent ways–sometimes to describe closed-loop material flows, sometimes business models, occasionally spatial configurations. Researchers risked talking past one another without a shared vocabulary, and practitioners lacked clear guidance. A common early finding amongst A+BE researchers was that in most ongoing CE ambitions, policies and (research) projects, space was understood as a container or a black box, whilst spatial context was often ignored and the meaning of places. More than 150 visions exist of how the circular economy relates to the building sector in the Netherlands alone (Barendregt *et al.*, 2024). However, only a few consider the implications of circularity for the built environment.

Built-environment disciplines–architecture, building engineering, urbanism and spatial planning–need a shared framework that links circular aspects (management, technology, design, resource flows, stakeholders and economy) to the scales they intervene in: materials, components, buildings, neighbourhoods, cities and regions. Aligning plans, visions and strategies with the ScalestoAspects framework can support steering development within planetary boundaries while promoting social equity. The CBE Hub members focused specifically on exploring the spatial implications of CE in the built environment. Therefore, the group increasingly prioritised using the term Circular Built Environment (CBE) over that of Circular Economy. But what is a Circular Built Environment? To facilitate this cross-disciplinary discussion and to further develop the concept of CBE, several members of the Hub collectively engaged in developing a shared definition of CBE. A core group of CBE Hub members–who are the authors of this paper–met regularly with a changing group of members of the CBE Hub over two years and actively participated in what was called 'Definition and Philosophy Workshops'. The group actively exchanged ideas, perspectives, and knowledge from their ongoing research projects and education.

This paper presents the interim results of these ongoing co-creative processes and a working definition of CBE through the 'scale to aspects' model, which depicts the systemic multifaceted characteristics of circularity in the built environment in a single diagram, based on a holistic matrix. Although the framework is still evolving, we share it here to invite critique and accelerate its uptake among architects, building engineers, urbanists and spatial planners.

Circular built environment: a definition

The structured exchanges of the group led to the development of the following tentative definition:

The Circular Built Environment (CBE) is a system designed to narrow, slow, and close resource loops at different spatial-temporal levels by transitioning cultural, environmental, economic, and social values towards a sustainable way of living. Thus, society can live within planetary boundaries.

The definition intentionally introduces the transition's spatial and temporal levels as core elements. Alternating between the three different loop cycles is not just about affecting business models or production lines. Moreover, the circular economy is fundamentally about how value is created and exchanged, and the CBE necessarily engages questions of political economy and land as critical factors in organising resource flows. New spaces are needed for storing, repairing, remanufacturing, and repurposing materials and components, as well as bringing together innovation initiatives and creating the conditions necessary for the free flow of information and knowledge for those initiatives to flourish. Space is also important when identifying land uses. In many European cities, planning has tended to relocate (re)manufacturing outside the urban fabric, pushing production further away. Only exceptional cases, like London, Brussels, and several French cities, have recently started to protect industrial and business areas in more central locations. Temporal considerations are of equal importance: how do decisions to transition to a circular built environment affect the current landscape of practices in urban planning and the building industry? Moreover, how can current demands for urban development and land allocation (for example, the growing housing need) be contextualised within a circular agenda? Questions like these also feed into the debate over competing spatial claims and spatial governance: how much space do we need, and/or how can we manage existing space?

The definition further delves into the requirements necessary for the transition: a shift of values across all four sustainable development domains (cultural, environmental, economic and social). Nevertheless, in the relevant literature, CE appears to be lacking with regard to the cultural and social aspects of the transition, mainly prioritising the techno-economic ones (Corvellec *et al.*, 2022). Circularity comes with a transformative premise that has yet to materialise: its core principles are directly challenging the capitalist system; however, so far, it is still breeding within it (Hobson & Lynch, 2016). This is why, upon developing the CBE definition, the group further identified the current status quo across different scales of the built environment while simultaneously capturing the systemic tensions that are compromising the transition.

The scales-to-aspects model: mapping circularity across the built environment

Scoping out the research activities of the CBE Hub members led the group to develop the 'Scales to Aspects' model. For the first time, the model links the multi-scalar and multidisciplinary nature of the CBE Hub's ongoing research on circularity. The model serves a triple purpose. First, it brings together, in a novel way, the prime constituents of circularity in a built environment context. Second, this approach allows the team to contextualise our cross-disciplinary (and cross-departmental) research into one coherent framework. Finally, it provides a canvas for circular education and research to be further built upon. As a result, the group published a position paper in 2022 on circular education, using the model as a canvas to inform circular educational programs (Ioannou *et al.*, 2022) and references in other works that highlight the urgency of bridging scientific knowledge with real policy for multi-scalar transitions (Dąbrowski & Wandl, 2024).

Figure 1 depicts the systemic character of circularity in a single diagram, starting from *Materials* and *Components*, the base ingredients of buildings, to *Buildings* as assemblies of large amounts of building M*aterials and Components*, and how they relate to circular performance. One step up, the *Neighbourhood* scale represents how circularity manifests in specific areas or districts of a town or city. The *Cities* scale explores the most important resource flows that enter, circulate, and leave the urban environment daily. Finally, the *Regional* scale refers to the characteristics of the territorial metabolism and the importance of investigating economic activities to identify the flows and stocks of materials, components, and waste beyond the urban scale. We use the term regional here as a proxy to describe areas with intensive internal metabolic relationships that cross the administrative boundaries of a single city, being well aware that megacities may be larger in population and size than some regions. In this sense, the region is a relative scale in the model.

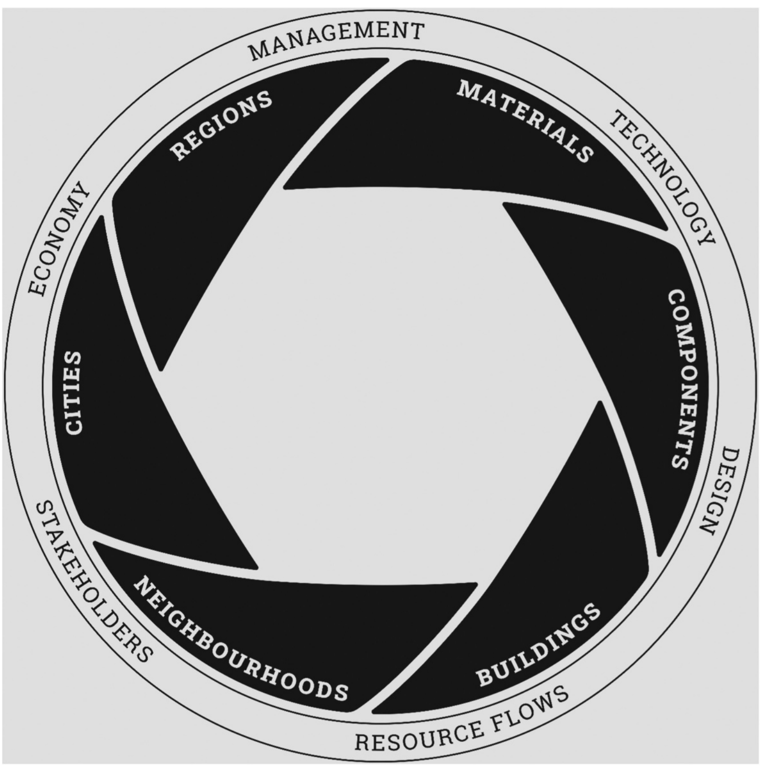

Figure 1. Visual representation of the scale-to-aspect model.

Encircling these scales are six interrelated aspects crucial for a circular transition: These include–but are not limited to–technological innovation, design practice, management models, economic incentives, resource flows, governance and the societal sphere in which stakeholders negotiate change. As implied by the lens metaphor, the focus of the interlocking scales aims at the circular built environment, whereas the outer ring provides the field depth.

The model embodies systems thinking and whole-value-network logic: it shows that every scale depends on every aspect, yet still offers a clear structure for discourse. The model is a product of ongoing research and simultaneously a canvas for contextualising this research. This signifies its significant contribution to the development of education and research around circularity: its capacity to explicitly showcase what has, so far, been identified as important, and how each part is ultimately related to the whole.

A companion Table 1 summarises thirty-six observed interactions between the six scales and six aspects, distilled from more than a dozen CBE-Hub projects since 2017. The six following sub-chapters examine each scale in turn, tracing its synergies with the aspects. The grid does not fragment reality; instead, it helps navigate the ontological entanglement of scales and aspects, which co-constitute one another (Barad, 2007).

Materials

The materials value chain stretches from geological exploration through mining, refining and standardisation to component manufacture and global distribution. Actors who create secondary material loops, like demolition contractors, recyclers, urban miners and designers of circular strategies, are equally important but remain peripheral to decision-making currently.

Material complexity has expanded rapidly: high-performance alloys, engineered polymers and bio-composites deliver unique functions that are hard to substitute. Beyond construction materials, many others have become suitable for technological applications in manufacturing circular buildings, like robotics, 3D printing, sensing, and other technologies that monitor or extend building life cycles. Discussing materials should extend beyond construction applications and consider technological applications, such as robotics, additive manufacturing, and sensing, that enable circular practices in buildings and manufacturing. Some materials, especially metals, also relate to resource criticality and supply chain disruptions that hamper the circular transition in key industries (Tercero Espinoza *et al*., 2020).

Achieving a net-zero circular built environment raises initial demand for primary materials because material-intensive renewable-energy and digital infrastructures must be deployed at speed. Urban mining and other secondary feedstocks can relieve pressure, but their volumes, quality and localisation remain uncertain. Also, repair, refurbishment, and remanufacturing-oriented strategies may require extra inputs up-front to secure longer service lives. Managing the supply and demand of these materials and localising the respective input/output flows is essential to realise circular ambitions (Tsui *et al*., 2021). Meanwhile, the role of industrial actors in fostering critical raw materials strategies can strongly affect the success of closed material loops (Cimprich *et al*., 2022).

The design of the components in which materials are embedded in determines the overall demand for primary and secondary materials. This includes designing new

Table 1. A comprehensive overview between scales and aspects

	TECHNOLOGY	MANAGEMENT	DESIGN	STAKEHOLDERS	RESOURCE FLOWS	ECONOMY
MATERIALS	A CBE transition requires technologies and materials. The new technologies offer solution pathways, but the demand for these materials is challenging to supply.	Materials are managed from either a primary or secondary perspective. Circular management strategies fall into either material (product) life extension or recycling. PLE often requires additional primary materials.	The issue of 'design' and 'materials' has two aspects: designing new materials and designing products and systems to facilitate PLE and/or recycling. Both these 'design' activities can facilitate a CBE.	Stakeholders can include citizens, policy makers, companies, industry, not-for-profits, and NGOs. Different scales apply across the materials value chain, both primary and secondary. The aims of stakeholder engagement can vary, including across the Global South and Global North.	CBE material resource flows break down into various material resources: Plastics, Bio-based, Metals, and Minerals. The analysis of the materials can differ, but standard tools can be used. Current systems of resource flows are broken.	The circular economy is influenced by linear economic approaches, such as financial pricing and economic growth, but it requires a radically new approach.
COMPONENTS	Production technologies, processes, component hardware, and digital tech (software) are included. R-strategies such as Reuse, Repair, Refurbish, and Remanufacture are typically used for component technologies.	Component lifecycle and (reverse) supply chain management, as well as (inter) organisational company operations, e.g. knowledge and expertise, fabrication facilities, outsourcing, sales, and marketing.	Design frameworks that allow regeneration, narrowing (e.g. material choice, design optimisation), slowing (e.g. DfD, reversible design), or closing (e.g. design for recycling).	Stakeholders are mostly related to industry and design, such as product suppliers, builders, architects, engineers, and facility managers, as well as standardisation and norming bodies (also include a line on how the stakeholders interact).	Complex resource and value chains must be programmed into components, considering a potential building use (before the building design has started). Flows need to be tracked (i.e. through material passports) and organised to a certain level of granularity.	The circular value chain calls for new business models that promote the circular use of components. As local supply chains are preferred over today's global supply chains, complex economic and relational structures emerge.

(*Continued*)

Table 1. (Continued).

	TECHNOLOGY	MANAGEMENT	DESIGN	STAKEHOLDERS	RESOURCE FLOWS	ECONOMY
BUILDINGS	Technology on a building scale concerns building construction, the separation of layers, and interfaces. Standardisation is important to create buildings that meet the qualities according to their intended long-term use. It also includes technologies to support monitoring, building maintenance, and long-term performance.	The management of building actors and processes, building company operations and procurement. On the level of the construction system, this requires new laws and norms with building specifications, as well as fiscal and financial stimuli.	Buildings are designed as carbon-neutral, temporary configurations of component assemblies, creating flexible spaces that stimulate well-being. This is achieved using frameworks, which focus on slowing and closing loops across the lifecycle of the building, components, and materials.	Stakeholders include investors and clients, product suppliers, builders, architects, engineers, facility managers, and building users who aim to realise circular ambitions on a project-by-project basis.	Resources are temporarily stored in building constructions and should be available in their original quality after the building's use ends. The building should be created and run by regenerative resources.	Circular building requires a TOC approach and business models that include the pricing of circular material use, residual value, and social functions.
NEIGHBOURHOODS	On the neighbourhood scale, we identify examples of (1) digital P2P platforms enabling circularity, (2) decentralised, community-based energy grids and shared facilities, and (3) shared tools and equipment (existing and new) that enable circularity on the neighbourhood scale. (4) (Concepts of) local material banks.	A circular transition on a local scale requires collective forms of governance to agree on shared concerns and fulfil the local community's needs. Co-creation combines enabling top-down (local government-led) and inspiring bottom-up (self-organised and community-driven) action, which leads to shared accountability and ownership of the circular neighbourhood.	Neighbourhoods, including buildings, public spaces, and (circular) infrastructures, are (re) designed as part of the city's future vision. Symbiotic adjacencies are crucial, and space is provided to enable the sharing and trading of resources. The spaces between buildings are functional, regenerative, and flexible, focusing on the health and well-being of stakeholders.	Suitable scale to go beyond individual practices towards collaboration and local democracy by engaging individual citizens, organised civil societies, local governments and businesses. Neighbourhood scales make circularity more relevant to citizens by impacting local liveability and social cohesion.	Resource flows are further optimised at the neighbourhood scale, exchanged or traded between stakeholders, buildings, public and private spaces through peer-to-peer networks and the required infrastructures. The neighbourhood scale is productive by processing, optimising, and regenerating resources.	Neighbourhoods are large enough to represent community interactions and small enough to innovate on a micro-scale. They offer a critical mass to experiment with emerging economic and ownership models with the potential to scale up. Controversies between centralisation and decentralisation become apparent.

(*Continued*)

Table 1. (Continued).

	TECHNOLOGY	MANAGEMENT	DESIGN	STAKEHOLDERS	RESOURCE FLOWS	ECONOMY
CITIES	Urban technological systems provide, overview, monitor, predict and match the (latent) supply and demand of materials in time and scale.	Transition management is a process wherein strategic, tactical and operational elements jointly enable a systemic shift towards circularity. Regulation, incentives, provision, and capacity building are levers to enable urban mining, markets for circular resources, the production of local circular resources, and circular systems of urban provision.	A city is designed at the macro scale. It comprises defined land use characteristics and the efficient and effective distribution of functionalities to facilitate the circular flows of resources based upon a future vision. This includes the spatial requirements for circular infrastructures and technologies to move, store, and reuse resources.	Stakeholders, including human and non-human entities, form networks across temporal scales. Collaboration and coordination work along the life cycle of products and materials, including urban manufacturing/ production stakeholders. It is challenging to engage individual citizens, so it is enacted in civil society and organisations in the public and private sectors.	City infrastructures, such as ports, airports, logistic hubs, drinking water provision, and treatment facilities, organise resource flows within the city and between cities and their hinterlands because of the need for a specific technology or critical mass. They also define the conditions for the lower scales, thereby defining the potential for narrowing, slowing, and closing loops.	An urban circular economy understands the (critical) dependencies and independencies in time and geography, and develops a socio-ecological system within the societal and ecological planetary boundaries.
REGIONS	At the regional scale, technology (measuring, monitoring, predicting, and mining) enables a cross-border perspective on (im) material flows and stocks.	Following numerous CE geographies in time and space, at the regional scale, different local to global public and private organisations collaborate, depending on the specific focus, to develop visions, strategies, and policies to govern stocks and flows, spatial land use distribution, and (in) tangible networks.	At the regional scale, multiple actors (quadruple helix) jointly design aspired visions, strategies, and policies for supralocal spatial (infra)structures.	Different levels of institutional actors interact with networks of stakeholders that may or may not act within territorial borders.	Some regions are starting to aim for localism (substitution of stocks and flows of resources; circular resources from other regions may be needed).	Some regions start to match the demand and supply within the planetary and societal boundaries.

A summary of thirty-six observed interactions between the six scales and six aspects.

materials with diverging properties that allow for the design of new components and using new materials in technologies that facilitate product life extension (PLE) and recycling. Design for disassembly (DfD) can facilitate PLE, which allows materials to be used for longer, slowing the demand for materials and enabling enhanced recycling in the final loop. Despite proven pilots, DfD is far from mainstream practice.

The globalised supply of minerals, metals, and timber carries uneven environmental and social burdens, disproportionately felt in the Global South. Therefore, land-use change, biodiversity loss, labour exploitation, and conflict minerals require rigorous due diligence within any circular strategy.

Market dynamics compound the material challenge. Construction still begins with a limited variety of material resources like plastics, metals, minerals and an expanding portfolio of engineered bio-based products. A small group of multinational firms often supplies primary resources, which weakens price competition, and opacity in global supply chains leaves researchers with fragmentary data on volumes, embodied emissions and social impacts. Prices for several primary and critical materials swing wildly, unsettling long-term investment in recycling plants. Secondary streams harvested from demolition waste and municipal collections are slowly becoming tradable commodities, yet their quality, traceability and scale lag far behind demand. Rising interest in timber and other bio-based materials intensifies land-use conflicts with food and fibre crops. Therefore, the net climate benefit hinges on responsible forestry and cascading use. Finally, the marketability of 'waste aesthetics' has spawned products labelled as circular on the strength of surface appearance alone, underscoring the need for verifiable standards to curb greenwashing.

Often touted as a quick fix, material substitution reveals deeper systemic frictions. Swapping one alloy for another can force a complete component redesign, while re-engineering a building service to accept alternative materials can disrupt established maintenance regimes and skill sets. Because new mines take a decade or more to commission, short-run supply cannot respond to the surging demand created by low-carbon technologies (Peck *et al.*, 2020), prompting policymakers to weigh short-term extraction against long-term decarbonisation. Microeconomic incentives pull in opposite directions: high commodity prices encourage recycling and substitution but spur fresh exploration. Low prices make secondary materials uncompetitive. At the macro scale, 'green-growth' versions of circular-economy discourse risk reinforcing absolute material throughput by seeking ever larger markets for circular technologies. The strategic task, therefore, is to align material-efficiency, substitution and dematerialisation policies so that primary demand peaks this decade and declines thereafter, without delaying the climate transition.

Components

CBE components utilise front-end manufacturing and R-strategy technologies to enhance Reuse, Repair, Refurbishment, and Remanufacturing while minimising the use of primary and secondary materials without sacrificing performance. Key technological aspects include software for new manufacturing processes and on-site component monitoring, integrating with BIM software for efficient maintenance and repairs. This is facilitated by sensors, QR codes, NFC tags, and material passports that track component information. A move towards prefabrication to minimise on-site waste also results in new manufacturing technologies and new software platforms that link in with material passports (Cetin *et al*., 2023). However, many digital infrastructures can increase energy and (critical) material demands.

R-strategies are implemented at the component scale through careful and extensive management and planning. This relates to the ever-extending lifecycle of components and the need for manufacturers to implement reverse supply chains. Facilitating (inter) organisational operation and cooperation to ensure knowledge and expertise are shared, along with fabrication and R-strategy facilities, outsourcing, sales, and marketing, is also becoming increasingly important. A CBE can only ensure its longevity if all organisations relating to urban development are experts in reverse supply chains and implementing R-strategies (Greco *et al*., 2024).

Design quality at the component scale largely determines circular performance, because buildings, and ultimately, the physical elements of cities, are made almost entirely from the interconnections of many different components. Therefore, the design of components as part of a CBE must guarantee attributes such as easy access and repairability in the components' first service life and the capability to be repaired, refurbished, and remanufactured in consecutive life cycles. Modularisation, standardisation, adaptability, longevity and design-for-disassembly ensure first-life accessibility and enable successive repair/refurbish cycles, thereby narrowing and slowing material flows (van Stijn & Gruis, 2020).

The stakeholders most closely related to components in a CBE are designers, building operators, and industry practitioners. These include manufacturers, product suppliers, builders, engineers, architects, facility and building managers, and standardisation bodies. These stakeholders work together and collaboratively to develop, produce, and use fit-for-purpose components that match the qualities required by a CBE. When considering PLE, another group of stakeholders emerges, which includes maintenance companies, refurbishing and remanufacturing companies, inspectors, dismantlers, and secondary materials retailers. Insurance companies and investors are also included as part of the stakeholder group at the macro scale.

The production of components is dependent on complex, and typically global, resource and value chains. In a CBE, components are made from local secondary materials, where possible, to minimise the use of global primary materials without compromising the component's performance. Both primary and secondary materials are tracked, at both the global and local scales, using material passports and organised to a certain level of granularity to ensure transparency without superfluous data creation. Tracking also applies to the component itself, which identifies its provenance, its maintenance and repair history, and any further R-strategy interventions.

The component scale is crucial to the circular transition for its capacity to keep the value of building products high, limiting the need for further material mining and extensive processing of raw material resources. However, this is currently compromised by the lack of information, integration issues and the discrepancy between inputs and outputs, as well as a lack of political will and fiscal measures. Furthermore, the spatial character of a reuse market is severely downplayed: increasing reuse of components requires spaces for remanufacturing and storage and new logistics networks. Moreover, there is also a growing demand for new professionals: especially for the inspection of reclaimed materials, for their remanufacturing, for certifying them and ultimately for rebranding and reselling them (Bestul & Gruis, 2024).

Buildings

The building scale employs advanced building information modelling (BIM) across all phases, including concept development, design, procurement, and maintenance. BIM software aligns with design philosophies like design for disassembly (DfD), reversible design, and open building design. Live BIM libraries ensure access to up-to-date components. Additionally, post-occupancy BIM integrations help monitor climate systems for maintenance scheduling and repairs.

Circular construction reshapes stakeholder roles (Kooter *et al.*, 2021). Contractors join early to share practical expertise, and clients adopt a deliberative, co-creative stance so that ambitions and measurable targets are co-created by the full project team. Stakeholders at this scale include public and private clients, developers, architects, engineers, contractors, product suppliers, facility managers, demolition-harvest firms, investors, and accreditors. Building users participate in the design process because their everyday practices govern resource flows and thus the circular performance of the asset.

Buildings utilise standardised configurations of components and construction interfaces, creating functional yet flexible spaces for diverse future uses through an open-building approach, thereby extending their lifespan. The internal design promotes the health and well-being of occupants, employing a co-creation approach. Configurations are temporary and utilise established frameworks for repair, reuse, remanufacturing, and recovery to minimise resource waste (van Uden *et al.*, 2024). Whenever possible, secondary materials and components are incorporated. These buildings are designed to be carbon-neutral, relying on renewable energy throughout their lifecycle and promoting regeneration.

Buildings are constructed from materials and components which, in some cases, might not need replacing over the lifetime of the building, such as structural frames and foundations. Other parts, such as the facade and roof, may require repair and refurbishment over the building's lifetime. The services within the building will need regular maintenance and may need to be replaced over time. Finally, the building's users demand heat, electricity, water, and other resources such as paper, cardboard, food, and other products, which move through the building almost daily. The building can internalise, narrow, slow, regenerate and close these resource flows in some instances, when resource processing is adopted at the building scale, thereby also reducing reliance on external infrastructure.

A CBE acknowledges the constraints of materials, both in performance and longevity. Business models consider buildings as temporary material banks, regarding the pricing of circular material use and residual value. To further facilitate this, circular hubs (Tsui *et al.*, 2024) temporarily store building components to generate a supply of secondary components. Circularity at the building level also uses business models to create flexibility of space and offer social functions. Meanwhile, building processes themselves may need to be reevaluated to reflect net-zero or near-zero standards, as well as to incorporate new technology materials for so-called 'smart' building infrastructures, which drive the question of critical raw materials supply in building systems (Peck, 2024).

Neighbourhoods

Neighbourhoods, in-between buildings and the city scale are ideal 'living-lab' arenas where mixed uses, short feedback loops, and close stakeholder proximity allow testing of circular governance tools. These include strengthening bottom-up initiatives, stakeholder collaboration, innovative small-scale developments, local decision-making processes, community self-organisation, housing cooperatives, participative design processes, and rebalancing power toward local government and communities. A circular transition on a local scale requires collective forms of governance to agree on shared concerns and to assist in narrowing, slowing, and closing resource loops. Co-creation processes result in shared accountability, civic connection, and appropriation of the circular neighbourhood. This sense of shared ownership and responsibility supports strong collaboration in design, maintenance, and space and resource sharing.

Circular Neighbourhoods are designed, redesigned, and adapted as part of a city's and citizens' future visions. They include public and private buildings, open spaces for various functions, common facilities, and circular and non-circular infrastructures. Symbiotic adjacencies are crucial to share, exchange, and transfer resources between buildings and people and space is provided to facilitate this. Examples are housing beside urban agriculture, cafés beside makerspaces, offices feeding waste heat to a swimming pool, and the exchange of energy, water, and materials between users in the form of microgrids. The remaining spaces between buildings are functional, regenerative, and flexible, focusing on the health and well-being of citizens. Flexible spaces allow citizens to engage in communal activities and provide small facilities and equipment to build their future and repair things when necessary. A circular neighbourhood is designed to promote circular behaviours, energy neutrality, and climate adaptivity and improve citizens' quality of life in collaboration with other stakeholders.

The scale is intimate enough for people to identify with, yet complex enough to attract businesses and institutions. Citizens, civil-society groups, entrepreneurs, local government, planners, and engineers collaborate through informal networks and formal working groups. Their interaction makes circularity tangible but also exposes conflicts that need continuous negotiation.

Neighbourhood systems intercept flows buildings cannot manage alone: makerspaces transform harvested components into new products; neighbourhood biorefineries, digesters and compost hubs convert organic waste to energy and soil; surplus heat, water and electricity circulate through local networks. These infrastructures slow, narrow and sometimes close loops, while surplus resources feed into wider city- or region-wide circuits.

Neighbourhoods are innovative testbeds for transforming urban economies towards circular models. They are large enough to offer a critical mass to experiment with diverse economic models on the micro-scale, with the potential to scale up successful instruments, models, and approaches. Since this scale is close to citizens' daily activities, neighbourhood economies are suitable for transitioning to local recycling, repair, and remanufacturing activities. Also, the spatial links and correlations between stakeholders along the supply chain can be strengthened at the neighbourhood scale. Local circular networks can be self-organised, P2P, or platform economies. They can combine a diversity of innovative small economic practices, such as gift economies, sharing economy, collaborative, and alternative monetary economies (community currencies). A shift in ownership models towards products-as-a-service, mobility-as-a-service, commons-based, or shared ownership can be tested at the neighbourhood scale (Egger *et al.*, 2024). Innovative land development models can be experimented with, including public-private partnership land developments or community land trusts. A circular economy will be fluid and most likely meander between centralisation and decentralisation, challenging traditional ownership and take-make-dispose models.

Cities

Cities as centres of production and consumption are often called crucial scales towards circularity; nevertheless, it is apparent that there will be no circular city on the planet for a foreseeable time. Therefore, the following paragraphs are predominantly based on the many circular visions and strategies that have been developed over the last decade and on our own research on these processes.

A future circular city is designed and planned in principle, focusing on a future vision through participative design and planning processes with stakeholders from neighbourhood and city scales. A circular city consists of defined land use characteristics and the efficient and effective distribution of functions to enable circularity. This includes the necessary provision of equipment and space to reuse, repair, refurbish, remanufacture, repurpose, and store materials and components and large-scale infrastructure to facilitate the transfer, exchange, and storage of electricity, heat, and water. Allocating space for circular industries, infrastructure, and storage will be a CBE's most significant physical and spatial impact and is considered one of the most critical challenges. The policies needed to achieve this are regarded as the most important change in urban planning and development since the mid-20th century.

The circular city requires a complex network of stakeholders from the neighbourhood scale and representatives to speak on behalf of these stakeholder groups at the city scale. In addition to these stakeholder groups, private sector stakeholders, such as those representing larger circular industries, transportation providers, service providers, and water and energy companies, become more involved. Local authorities coordinate and oversee these interactions. Central governments set policy frameworks at a national level to guide the circular development of cities. There is also a need to directly engage with material, component, and building scale stakeholders to ensure that the goals of the city are reflected in the working practices of these stakeholder groups. The stakeholders associated with the city scale represent the most impactful yet complex stakeholder group across a CBE. Due to this, this stakeholder group requires substantial and ongoing management to remain effective.

Ideally, through transition management, the city scale is managed by a process whereby strategic (political agenda and spatial visions and strategies), tactical (policy instruments such as regulation, economic measures, information, and participative processes), and operational elements (e.g. experimentation, projects, and innovative solutions) come together to enable a systemic shift towards circularity. In practice, transition management is often fragmented, contested and influenced by powerful interests with divergent goals. Therefore, strategic, tactical and operational efforts require strong public governance, clear regulatory signals and accountability, and experimentation so that vested interests cannot steer policy and programmes to their own benefit, ensuring equitable outcomes.

The monitoring systems in development to be used throughout cities are considered essential infrastructure and offer an avenue to reflect and evaluate interventions and processes, which can be used as a learning tool to provide feedback on management strategies. Clear policy signals are necessary to guide stakeholders, technologies, and supply chains towards successful outcomes. Regulations, incentives, provisions, and capacity building play key roles as levers and fulcrums to enable urban mining, develop markets for circular resource flows, produce local circular resources, and provide circular systems of increasing efficiency and effectiveness.

Resources, materials, and components enter and leave the city through ports, airports, and other logistical hubs. When entering the city, these resources need to be efficiently distributed to industries, companies, and households using low-carbon transport solutions. Cities are experimenting with several spatial strategies to achieve this. The most prominent are networks of circular hubs and clusters. There are also the first implementations of smart grids to support the effective and efficient storage and distribution of resources.

Although often privatised, or outsourced to publicly (co)owned enterprises, in many contexts cities can influence resource flows such as water, energy, and sewage, which are not processed at the neighbourhood scale due to a lack of critical mass or available equipment. These infrastructures, including waste collection and recycling plants or sewage treatment plants, have long planning and operational time spans and hold considerable investment risk and path dependencies for cities. Numerous pilot plants and tests are striving to develop these infrastructures to recover materials and components for higher r-levels, as well as close nutrient and water cycles. Other fields of technology test and pilot implementation include P2P technologies, along with digital ledgers and the use of digital twins to monitor the ever-changing characteristics of circular cities in terms of physical form, material and component banks, and the material, component, and resource availability and demands throughout the city.

While a circular economy is mainly concerned with sustainable economic output, a circular city deals with the interdependencies in time and geography to develop a socio-ecological urban system within the planetary boundaries. Current unsustainable patterns of urbanisation resulted from linear ways of production and consumption in the 20^{th} and 21st centuries. Thus, a city seeking to become circular deals not only with a linear economy but with its impacts in space, which range from the street-level effect, such as impermeable ground, to local ecosystem degradation. It is at the city level that questions of land gain become relevant, as circular activities require space to function and enable circular economic output. Local authorities often have planning responsibilities and sometimes own land. Enabling circular activities in cities, therefore, requires the allocation of land for the commercialisation, movement, and storage of secondary materials, products and services, whilst ensuring the fair and equitable distribution of benefits and minimising the negative externalities of circular activities across the urban space, for the diverse social groups that populate the city. There is a widespread agreement that this also requires highly complex and ubiquitous monitoring systems based on the advocacy of circular technologies, circular industries, and stakeholders throughout the entire supply chain in both directions. These monitoring systems can also be used to identify inefficiencies throughout the city as well as areas for innovation, and to hold organisations accountable for their circularity promises.

Regions

Whilst it is necessary to close resource loops locally, where possible, in a CBE, materials and components will continually cross administrative boundaries. These resources will flow domestically between regions and globally between regions (Furlan *et al.*, 2022). Much like the city scale deals with processes that cannot be included at the neighbourhood scale, the regional scale deals with processes that either cannot be, or are not necessary or beneficial to be, included at the city scale for each and every city. Furthermore, regions include land uses that traditionally are not considered part of the built environment, such as agriculture, forestry, mining areas, and bodies of water, for example. It is from these land types that the majority of primary resources are extracted and where most of our 'waste' ends up; therefore, it's important to include them as part of a CBE to avoid thinking, planning, and policy-making that relies on an urban-rural dichotomy. Similar to cities, there are no circular regions in existence; in contrary to cities, there are very few regional circular strategies and hardly any spatial circularity strategies. Therefore, the following paragraphs look more at the future than the other scales, considering that transitioning towards a regional circular built environment is a generational task.

Many of the technologies required at the city scale are also present at the regional scale to measure and monitor the supply, demand, stocks, and movements of materials and resources. This will provide information not only on regional metabolisms but also the global metabolism for those who wish to report or publish their data across national boundaries. Due to existing logistical technologies that could be repurposed, this could be achieved in years rather than decades. Conversely, predicting and providing insights on resource flows and necessary diversions based on supply chains and demands at the regional scale will be challenging and will most likely require machine learning and AI to achieve this in an efficient and automated way.

The macro vision of a CBE is conceived, implemented, and managed at the regional scale. This includes the development of strategies, policies, incentives, certifications and initiatives by private and public bodies across the globe and demands close collaborations between these organisations. The decisions made at the regional scale will ripple throughout a CBE and back again, influencing all the scales. Ultimately, these decisions will seek to govern resource flows across time and space to ensure a circular built environment. Due to the complexity of the task, clear adaptive roadmaps will need to be developed to explain this approach and to determine the existing and new organisations required to facilitate and support the transition and, later, the operation and management of a CBE.

The regional scale should consider the spatial and systems design of a CBE. Multiple actors from academia, governance, industry, society, and the environment jointly discuss the spatial needs and implications of a CBE as well as the strategies and policies necessary to achieve a shared vision. This would include the (re)design and development of necessary transport and resource infrastructures to enable the movement of resources across and throughout regions and physical and non-physical linkages with adjacent and non-adjacent regions.

Regional planning will be required to determine the placement of necessary processing facilities that operate most effectively at larger scales and other infrastructures, which require a specific spatial condition, such as access to rivers and seas, or specific soil conditions. The design of the systems that ultimately underpin and facilitate the CBE will also need to be designed and developed at the macro, meso, and micro scales to ensure applicability, longevity, plasticity, modularity, scalability, and resiliency.

The few examples of regional spatial circularity strategies plead for a close cooperation of public and private organisations throughout the development, implementation, and management of the CBE. These organisations must engage with stakeholder groups from all the other scales to ensure that they capture and take into consideration the wants and needs of these stakeholders. Much like resource flows, companies are at liberty to expand and operate across regional boundaries (Furlan *et al*., 2020). As such, they will operationalise cross-regional resource flows in adherence with explicit policies that govern these movements. The involvement of these companies alongside municipalities and governments will be critical at the regional scale to achieve this. So far, narrative-based strategic planning exercises seem to be the most promising approach to achieving this.

Across time and space, all resource flows must be considered at the regional scale. This includes the basic building blocks of human life, such as water and soil, household waste streams, energy, materials and building components. Regions are beginning to seek to substitute certain materials and components from other regions in favour of local supplies. The regional scale includes intra-regional and inter-regional resource flows. However, it should strive to limit its resource interactions with other adjacent and non-adjacent regions to maintain a critical mass by slowing, narrowing and closing circular intra-regional resource flows.

Narrowing, slowing and closing loops at the regional scale will gain importance, specifically in uncertain geo-political situations where the control over critical raw materials may rely less on free trade. This implies a significant redrawing of the (spatial) economy after decades of so-called 'glocalisation'. Many regions may increasingly seek to match supply and demand with planetary and societal boundaries, yet progress will be uneven and contingent on politicaland economic choices. This regionalisation of the economy will require reshoring value chains with their positive and negative aspects. It will require new (spatial) planning and design approaches that consider the potential adverse social and environmental effects that have been outsourced over the last decades.

Conclusion, reflection – future research themes

Cross-scale crossovers

Circularity measures are most advanced at the material, component and building scales, whereas neighbourhoods, cities and regions remain largely aspirational because governance, spatial planning and stakeholder coordination become exponentially more complex as scale increases. Future research should map the barriers at higher scales and the interactions that connect them to lower ones (Van der Leer *et al*., 2018).

The relationship between primary or secondary materials, critical primary materials, and their impact at the regional scale is a key aspect of developing a circular built environment. Regions can reduce supply risks through urban mining and substitution, but only if industrial incentives align with regional resource cycles. This might involve studying regional resource cycles, examining how regions can become more self-sufficient, and analysing the influence of regional policies on circularity. By understanding how regions integrate circularity into their resource management, we can create sustainable regional spatial models that balance local resource availability with the demands of a circular built environment.

Neighbourhoods make circularity tangible for citizens. Direct resident participation can pilot decentralised waste treatment, local energy generation, shared repair workshops, and mobility schemes. This scale also plays a critical role in fostering social cohesion through collective engagement in sustainable practices, promoting behaviour change towards more circular lifestyles. In this context, research should explore how neighbourhoods can be designed or retrofitted to enable circularity while addressing issues such as equity, accessibility, and community resilience.

Stakeholder constellations expand with scale. Materials and components involve designers, manufacturers and suppliers; neighbourhoods add citizens, community groups and planners; cities and regions must bring public authorities, infrastructure operators, investors and NGOs together. As resource flows cross (national) administrative borders, a governance gap persists at mega-regional levels: no single body manages the whole network (Remøy & Wandl, 2022). Collaboration platforms and shared data protocols are needed to coordinate extraction, transport, reuse and disposal decisions. Effective cross-scale governance will require new professional profiles–circular resource managers, spatial planners versed in reverse logistics and other circular infrastructures, and facilitators who mediate among sectors.

Economic factors pose significant challenges to the adoption of circular strategies in the built environment. Traditional business models often focus on short-term gains, prioritising linear production over long-term sustainability. Circular initiatives frequently struggle to compete due to the need for upfront investments and a lack of incentives within existing financial systems. Additionally, there is a scarcity of effective circular business models that operate across various scales, from material reuse to urban regeneration. To address this, innovative economic frameworks are essential–such as product-as-a-service models and shared ownership schemes–that align financial incentives with circular principles. These models should be adaptable to different scales, ensuring that circularity is both financially viable and sustainable in the long term.

Tensions identified

The spatial dimension of the circular economy is often overlooked in current policies. While there is a focus on material flows and resource efficiency, the need for circular activities to occur in limited and contested spaces is frequently ignored. This neglect fails to recognise that land is a finite resource, pressured by competing demands for housing, infrastructure, biodiversity, and climate adaptation. Integrating spatial planning into circular economy strategies is essential. Otherwise, we risk unsustainable land use, exacerbating issues like biodiversity loss and climate vulnerability. A comprehensive approach that considers spatial constraints and opportunities is vital for the success of circular economy initiatives (Van den Berghe *et al.*, 2024).

Scaling circular initiatives is still difficult. Traditional linear practices enjoy entrenched economic, legal and fiscal advantages; circular pilots struggle to secure investment and supportive regulation, as seen in the Netherlands. Levelling this playing field will require systemic reform.

Current solutions often focus on 'end-of-the-pipe' methods, targeting the final stages of the production and consumption chains. This is especially true in regions where most production occurs elsewhere, limiting circular strategies to the consumption phase. Such a narrow focus overlooks critical systemic opportunities that could be harnessed by integrating value chains earlier in the process. A comprehensive, life-cycle approach is essential, allowing circular strategies to span both production and consumption. This would enhance innovation and resource efficiency, fostering integrated ecosystems across industries and urban systems. For instance, materials from industrial activities can be repurposed for urban development, while local circular initiatives can connect to larger regional networks. By recognising and leveraging these cross-sector synergies, we can unlock the full potential of circularity, benefiting both industries and the built environment as a whole.

Finally, time cuts across all tensions. Accelerating circular projects without synchronising them with climate, biodiversity and renewable-energy agendas risks new contradictions–for instance, a rush for critical minerals that breaches other environmental thresholds. The real task is to advance the circular built environment quickly and coherently with other urgent transitions.

Time is a critical factor in transitioning to a circular built environment, but it should align with other key goals, such as climate adaptation, mitigation, and the shift to renewable energy. While there's urgency in implementing circular initiatives, rushing these without considering their broader societal and environmental impacts may lead to negative consequences. For example, quickly extracting critical raw materials for renewable energy could hinder long-term climate targets like those in the Paris Agreement. The challenge lies in balancing the urgency of the transition with the need for integration across various sustainability efforts to avoid creating new tensions. Ensuring that the circular built environment supports wider sustainability goals is essential.

Fields of future research

Greenwashing threatens the credibility and progress of circular initiatives in the built environment. To ensure that circular strategies yield real environmental and social benefits, it's crucial to develop robust tools to combat circular washing. Future research should focus on creating clear, standardised indicators and evaluation frameworks that assess the environmental and societal impacts of circular practices. These indicators must be integrated into policy and regulatory frameworks, ensuring that claims of circularity can be measured against rigorous, transparent criteria. This would promote accountability, enabling stakeholders to make informed decisions and differentiating between genuinely circular initiatives and those that merely appear sustainable on the surface.

Additionally, a comprehensive view of these value chains should identify synergies among sectors like construction, manufacturing, and energy production.

For instance, materials from deconstructed buildings can be reused in new projects. When developing a comprehensive understanding across the totality of value-chains, zooming out is as essential as zooming in. In the circular built environment, understanding value chains across materials, components, and processes is essential to fully unlocking the potential of circularity. The built environment involves complex interactions between construction materials, building systems, energy flows, and infrastructure, all of which are influenced by local, regional, and global value chains. Future research must focus on both the macro (zooming out) and micro (zooming in) levels of these value chains, from the extraction and production of building materials to their use, reuse, and recycling within urban and rural contexts.

At a macro level, we must consider how resource flows move between different regions, cities, and neighbourhoods, identifying opportunities for circular interventions at each scale. At the micro level, attention must be given to specific building materials and systems, exploring how circular strategies, such as design for disassembly, material reuse, and adaptive reuse, can be integrated into the planning, construction, and renovation of buildings, neighbourhoods and infrastructures (Hamida *et al.*, 2023; Vafaie *et al.*, 2023).

At both national and EU levels, open strategic autonomy policies are essential for reducing dependence on global resources, especially in construction and infrastructure. These policies can enhance the circular built environment by promoting regional resource flows while acknowledging that complete self-sufficiency is neither practical nor beneficial. Rather than pursuing self-sufficiency, the objective is to establish a balanced approach where local resource management strengthens resilience while maintaining connections to global markets. Future research should explore how cities and regions can leverage localised resource loops and recovery systems to minimise reliance on imports while aligning with broader European and global supply chains. By fostering urban mining, local recycling, and circular manufacturing, cities can enhance resource resilience, viewing local systems as complementary to global resources to ensure adaptability in times of disruption.

The transition to a circular built environment requires a fundamental shift in economic and social values, moving beyond traditional capital-driven models to value-centric approaches. This reimagining of how value is created, exchanged, and consumed must prioritise community well-being and social cohesion, ensuring that the built environment promotes ecological sustainability alongside resilience.

Future research should focus on understanding how these value cycles can operate within the built environment by exploring alternative economic models that prioritise long-term sustainability, equity, and social justice over short-term profit. This includes studying marginal and peripheral practices often overlooked in mainstream approaches to the built environment, and identifying how they can be scaled or integrated into broader systems. By building alliances across sectors–such as housing, infrastructure, and community organisations–there is an opportunity to create organisational structures that foster inclusivity and social equity.

Acknowledgments

We want to thank all Circular Built Environment Hub members who contributed to the two-year discussion that led to this paper.

AI statement

Version 1.2.203 of Grammarly was used to improve language in terms of correctness, clarity, and delivery.

Disclosure statement

No potential conflict of interest was reported by the author(s).

ORCID

A. Wandl http://orcid.org/0000-0003-1163-0529
O. Ioannou http://orcid.org/0000-0003-2571-2509
V. Gruis http://orcid.org/0000-0003-1472-7641
D. Peck http://orcid.org/0000-0001-5698-5492
B. Geldermans http://orcid.org/0000-0003-0897-5542
K. van den Berghe http://orcid.org/0000-0001-8395-0586
F. Bucci-Ancapi http://orcid.org/0000-0002-8634-8117
T. Tsui http://orcid.org/0000-0003-1069-7422
M. van Uden http://orcid.org/0000-0002-8295-3627
T. Egger http://orcid.org/0000-0002-4971-7649

Memoriam

We dedicate this article to Tillmann Klein, founder of the Circular Built Environment Hub. Without his collaborative spirit and kindness, the Hub would not have become the interdisciplinary movement it is today.

References

Barad, K. (2007) *Meeting the Universe Halfway* (Durham & London: Duke University Press).

Barendregt, E., Gerritse, E., van Raak, R., van't Zelfde, J., & Ooms, J. (2024) Toekomstbeelden Bouw Auteur(s). Available at https://www.pbl.nl/monitoringhttps://www.pbl.nl/monitoring-

Bestul, B., & Gruis, V. (2024) Six business model types for circular building component reuse actors, *Sustainability*, 16(13), Article 5425. doi:10.3390/su16135425.

Cetin, S., Raghu, D., Honic, M., Straub, A., & Gruis, V. (2023) Data requirements and availabilities for material passports: A digitally enabled framework for improving the circularity of existing buildings, *Sustainable Production and Consumption*, 40, pp. 422–437. doi:10.1016/j.spc.2023.07.011.

Cimprich, A., Schrijvers, D., Ku, A. Y., Hagelüken, C., Christmann, P., Eggert, R., Hirohata, A., Peck, D., & Hool, A. (2022) The role of industrial actors in the circular economy for critical raw materials: A framework with case studies across a range of industries, *Mineral Economics*, 36(2), pp. 301–319. doi:10.1007/s13563-022-00304-8.

Corvellec, H., Stowell, A. F., & Johansson, N. (2022) Critiques of the circular economy, *Journal of Industrial Ecology*, 26(2), pp. 421–432. doi:10.1111/jiec.13187.

Dąbrowski, M., & Wandl, A. (2024) Assessing circular economy transitions, *Regional Studies Policy Impact Books*, 6(1), pp. 81–98. doi:10.1080/2578711X.2024.2418234.

Egger, T., van Dorst, M., Ioannou, O., & den Heijer, A. (2024) Circular commons: Exploring innate spatial tactics as pathways toward a circular built environment, *Circular Economy and Sustainability*, 5(2), pp. 1157–1199. doi:10.1007/s43615-024-00473-4.

Furlan, C., Wandl, A., Cavalieri, C., & Unceta, P. M. (2022) Territorialising circularity, in: L. Amenta, M. Russo, & A. Van Timmeren (Eds) *Regenerative Territories: Dimensions of Circularity for Healthy Metabolisms*, Vol. 128, pp. 31–49 (Springer: GeoJournal Library). doi:10.1007/978-3-030-78536-9_2.

Furlan, C., Wandl, A., Geldermans, B., & Ŝileryté, R. (2020) A refined waste flow mapping method: Addressing the material and spatial dimensions of waste flows in the urban territory through big data: The case of the Amsterdam metropolitan area, *Contesti Città, Territori, Progetti*, 2020(1), pp. 74–89. doi:10.13128/contest-11909.

Greco, A., van Laar, B., Remøy, H., & Gruis, V. (2024) Accelerating circularity systemically: Three directions for impactful research, *NPJ Urban Sustainability*, 4(1), Article 45. doi:10.1038/s42949-024-00183-8.

Hamida, M. B., Remøy, H., Gruis, V., & Jylhä, T. (2023) Circular building adaptability in adaptive reuse: Multiple case studies in the Netherlands, *Journal of Engineering, Design and Technology*, 23(1), 161–183. doi:10.1108/JEDT-08-2022-0428.

Hobson, K., & Lynch, N. (2016) Diversifying and de-growing the circular economy: Radical social transformation in a resource-scarce world, *Futures*, 82, pp. 15–25. doi:10.1016/j.futures.2016.05.012.

Ioannou, O., Geldermans, B., Klein, T., & Wandl, A. (2022) Planning for change: A methodological framework for integrating circularity at tu Delft's faculty of architecture and the built environment curricula, *Serbian Architectural Journal*, 12(3), pp. 234–269. doi:10.5937/saj2003234I.

Kooter, E., Uden, M. V., Marrewijk, A. V., Wamelink, H., Bueren, E. V., & Heurkens, E. (2021) Sustainability transition through the dynamics of circular construction projects, *Sustainability*, 13(21), pp. 12101. doi:10.3390/su132112101.

Peck, D. (2024) Buildings, in: C. Meskers, E. Worrell, & M. A. Reuter (Eds) H*andbook of Recycling: State-of-the-Art for Practitioners, Analysts, and Scientists*, 2nd ed., pp. 235–247 (Cambridge, MA: Elsevier). doi:10.1016/B978-0-323-85514-3.00034-8.

Peck, D., Eberl, H.-C., & Charter, M. (2020) *Products and Circular Economy, Policy Recommendations Derived from Research & Innovation Projects* (Brussels, Belgium: European Commission). doi:10.2777/15587.

Remøy, H., & Wandl, A. (2022) Challenges for circular urban development, in: N. J. A. Buchoud, A. Charlambous, G. Hartmann, K. Karampourniotis, H. Kuhle, & M. Molnár (Eds) *Intersecting: Bending the Linear Economy on Urban Metabolism #Resources #Well-Being #Policies*, Vol. 9, p. 128 (Berlin, Germany: New Dialogues Berlin).

Tercero Espinoza, L., Schrijvers, D., Chen, W.-Q., Dewulf, J., Eggert, R., Goddin, J., Habib, K., Peck, D., Hool, A., Kleijn, R., & Ku, A.Y. (2020) Greater circularity leads to lower criticality, and other links between criticality and the circular economy, *Resources, Conservation and Recycling*, 159, Article 104718. doi:10.1016/j.resconrec.2020.104718.

Tsui, T., Furlan, C., Wandl, A., & van Timmeren, A. (2024) Spatial parameters for circular construction hubs: Location criteria for a circular built environment, *Circular Economy and Sustainability*, 4(1), pp. 317–338. doi:10.1007/s43615-023-00285-y.

Tsui, T., Peck, D., Geldermans, B., & van Timmeren, A. (2021) The role of urban manufacturing for a circular economy in cities, *Sustainability*, 13(1), Article 23. doi:10.3390/su13010023.

Vafaie, F., Remøy, H., & Gruis, V. (2023) Adaptive reuse of heritage buildings: A systematic literature review of success factors, *Habitat International*, 142, Article 102926. doi:10.1016/j.habitatint.2023.102926.

van den Berghe, K. B. J., Dąbrowski, M. M., van Bueren, E., & Williams, J. (2024) Policy recommendations for facilitating an urban and regional circular economy, in: M. Dąbrowski, K. Van den Berghe, J. Williams, & E. van Bueren (Eds) *Going Circular: Unlocking the Potential of*

Regions and Cities to Drive the Circular Economy Transition, Vol. 6, No. 1, pp. 99–108 (Abingdon, Oxon/New York, NY: Regional Studies Policy Impact Books; Routledge – Taylor & Francis Group). doi:10.1080/2578711X.2024.2418236.

van der Leer, J., van Timmeren, A., & Wandl, A. (2018) Social-ecological-technical systems in urban planning for a circular economy: An opportunity for horizontal integration, *Architectural Science Review*, 61(5), pp. 298–304. doi:10.1080/00038628.2018.1505598.

van Stijn, A., & Gruis, V. (2020) Towards a circular built environment: An integral design tool for circular building components, *Smart and Sustainable Built Environment*, 9(4), pp. 635–653. doi:10.1108/SASBE-05-2019-0063.

van Uden, M., Wamelink, H., van Bueren, E., & Heurkens, E. (2024) Aligning practices towards a circular economy in the architecture, engineering, and construction sector: Seven transitions in different stages of reconfiguration, *Construction Management and Economics*, 43(2), pp. 1–22. doi:10.1080/01446193.2024.2401829.