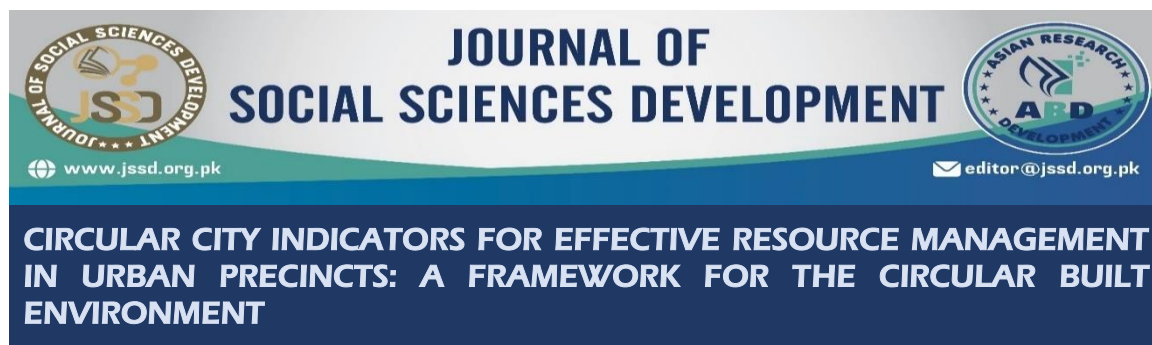




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| KEYWORDS                                                                                                                                            | ABSTRACT                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |
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| circular economy, circular city, urban precinct, circularity indicators, resource management, built environment, material reuse, waste minimization | Rapid urbanisation, increasing material consumption, construction waste, land pressure and climate-related challenges have intensified the need to move urban development away from linear patterns of resource use. Circular economy principles offer an alternative approach in which resources are retained in productive use for longer, waste is minimised, materials are recirculated, and natural systems are regenerated. Although circular-city concepts have gained substantial policy and academic attention, their practical application remains constrained by the absence of clear, locally applicable and action-oriented indicators. This paper develops a conceptual framework for identifying and applying circular city indicators for effective resource management at the urban precinct scale, with particular relevance to the Australian built environment. The study adopts a structured literature-based methodology drawing on circular economy theory, urban metabolism, circular-city assessment, built-environment research, resource-management approaches and Australian circular-economy studies. The analysis organises circularity into six interconnected indicator domains: resource efficiency, design longevity and adaptability, material reuse and recovery, waste minimisation, efficient and regenerative land use, and socio-economic and governance performance. These domains are interpreted through circular economy strategies including regeneration, sharing, optimisation, looping, virtualisation and exchange, while recognising that precinct implementation requires collaboration among government, built-environment professionals, investors, construction clients and communities. The results show that circularity at precinct scale cannot be represented adequately by a single waste or recycling measure. Instead, effective assessment requires a balanced set of indicators capable of linking resource flows, built assets, land use, environmental performance, stakeholder participation and long-term community value. The paper proposes a staged framework for indicator identification, baseline assessment, implementation, monitoring and iterative improvement. The framework provides a practical basis for future application in Australian urban precincts and contributes to the transition from conceptual circular-city ambitions toward measurable and locally responsive resource-management practices. |
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## Introduction

Cities are central to contemporary economic and social life, but they are also major centres of resource consumption, material accumulation and waste generation. Urban areas concentrate buildings, infrastructure, transport systems, services and population, creating intensive demand for energy, water, construction materials and land. The prevailing model of urban development has historically followed a linear pattern in which resources are extracted, transformed into products and built assets, consumed and eventually discarded. This “take, make and dispose” model has generated economic growth, yet it has also contributed to resource depletion, environmental degradation, greenhouse-gas emissions and increasing volumes of waste. As urban populations continue to grow, the limitations of linear resource management are becoming increasingly evident [2–4].

The circular economy (CE) has emerged as an alternative model that seeks to decouple economic and social development from the continuous consumption of finite resources. The Ellen MacArthur Foundation defines the circular economy through three broad principles: eliminating waste and pollution, circulating products and materials, and regenerating natural systems [5]. Rather than treating waste as an unavoidable outcome of development, circularity considers how products, components, materials, buildings and infrastructure can retain their value and usefulness over longer periods. This shift has significant implications for the built environment because urban development determines large and long-lasting stocks of materials, infrastructure and land-use patterns.

At the urban scale, the concept of the circular city extends CE principles beyond individual products or organisations. A circular city aims to manage resources as interconnected flows, reduce unnecessary consumption, preserve existing value, recover materials, improve environmental quality and create social and economic benefits. Urban metabolism research provides an important conceptual foundation for this approach because it examines the flows of materials and resources entering, circulating within and leaving urban systems [8]. Circular-city thinking adds a strategic dimension by asking how those flows can be redesigned so that cities become less dependent on nonrenewable resources and less productive of waste.

However, translating circular-city principles into practical urban action remains difficult. The circular economy has generated numerous conceptual models, policy strategies and indicators, but practitioners frequently face uncertainty about which indicators should be measured, at what spatial scale they should be applied and how indicator results should influence planning and resource-management decisions. Acharya, Boyd and Finch [1] emphasised the need to move from principles toward practical actions in the circular built environment. This implementation challenge is particularly important because broad city-wide indicators may conceal substantial differences between neighbourhoods, development areas and infrastructure systems. Recent reviews reinforce this concern: the challenge is not a shortage of possible measures, but the selection of indicators that are coherent, comparable and useful for urban decision-making [15].

Built-environment research likewise shows that indicator systems remain diverse in scope and structure, which strengthens the case for a clearly defined assessment scale and purpose [19,22].

The urban precinct provides a useful intermediate scale for addressing this problem. A precinct is large enough to include multiple buildings, infrastructure systems, public spaces, land uses and stakeholder groups, but sufficiently local to allow targeted intervention. At this scale, circularity can be connected to decisions concerning development patterns, asset retention, construction and demolition waste, resource efficiency, material reuse, public space, community needs and local economic activity. Precinct-level assessment therefore offers an opportunity to bridge the gap between high-level circular-city ambitions and the project-level decisions through which urban environments are actually created and transformed. This scale is also justified by recent assessment research showing that circularity measurement is still concentrated predominantly at building level, while neighbourhood and wider urban scales remain comparatively less developed [22]. A precinct framework can therefore complement building-level taxonomies by capturing shared infrastructure, land, public space and cross-project resource relationships [19,22].

The Australian context is especially relevant. Circular-economy principles are receiving increasing attention in Australian policy and the architecture, engineering and construction sector, yet research has identified continuing barriers to implementation. Zaman et al. [12] highlighted the need for circular economy design guidance for the Australian built environment, while Shooshtarian et al. [13] identified barriers and enablers affecting CE adoption in the Australian AEC industry. These studies demonstrate growing institutional and professional interest but also show that implementation requires clearer methods, stakeholder awareness, supportive governance and measurable outcomes.

This paper addresses these challenges by developing a precinct-level framework for circular city indicators focused on effective resource management in the built environment. The framework concentrates on design longevity, resource efficiency, material reuse and recovery, waste minimisation, efficient and regenerative land use, and economic and community benefits. Rather than treating circularity as a single numerical score, the paper proposes a structured set of indicator domains that can be adapted to different urban precincts while maintaining a coherent conceptual basis.

Accordingly, the paper has four objectives. First, it identifies key circular-city indicator domains relevant to the built environment at urban precinct scale. Second, it examines how these indicators can be assessed as part of an integrated resource-management approach. Third, it develops a practical framework for applying, monitoring and reviewing circularity indicators. Fourth, it discusses how the framework can support implementation in Australian urban precincts through stakeholder and community participation. In doing so, the paper responds to the need for a more action-oriented approach to circular urban development and provides a foundation for subsequent empirical case-study validation.

## Literature Review

### Circular economy and the transition from linear to circular urban development

The circular economy represents a systemic departure from conventional linear production and consumption. While definitions vary across sectors and disciplines, most CE approaches share an emphasis on reducing resource extraction, extending product and asset life, maintaining material value and preventing waste. The Ellen MacArthur Foundation's formulation of eliminating waste and pollution, circulating products and materials, and regenerating natural systems has become particularly influential [5]. These principles suggest that circularity is not simply a more efficient form of waste management. It requires intervention throughout the lifecycle of products, buildings, infrastructure and urban systems.

Prieto-Sandoval et al. [6] demonstrate that CE implementation depends on combinations of strategies, resources and organisational capabilities. Although their work focuses on industrial small and medium enterprises, the underlying lesson is relevant to urban systems: circularity requires enabling capacities as well as environmental intentions. In cities, those capacities include planning institutions, regulatory frameworks, market structures, design knowledge, stakeholder collaboration and the ability to identify opportunities for reuse and value retention.

Kirchherr and Piscicelli [4] further emphasise that circular-economy transitions require changes in knowledge and behaviour. Their discussion of education for the circular economy indicates that CE is not achieved solely through technical measures. It requires systems thinking, interdisciplinary understanding and the capacity to recognise relationships between actions across a lifecycle. This is particularly important in the built environment, where decisions made during planning and design can determine resource use and waste generation decades later.

The circular-city concept applies these systemic ideas to urban development. Girard [9] describes the transition toward a circular economic model in metropolitan contexts as a process involving interconnected economic, environmental and spatial dimensions. Brglez, Perc and Lukman [11] similarly emphasise the complexity and interconnectedness of circular cities and the circular economy. Their work reinforces the need to avoid narrowly defined indicators that measure isolated outputs without considering relationships among urban systems.

Consequently, a circular urban precinct should be understood as a socio-spatial system in which built assets, land, resources, institutions and communities interact. A successful circularity framework must therefore capture more than the quantity of waste recycled. It should consider whether existing assets are retained, whether buildings can adapt to changing needs, whether secondary materials substitute for nonrenewable resources, whether land is used efficiently without undermining environmental quality, and whether circular strategies create lasting community and economic value.

### **Urban metabolism and resource management**

Urban metabolism provides a useful analytical perspective for understanding resource management in cities. It conceptualises urban areas as systems through which materials, energy, water and other resources flow. Cui [8], through a bibliometric analysis of urban metabolism, shows the increasing relevance of this perspective to urban sustainability research. Metabolism-based thinking is valuable because it shifts attention from individual environmental problems toward the relationships between resource inputs, urban stocks, consumption processes and outputs. More recent urban-metabolism research extends this logic by explicitly linking material-flow analysis with circularity potential and locally targeted resource strategies, demonstrating how the metabolism perspective can move from description toward circular intervention [16].

From a circular perspective, the objective is not only to measure these flows but to change their direction and intensity. Resource management should reduce unnecessary inputs, extend the productive life of existing stocks, enable internal circulation where appropriate and minimise residual outputs. In the built environment, this can involve retaining and adapting buildings instead of demolishing them, reusing construction components, recovering materials from obsolete infrastructure, reducing water and energy demand, and designing development patterns that make efficient use of existing urban land and infrastructure.

Urban mining illustrates this shift. Instead of viewing the existing city merely as a consumer of new resources, urban mining recognises buildings, infrastructure and accumulated waste as potential reservoirs of valuable materials. Brglez et al. [11] discuss the interconnected character of circular cities, within which resource recovery and reuse form part of wider sustainability processes. At precinct scale, urban mining can be linked to redevelopment by identifying opportunities to retain, reuse or recover resources already present within the site before importing new materials.

Effective resource management also requires attention to hierarchy. Avoiding unnecessary resource consumption is generally preferable to managing waste after it has been generated. Retention of an existing structure can preserve more embedded value than demolition followed by material recycling. Reuse of components can retain more value than processing them into lower-grade materials. Therefore, circular-city indicators should be designed to recognise value preservation and not inadvertently reward high waste generation simply because a large percentage is subsequently recycled.

### **Circular city indicators and measurement challenges**

Indicators translate broad sustainability or circularity goals into observable measures. In the circular-city context, they can support baseline assessment, comparison, monitoring, target setting and policy evaluation. Beccarello and Di Foggia [7] propose a circularity mapping framework for urban policymaking, highlighting the importance of linking circularity concepts with decision-

making. The value of indicators therefore lies not only in measurement but in their capacity to guide interventions.

Despite this potential, circularity measurement remains fragmented. Different studies emphasise different sectors, scales and dimensions, making it difficult to identify a universally applicable indicator set. Some approaches focus strongly on material flows and waste while others incorporate economic activity, environmental quality or social outcomes. The absence of a single standard set is partly a consequence of the diversity of cities. A dense inner-city renewal precinct, an industrial precinct and a suburban growth area have different resource profiles and development pressures. A useful framework must therefore combine a common core with context-specific flexibility. Systematic reviews confirm that circular-city and built-environment measurement now contains a large and heterogeneous range of indicators rather than a single accepted set [15,19,22]. This diversity is useful for capturing different dimensions of circularity, but it also creates a methodological problem: indicators need to be selected according to spatial scale, decision purpose and data feasibility rather than accumulated indiscriminately [15,22].

Data availability presents another challenge. The CIRCulT project's work on data and indicators for a circular built environment [10] identifies the importance of data accessibility, accuracy, granularity and interoperability. If indicators depend on information that cannot be collected consistently, the framework may remain conceptually attractive but operationally weak. Indicator selection should therefore consider not only theoretical relevance but also measurability, transparency and the cost of monitoring.

Scale is equally important. City-wide averages may conceal local differences, while individual building assessments may overlook shared infrastructure, public space and cross-project resource opportunities. The precinct scale provides a practical middle ground. It allows assessment of built assets and land-use patterns while also recognising collective systems and stakeholder relationships. This scale is particularly appropriate for redevelopment areas where multiple projects are planned under a common vision or planning framework. Recent evidence is particularly relevant to the present study because assessments beyond the individual building remain less mature, and the relationships among different dimensions of circularity are not yet consistently represented [22]. This supports the use of the precinct as a distinct analytical level rather than treating it as a simple aggregation of building scores.

A further challenge concerns aggregation. Circularity is multidimensional, and combining diverse indicators into a single index can conceal trade-offs. For example, a precinct may perform well in waste recovery but poorly in asset retention, or may achieve high land-use efficiency while providing inadequate ecological space. A transparent indicator profile is therefore often more useful than a single composite score. Where aggregation is used, the assumptions and weightings should be clearly explained.

### **Circularity in the built environment**

The construction sector is a critical arena for circular-economy implementation because it consumes large quantities of materials and produces significant waste. Buildings and infrastructure also have long lifespans, meaning that present decisions shape resource demand and waste generation far into the future. Circular built-environment strategies therefore need to address both existing urban stocks and new development.

Design longevity is fundamental. A building that remains useful for a long period avoids or delays the resource demand associated with replacement. Longevity is influenced by construction quality, maintenance, adaptability and the capacity to accommodate changing uses. Adaptable design allows buildings and spaces to respond to demographic, economic and functional changes without major demolition. This makes adaptability a resource-management strategy as well as a design consideration. Recent reviews of building adaptability show that long-term usefulness depends on a combination of spatial flexibility, functional convertibility, maintainability, dismantlability, material reversibility and the capacity for refitting or reuse [17,18]. From a circular perspective, these characteristics are significant because they can reduce premature replacement while preserving both functional and material value over time [17,18].

Material reuse is another core principle. Reuse can occur at different levels, from retaining entire structures to reusing components and incorporating recovered materials into new construction. Circular design should facilitate future recovery by considering how components are assembled, maintained, replaced and eventually separated. Although recycling remains important, a circular hierarchy should prioritise strategies that preserve greater material and functional value. Research on design for disassembly and design for deconstruction further indicates that recovery potential is strongly influenced by decisions made before end-of-life, including how elements are connected, separated and made available for reuse [20,21]. This means that circular material management should address both present recovery practices and the future recoverability of new construction.

Zaman et al. [12] developed circular economy design guidelines for the Australian built environment sector and highlight the importance of integrating circular principles into design practice. Their work is particularly relevant because design decisions influence material selection, waste generation, adaptability and end-of-life options. Shooshtarian et al. [13], examining the Australian AEC industry, demonstrate that CE adoption is shaped by both barriers and enablers. Awareness, perceived benefits, regulatory conditions, knowledge and market support all influence whether circular strategies are implemented.

These findings indicate that built-environment circularity cannot be assessed exclusively through physical performance. Governance and stakeholder capacity are part of the implementation system. A precinct may possess substantial theoretical opportunities for reuse, for example, but these opportunities will not be realised if procurement practices, regulations or stakeholder coordination favour conventional disposal and replacement.

### **Land use, regeneration and the precinct scale**

Land is a finite urban resource and should form part of circular-city assessment. Efficient land use can reduce pressure for outward expansion, make better use of existing infrastructure and support more compact patterns of development. However, efficiency should not be interpreted as maximising built density without qualification. Circular land use should also consider the reuse of previously developed land, the adaptability of urban spaces, ecological regeneration, accessibility and the long-term capacity of a precinct to meet changing community needs.

The regenerative dimension of circularity is particularly important. The Ellen MacArthur Foundation's principles extend beyond keeping materials in circulation to include regeneration of natural systems [5]. At precinct scale, this can be interpreted through protection and enhancement of green and open spaces, soil and water-sensitive practices, biodiversity, urban vegetation and environmental quality. The objective is not simply to consume fewer resources but to improve the ecological functioning of urban areas.

Precinct-scale planning is well positioned to integrate these considerations because land use, infrastructure, public realm and development controls are often coordinated at this level. It also allows circular strategies to be tailored to local characteristics. A former industrial precinct may prioritise contaminated-land regeneration, adaptive reuse and material recovery, whereas a new growth precinct may place greater emphasis on long-life design, resource-efficient infrastructure and prevention of future waste.

### **Stakeholder and community dimensions**

Circular urban development involves multiple actors whose decisions occur at different stages of the built-environment lifecycle. Policymakers establish regulatory conditions, while landowners and investors influence development priorities. Designers specify materials and systems, contractors determine construction practices, waste and resource-recovery organisations manage outputs, and communities ultimately use and experience the resulting places. Circularity therefore depends on coordination across the value chain.

Shooshtarian et al. [13] found that awareness of CE affects willingness to adopt circular practices and perceptions of their benefits within the Australian AEC industry. This suggests that indicator frameworks should not be designed only for technical assessment. They should also create a shared language through which stakeholders can understand objectives, responsibilities and progress.

Community participation is similarly important. Circular-city strategies may alter patterns of consumption, sharing, repair, mobility, public-space use and waste separation. Long-term implementation is more likely when local communities understand the purpose of interventions and perceive tangible benefits. Economic and community indicators are therefore necessary to complement environmental and material measures. Circular development should contribute to

liveability, local opportunity, affordability where relevant, health and a sense of shared responsibility for resources.

The literature reviewed above establishes the need for an integrated precinct-scale approach. Circular-city measurement should combine resource flows, built-asset performance, waste prevention, land and ecological considerations, governance and social value. The following methodology explains how these dimensions were synthesised into a structured framework.

## Methodology

This study adopts a qualitative, conceptual research design based on structured review and synthesis of literature. The purpose is framework development rather than empirical testing. This approach is appropriate because the research problem concerns the identification, organisation and operational interpretation of circular-city indicators at the urban precinct scale. The study does not claim to report completed field measurements, stakeholder surveys or statistical relationships. Instead, it establishes a theoretically grounded framework that can be tested through future case-study research.

The analytical procedure was undertaken in four stages. First, the literature was examined to identify recurring principles relevant to urban circularity and the built environment. Particular attention was given to resource reduction, value retention, reuse, waste prevention, regeneration, efficiency, stakeholder participation and implementation barriers. Second, the identified concepts were grouped according to their relevance to precinct-scale resource management. Concepts that addressed similar outcomes were consolidated to avoid an excessively large and impractical indicator list.

Third, the grouped concepts were interpreted through the logic of circular-economy action. The ReSOLVE approach provides a useful organising lens because it frames circular strategies through regeneration, sharing, optimisation, looping, virtualisation and exchange. In this paper, ReSOLVE is not treated as a rigid scoring system. Instead, it is used to test whether the proposed indicator domains collectively encourage actions that reduce resource inputs, retain value, circulate resources and regenerate urban systems.

Fourth, each proposed indicator domain was evaluated against five criteria: relevance to circular-economy principles; relevance to the built environment; applicability at urban precinct scale; potential measurability; and usefulness for decision-making. This process produced six principal domains: (1) resource efficiency, (2) design longevity and adaptability, (3) material reuse, recovery and urban mining, (4) waste minimisation and circular resource flows, (5) efficient and regenerative land use, and (6) socio-economic, governance and community performance.

The framework is designed as a staged process rather than a fixed universal index. A precinct first establishes its system boundary and development context, then develops a baseline for the six indicator domains. Relevant indicators are selected according to local conditions and available

evidence. Strategies are then implemented, monitored and reviewed. This approach recognises that circularity is dynamic: the relevance of indicators may change as a precinct develops, infrastructure is upgraded and new resource-management opportunities emerge.

For future empirical applications, a mixed-method case-study design is recommended. Quantitative data could be used for measures such as resource consumption, material recovery, waste generation, land-use intensity and economic outcomes. Qualitative evidence from policy documents, planning reports, stakeholder interviews, site observation and community engagement could be used to interpret governance, implementation barriers, design quality and participation. The combination would allow measurable performance to be understood within its institutional and spatial context.

## Results and Discussion

### Development of the precinct-level circular city indicator framework

Literature demonstrates that no single indicator can represent circularity in an urban precinct. Circularity is produced through relationships between resource consumption, built assets, waste, land, ecological systems, institutions and communities. The principal result of this study is therefore a six-domain framework intended to convert these relationships into an operational assessment structure.

The first domain, resource efficiency, evaluates whether the precinct reduces demand for non-renewable resources while obtaining greater value from the resources it uses. Relevant measures can include material consumption intensity, water demand, energy demand, the proportion of renewable or recovered resources and changes in resource productivity. The importance of this domain is supported by the broader CE literature, which positions resource efficiency as a central mechanism for reducing environmental pressure [5–7]. However, efficiency should be interpreted carefully. A reduction in resource use per unit of floor area may not represent absolute improvement if total development increases rapidly. Both intensity and total consumption should therefore be considered where data permit.

The second domain, design longevity and adaptability, addresses the lifespan and continuing usefulness of buildings, infrastructure and public spaces. A circular precinct should avoid premature obsolescence. Indicators may therefore assess the proportion of existing assets retained, the capacity of buildings to accommodate changing functions, maintenance performance, durability and the extent to which new development incorporates adaptable design. This domain is particularly important because demolition can destroy substantial embodied material and economic value even when demolition waste is subsequently recycled. This interpretation is consistent with recent adaptability research, which treats circularity and adaptability as mutually reinforcing when buildings can respond to changing needs while retaining asset and material value [17,18]. Accordingly, the domain should assess not only nominal service life but

also the characteristics that make continued use, conversion, maintenance and recovery practically achievable.

The third domain, material reuse, recovery and urban mining, evaluates whether existing material stocks are treated as resources. Indicators can examine the proportion of construction materials sourced from reused or recycled inputs, the quantity of components directly reused, the recovery potential of buildings scheduled for alteration or demolition, and the existence of systems that connect available materials with new demand. This domain operationalises the principle of keeping products and materials in circulation [5] and recognises the existing city as a potential resource reservoir rather than simply a destination for new materials. Evidence from recent disassembly and deconstruction reviews suggests that the technical possibility of reuse depends on building systems, connections, material condition and the sequencing of recovery operations [20,21]. The indicator domain should therefore distinguish direct component reuse from lower-value material recycling and recognise design choices that improve future recovery.

The fourth domain, waste minimisation and circular resource flows, focuses on prevention and management of residual outputs. Measures may include construction and demolition waste generation, waste generated per unit of development, diversion from landfill, separation quality, organic-resource recovery and the extent to which outputs from one activity become inputs for another. Importantly, the framework places waste prevention ahead of recovery. High recycling rates should not be interpreted as strong circular performance if the precinct continues to generate unnecessarily large waste volumes.

The fifth domain, efficient and regenerative land use, expands circularity beyond material flows. Indicators can consider reuse of previously developed land, intensity of use, vacancy or underutilisation, access to existing infrastructure, adaptability of public space, ecological restoration and the protection or enhancement of green systems. This reflects the regenerative principle of the circular economy and responds to the fact that urban land itself is a limited resource. Efficient land use should be balanced with liveability and ecological performance rather than pursued as density alone.

The sixth domain, socio-economic, governance and community performance, captures the enabling conditions that determine whether circular strategies are sustained. Potential indicators include the presence of circular procurement requirements, stakeholder participation, local reuse and repair activity, circular-economy employment, community awareness, institutional collaboration and the incorporation of circularity objectives into planning and development processes. This domain is strongly supported by Australian research showing that awareness, regulation, incentives and perceived benefits influence CE adoption [12,13].

## Proposed indicator structure

Table 1 Proposed indicator domains for precinct-scale circularity assessment

| Indicator domain                                            | Indicative measures                                                                                                 | Circularity purpose                                                           | Potential evidence                                                          |
|-------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------|-----------------------------------------------------------------------------|
| <b>Resource efficiency</b>                                  | Material, water and energy intensity; renewable/recovered resource share; resource productivity                     | Reduce nonrenewable resource demand and improve value obtained from resources | Utility records, development data, procurement records, resource audits     |
| <b>Design longevity and adaptability</b>                    | Asset retention; building/service life; adaptability; maintenance; flexible use                                     | Preserve embedded value and avoid premature replacement                       | Building records, planning documents, design assessment, site observation   |
| <b>Material reuse, recovery and urban mining</b>            | Reused components; recycled-content materials; recovery potential; secondary-material use                           | Keep products, components and materials at higher value for longer            | Construction records, material audits, demolition/resource-recovery records |
| <b>Waste minimisation and circular flows</b>                | Waste generation; landfill diversion; source separation; by-product exchange; organic recovery                      | Preventing waste and close resource loops                                     | Waste audits, contractor reports, municipal/resource-recovery data          |
| <b>Efficient and regenerative land use</b>                  | Reuse of developed land; utilisation; vacant/underused space; green/open-space performance; ecological regeneration | Use land efficiently while regenerating natural systems                       | Planning data, land-use records, environmental reports, site assessment     |
| <b>Socio-economic, governance and community performance</b> | Circular procurement; stakeholder collaboration; community participation; circular jobs/businesses; awareness       | Create enabling conditions and distribute circularity benefits                | Policy and procurement documents, interviews, surveys, engagement records   |

## Relationship with the ReSOLVE framework

The six indicator domains can be interpreted through the ReSOLVE logic to ensure that assessment remains action-oriented. Regenerate is reflected in renewable-resource use,

ecological restoration and land regeneration. Share is represented through more intensive and flexible use of buildings, spaces and resources. Optimise relates to resource efficiency, maintenance, waste prevention and improved performance of existing assets. Loop is directly addressed through reuse, repair, recovery, recycling and urban mining. Exchange is reflected in the substitution of conventional resource-intensive practices with circular alternatives. Virtualisation can contribute to dematerialisation and service-based solutions, although it should be assessed according to local relevance rather than assumed to be inherently circular.

This relationship is valuable because indicators can otherwise become passive reporting measures. Connecting indicators to action strategies helps decision-makers ask not only “How circular is the precinct?” but also “What intervention would improve this result?” For example, a low asset-retention indicator can prompt investigation of adaptive-reuse policies; low secondary-material use can prompt circular procurement requirements; high waste generation can lead to prevention targets; and weak community participation can trigger new engagement mechanisms.

### **A staged process for application**

The proposed framework is applied through five stages. Stage 1 defines the precinct boundary, development context and circularity objectives. Clear boundaries are essential because resource flows and responsibilities extend beyond administrative lines. The assessment should state what is included, the period being measured and whether the precinct is an established area, redevelopment precinct or new development.

Stage 2 establishes a baseline. Available evidence is collected for the six indicator domains to identify current conditions, data gaps and areas of strongest and weakest performance. The baseline should distinguish between absolute quantities and relative indicators. It should also record uncertainty rather than presenting incomplete data as precise measurement.

Stage 3 prioritises strategies. Indicator results are interpreted alongside local planning priorities, feasibility and stakeholder responsibilities. Not every precinct requires the same intervention. A redevelopment precinct with substantial existing structures may prioritise retention, adaptive reuse and urban mining, whereas a new precinct may prioritise long-life design, resource-efficient infrastructure and prevention of future waste.

Stage 4 implements and monitors actions. Responsibilities should be assigned to relevant actors, and indicators should be connected to planning conditions, procurement, development agreements, operational management or community programmes where appropriate. Monitoring intervals should reflect the nature of the indicator. Some resource-flow measures may be reviewed annually, while asset longevity or land-use transformation may require longer periods.

Stage 5 reviews performance and adapts the framework. Circularity is an evolving process rather than a fixed end state. Indicator definitions, targets and strategies should therefore be revised when better information becomes available or when unintended effects are identified. This

iterative structure supports continuous learning and avoids locking precincts into measures that cease to be useful.

### **Implications for Australian urban precincts**

The framework has relevance to Australian urban development because the country combines high levels of urbanisation with continuing construction activity and substantial resource demand. Australian circular-economy policy is increasingly emphasising resource recovery and more sustainable production and consumption, but implementation within the built environment remains uneven. The findings of Zaman et al. [12] and Shooshtarian et al. [13] suggest that practical guidance and institutional support are required to translate CE principles into routine design and construction decisions.

At precinct scale, the framework can provide a common structure for government agencies, developers, designers, construction organisations, resource-recovery businesses and communities. Rather than each stakeholder interpreting circularity differently, the six domains establish a shared set of questions. Are fewer nonrenewable resources being consumed? Are existing buildings and infrastructure being retained where feasible? Are new assets designed for longevity and change? Are materials being reused at their highest practicable value? Is waste being prevented before it is recycled? Is land being used and regenerated responsibly? Are governance arrangements and communities capable of sustaining the transition?

The research identified Australian urban precincts such as Arden and Fishermans Bend as potential case-study locations. These types of major redevelopment areas are appropriate because they combine planning, infrastructure, construction and community objectives within a defined geography. Application should begin with a baseline assessment rather than assuming that existing sustainability initiatives are equivalent to circularity. Sustainability and circularity overlap, but circular assessment places particular emphasis on resource loops, value retention and avoidance of waste.

The framework could also support comparison between precincts, but comparison should be undertaken cautiously. Different precincts vary in age, function, population, development stage and available infrastructure. A mature mixed-use precinct should not be judged against a redevelopment site solely through raw quantities. Comparison is more meaningful when indicators are normalised appropriately and contextual differences are reported transparently.

### **Stakeholder engagement as an implementation mechanism**

A central finding of the synthesis is that circularity is not produced by technical performance alone. Stakeholder engagement is an implementation mechanism. Policymakers can establish circular requirements and provide appropriate incentives. Investors and clients can create demand for circular outcomes, while designers can prioritise longevity and adaptability. Contractors can improve material management, and recovery organisations can create pathways

for secondary resources. Communities can also contribute by supporting sharing, repair, reuse, and responsible consumption.

This has implications for indicator design. A framework that measures only physical flows may identify poor performance without explaining why it occurs. Governance and participation indicators provide information about implementation capacity. For example, low material reuse may reflect lack of market availability, uncertainty regarding quality, procurement rules or limited coordination between demolition and new construction projects. Understanding these barriers is necessary before effective strategies can be designed.

Community involvement is especially important at the micro scale. Residents and users experience the practical outcomes of urban circularity, including public-space quality, local services, waste systems, access to shared resources and environmental conditions. Engagement should therefore extend beyond awareness campaigns. Communities can contribute local knowledge, identify priorities and participate in monitoring. This strengthens legitimacy and can help ensure that circular-economy strategies produce visible improvements in everyday urban life.

### **Contribution and limitations**

The principal contribution of this study is the integration of multiple circular-economy dimensions into a precinct-level indicator framework. Existing literature provides important knowledge about CE principles, urban metabolism, circular cities, design guidelines and implementation barriers, but these strands are often treated separately. The framework brings them together around a scale at which planning and built-environment decisions can be coordinated. This contribution is timely because recent reviews identify substantial fragmentation in existing circularity assessment methods and a continuing concentration of assessment at building scale [19,22]. The proposed framework responds by organising indicators around a defined precinct boundary and by linking physical resource performance with land, governance and community conditions rather than treating these dimensions independently.

The framework also reinforces a hierarchy of circular action. Prevention, retention, longevity and reuse should be considered before lower-value recovery. This distinction is important because conventional sustainability reporting can sometimes present high recycling rates as evidence of strong performance without questioning why the waste was created. A circular precinct should progressively reduce the need to generate waste in the first place.

Several limitations should be acknowledged. First, this is a conceptual study based on the literature that does not provide empirical validation. Second, indicator definitions require further operational specification before field application. Third, data availability may vary significantly between precincts and institutions. Fourth, the relative importance of indicator domains may differ according to local environmental, economic and social conditions. Finally, the framework should not be interpreted as a substitute for broader sustainability assessment. Circularity is one

important pathway toward sustainable urban development, but circular strategies should still be evaluated for their wider environmental and social consequences.

These limitations define the next research stage. Future work should apply the framework to one or more Australian precincts, develop measurable definitions for individual indicators, test data availability, engage stakeholders in indicator prioritisation and evaluate how indicator results influence actual resource-management decisions. Longitudinal monitoring would be particularly valuable because circularity outcomes often emerge over extended periods.

## Conclusion

The transition toward circular cities requires more than ambitious principles. It requires practical methods capable of showing how resources are used, where value is lost and which interventions can improve urban performance. This paper has developed a conceptual framework for circular city indicators at the urban precinct scale, responding to the gap between broad city-level ambitions and individual building or project decisions.

The literature demonstrates that circularity is inherently multidimensional. Resource efficiency, design longevity, material reuse, waste minimisation, land use, ecological regeneration, governance and community participation are interdependent. For this reason, the proposed framework rejects reliance on a single recycling rate or composite score. Instead, it organises assessment into six complementary domains: resource efficiency; design longevity and adaptability; material reuse, recovery and urban mining; waste minimisation and circular resource flows; efficient and regenerative land use; and socio-economic, governance and community performance.

The framework is designed for implementation through a staged process of boundary definition, baseline assessment, strategy prioritisation, implementation and monitoring, followed by iterative review. Its relationship with the ReSOLVE approach keeps the assessment connected to practical circular actions rather than allowing indicators to become an end in themselves. The framework also recognises that successful implementation depends on collaboration among policymakers, investors, clients, built-environment professionals, resource-management organisations and communities.

For the Australian built environment, precinct-scale application offers an opportunity to connect circular-economy objectives with urban redevelopment and resource-management practice. Future empirical research should test the framework in selected Australian precincts, refine indicator definitions and determine which measures provide the strongest combination of scientific validity, data feasibility and decision usefulness. Such validation can contribute to a practical model that is locally responsive while remaining adaptable to other urban contexts.

Ultimately, a circular precinct is not defined simply by how much waste it diverts from landfill. It is defined by how effectively it preserves value, reduces unnecessary resource demand, extends

the useful life of urban assets, circulates materials, regenerates land and natural systems, and creates lasting benefits for communities. Measuring these dimensions coherently is an essential step toward moving circular-city thinking from aspiration to implementation.

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