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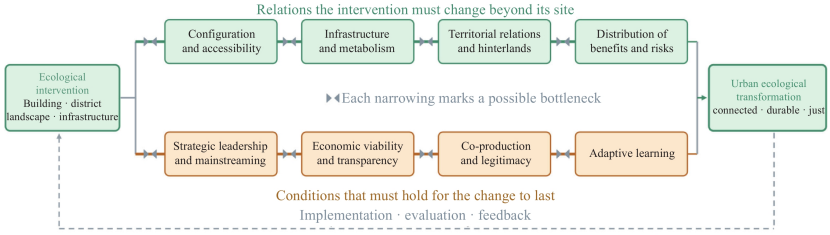
The Ecological City after Four Decades: A Spatial-Relational Perspective on Urban Ecological Transformation

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GRAPHICAL ABSTRACT



HIGHLIGHTS

- Four decades of eco-city ideas accumulated in parallel rather than replacing one another.
- Projects become transformative only when they change relations beyond their own site.
- A spatial-relational framework links four spatial domains with four enabling conditions.
- Durability rests on leadership, mainstreaming, viability, co-production and learning.
- Locating the bottleneck is more informative than a composite eco-city score.

ABSTRACT Over four decades, the ecological city has moved from a largely normative critique of environmentally damaging urbanization into a varied field of municipal policies, demonstration projects, retrofit programs, and city-wide strategies. Its immediate background lies in the environmental and urban debates of the 1970s, although ecological planning and urban-metabolism research had already established important foundations in the preceding decade. Older traditions of public-health reform, garden-city planning, and regional thought remained present. No linear sequence adequately describes this history. Normative reform, urban form, metabolism, infrastructure, and community action continued alongside one another. They were reshaped as climate policy, resilience, circularity, regeneration, social justice, and digital management entered the debate. An ecological intervention begins to change the course of urban development only when its consequences extend beyond the site that contains it. A building, district, landscape, or infrastructure system acquires wider significance through the relations it changes: urban configuration and accessibility, infrastructural and metabolic integration, links across territorial scales, and the distribution of benefits and risks. Whether such changes last depends on four enabling conditions: strategic leadership and institutional mainstreaming, economic viability, social co-production, and adaptive learning. Keeping the distinction visible makes it possible to identify where ecological ambitions enter ordinary planning and where they are blocked, displaced, or confined to exceptional projects. Drawing on this insight, this article further develops a spatial-relational diagnostic framework composed of four spatial domains and four enabling conditions to assess whether ecological projects result in durable urban transformation.

KEYWORDS Ecological city; Urban ecological transformation; Spatial planning; Green infrastructure; Spatial-relational perspective

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1 Introduction: The Ecological City after Four Decades

For more than forty years since the term "eco-city" was coined by Richard Register, the ecological city has provided both a critique of prevailing urban development and a proposition for changing it. The critique addressed pollution, automobile dependence, land consumption, resource-intensive growth, and the treatment of nature as something alien to the city. The proposition was more demanding: settlement patterns, infrastructure, resource use, and everyday life should be planned in closer relation to ecological processes and limits [1–3].

We use the term ecological city here in a bounded sense. It denotes a tradition of thought and practice concerned with the reorganization of urban–ecological relations through spatial form, land use, infrastructure, resource flows, restoration, and collective action. It is neither a short form for sustainable development nor an umbrella under which every environmentally oriented urban concept can be placed. Green, low-carbon, resilient, circular, smart, and regenerative cities meet the ecological city debate at particular points, but they begin from different problems and have their own histories and policy vocabularies [4]. They matter here only where they have altered what ecological urban development is expected to address.

No city is ecologically self-contained. Cities concentrate buildings, infrastructure, economic activity, energy and material demand, but they depend on territories that supply water, food, energy, labor, and construction materials and receive waste and environmental burdens. Climate change, biodiversity loss, ageing infrastructure, and unequal exposure to risk make it difficult to separate technical performance from spatial structure, institutions, markets, and daily practices [5]. An apparently favorable result in one place may rely on resource use or social costs elsewhere.

Nor is there one typical eco-city intervention. The label has been attached to community initiatives, municipal strategies, eco-neighborhoods, new towns, retrofit programs, indicator systems, and urban branding. In an international survey of 79 initiatives, Joss [6] found a mixture of new development, urban expansion, and, most frequently, the retrofit of existing areas. Diversity is thus a fact of practice, not sufficient evidence of fragmentation, understood here as disconnection between initiatives and mainstream planning institutions. Before asking why the ecological city has fragmented, one must first ask whether fragmentation is actually present, at which scale, and with what consequences. This distinction matters because a project can achieve a measurable ecological improvement within a site, sector, or accounting period without altering the relations through which pressures and benefits are produced: relations between land use and mobility, buildings and infrastructure, cities and their hinterlands, investment and maintenance, environmental quality and social access. The project is where change often becomes visible; the city-region is where many of its consequences unfold. Therefore, questions such as "Ecological for whom?", "Within which boundary?" and "For how long?" are planning questions, not qualifications to be added after performance has been calculated.

Projects and transformation are not opposites. Cities are altered through projects, repairs, regulatory decisions, operating practices, and cumulative investment. Small interventions may open a path for learning and institutional change; large flagship projects may remain exceptional. The issue is whether an intervention enters ordinary planning, finance, operation, and maintenance and begins to affect subsequent decisions. This is why the term perspective is preferable to another all-encompassing capacity concept. Institutional, adaptive, transformative, territorial, planning, and community capacities already have established meanings. Combining them into a single spatial capacity would obscure the differences between spatial and material objects of change, available resources, and processes through which change is achieved.

Spatial planning matters because ecological processes rarely conform to the boundaries within which projects are authorized and financed. Planning can connect land policy, infrastructure investment, environmental regulation, and fiscal choices across sites and levels of government. Its authority is always partial, and neither knowledge nor public legitimacy can be taken for granted. Even so, few other public institutions are charged with bringing long-term and cross-boundary consequences into present decisions. Where short-term development returns diverge from long-term public costs, that coordinative responsibility becomes central to the ecological city project.

2 Four Decades of Eco-City Development and Their Intellectual Roots

The ecological city has a history of roughly four decades as a recognizable planning and policy agenda. Its intellectual prehistory is much longer. For example, it draws from urban ecology approaches, which posit that nature significantly influences urban form, and from socio-ecological transition research, which considers social aspects to be integral components of sustainable urban development [7,8]. Environmental and urban

debates in the 1970s prepared the immediate ground, while influential work on ecological planning and urban metabolism appeared in the 1960s. Older traditions of sanitation, housing reform, green-space provision, and regional planning supplied further elements. These lines of thought did not form a sequence of stages. They emerged at different moments, continued in parallel, and repeatedly crossed.

2.1 Urban reform established the enduring ecological questions

Concern about the relations between settlement and nature long predates the eco-city label. Nineteenth- and early twentieth-century reforms in the wake of the industrial revolution addressed overcrowding, pollution, sanitation, unhealthy housing, and the loss of accessible green space. Ebenezer Howard's garden-city concept brought together social reform, planned settlement, open space, and a limit to expansion; regional approaches located the city within a wider geographical and economic setting [9]. Yet there is no single genealogy. European municipal and regional planning drew on compact settlement, public transport, social housing, and the provision of common services, while environmental activism, community action, ecological design, and opposition to automobile-dependent expansion were especially influential in the United States. The contrast matters because ecological urban thought contained a social dimension from the outset, even if later applications sometimes narrowed the agenda to technical performance.

Ecological planning and urban metabolism supplied two analytical moves that remain central. McHarg [10] made land, water, soil, vegetation, and ecological suitability part of the basis for deciding where and how development should occur. Wolman [11], working from a different direction, described the city through its inputs of water, food, fuel, and materials and its outputs of waste and pollution. One approach read ecological processes in space; the other followed flows through the city. Together they made it difficult to regard the urban area as either detached from nature or contained by its administrative boundary.

The later eco-city debate retained the concern with urban form while reopening the city to dependencies beyond its boundary and to the connection between environmental change and public welfare. The contemporary ecological city recombined these concerns under new technological, political, and economic conditions rather than replacing them. The enduring contribution of these antecedents lies less in any particular physical model than in their insistence on integration. Land use, infrastructure, settlement structure, and ecological processes cannot be coordinated through isolated sectoral decisions alone. Markets and individual projects tend to privilege effects that can be assigned to a site, owner, budget, or short time horizon; regional ecosystems and long-lived infrastructure rarely fit those limits. Spatial planning therefore has an anticipatory function: it can represent and take into account consequences that are distant, cumulative, or weakly represented in the immediate development decision. Whether it actually does so depends on its statutory position, political mandate, technical competence, and relation to investment.

2.2 The Eco-City began as a normative reform agenda

The term Eco-City acquired prominence through the environmental movements of the 1970s and 1980s and, in particular, through the work of Richard Register. Register's organization Urban Ecology and his book *Ecocity Berkeley* opposed automobile dependence, dispersed development, and the separation of urban life from ecological processes, and they promoted social justice and cooperation with the business sector to support ecologically conscious economic activities [2]. It was a reform proposal before it was a performance category. Roseland [3] widened the proposition by emphasizing ecological design to local economic development, participation, and social justice. Thus, questions of community, access, and the sharing of environmental benefits were not late additions to an otherwise technical concept.

International environmental policy gave local experimentation a wider institutional setting. From Local Agenda 21 in 1992 to the Agenda and the New Urban Agenda in 2015 and 2016, municipalities were asked to connect environmental goals with housing, mobility, services, inclusion, and the governance of urbanization [12–14]. In Europe, the New Leipzig Charter subsequently placed the just, green, and productive city within an integrated, place-based approach to the common good [15]. These agendas do not turn every urban policy into an ecological city policy. They raise the standard against which an eco-city initiative is judged: ecological objectives have to enter normal planning and investment decisions rather than remain attributes of a named project. Joss [6] describes a related movement from predominantly normative visions towards more innovation- and regulation-oriented practices, but community initiatives, municipal policy, technical experiments, and property development continue to coexist, sometimes within the same program.

2.3 Urban form moved the agenda from vision to demonstration

One persistent line of thought concerns urban form.

Compact development, functional diversity, public transport, walkability, connected open space, and energy-conscious design were expected to reduce land conversion, infrastructure demand, and automobile dependence [16]. The 15-minute city concept by Carlos Moreno, which gained strong international traction after the City of Paris championed it, is a recent formulation of this older concern with proximity and everyday accessibility [17]. It does not, however, settle the metropolitan dependencies or affordability conditions on which proximity rests. Density may support public transport and services, but its effects depend on land-use mix, design quality, climate, mobility systems, and the metropolitan setting [18]. Evidence from Chinese cities likewise indicates that the configuration and spacing of buildings, rather than density or polycentricity alone, shape transport-related carbon emissions [19]. Form matters, but never as an isolated variable.

Eco-neighborhoods and demonstration districts made this line of thought visible. A defined site allowed energy, water, waste, mobility, landscape, and buildings to be planned together and new organizational arrangements to be tested. Such projects produced practical knowledge, but they also helped create an international image of the eco-city dominated by exceptional new settlements. Masdar, for example, drew attention through technological ambition while raising questions about implementation, branding, and metropolitan integration [20]. The prominence of such cases is misleading. In Joss's [6] survey, new settlements accounted for less than one quarter of the initiatives, whereas retrofit in existing urban areas approached one half. Neighborhood renewal, transport reform, building retrofit, and the reorganization of energy and waste systems belong as much to eco-city practice as new towns. The planning conditions differ fundamentally: new development offers control over layout and infrastructure; the existing city brings inherited networks, property rights, institutions, cultural values, and residents into every decision.

Comparative work on urban expansion in Europe and China points to a related distinction. Controlling the outward growth of urban land is only part of the task. A shift from land-centered expansion towards people-centered development connects land-use regulation and urban design with infrastructure provision, collaborative planning, and community development [21]. New districts also require a social fabric, accessible services, functioning public space, and institutions able to remain after construction has ended. A district cannot be assessed only as a completed physical product; the decisive question is whether it becomes a viable part of the city in which people can live, participate, and adapt over time.

2.4 Metabolic and infrastructural thinking opened the city to wider territories

Another line of inquiry shifted the emphasis from visible form to flows, stocks, and networks. Urban-metabolism studies ask where resources originate, how they pass through cities, where they accumulate, and where residuals are sent [22]. Life-cycle approaches extend the accounting boundary beyond the municipal territory and the operating phase of a building [23]. The city appears here less as a bounded object than as a concentration of dependencies, while infrastructure gives those dependencies a durable spatial form. Energy, transport, water, waste, communication, and public-service networks connect households and firms with landscapes and regions; they organize access, exposure, and future development possibilities. Once built, they may enable ecological alternatives or close them off for decades. A high-performing building or district is therefore inseparable from the networks to which it is connected.

The discussion about green infrastructure and nature-based solutions brought urban nature into this infrastructural reading. Parks, trees, wetlands, rivers, soils, and ecological corridors came to be understood as a connected system with multiple functions. Cooling, drainage, biodiversity, health, and recreation can be provided in the same spatial network, but not by designation alone. Land security, maintenance, finance, and statutory planning determine whether those functions endure. Without institutionalization through comprehensive urban and regional planning, green infrastructure remains vulnerable to sectoral mandates and project-by-project implementation [24]. Nature-based solutions have subsequently connected ecological restoration more explicitly to climate adaptation and well-being [25].

Climate change sharpened the discussion. Mitigation brought energy demand, supply, mobility, and embodied emissions to the fore; adaptation drew attention to heat, flood, drought, and the capacity to live with disturbance. These agendas frequently reinforce one another, but they can also produce difficult choices—for example, between compactness and heat exposure, protection and displacement, or rapid decarbonization and affordability. Resilience is itself a multipurpose concept. Its planning meaning depends on resilience of what, to what, and for whom [26,27].

2.5 Circular, regenerative, and digital approaches broadened the field

Circular-city approaches continue the metabolic line by seeking to slow, narrow, and close resource loops. Repair, sharing, adaptive reuse, remanufacturing, recycling, industrial symbiosis, and design for disassembly aim

to retain the value of buildings, materials, products, water, and land [28]. The apparently simple image of a loop has demanding spatial implications: land must be reserved, facilities and logistics connected, and relationships among producers and users maintained. Regenerative design begins from a different ambition. Instead of doing less damage, it asks whether development can contribute to the renewal of ecological and social systems. Soils, water cycles, biodiversity, place-based knowledge, and stewardship come into view [29]. The question is attractive but not innocent. Regeneration requires a baseline, a territory, and actors with the authority to decide what is to be restored and for whom.

Digital technologies have added another set of instruments. Sensors, geographic information systems, building-information models, artificial intelligence, and digital twins can support monitoring, scenarios, maintenance, and the representation of environmental inequality. Their growing use explains the frequent intersection of smart-city and eco-city programs. Digital capability, however, is only consequential when information enters planning and operational decisions. Objectives, data ownership, model transparency, organizational capacity, and public legitimacy are as important as technical sophistication [30].

2.6 A diverse field still retains an ecological core

The streams in Fig. 1 overlap. The dates indicate approximate emergence or renewed prominence, not a succession of models. Pollution control did not become obsolete when climate policy appeared; urban form remains relevant beside metabolism; digital management does not displace ecological knowledge or community action. What changed was the combination and relative weight of the concerns.

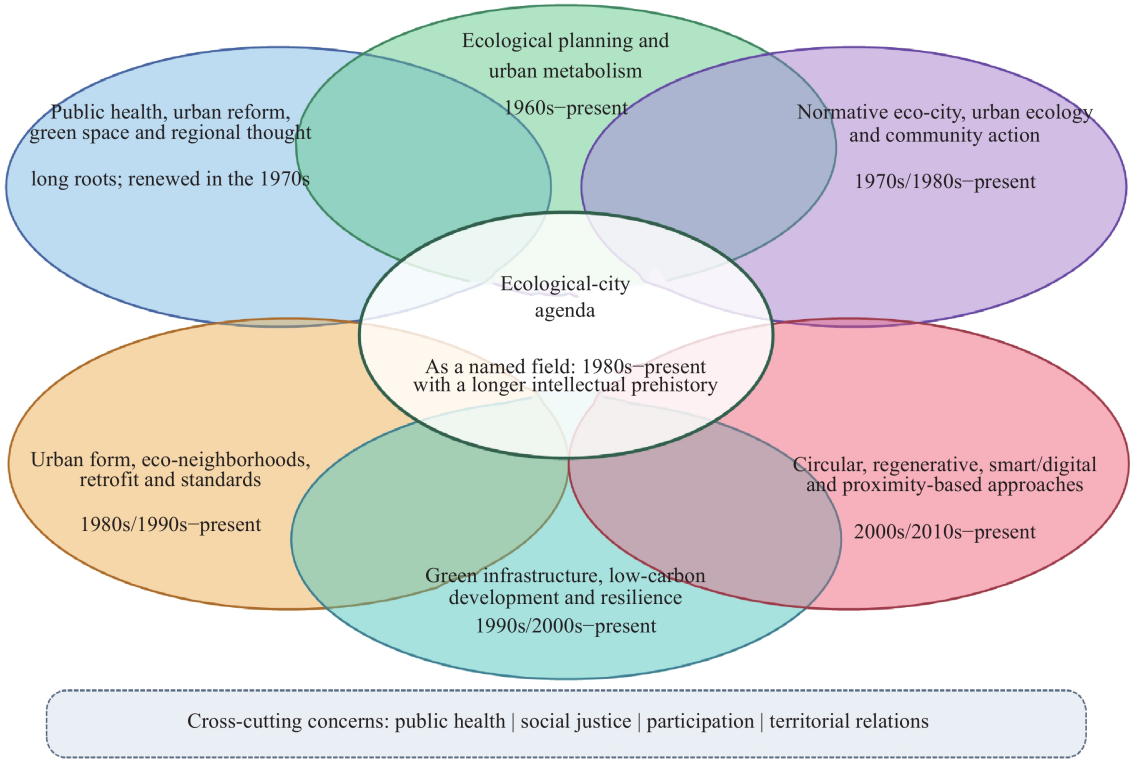


Fig. 1 Overlapping intellectual and practical streams shaping the ecological city agenda. Dates indicate approximate emergence or renewed prominence, not discrete phases.

Diversity has been accompanied by efforts to standardize. Indicators, certification schemes, international networks, and city comparisons translate ecological ambitions into comparable objects. The Leverhulme International Network "Tomorrow's City Today" found common themes among eco-city frameworks but also marked differences in indicators, standards, governance, and local interpretation [31]. Standardization may clarify a commitment and make comparison possible. It may equally favor what can be counted, detach an indicator from its planning context, or reduce the eco-city to a mobile brand.

After four decades, the common ground is modest but identifiable: an effort to reorganize urban development in relation to ecological systems through spatial planning, infrastructure, resource use, restoration, and collective action. This is also the boundary of the concept. A low-energy building belongs to the ecological city tradition when its location, infrastructural connections, embodied resource demand, and effects on later development are considered together; a digital platform becomes relevant when information alters the management of energy, water, mobility, land, or ecological risk. Technology, greening, or certification alone is insufficient. The boundary will remain disputed, but without it the ecological city becomes little more than a promotional synonym for desirable urban development. Nor can it be reduced to the efficient management of urban resource demand if improved environmental performance leaves patterns of exclusion or exposure intact. A socially beneficial project, conversely, cannot claim ecological significance without confronting material demand and territorial dependency. Ecological and social relations are analytically distinguishable, but urban practice binds them together.

3 From Ecological Initiatives to Sustained Urban Eco-Transformation

Ecological city ideas acquire practical meaning through projects, policies, investment, maintenance, and changes in use. The difficulty is not to choose between project and transformation. It is to understand how an intervention enters a wider urban system and whether successive interventions begin to influence ordinary decisions.

Incrementalism is not the problem in itself. Most urban transformation is incremental because cities cannot be rebuilt as a whole. The issue is cumulative direction. Repeated investments in road expansion, peripheral land development, or premature replacement can lock in pressure, just as successive retrofit, transit investment, and protection of ecological networks can redirect it. Projects become transformative through the path they reinforce or interrupt, not through novelty or scale alone. Transformation is therefore a matter of managing sequences and dependencies, not simply delivering a portfolio.

3.1 Projects become transformative through urban and territorial relations

Urban ecological action usually takes the form of a recognizable object: a certified building, an ecological district, a restored river, a transit line, a renewable-energy installation, a green corridor, or a digital platform. This is unavoidable. Change has to be designed, financed, built, operated, and experienced somewhere. The problem begins when the boundary that makes the project manageable is also used as the boundary of explanation.

A highly efficient building may produce substantial travel demand when employment and services are distant. A landscaped district may cool its immediate surroundings while requiring intensive irrigation and maintenance. A waste-recovery facility may raise the recycling rate while material consumption continues to increase. The reverse is also possible: a modest project may influence regulation, professional practice, investment priorities, or user behavior. Project performance and transformative effect are therefore related but different matters. Masdar makes the distinction especially visible: it was reduced in scope and repositioned around clean-technology development [20]. The case is exceptional, not representative, but it shows why a plan, a technical system, its implementation path, and its metropolitan connections cannot be assessed separately.

Projects and municipal policies require boundaries; ecological processes and resource systems rarely respect them. Water security depends on catchments, electricity on regional grids and generation sites, mobility on labor and housing markets, and construction on distant material sources. Waste may disappear from the municipal account because it is treated elsewhere. A favorable balance within one territory may thus be produced by burdens carried in another. Drawing an ever-larger boundary is not a solution, because different processes have different geographies. Building performance must be related to neighborhood form; neighborhood development to metropolitan mobility and housing markets; municipal land use to ecosystems and watersheds; local consumption to resource-producing territories. A useful boundary does not claim to be complete. Rather, it explicitly states which relationships, benefits, and burdens it includes and which it leaves out.

Construction makes these relations particularly tangible. Demand in a growing city affects extraction landscapes and communities elsewhere, while demolition and replacement create material flows that disappear from site-based accounts. Urban demand, material supply, life-cycle impacts, land-use regulation, and responsibilities after extraction or disposal therefore belong to the same analytical field [22,23]. The same territorial reading changes the status of urban nature. Rivers, biodiversity networks, ventilation corridors, soils, and food systems cannot be planned from the center outwards and stopped at the municipal border. The ecological city is a node within urban–regional and urban–rural relations, not a green enclave with an improved internal balance.

3.2 Long-term performance depends on stocks, life cycles, and maintenance

Eco-city projects are often judged at approval or completion. Targets for energy, water, green space, transport, and waste are compared with a baseline, and success is demonstrated through projected or initial performance. Cities, however, consist mainly of accumulated stocks—buildings, roads, pipes, utilities, public spaces, soils, and vegetation—that outlast both project organizations and political terms.

What happens after completion is consequently part of ecological performance. Green and blue infrastructure needs secure land and care; energy systems need monitoring and renewal; public transport needs service finance; digital platforms need maintained data and interoperability. Use, climate, technical ageing, institutional continuity, and recurrent budgets may confirm a design assumption or render it meaningless. Responsibility for operation is not a minor implementation detail.

Life-cycle analysis also unsettles the preference for the new. Existing buildings and infrastructure embody carbon, materials, capital, labor, cultural meaning, and social relations. A replacement may be efficient in operation while producing construction emissions, waste, financial burdens, and displacement. Continued use, repair, retrofit, adaptation, selective replacement, and reuse must therefore be compared rather than arranged in a presumed hierarchy [23]. For cities with long histories in particular, the ecological city agenda is largely an agenda for working with what already exists.

3.3 Technical options require institutionalization and strategic leadership

Many urban ecological problems persist in the presence of workable technical options. Green roofs, district energy, water-sensitive design, material recovery, building retrofit, low-carbon mobility, and real-time monitoring are never implemented by technology alone. They pass through planning law, land ownership, engineering standards, procurement, finance, organizational mandates, operating budgets, and political priorities.

Institutional arrangements enter the substance of a project long before implementation. They shape which problem reaches the brief, which alternatives can be considered, which costs are recognized, and who remains responsible. Green infrastructure makes the problem unusually clear: drainage, cooling, biodiversity, recreation, and health benefits fall across several agencies and may consequently fall between their mandates. Its effectiveness therefore depends on comprehensive urban and regional planning rather than environmental designation alone [24]. Exceptional funding may deliver a pilot, but it does not settle land status, recurrent finance, or responsibility for maintenance.

Institutionalization means “mainstreaming”, i.e., moving ecological objectives into ordinary strategies, land policies, appraisal procedures, regulations, budgets, and maintenance responsibilities. Coordination is necessary but insufficient. Strategic leadership has to establish priorities, decide under conflict, align organizations, and sustain a direction across political cycles. It also has to recognize opposition. Residents may support environmental goals in general and resist particular changes to density, mobility, taxation, land use, or local amenities. Invoking the public interest does not dissolve these differences. Leadership requires accountability and must be coupled with deliberation and co-production.

From a spatial-planning perspective, this is a problem of horizontal and vertical integration. Horizontal integration concerns the relation among departments and infrastructure providers whose decisions shape the same place but follow different legal mandates, technical standards, and budget cycles. Vertical integration concerns the relation among municipal, metropolitan, regional, and national decisions. A municipality may control local land use yet depend on another authority for energy systems, transport investment, flood management, or housing finance. Conversely, national targets may remain spatially indeterminate until local and regional planning assigns land, sequences investment, and reconciles competing uses. An ecological city strategy that lacks either form of integration may be ambitious in language but weak in consequence.

Comparative experience cautions against treating integration as the product of a particular administrative form. Chinese city-building can align land development, infrastructure finance, and construction at considerable speed; yet continuity may weaken when a project organization withdraws, recurrent budgets are thin, or residents have little influence over later adjustment. Many European systems offer more settled municipal procedures and channels for participation, but dispersed authority and slow investment coordination can frustrate action across metropolitan and ecological territories. Neither arrangement guarantees an ecological result.

In both settings, the decisive issue is whether decisions about land, infrastructure, services, finance, and community life remain connected from development through use. From a people-centered perspective, an urban extension becomes part of the city through durable services, public space, community relations, and governance, not through construction alone [21]. The same principle applies to retrofit. Technical renewal becomes urban change only when it remains affordable, usable, maintained, and open to revision by those who live with its consequences.

Strategic leadership should not be confused with administrative centralization or the personal authority of a prominent office-holder. It requires a defensible direction, continuity across organizational boundaries, and a willingness to revise decisions when evidence or public deliberation demands it. Ecological priorities become credible when they survive a funding program, a single political term, or a flagship site and begin to influence routine land allocation, infrastructure renewal, procurement, and operating expenditure. Implementation is not a final phase after planning. It is the process which informs planning, and through which a planning proposition acquires institutional reality.

3.4 Efficiency gains must be tested against demand and distributed burdens

Ecological performance has an economic history. Capital requirements, land values, operating costs, maintenance obligations, household affordability, municipal revenue, and access to finance shape what is built and what endures. Growth and real-estate development may provide resources for environmental investment while simultaneously increasing floor area, land consumption, mobility, and material demand. Relative efficiency should therefore not be confused with an absolute reduction in pressure. Efficient buildings may become larger or be operated at higher comfort levels; faster mobility may generate additional travel; improved recycling may accompany growing throughput. Rebound effects do not negate efficiency measures, but they show that technology does not determine the scale of demand on its own [32].

The financial cost reported by one organization is equally not the total burden of a project. Maintenance may be transferred to another department; health effects to households; displacement risk to tenants; environmental damage to another territory or a later generation. Economic appraisal should make visible who pays initially and over the life cycle, who receives savings and increases in value, and which effects remain outside the calculation. Not every ecological or social value has to be monetized for these responsibilities and trade-offs to be made explicit.

The economic question is ultimately directional: whether ecological action redirects investment and demand. Land-use policy matters when it reduces the need to travel; building policy when it extends useful life; circular strategies when they displace primary material demand; and infrastructure budgets when they privilege maintenance and adaptation over continual expansion. These are matters of political economy as much as technical optimization.

3.5 Ecological improvement is inseparable from spatial justice

Ecological interventions redistribute access to land, housing, mobility, green space, infrastructure services, and protection from risk. They influence property values, employment, public expenditure, and the ability to take part in decisions. Justice cannot therefore be attached to an environmental assessment at the end; it is present in the production and durability of the outcome itself.

Urban greening is a case in point. New parks, restored waterways, and improved public space can provide substantial environmental and health benefits. Under particular market and policy conditions, the same improvements may raise property values and contribute to displacement [33]. Retrofit can lower energy demand and raise rent; protective infrastructure can favor high-value districts; digital services can widen access while excluding residents who are poorly connected or not tech-savvy. Environmental quality and social integration cannot be planned in separate phases because the distributional effect begins with the location, ownership, and financing of the intervention.

Participation does not in itself correct unequal control over land, finance, knowledge, and infrastructure. Co-production is a stronger proposition: affected residents and community organizations work with planning authorities, service providers, businesses, and research institutions to define the problem, design and implement a response, and assess its consequences. It has to reveal whose knowledge counts, who can initiate action, and who receives the benefit, carries the burden, or receives protection from displacement. Co-production will not remove conflict, but it can expose spatial knowledge otherwise missed and create a more credible basis for stewardship.

3.6 Transformation depends on the connections that projects create

Across these mismatches, the same planning difficulty appears: a relation that matters to the result lies outside the immediate object, mandate, period, or account. Better communication may help, but connection sometimes requires a material or institutional reconfiguration—redirecting investment, changing land-use patterns, adapting inherited infrastructure, reallocating responsibility, or phasing out a damaging practice. Collecting all these factors under a new capacity concept would create more confusion than clarity. Spatial conditions, actor capabilities, material resources, and processes of change are related, but they are not interchangeable. The object of transformation has to be specified before the resources and capabilities available to change it can be assessed.

4 A Spatial-Relational Perspective on Ecological Transformation

4.1 Spatial relations are not another form of capacity

Capacity concepts already have established meanings in planning, governance, resilience, and transition research. Institutional capacity directs attention to knowledge, networks, legitimacy, and resources for collective action; in Healey's account, this was never only an organizational matter, because relational planning and place-making affect what can be known and achieved in a place [34]. Adaptive capacity concerns adjustment under changing conditions; transformative capacity concerns the agency, learning, experimentation, and networks through which systemic change may occur [35]. Spatial-planning research has, in addition, developed concepts of territorial capital, territorial governance, and place-based development.

Leadership, collaboration, finance, and learning become consequential only through changes made somewhere: to land-use patterns, buildings, infrastructure, ecological processes, resource flows, territorial relations, and access to environmental goods. Capacity research explains what actors and institutions are able to mobilize. A spatial-relational perspective understands space not as a container but as a network of relationships, interactions, and processes between objects and people, and it directs attention to where those capabilities become effective and which urban relations they alter.

The term "spatial" refers here to more than urban form. Buildings, parcels, networks, landscapes, and ecological systems have location, material form, and durability. Their significance arises partly from connections with other places, scales, actors, and flows. Those relations are also socially produced: land values, segregation, access, exposure, and development priorities bear the imprint of political power and collective practice. The concept is broad enough to include territorial relations without becoming a synonym for everything that happens in a city.

A capacity normally belongs to an actor, organization, network, or governance system and describes an ability to mobilize resources or accomplish a task. The spatial-relational perspective instead takes an intervention and the relations it changes as its primary object. Actor capacities remain part of the explanation, but they are not conflated with the object being explained. This matters empirically. A city may possess substantial technical expertise and fiscal resources while producing an intervention poorly related to metropolitan mobility or regional water systems. By contrast, another city may work with limited resources yet alter a strategically important relation through land policy, infrastructure coordination, or a durable community arrangement where institutional and political conditions permit.

4.2 The spatial core has four domains

The spatial core of transformation, i.e., the territory where transformation materializes, is characterized by four domains:

Urban configuration and accessibility concerns the arrangement and connection of land uses, density, built form, public space, ecological networks, and mobility. Analysis centers on whether daily services are accessible, housing and employment patterns support low-carbon mobility, and ecological networks are continuous enough to perform their intended functions. Compactness is not treated as a universal prescription. Its consequences vary with land-use mix, climate, design, infrastructure, and social conditions [16,18,19].

Infrastructural and metabolic integration follows energy, water, materials, waste, mobility, buildings, green infrastructure, and digital systems across their life cycles [22,23]. Existing stocks may be maintained, adapted, reused, connected, or replaced; the choice affects both present performance and future options. Efficiency gains count as ecological progress only when their effects on total resource demand and displaced burdens are also visible. Here ecological ambition encounters the material systems that engineering and planning can most directly influence.

Multiscalar territorial relations connect buildings and neighborhoods with municipalities, metropolitan regions, watersheds, ecological networks, supply systems, and hinterlands. Administrative and project boundaries seldom correspond neatly to the processes being governed. Changing the boundary may reveal that a local gain rests on resource extraction, pollution, or risk elsewhere. There is no single optimal scale: functional territories overlap, and planning institutions must decide which of them matter for the decision at hand.

The distribution of benefits, risks, and opportunities brings housing, mobility, green space, infrastructure, environmental quality, and climate protection into the same spatial account as pollution, displacement, transition costs, and exclusion [33]. Location and connectivity matter, but so do property, price, regulation, and political influence. Distribution belongs to the spatial core because justice is produced through the intervention itself; it is not a social qualification added after implementation.

4.3 Transformation has four enabling conditions

Change in these domains depends on four enabling

conditions, i.e., factors which make transformation possible and durable. They are essential to spatial transformation:

Strategic leadership and institutional mainstreaming establish priorities, manage conflict, align organizations, and place ecological objectives within rules, standards, land policy, procurement, investment, operating budgets, and maintenance [24]. Leadership may be distributed across public and civic actors; accountability and decision-making authority cannot be left indefinite.

Economic viability and transparency concern credible finance, life-cycle budgets, affordability, maintenance, opportunity costs, external effects, and the allocation of burdens [32]. The relevant test is not only whether construction can be financed, but whether investment can be redirected and the resulting system can be operated without concealing who bears the burdens.

Social co-production and legitimacy bring residents, communities, public bodies, infrastructure providers, firms, and knowledge institutions into problem definition, planning, design, implementation, monitoring, and stewardship [21]. The distinction from consultation is important: co-production allows practical and place-based knowledge to change the decision rather than merely respond to it.

Adaptive learning is required because ecological change unfolds under uncertainty. Monitoring, evaluation, institutional memory, experimentation, and public reasoning have to lead back into plans, standards, budgets, and responsibilities [35]. Data and findings that do not influence decisions remain information; they do not contribute to learning.

4.4 The spatial core and enabling conditions of transformation are interrelated

Fig. 2 brings the four spatial domains and four enabling conditions into a relational diagnostic cycle linking bottleneck identification with implementation, effectiveness evaluation, and feedback. Urban ecological transformation depends not on the presence of these elements alone, but on how they interact. Examining their connections, dependencies, and trade-offs helps to identify the bottlenecks that prevent ecological interventions from becoming connected, durable, and just forms of urban transformation.

4.5 A relational and bottleneck-sensitive diagnostic framework is required

The domains should be read through their relations. Configuration influences infrastructure demand; infrastructure shapes access and development; territorial connections determine where resources and burdens appear; distribution affects legitimacy and political durability. The enabling conditions have comparable dependencies. Leadership without finance cannot sustain action; finance without legitimacy may intensify opposition or displacement; monitoring without authority may leave decisions unchanged. Because these relations are interdependent, bottlenecks matter. A city may have sophisticated environmental data and little authority to act, ambitious plans and no operating budget, or high-performing infrastructure poorly connected to land use. An ecological improvement may be politically fragile

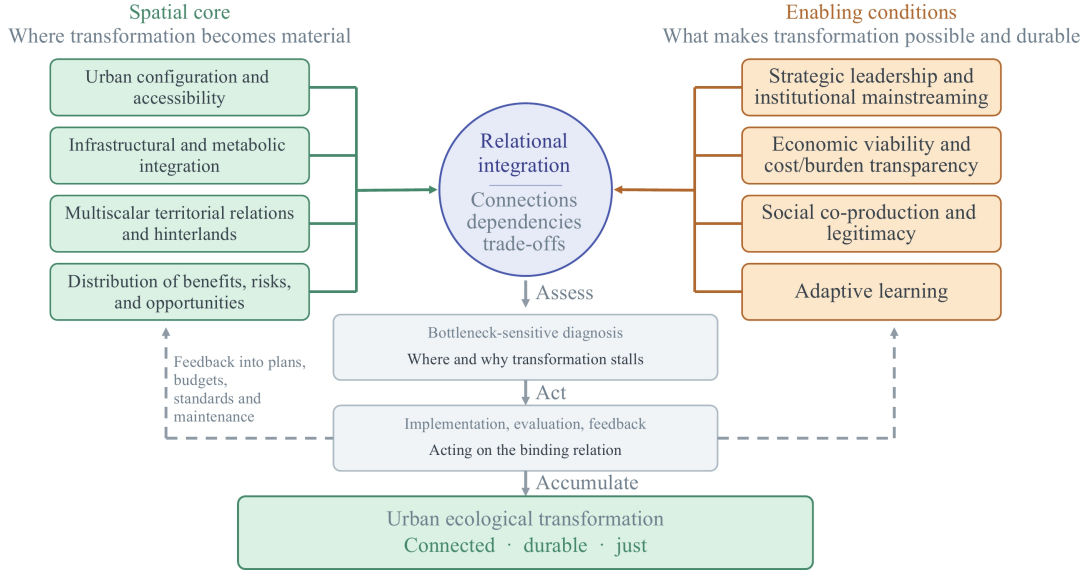


Fig. 2 Spatial-relational diagnostic cycle for urban ecological transformation: spatial domains, enabling conditions, bottleneck diagnosis, and the implementation, evaluation, and feedback through which transformation accumulates.

because it produces displacement. In such cases, identifying the binding relation is more informative than calculating an aggregate score.

Physical size is a poor proxy for transformative importance. A modest retrofit program that changes building regulation, finance, professional skills, and/or municipal procurement may have wider consequences than a large new district protected by exceptional administrative and financial arrangements. What travels beyond the site is not necessarily the project model. It may be a standard, a budget rule, a professional routine, or a different expectation about what urban development should deliver.

In practice, the path from project performance to wider change is often broken at one point. Strong design, finance, and data cannot compensate for an unresolved land conflict, the absence of operating responsibility, or an infrastructure network that prevents connection. The weakest relation does not determine every outcome mechanically, but some constraints are binding. Finding them is usually more informative than producing an average score for an otherwise impressive project. Persistence supplies a different test. An intervention becomes part of urban transformation when plans are revised, budgets reassigned, standards changed, maintenance secured, and professional routines adapted. Affected groups must also retain ways to contest what the intervention produces. Replication is only one possible sign of influence; elsewhere, learning may lead to modification, or to a decision not to repeat a form of development whose ecological or social costs have become apparent.

No single urban form or institutional arrangement follows from this analysis. Fast-growing, stagnating and shrinking cities confront different stocks, demands, and fiscal conditions; metropolitan regions, small cities, informal settlements, and places dependent on extractive economies do not begin from the same position. Comparison remains possible if it starts with the relations that are decisive in each context and the bottlenecks that prevent an initiative from altering the wider course of development.

4.6 Reading outcomes over time

Carbon emissions, energy intensity, water use, green-space provision, transit share, biodiversity, and waste recovery remain indispensable measures. They indicate a condition or change, but rarely explain how it was produced or whether it will last. A spatial-relational assessment therefore follows an outcome back to the decisions, territories, infrastructures, and groups through which it came about. Time is central. A favorable outcome may be temporary because it depends on exceptional finance, unmaintained infrastructure, or a project organization that disappears. Strong institutions with modest initial performance may, conversely, create the basis for cumulative change. Assessment should distinguish a result at completion from a transformation path and revisit both after use, maintenance, political change, and new investment have taken effect.

5 Implications and Conclusions

5.1 Four decades produced accumulation, not succession

After four decades, the ecological city cannot be described as a succession in which one model replaced another. Normative reform, urban form, metabolism, infrastructure, climate action, circularity, regeneration, justice, and digital management accumulated and interacted. The field became richer, although its widening vocabulary made conceptual boundaries less secure. The diversity of initiatives does not establish that there has been fragmentation. Projects are a normal means of organizing urban change, and retrofit has been at least as important as new settlement. Diversity may reflect the complexity of urban–ecological relations, differences in political and institutional settings, and distinct problem framings; fragmentation begins when separate actions remain isolated from one another and leave the surrounding rules, investments, and practices unchanged.

The difference between improvement and transformation is conditional, not categorical. An initiative acquires transformative significance as it changes relations outside its immediate object, addresses inherited stocks and wider territories, enters ordinary budgets and responsibilities, remains viable in use, and can be contested and revised by those affected. No project will satisfy all these conditions at once. The point is to establish how far an intervention has begun to influence the development path beyond its own completion.

5.2 There are implications for urban science, engineering, and planning

The unit of analysis is crucial for urban science, engineering, and planning. Buildings, transport, energy, drainage, ecological networks, land use, and digital services cannot be optimized independently and then assumed to form an ecological whole. Technical performance has to be read against spatial change, user behavior, climate risk, demographic development, and distributional effects. In many urban regions, the decisive

ecological work lies in maintenance, retrofit, adaptation, and reuse. Life-cycle evidence can inform choices among demolition, refurbishment, infrastructure renewal, and continued use, but operational efficiency is not the only criterion. Existing buildings and networks embody materials, public investment, cultural meaning, and social relations. The technically most efficient replacement may still be the poorer urban decision.

Evaluation has to look beyond completion. Emission reduction, lower energy use, improved cooling, and reduced flood risk remain important, but they say little about whether later investment and demand have changed, an operating responsibility has been established, or a local benefit has been connected to regional systems. Displacement and transferred burdens may also appear only after the reported performance target has been met. Economic and distributional evidence must therefore enter the same decision rather than be placed in separate assessments. Capital cost, operating finance, affordability, maintenance, increases in value, environmental externalities, and the allocation of risk have to be visible across actors and life-cycle stages. Zero-sum considerations become relevant: One actor's saving may otherwise be secured by another group, department, or territory carrying the burden. This is the difference between documenting a project's performance and establishing its place in a transformation path.

For planning practice, the broader implication is a renewed emphasis on public responsibility for spatial consequences. This does not prescribe one administrative model. European systems of municipal and regional planning, Chinese forms of state-led urban development, and the more fragmented arrangements found elsewhere distribute authority differently. Comparison is useful when it examines how land, infrastructure, finance, and participation are connected in each setting, not when it transfers an institutional instrument without its legal and political conditions. The ecological city should therefore be evaluated through the effectiveness and legitimacy of its planning relations: which authority can commit land and investment, which institutions can work across functional territories, and which publics can influence decisions that redistribute environmental benefits and burdens.

Integrated planning also requires selectivity. Not every interdependence can be governed simultaneously, and the call for integration can become a substitute for deciding what matters. Strategic planning contributes by identifying a limited number of relations whose alteration would redirect the development path, for example, the relation between housing growth and regional transport, between flood protection and land development, or between building renewal and energy infrastructure. The task is to establish priorities without losing sight of effects that appear beyond the chosen sector, territory, or time horizon.

Digital technologies are planning support, not evidence of ecological progress in themselves. Sensors, artificial intelligence, geographic information systems, and digital twins can reveal flows and inequalities, compare scenarios, and support maintenance. Their contribution rests on transparent models, accountable use, and the ability of organizations and publics to act on the information. A zero-energy target, for example, becomes more than a technical benchmark when it is treated as a planning object between city-scale ambition and operational spatial decisions [36]. Technical systems then become structuring elements of planning, not add-ons assessed after spatial choices have been fixed.

5.3 Research agendas may need to be altered

The conceptual history remains uneven. European municipal and regional planning, North American environmental activism and ecological design, Asian state-led development, and initiatives in the Global South have not entered the international eco-city literature on equal terms. Comparative research needs to recover these distinct traditions before common concerns can be identified without imposing a universal chronology. It also needs time. New developments, urban extensions, and retrofit programs have to be followed beyond approval and completion because maintenance, institutional continuity, social consequences, economic viability, and effects on surrounding systems may become visible only after five, ten, or twenty years. Planning histories, budget and procurement records, infrastructure data, interviews, and residents' experience would reveal different parts of that trajectory; no single performance dataset is likely to be sufficient.

Causal claims also require more care. Ecological projects emerge from prior institutional capabilities, favorable coalitions, investment decisions, and spatial conditions. The same projects may later alter regulation, infrastructure, land markets, professional practice, and public behavior. Research designs must account for this reciprocity if they are to explain why incremental interventions accumulate in one city yet remain isolated in another.

Operationalization presents a different problem. Indicators can be developed for spatial domains and enabling conditions, but combining them into a single ranking too quickly would remove the relations that matter most. In many cases, the location of a bottleneck will be more useful than a composite eco-city score. Comparative case studies could begin with a common set

of questions while allowing the relevant territorial boundary and institutional arrangement to vary by context. The available evidence is strongest for formally planned projects in cities with comparatively well-developed administrative and technical institutions. The account is less empirically grounded where informal urbanization is extensive, public authority is fragmented, or basic service provision remains unsettled. The literature and examples discussed here are drawn mainly from formally planned contexts in Europe, North America and Asia, especially China; their transferability therefore requires further comparative testing. Comparative work in the Global South and in post-socialist and transitional contexts is particularly needed because enabling conditions may differ fundamentally. Political-economic structures, public resistance, and unequal possibilities to shape ecological change are likely to alter both the relevant spatial relations and the meaning of institutional capacity.

5.4 Conclusion: the ecological city is a transformational planning task

The concept of the ecological city is not obsolete after four decades, but its use requires discipline. It cannot denote a finished urban image, a standard development package, or the sum of available green technologies. Ecological urban development is consequential when it reorganizes the spatial relations among settlements, infrastructure, resource territories, ecological processes, and social access, and when these changes enter the institutions that shape subsequent development.

The ecological city is therefore better understood as a continuing and contested planning task than as a model. Its test lies in the ordinary city: in decisions about land, maintenance, repair, adaptation, infrastructure renewal, and the distribution of costs and protection. Ecological transformation becomes credible when those routine decisions change and when the resulting benefits and burdens can be negotiated openly across places and groups.

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Author contributions Bernhard Müller contributed to the conceptual and theoretical development of the article and substantially revised the manuscript. As the main author, Ting Yang elaborated the original line of argumentation, based on her recent work, and prepared the original draft and figures of the manuscript, reviewed the relevant literature, and coordinated the internal revision process. Paulina Schiappacasse contributed to the conceptual development and critically reviewed and revised the manuscript. All authors reviewed and approved the final manuscript.

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