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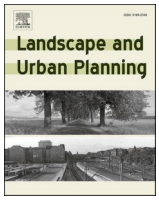

Stakeholder networks underpinning the transformative practice of urban roadside verge greening

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HIGHLIGHTS

- Diverse sectors and stakeholders were connected and contributed to urban verge greening and management.
- Information flows comprised almost 80% of the network resource flows.
- Local government authorities, a water utility program and peak bodies were key knowledge brokers.
- Network communities had distinct functions and composition that transcended traditional silos.
- Social network analysis can aid in understanding the adoption of marginal urban greening or sustainability actions.

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ABSTRACT

Understanding how social networks facilitate the adoption of marginal urban greening actions can provide valuable impetus to guide transformative change in urban landscapes, which are under multiple social and environmental stressors globally. Social network mapping of resource flows, particularly information sharing, is one tool for understanding the emergent and transformative urban greening practice of landscaping roadside verges with native and/or waterwise plants. Urban roadside greening in Perth, Western Australia, while formerly prohibited, is now increasingly accepted and advocated for by multiple sectors, as a nature-based solution that provides multiple ecosystem services and social-ecological benefits. This study drew on participatory stakeholder mapping to examine the stakeholder network of non-residential actors connected with verge greening. Using social network analysis, we found almost 80% of resource flows across a large network of diverse stakeholders were information related. We identified top providers, recipients, brokers, as local and state governments and peak bodies, and, to a lesser extent, key individuals, community groups, nurseries, residents and environmental consultants and developers. The network was characterized by four dominant and five smaller communities, which we classified into a typology based on composition, structure (quantitative material), and contextual knowledge, including function, dominant roles and responsibilities (qualitative material). These were the 'planning and development hub', 'governance enablers', 'water efficient hub', 'greenspace hub'. The five smaller communities were 'advocates', 'transformers', 'new vision', 'local networks' and 'early adopters'. The network analysis provides evidence of communities that transcend traditional sector or actor silos, commonly converging around local governments as key knowledge brokers.

1. Introduction

Globally, cities are facing intersecting environmental and social pressures, including growing human population, climate change, declining biodiversity and tree canopy cover, and loss of human-nature connection. As a result, public green spaces are under increasing pressure to deliver multiple objectives (Grose, 2009; Norton et al., 2015; Reyes-Riveros et al., 2021). The linear strips of publicly owned land

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along roadsides, variously termed street verges, urban roadside vegetation, nature strips or easements, are notable for their potentially substantive contribution to the overall area of public open space (Marshall, Grose, & Williams, 2019; Nassauer, Webster, Sampson, & Li, 2021). Street verges accommodate a mix of objectives, including access, provision of utilities (water, energy and communication), aesthetics (such as providing a pleasant streetscape), and ecosystem services, including habitat provision for native species, water quality management and temperature regulation (Ligtermoet et al., 2022; Säumel et al., 2016). Prior work has identified the contribution of street greening or gardening to a range of social-ecological issues, including social outcomes related to mobility, equity and social activation (Dushkova et al., 2021; Marshall et al., 2019), health (De Vries et al., 2013; Pereira et al., 2013; Vich et al., 2019), equity and justice aspects (Cooke et al., 2020; Porter et al., 2020), education and learning (Church, 2015), as well as environmental benefits (Aronson et al., 2017) within the urban environment.

Street verges represent the intersection of public and private open space, often jointly managed by public authorities (for instance, maintaining street trees) and private residents (for instance, mowing grass on the verge adjoining their home). Public authorities in some European cities have introduced initiatives to manage streetside vegetation as wildflower meadows to support pollinators and urban biodiversity (Mody et al., 2020). In many cities, a small but growing proportion of local residents are becoming more actively involved in managing low-growing vegetation on the street verge, often by extending the area of garden space from their property boundary to the edge of the road. Such forms of citizen-led 'civic greening' are subject to varying levels of regulation and restriction, depending on the location (Bendt et al., 2013).

Cities are increasingly requiring nature-based solutions to address interacting social, environmental and human health issues, though adoption of such solutions can be challenging given the knowledge, resources, behaviour change, and cross-sectoral support required. In the Perth Metropolitan Area, Australia, street trees have been recognised as a crucial solution to mitigate urban heat effects, support native biodiversity and threatened species, and contribute to residents' place attachment (Dickinson & Ramalho, 2022; McGrath et al., 2024; Norton et al., 2015). The installation of low growing, waterwise, native vegetation by residents along metropolitan street verges, however, has progressed from being generally prohibited to generally permitted within less than two decades. Initially inspired by various instances of 'guerrilla' gardening, one particular Local Government Authority (LGA) decided to change their restrictive verge gardening policy (Young, 27AD), which received national attention and prompted shifts in LGA verge policies. A recent audit indicated that 30 out of 31 LGAs in the Perth Metropolitan Area now permit some form of residential verge garden, mostly bound by guidelines on species characteristics, permissible height, and pedestrian access (Ligtermoet et al., 2021). Concurrently, the verges of arterial roads and intersections at many locations have been planted with mixes of native species (e.g. City of Joondalup, 2009; White Landscape, 2018). This emerging trend stands in stark contrast to the 'traditional' conception of street verges as a generally grassed area, originating with the historical 'lawnscape era' of the 20th century (Gaynor, 2020) and reserved for access, utilities, and off-street vehicle parking. Combined with the added pressure on public open spaces to fulfill multiple functions, the uptake of verge gardening and landscaping means that a growing number of stakeholders across the community, government and industry now have an interest, or stake, in verge management.

Understanding stakeholder social networks is a key consideration for natural resource management (Fazey et al., 2013; Reed et al., 2014) aiding in understanding power differentials, competing and/or shared interests (Prell et al., 2009), and opportunities for resource sharing (Barnes et al., 2020). As such, social network analysis (SNA) has been applied in various natural resource management contexts (Bodin & Prell, 2011; Groce et al., 2019; Guerrero et al., 2020). Yet, within the urban greening realm, its application (Bodin et al., 2019) to understanding flows of information and other resources among stakeholders has been limited to environmental stewardship of urban parkland (Enqvist et al., 2014; Ernston et al., 2010; Guenat et al., 2020).

In this study, we use social network analysis (SNA) to understand the uptake of verge greening among a network of stakeholders with substantially different roles in the management of street verges in the Perth Metropolitan Area, Australia. Drawing from interviews with government, industry, not-for-profit and community bodies, we map the exchange of resources (e.g. information, funding, materials, labour) between stakeholders to understand how their interactions influence the management of street verges, and how this has contributed to the acceptance and normalisation of a nationally uncommon, 'rebellious' civic greening practice. Residents, while recognised as an important stakeholder group, were not a focus of this network study, which focused instead on the entities shaping the conditions and norms to which residents respond. While there are several papers examining Perth residents' experiences and preferences related to verge gardening (Babington et al., 2023; Doll et al., 2023, 2024; Hughes et al., 2023; Hunt et al., 2022; Pauli et al., 2020) the gap remains in understanding the network shaping the conditions to which residents respond. The resources exchanged between stakeholders enable us to compile a matrix, which is used to conduct a SNA to elucidate how information and other resources flow between people, organisations and programs linked with verge greening. Coupled with information from interviews to gain a deep understanding of the complexities of network relations (see for example Bixler et al., 2020; Wutich et al., 2020), SNA is used to address the following objectives:

1) Identify network stakeholders and characterise resource flows related to verge management and greening;
2) Map the resource flows within the verge management and greening network to understand providers, recipients and brokers;
3) Characterise the community structure of the verge management and greening stakeholder network, and evaluate the key differences among and within different communities of stakeholders.

Our study provides insight into the resource flows, particularly information flows, supporting the normalisation of novel and transformative urban verge management practices, where multiple stakeholders with diverse roles and interests in the verge are involved, which may be relevant in a variety of other pressing environmental, public health, urban planning or sustainability transition contexts.

2. Methods

2.1. Study area and management context

The Perth Metropolitan Area lies within the South West Australian Floristic Region, a global biodiversity hotspot with exceptionally high plant species diversity and endemism, which has suffered extensive loss of natural habitats (Hopper & Gioia, 2004; Myers et al., 2000). The city has a Mediterranean-type climate with hot, dry summers and predominantly winter rainfall (Bureau of Meteorology, 2022). Total annual rainfall has declined since the 1970s, a trend that is predicted to continue due to climate change (Frederiksen et al., 2017). The city is home to around 2.2 million people (Australian Bureau of Statistics, 2021), with a sprawling suburban footprint of over 1,700 square kilometres (Demographia, 2022).

The responsibility for managing road verges in the greater Perth Metropolitan Area is split across different agencies and residents. A Western Australian (WA) State Government agency (Main Roads WA) has responsibility for verges adjacent to arterial roads. For all other roads, verges are vested with one of 31 distinct Local Government Authorities (LGAs). Management of trees within the road verge generally

falls to the LGA, while residents of adjacent properties are generally responsible for managing low-growing vegetation on the street verge. Utility agencies have authority over delineated above-ground and below-ground easements along the road that are used for the delivery of various services (*i.e.*, water, gas, electricity and communications) (Utility Providers Services Committee, 2018).

The typical view of Perth's street verges as under-utilised spaces occupied by grasses and weeds is being challenged by ideas that include greater plant structural and species diversity (Babington et al., 2023; Ligtermoet et al., 2022). Prior to about 2010, the prevailing approach of most LGAs was to restrict unapproved verge gardening by residents, and limit 'acceptable' verge coverings to lawn, gravel or other pervious treatments. Residents who 'broke the rules' were initially mostly in conflict with local authorities (e.g. Young, 15/2/2016). However, a growth in public interest for verge gardening, including with native and/or waterwise plants, has influenced policy change at the local government level in alignment with sustainability goals (e.g., reduce water use, improve liveability). Vibrant social media groups and neighbourhood initiatives have emerged around verge gardening,[1] and gardening television programs regularly feature 'verge gardening' segments. The City of Bayswater, northeast of central Perth, was the first LGA in Australia to completely remove restrictions on residential verge gardening, provided that safety and water management requirements were met (Young, 27AD). A councillor, prompted by a group of 'guerrilla' gardeners, championed the shift. Nowadays, many LGAs offer rebates, plants, subsidies, information, workshops and other incentives to residents interested in verge gardening (Pauli et al., 2021).

Beyond LGAs and residents, other actors have contributed to the uptake of verge greening. Water Corporation WA is a State Government Trading Enterprise (i.e., the public water utility provider) that has played a significant role by combining community education on waterwise gardening with support for LGA-led verge conversion incentives (Ligtermoet et al., 2021). In new urban subdivisions, some developers are including waterwise verge landscaping as part of the streetscape. Environmental consultants are increasingly incorporating water sensitive design elements along roadsides in new greenfield developments. Main Roads WA enacted the 'Wildflower Capital Initiative' to landscape major road interchanges with native plants (Main Roads, 2018, p.71). Authors have directly observed specialist landscaping small businesses and both mainstream and specialist native plant nurseries in Perth that now market services and products specifically targeting 'verge conversion' and verge gardening. While native or waterwise verges are still the exception rather than the norm (one recent audit of the Bayswater LGA indicated that 8 % of residential street verges are now gardens; Hunt et al., 2022), the trend is likely to grow in Perth, as well as in other cities facing similar intersecting pressures of water scarcity, biodiversity loss, climate change and population growth.

2.2. Participant identification and stakeholder initial categorisation

Informal urban green spaces, including street verges, are 'contested' spaces, where a range of different stakeholders exert some form of management authority, activity or interest (Stanford et al., 2022). A three-stage process was undertaken to ensure we adequately identified the stakeholder groups within the network (Ligtermoet et al., 2022).

Firstly, we undertook a comprehensive online review of relevant planning policies from LGAs, State Government departments, and utility providers, as well as of roles and position statements by advocacy, peak body, environmental consultancy, and landscaping organisations. The results of this review were combined with the subject knowledge and professional networks of the authors, and eight key stakeholder groups were identified: utility companies, State Government, Local Government Authorities, champions of change (urban greening advocates), peak bodies, developers, allied industries (horticulture, turf and irrigation), and environmental consultants.

Secondly, we conducted a stakeholder analysis to validate this grouping (following Reed et al., 2009), which resulted in no grouping changes, other than minor name changes. Fig. 2 depicts an 'interest-influence' conceptual diagram (after Reed et al., 2009), illustrating the relative positions of the eight stakeholder groups in relation to their power (influence) and interest in the verge space. We initially developed this diagram to conceptualise and refine the results of the interviews and social network analysis. Stakeholder groups with greatest influence are those with land ownership rights (State and Local Governments) or overriding access permission for utility maintenance (utilities), followed by direct verge management responsibilities (residents). Low influence was characterised by no ownership, direct management or regulatory responsibility, such as in the case of peak bodies. In addition, here 'influence' can also represent the 'level of' ongoing ownership or management (via policy, strategies and activities), and this may shape management over varying lengths of time. For example, developers may only have a short influence or level of activity shaping verges with suburban development plans and implementation, but this could have a lasting impact on how residents manage their verge. For several stakeholder categories, 'interest' in verge greening ranged from high to limited interest (Fig. 2). Further, within stakeholder categories, there are individuals or organisations highly interested in greening verges, as well as those for whom it is not core business or who are not engaged in this activity at all, as represented by the variable length of bars along the horizontal 'interest' axis of Fig. 2.

Residents were not interviewed in this research, as the focus was on entities shaping the conditions to which residents respond. This includes those who directly connect with residents through their role in managing verges, services provision, or education regarding verge gardening. Further, the group of urban greening advocates, or 'champions of change', includes individuals who are also resident verge gardeners, reflecting the perspectives of residents interested in verge gardening.

Thirdly, our data collection (see 2.3) provided a further opportunity to ensure we had adequately represented the stakeholder groups via our interview subset.

2.3. Data collection

From an initial list of 62 stakeholders (organisations, departments, companies or individuals), a subset of 42 leading or knowledgeable practitioners, policy makers, change makers, industry representatives and businesses were invited to participate, of which 24 were interviewed (13 were unresponsive and five declined). These interviews generated opportunities for snowball sampling (after Noy, 2008), with 25 contacts further suggested (spanning across all stakeholder groups except Utility). From these, six were chosen for interview, prioritising diversity across groups and given project resourcing constraints. No new stakeholder groups emerged during this process, providing confidence we had adequately identified the range of stakeholder groups within the verge management/greening network.

A total of 30 semi-structured stakeholder interviews, ranging from 45 minutes to 2.5 hours in length (an average of 1.5 hours), were audio recorded and transcribed. The central interview themes covered stakeholder interactions and awareness, local policy, governance, verge values, impacts and outcomes from verge greening, community feedback, and future preferences. Interviewees were asked to hand-draw social network maps on A2-sized paper (following Prell et al., 2009), placing the interviewee's own organisation (or self, in the case of 'champions of change') at the centre. The mapping process was filmed to

[1] One example combining social media and neighbourhood-based initiatives is 'Valley Verges' (https://www.facebook.com/valleyverges/), where members share resources to plant out verges in the suburb of White Gum Valley. Similar groups exist for other parts of Perth, as well as umbrella social media pages covering all of the city.

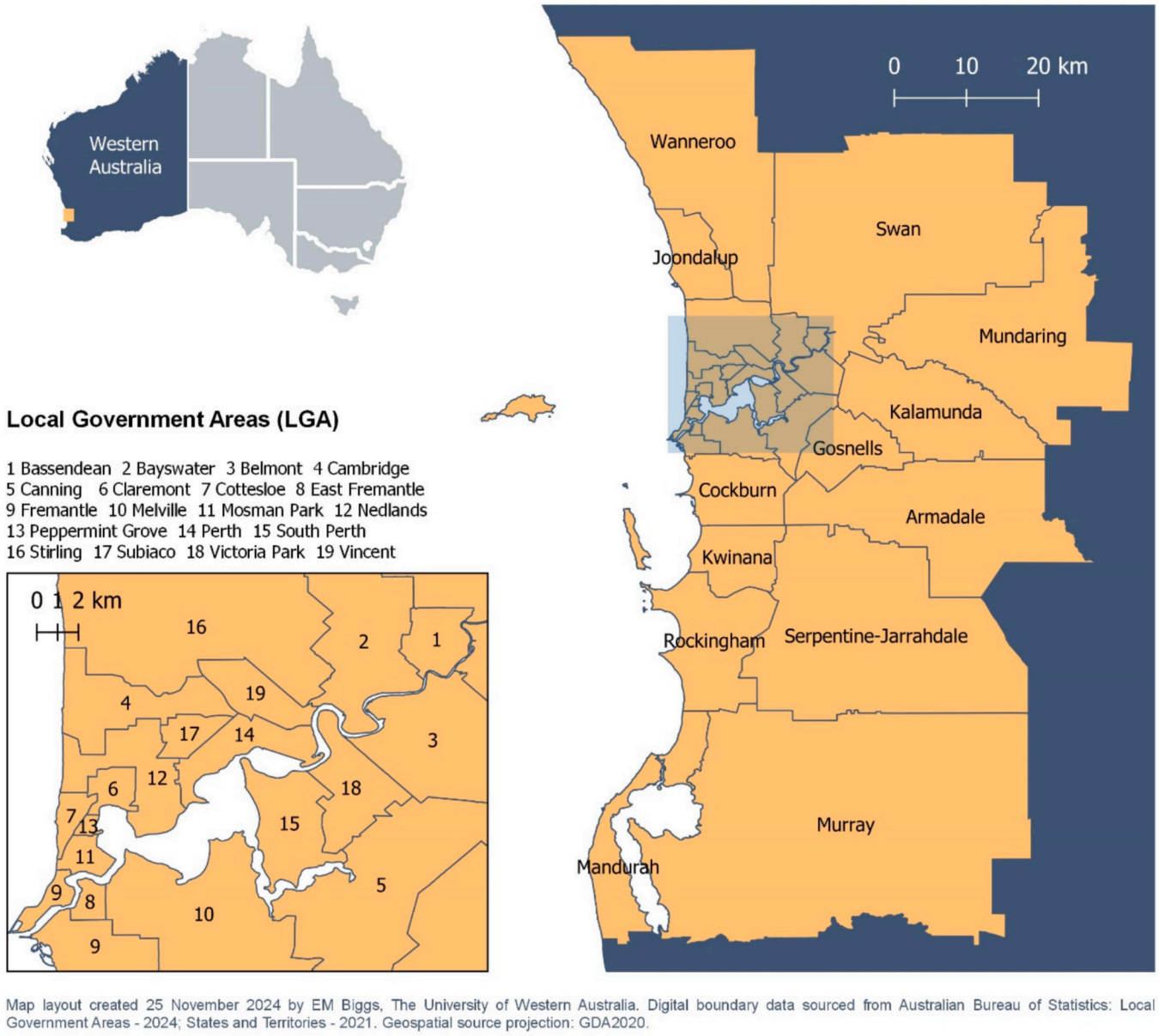

Fig. 1. Map of Perth Metropolitan Area (Australia), showing Local Government Authorities.

capture the verbal explanations as interviewees drew the network of their professional connections related to verge management and urban greening, including what they exchanged in those connections.

Following social network analysis (SNA) terminology, the organisations, people, and programs named by the interviewee became network **nodes**, and the resources exchanged between them depicted as the **ties** (*i.e.*, a tie or 'edge' is the link between two nodes in a network). When hand-drawing the social network maps, interviewees were provided a legend that suggested using: 1) the size of circles to indicate the importance of a node in their network, and 2) the arrow direction (uni- or bi-directional) between nodes to represent four types of resource flows (i.e., ties): information, financial, labour, or material (Table 1). Interviewees were also asked to list the attributes of these resource flows, such as frequency of interaction and importance (high, medium, low). This information was later used qualitatively to support the quantitative SNA outputs.

2.4. Data preparation

Interview data was thematically coded in two stages using NVivo (Release 1.7.2). In the first round of coding, all interview responses related to the social network mapping, stakeholder relationships, or interactions were coded as 'social network interactions'. The second round of coding focused on extracting information on the type of resource flows and on identifying stakeholders mentioned in the interviews but not included in the interviewees hand-drawn maps. Following this, the nodes were organised into 20 stakeholder groups or entities (12 in addition to our initial stakeholder groups). Table 2 provides these stakeholder groups, the number of interviewees and nodes in each group, and the proportion of nodes that were identified by name.

A resource exchange directed matrix was then constructed to demonstrate the direction of resource flows between nodes, as per Table 3. Each node was assigned a unique identifying number (ID), which was used to pair the nodes (column A) from which a resource was sourced with recipient nodes (column C). The matrix also identified the type of stakeholder group (column B and D), and the type of resource

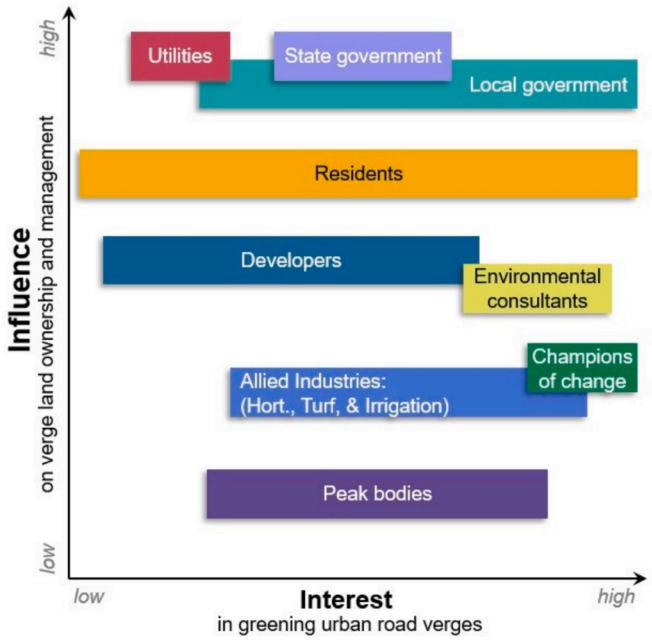

Fig. 2. A conceptual interest/influence schematic of stakeholder groups identified based on the authors experience, stakeholder roles and responsibilities. The low–high scale is qualitative. The length of the bars represents the likely varying levels of interest in urban road greening within a stakeholder group.

Table 1
Types of resource flows between nodes.

Resource Type	Definition
Information	Information* and inspiration related to: • Policy, planning and governance • Practical knowledge on design, installation, management, maintenance of verge gardens and on accessing support for installation
Financial	Payments for services or materials provided
Labour	Personnel time providing verge-related skills or experience
Material	Physical supplies (i.e. related to site preparation and garden installation – soil, mulch, chemical treatment, irrigation, plants, equipment)

* Note: information may be shared for different reasons, for example for education, advocacy or regulatory purposes.

flows (column E), i.e., information, financial, labour, or material, added as an edge (i.e., link between two nodes) attribute. Nodes were labelled 'generic' or 'specific' depending on whether the interviewee named the individual/organisation or provided a general 'sector' (e.g. landscape architects, councillors, contractors, LGAs, etc). Local Government Authorities were referred to in specific (i.e., a named individual LGA) and generic (i.e., LGAs collectively as a general stakeholder) terms. The matrix was cross-checked for consistency, with any duplicate and self-referenced (i.e., closed loop) nodes deleted. In total, there were 966 resource exchange ties between 268 nodes extracted from the 30 interviewees.

2.5. Social network analysis (SNA)

A SNA was conducted on the resource exchange directed matrix using the open-source program Gephi. SNA is a tool to understand how resources flow between people, organisations, or places. It has been widely applied in sociology, social and behaviour sciences, as well as economics and business studies, and more recently in human geography to unpack how complex human relations extend and are formed across space (Sigler et al., 2021). As such, SNA was well suited to explore urban verge greening stakeholder relationships and interactions. It has been previously applied in various natural resource management contexts (Barnes et al., 2020; Bodin & Prell, 2011; Guerrero et al., 2020; Prell et al., 2009), though it has had limited use in urban greening (for example, Ernstson et al., 2008; Guenat et al., 2020; Jasny et al., 2019).

No weightings were applied to the nodes or ties of the resource exchange directed matrix, as all ties and nodes were considered equally important. Given the diverse ways in which groups engage with verge gardening or management and interact with one another, it is impossible to ascribe weightings, despite conceptually we recognise there are different levels of interest or capacity to influence verge gardening or management among stakeholders (Fig. 2).

The SNA was conducted in two stages. In the first stage, the network position of all nodes was calculated to understand the providers, recipients, and brokers of resource flows. There were four node centrality measures of relevance. First, indegree centrality of a node (c^i) is calculated as the number of resource flows from other nodes (Eq. (1). Nodes with a high indegree received the most flows and were resource gatherers. Second, outdegree centrality of a node (c^o) is calculated as the number of resources flows sent to other nodes (Eq. (2). Nodes with a high outdegree sent a large number of resources to other nodes and were resource distributors. These centrality measures are represented by the following equations:

$$c_a^i = \sum_{a:a\neq b} y_{a,b} \tag{1}$$

$$c_a^o = \sum_{a:a\neq b} y_{a,b} \tag{2}$$

Where a and b are nodes in network of total n nodes, but where $a \neq b$. y is the edge connecting two nodes.

Third, betweenness centrality of a node (c^{be}) is calculated as the number of times the node was positioned in the middle of the shortest path between two other nodes (Eq. (3). A high betweenness centrality value indicated nodes that were positioned the most time between other nodes, and therefore are the most powerful brokers or mediators of resource flows. Fourth, eigenvector centrality of a node (c^e) is calculate based on how connected the node is to the most connected nodes in the network (Eq. (4). It is not a measure of the resources that flow in and out of the node (i.e., indegree and outdegree), but a measure of proximity to the resources of the most connected nodes. A high eigenvalue centrality indicates nodes that are influential in the network, due to their proximity to the most 'powerful' nodes. These centrality measures are represented by the following:

$$c_a^{be} = \sum_{b<c} \frac{x_{b,c}(a)}{x_{b,c}} \tag{3}$$

$$c_a^e = \frac{1}{\lambda} \sum_{b:b\neq a} y_{a,b} c_b^e \tag{4}$$

Where a, b and c are nodes in a network of total n nodes. x is the shortest path between two nodes (b,c) on which node a sits; and λ represents the eigenvalue of the matrix, and acts as a scaling factor according the centrality of a node's neighbour.

In the second stage, nodes were allocated to sub-networks or communities of similarity to better understand which nodes interacted and connected in similar ways. To do this, we applied the Louvain clustering method (Blondel et al., 2008), where communities are identified by grouping nodes that are more densely connected to each other. This method examines the network according to the strength of node internal sub-network connections, and it identifies communities that share more links among themselves than they do with other communities in the network. Communities identified through this method tend to align with functional real-world interactions (cf. Chen et al., 2018). For this reason, it is a more suitable clustering method for the study than others focusing

Table 2
Breakdown of stakeholder groups by type, number of interviewees, nodes, and percent of nodes within each stakeholder group that were specifically named.

Stakeholder group or entity	Number of interviewees	Number of nodes	% node specifically named^
Peak Body*	4	42	98
• Includes representative bodies for: Urban developers, Irrigation, Turf/Playing fields, Local Government			
Horticulture, landscaping and irrigation businesses*	4	30	40
State Government*	3	24	96
• Includes Department of Planning, Lands and Heritage, Main Roads, and Water Corporation's Water Efficiency Partnerships (WC-WEP)			
Greening advocacy or education (not-for-profit)		20	95
Residents* (includes 'clients', 'community' and 'public')		18	33
Champions of Change*	5	17	94
Local Government Authorities (LGA)*	5	14	79
Media (including social media)		14	79
Environmental Consultants*	5	13	62
Research and Development		13	77
Developers* and affiliates	2	11	36
Elected members (LGA or State government)		9	56
Urban planner or landscape architect		8	25
Policy, strategic plan or program		7	100
Federal Government		5	100
Financial institutions and insurers		5	80
Nature		5	0
Reference group or committee		5	20
Utilities*	2	5	80
Contractors		3	0

Notes: *denotes initial stakeholder groups identified, prior to the interviews.^refers to the percentage that a specific person, organisation or program (node) was named out of all named and unnamed references in the group. Those who were not specifically named include generic classifications such as 'contractors', 'the public' or 'LGAs'.

Table 3
Extract of node resource exchange matrix.

A	B	C	D	E
Source ID	**Source Stakeholder Group**	**Recipient ID**	**Recipient Stakeholder Group**	**Resource Type**
62	Developers and affiliates	10	Environmental Consultancy	Financial
181	Contractors	10	Environmental Consultancy	Financial
10	Environmental Consultancy	1	Policy / Strategic Plan / Program	Information
202	Environmental Consultancy	10	Environmental Consultancy	Information
128	LGA	119	Urban planner / landscape architect	Financial
10	Environmental Consultancy	226	Environmental Consultancy	Information

on other network attributes (hierarchical organisation, k-means or spectral, etc). Computation of the Louvain method identified nine communities, which were analysed to develop a verge greening stakeholder typology, with interview data being used to provide context and nuance.

3. Results

3.1. Summary data: Key network stakeholders and resource flows

Drawing on the interviews, 268 unique nodes, including organizations, people, and programs, were identified in the verge greening network of the Perth Metropolitan Area. The stakeholder groups with the largest number of nodes were peak bodies, State Government agencies, and LGAs. Many respondents described how integral their networks were to achieve organisational purposes or advocacy values, but also to navigate resource sharing and the increasing competing demands upon verge spaces. For example,

"The more we get into the space of wanting more [green] and trees in urban spaces, the more there is going to be interaction and the more there is going to have to be a collaborative approach" (Env Consultant).

"So it's about finding resources that are underutilized, and then redistributing, or connecting people that can use them… What my capacity, my skills are about is about trying to help motivate others to do it, or put them in contact with people who can help them." (Advocate/Champion of Change).

Respondents from multiple stakeholder groups also expressed the desire for *early* and *ongoing* collaborative interaction to facilitate not only information sharing but the means of achieving more sustainable outcomes. For example, *throughout* the design processes where there are interactions between urban planning and landscape consultants, arborists and developers, and the approvals processes with State (roads, utilities, planning) and Local Governments.

Information resources, relating to verge greening regulation, education or advocacy, were the predominant type of resource exchanged. 79.6% of the resource flows between two nodes were information, while 11.4% were financial, 6.5% material, and 2.5% were labour flows. As such, the remainder of the analysis focused on the information exchanges between stakeholders. Information sharing and education were identified as key roles by respondents from environmental consultancies, the horticulture (nurseries), irrigation and turf industries, advocates/champions of change, LGAs, and the State Government utility's Waterwise Education Program (cf. Ligtermoet et al. 2022, 2021). Additionally, there was consensus across all stakeholders interviewed (except Utilities) that education and awareness - not just 'resources' (e.g. material or financial incentives) - were enabling factors in verge or streetscape transformation, with lack of it limiting adoption. For example:

"Information giving and, I think, subsidies - people really love it, any incentive… from council… anything that helps people get information. But it needs to be good information, with some substance. People need good information." (Horticulture 1 –NFP Nursery).

"To share information, to provide an enabling space, encouragement, or inspiration that is disconnected from any official business or government agency. And capture the balance between what the resident wants, and how they are to interact within the limitations of the local policy, and what the accepted social norms for verges are within their community." (Social media 1- Advocate/champion of change).

"We're probably halfway along that journey. So, what we are hoping to do, once we've got some really clear lessons, is to convey that information into the Local Government. […] I think we're learning from a maintenance perspective, what treatments [other examples]… And Local Governments have been coming to us to give us this information. […] That [councils] are actually coming to [us] to learn about species or how to incorporate [native streetscapes], that is some positive feedback because it means what we've been changing in our verge landscape has actually been picked up by somebody else." (State Gov 3).

3.2. Key providers, recipients, and brokers of resource flows

Table 4 depicts the top ranked nodes by their position as providers, recipients, and brokers of resource flows in the verge management and greening network. To avoid identifying the nodes by name, we refer to each node using their stakeholder group affiliation or role (see Table 2), augmented with a broad description of their role where relevant to the interpretation of results. Further illustrative quotes can be found in Supplementary material (Table 1).

Four of the five top-ranked resource providers (outdegree) or recipients (indegree) were two peak bodies and two State Government agencies, all with strong links in the water, green space, and urban planning sectors. Local Government Authorities were also prominent, both as a generic group, and for the specific 'early adopter' LGA[2] identified by interviewees. Highly ranked resource providers (by outdegree) included utilities, other peak bodies, State Government agencies (focussed on water and urban planning), and developers. Landscape architects were the profession most frequently highlighted as both providing and receiving resources, indicating their role in driving verge transformations. One champion of change appeared in the top 10 recipients of resources; this individual had played a key role in influencing LGA policy on verge gardening. Additionally, Social media #1 and Advocacy 1 (Table 4) prioritised information sharing to increase adoption and used social and traditional media, respectively, in a highly effective way. The effectiveness of this was noticed, for example, by an LGA early adopter: "*We've been doing that for ages, but we hadn't been pushing the media as hard. But I think that's another thing that helps get the momentum in that space*". Additionally, 'Horticulture 1' (a not-for-profit nursery) described the important (and growing) role of nurseries in information provision and education of residents, alongside supplying plants when partnering with LGA resident verge greening incentive schemes to subsidise native plants for residents.

The top four nodes that acted as brokers or mediators of resource flows, as assessed by betweenness centrality, were the same as those for in-degree, out-degree, and eigenvector centrality (Table 4). Peak body 3 (representing Local Governments and thus strongly connected to LGAs), a champion of change, and an early adopter LGA were also in the top five for betweenness centrality (Table 4). Various different stakeholders followed with relatively similar betweenness centrality measures. This suggests brokerage or mediation of verge-related resource flows occurs across a diversity of stakeholders and sectors. Interestingly, 'residents' were cited by other stakeholder groups who engaged with residents in their roles of verge management or verge gardening service provision or education – such as Local Government Authorities, environmental consultants, or Waterwise education programs.

[2] 'Early adopter' LGA refers to a Local Government Authority that provided early and ongoing leadership in the provision of verge policy, information or incentives supportive of verge gardening.

Many of the top nodes for eigenvector centrality were also the highest ranked in resource provision, brokerage, and reception (Table 4). This indicates that these nodes are not only well connected to the greatest resource exchange stakeholders, but are also essential in resource transfer. For example, a multi-stakeholder program focusing on knowledge transfer for sustainable urban water planning was ranked 13th according to its eigenvector centrality value, indicating its efficacy in connecting different stakeholders.

3.3. Community structure of the verge management and greening network

In this section, we characterise the nine verge greening stakeholder communities that emerged from the clustering analysis (Fig. 3, Table 5). Each community (Fig. 3A) was named and described by: ranking the nodes and stakeholder groups within them from highest to lowest according to their total degree centrality (i.e., by adding in-degree and out-degree centrality) (Fig. 3B and 3C); assessing the types of flows (ties) between nodes; evaluating their position within the network; and drawing on context information from interviews and the authors' expert knowledge of Perth's urban greening.

There were four communities who appeared most well-connected and central to the network (Fig. 3B, Table 5). The two with the most nodes and positioned at the network centre, indicating their overall connectivity in the resource exchange network, were named the *Water efficient hub* and the *Governance enablers* (Fig. 3, Table 5). These, along with the *Greenspace hub,* shared a similar structure with one 'central' node with high degree centrality, surrounded by a number of nodes with lower degree centrality (Fig. 3A). *Planning and servicing hub,* while the largest in terms of ties and nodes, had a slightly different structure, with three nodes having higher degree centrality (Fig. 3A). The nodes in this hub were associated with creating and servicing urban places and suburbs, albeit with a focus on rules, utilities, and planning, with regulatory connections with the *Governance enablers* hub (Fig. 3A). With the exception of the *Governance enablers*, these three groups featured influential peak bodies, all of which were well-connected nodes with high numbers of ties (Fig. 3B). *Governance enablers*, on the other hand, comprised a relatively evenly proportioned collection of stakeholder nodes (Fig. 3B).

Members of the *Water efficient hub* had the most prominent and numerous nodes involved in running, promoting, or supporting water efficiency programs or waterwise partnerships (Fig. 3B, Table 5), which support several verge transformation programs and have close ties to nodes in the *Governance enablers* hub (Table 5). The fourth largest community was the *Greenspace hub* (Table 5), comprised of nodes predominantly representing the turf and associated industries, as well as green space advocates, emphasising the importance of green spaces and living turf in creating liveable urban spaces. While many of the *Greenspace hub* nodes were on the periphery of the network, central nodes were positioned in the middle of other key communities, particularly the *Water efficient hub* (Fig. 3A).

The smaller communities identified, even those with many peripheral nodes, all had multiple ties with communities that had high degree centrality. The *Advocates* community was diverse, and the fifth-largest, with a central focus on driving change in verge greening. It includes key individuals who have been vocal in pushing for change, hosting community education events and social media platforms. Champions of change included several events and groups acting as inspiring catalysts for their action within their network, for example the 2020 Vision, edible gardens or local community garden groups, and actors in the not-for-profit sustainability sector. *Advocates* connect more centrally with *Governance enablers* via an influential councillor and some shared sustainability advocacy with the *Greenspace hub*. The *Transformers* community was largely focused on the physical work of verge transformation, with more exchanges in finance material and labour than in other communities (Fig. 3C, Table 5). *New Vision* community is a diverse collective where progressive developers are putting research

Table 4
Summary of key (top 16) resource providers, recipients, and brokers. Node names in **italics* denote generic categories. Note that 'resident' refers to an individual generic resident who access resources for verge conversion, while 'community' refers to local community groups who access resources through collective processes and visions.

	Resource providers		Resource recipients		Knowledge brokers		Proximate to nodes with highest access to resources	
Rank	Node	Out degree	Node	In degree	Node	Betweenness centrality	Node	Eigen −centrality
1	Peak body 1 (living turf industries)	44	Peak body 1 (living turf industries)	44	**LGA*	16184.9	**LGA*	1.0
2	State Gov 1 (water efficiency)	40	State Gov 1 (water efficiency)	38	State Gov 1 (water efficiency)	14808.6	State Gov 1 (water efficiency)	0.9
3	Peak body 2 (urban development)	36	Peak body 2 (urban development)	37	Peak body 1 (living turf industries)	12961.5	Peak body 1 (living turf industries)	0.8
4	**LGA*	34	**LGA*	35	Peak body 2 (urban development)	11006.3	State Gov 2 (planning policy & regulations)	0.7
5	State Gov 2 (planning policy & regulations)	19	State Gov 2 (planning policy & regulations)	20	Peak body 3 (for LGAs)	7578.6	Peak body 2 (urban development)	0.6
6	LGA early adopter	18	Peak body 3 (for LGAs)	20	Champion of change 1 (policy influencer)	5909.4	Peak body 3 (for LGAs)	0.6
7	Peak body 3 (for LGAs)	17	LGA early adopter	16	LGA early adopter	5495.6	Developer 1 (government affiliated)	0.5
8	Utility 1 (energy)	14	Champion of change 1 (policy influencer)	16	**Resident*	3651.8	State Gov 4 (water & environmental regulations)	0.4
9	Horticulture 1 (not for profit)	14	**Landscape architect*	15	State Gov 2 (planning policy & regulations)	3357.2	**Developer*	0.4
10	Developer 1 (government affiliated)	13	Developer 1 (government affiliated)	14	Champion of change 2 (guerrilla gardener)	3155.5	**Landscape architect*	0.4
11	**Landscape architect*	13	Peak body 4 (irrigation)	14	Environmental consultant 1	2960.8	Peak body 4 (irrigation)	0.4
12	Peak body 4 (irrigation)	13	Utility 1 (energy)	13	Utility 2 (water)	2923.5	Utility 1 (energy)	0.4
13	State Gov 3 (roads)	12	State Gov 3 (roads)	13	Developer 2 (commercial)	2514.5	Program 1 (sustainable urban water planning)	0.4
14	Developer 2 (commercial)	12	Environmental consultant 1	12	**Plant nurseries*	2464.2	State Gov 3 (Roads)	0.4
15	Environmental consultant 1	12	**Resident*	11	Social media 1 (group on social media)	2292.5	**Community*	0.3
16	State Gov 4 (water & environmental regulations)	11	**Plant nurseries*	11	Advocacy 1	2270.7	**Resident*	0.3

into practice. In particular, the State Government development entity had more ties to peak bodies and research organisations. The members within *New vision* and *Transformers* have led and implemented several novel and innovative prototypes in verge greening along major roads and in new urban developments. The final two communities both had a spatially localised focus (Table 5). The *Local networks* community was associated with specific, place-based residential verge greening programs in several proactive early adopter LGAs. The smallest community, *Early adopters,* had a particular geographic focus, where long-standing environmental degradation and rapid suburban growth had combined to make implementing proactive social-environmental policies a high priority for LGAs and advocacy groups (Fig. 3C).

From the clustering analysis, it is thus possible to distinguish multiple, unique orientations or 'broad roles' comprising a typology of communities in the verge greening space. Despite the unique roles, each of the more peripheral groups was still well connected with the four highest degree centrality communities, around which peak bodies, LGAs, and State Government entities played central intermediary or brokering roles.

4. Discussion

Interactions among stakeholders in natural resource management and in urban systems are complex, marked by a spectrum of shared and divergent goals, priorities, and resourcing. Social network analysis (SNA) can assist in understanding how structures of social relations affect natural resource management, decision making, and adaptation (Bodin et al., 2006; Bodin & Crona, 2009; Bodin & Prell, 2011; Groce et al., 2019; Guerrero et al., 2020). We demonstrated how SNA, combined with qualitative material can aid understanding how resources are shared across the diverse sectors and stakeholders engaged with urban greening and verge management. Our multi-stakeholder analysis engaged a diverse actor network, rather than focussing on a singular-interest stakeholder group (e.g. Enqvist et al., 2014; Jasny et al., 2019). Indeed, this work responds directly to the call by Jasny et al. (2019) for research to explore cross-sector collaborations among civic, private, and public sectors. In our research, qualitative mapping and rich interview material build on the explanatory power of SNA by providing the context around influence and change processes, as identified also by Wutich et al. (2020). In the discussion that follows, we explore the diversity and character of the network; highlight key partnerships, stakeholders and individuals; provide a narrative exploration of the relatively rapid acceptance of a previously marginal urban greening practice, and discuss transferrable insights and lessons.

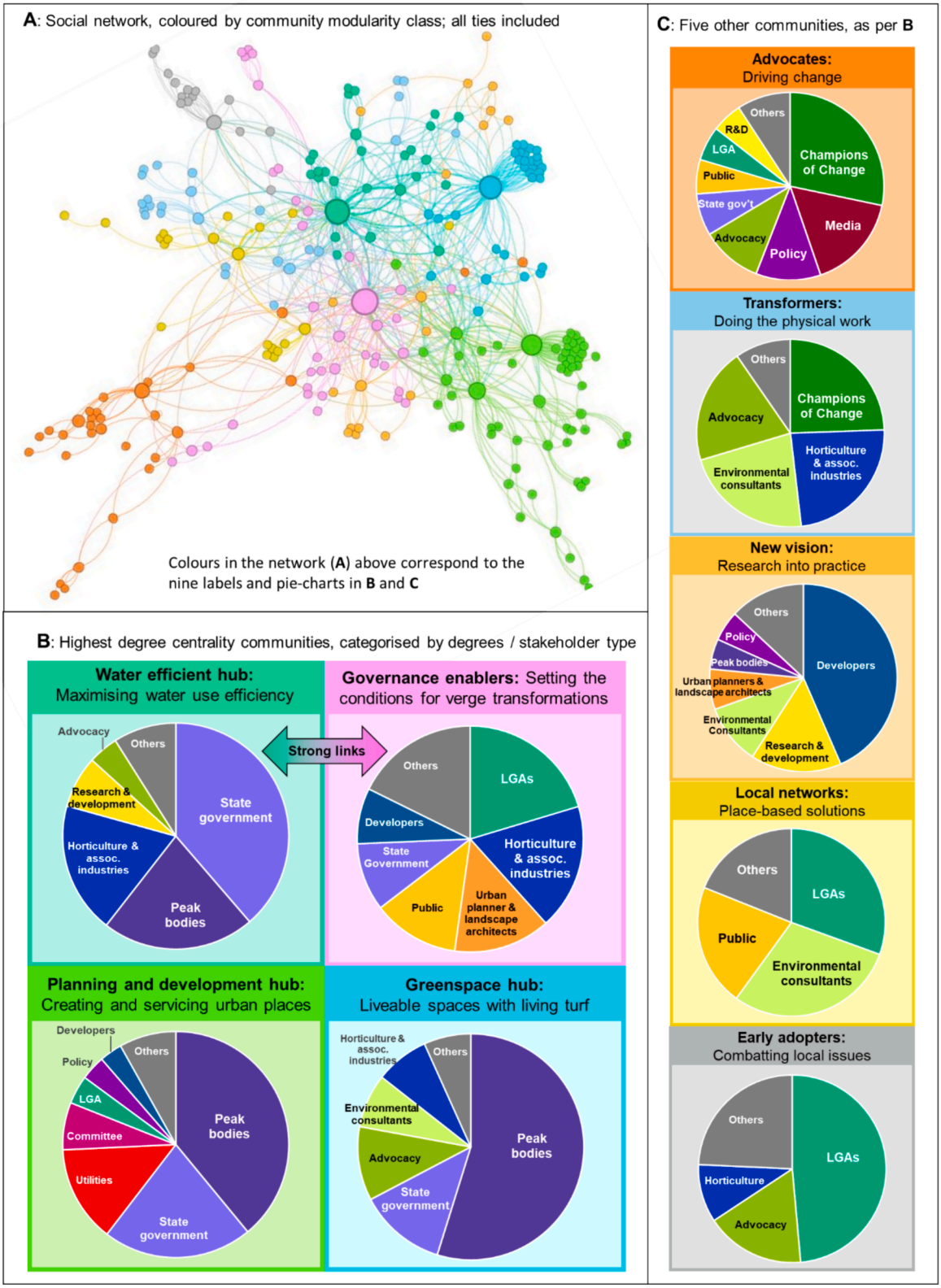

Fig. 3. Typology of communities in the verge greening and management stakeholder network of the Perth Metropolitan Area, as identified via clustering analysis. (A) Communities of nodes more densely connected to each other than to nodes in other communities. Communities were assigned different colours, with inter-nodal ties including all flows (primarily information, but also finance, material and labour). (B) Four largest communities based on total in-degree and out-degree flows, with the title block colour referring to the community colour shown in (A). Each wedge represents the proportion of flows (i.e., in-degree plus out-degree) attributed to each stakeholder group within that nodal community. There may be more than one node represented within each stakeholder group wedge. (C) Five smaller nodal communities based on total in-degree and out-degree flows are depicted as per (B), with the title block colour referring to the community colour of (A).

Table 5
Typology of communities in the verge greening and management stakeholder network of the Perth Metropolitan Area, as identified via the clustering algorithm.

Community typology	Node unifying features	Community description in network (see also Fig. 3A)	No. of ties	No. of Nodes	Top nodes (based on degree centrality)
Largest communities (see Fig. 3B)					
Planning and development hub	Creating and servicing urban planning and development.	Three influential, well-connected nodes, many nodes with single links.	369	61	Peak bodies (development, utilities and LGAs). State Government (planning and development), policy, LGAs.
Governance enablers	Setting conditions for verge transformation, through both i) capacity to change the rules to 'enable'/allow verge gardening and ii) developing and implementing policies and guidelines.	Centrally located. Largest connected nodes distributed relatively evenly across diverse stakeholders (See Fig. 3B).	339	38	LGAs most prominent, interacting with horticulture and allied industries, urban planners and landscape architects, the public, State Government agencies, and developers.
Water efficient hub	Running, supporting, or promoting water saving and efficiency partnerships, programs or materials. Directly support many verge transformation programs for both LGAs and residents.	Centrally located, including a single well-connected node. Many ties to *Governance enablers.*	256	27	State Government (water efficiency), peak bodies related to horticulture and irrigation industries.
Greenspace hub	Promoting liveable spaces featuring vegetation and living turf (*i.e.*, not artificial turf). Improving sustainability credentials / retaining social licence to contribute to urban spaces in a drying and warming climate.	One influential, well-connected node and well embedded network.	208	31	Peak body (living turf industries) and associated suppliers, State Government (water regulation, and roads), environmental consultants, urban greening advocates.
Smaller communities (see Fig. 3C)					
Advocates	Driving change through community focal points, leveraging social and traditional media forms, and advocating for verge greening.	Nodes were well connected to each other, but located on the network periphery, with a small number of centrally embedded nodes. Some of *Advocates* nodes connected to nodes in *Local networks*, and some to members of the *Governance enablers*.	152	31	Champions of change, State Government (planning policy), media, various advocacy groups, research and development.
Transformers	Implementing, installing, and educating via exemplars – this group includes leading practitioners and local suppliers of plants and other materials. Exchanges are more frequently in finance, material and labour compared with other communities.	Diverse and well distributed, nodes with more ties to nodes on the outer edge of the network.	135	26	Nurseries, champions of change, advocacy groups, landscape and environmental consultancies, suppliers.
New vision	Putting urban greening sustainability research into practice. Strong links with universities and knowledge hubs. Trialling new greening methods and generating exemplars for the public.	This community is distributed throughout the network, with no single 'feature' node, with ties to three of the highest degree centrality communities.	115	38	Developers, research and development, professional services such as consultants, planners, and landscape architects, peak bodies and policy.
Local networks	Driving place-based solutions – locally generated, strong public engagement.	Has ties with the *Governance enablers*, *Water efficiency hub* and *transformers* communities.	95	20	Primarily LGAs and environmental consultants interacting with the public.
Early adopters	Combatting local issues. Includes an LGA responding to unique contextual social and environmental changes, with one of the longest histories of Local Government support for verge transformation in residential areas.	Small number of nodes, more peripheral to the overall network.	77	15	Early adopter LGA, local and national collective of waterwise, urban greening and community advocacy groups.

4.1. Diverse verge greening network with information exchange at its core

Our analysis revealed a wide and diverse network of stakeholders involved in Perth's verge greening. The involvement of stakeholders with individual networks spanning local, city-wide and national connections, and across government, industry, and community sectors, demonstrate how verge greening has become widely embedded in policy and further normalised in practice. Indeed, Local Government-led incentive programs exist in multiple LGAs (Ligtermoet et al., 2021), verge greening guidelines for new developments have been released by State Government agencies (Water Corporation, 2022), and diverse stakeholders share similar views on the ecosystem services that verges can deliver (Ligtermoet et al., 2022). The diverse actor network possibly also reflects a coalescing of sustainability concerns beyond immediate verge gardening, with recognition of multiple, related environmental crises across biodiversity loss, climate, and urban planning (water scarcity and urban heat). This has likely contributed to the building of diverse network connections, particularly where multiple initiatives are in place to address related sustainability objectives. Verges could be viewed in this sense, as reflecting a microcosm of the tensions and opportunities that arise in attempting to maximise the use of public space for multiple purposes, while also bringing along residents, and the private sector. The diverse network underlines the importance of street verges and the interests that people hold for these spaces.

Our study found that information exchange generates most of the social network architecture. In Perth, professionals and community leaders tend to mix in relatively small circles with compressed hierarchies, enabling ideas and information to spread rapidly. Additionally, the relative lack of money exchanged may suggest cost is less important in this context, and that verge greening is a relatively low-cost initiative. However, the exclusion of residents from this study may also influence this finding, as residents can contribute substantial personal labour and financial contribution to verge gardening (Doll et al., 2023). Understanding the economic costs and benefits of verge greening and 'green infrastructure' (e.g., urban forest) for different stakeholders (developers, LGAs, private residents) would be important future work, given the challenges associated with increasing urban infill while retaining and growing green infrastructure on both public and private land.

4.2. Roles, responsibilities and key points of connection

Many of the top-ranked nodes in terms of proximity to resources

were also some of the highest ranked in terms of resource provision, brokerage, and reception (Table 4). This indicates that these nodes are not only connected to the key resource exchange stakeholders, but they themselves are also critical to the transfer of resources. This is likely shaped by the context of multi-stakeholder management, where information, as the main resource being exchanged, requires effective connectivity in enabling and facilitating verge greening action. The network analysis reflected the roles that specific State Government agencies and LGAs play in setting verge and street greening policy, as well as in delivering water usage and urban greening behaviour change programs. For example, a State Government utility delivers the 'Water Partnerships Efficiency' program, which supports LGAs and residents reduce their water use, and partners with LGAs to provide incentives for residents to engage in verge gardening. It is unsurprising that LGAs are central brokers in the network, given their responsibility in setting residential verge policy and given that many now provide incentives to residents for verge gardening. Here LGAs play a central and pivotal role in information sharing, echoing findings from Guenat et al. (2020) and Ernston et al. (2010) in greenspace conservation. While peak bodies do not have a direct 'regulatory' role in verge greening, the SNA results highlighted several peak bodies (particularly those supporting LGAs, living turf and urban development) acting as highly effective intermediaries within the network. Being positioned proximate to information, these peak bodies, as well as landscape architects, environmental consultants, and progressive developers, may actually hold considerable 'soft power' and influence in spreading novel street and verge greening approaches.

Elucidating the role of individuals and community members through SNA, however, is complicated. Only two champions of change scored highly as knowledge brokers, and none were ranked highly as knowledge providers or as proximate to knowledge (Table 4). However, this doesn't mean that the role of individuals or 'champions of change' is not important, and they were significant within advocates, transformers, and early adopter network communities. Qualitative information was particularly useful in understanding the nuances in the network (Wutich et al., 2020), especially the influence of individuals and community groups in major nodes. Interviewees mentioned key individuals within power-holding agencies that made a difference, for example by championing new initiatives that went on to shift values and entire programs of work within their organisations. Interviewees also mentioned some champions of change with close connections with powerbrokers who then can exert considerable influence. Social media and traditional media supporting advocacy and community groups also played a significant intermediatory role. They provided gardening information and connected geographically dispersed individuals and community groups with knowledge providers who share their information both via social media and face-to-face events.

Environmental consultants, for example, operated within multiple network communities and this is reflective of their different expertise and scale of their network. Environmental consultants, as a stakeholder group, may not immediately be thought of as scale-spanning brokers (after Ernston et al., 2010). Verge garden designers, installers, and landscapers often operate at smaller, residential scales but also contract with LGAs and occasionally State Government (e.g. transport authority) or developers with larger geographical reach. Environmental planning consultancies were mostly connected to State Government and private urban developers, and had a role in community education. Several consultants had strong relationships with research institutions, and one consultant provided a uniquely relational standpoint map with 'Western Australian plants' at its centre, with all flows connected to this, including soil, insects, and water, foregrounding human-environmental relations. We acknowledge that the generic, role-specific names include multiple individual stakeholders, and future research could perhaps distinguish these further to provide actual counts of the organisations/entities acting in this space.

The relatively strong connection of community members and residents suggests they are also well connected to stakeholders who have access to most resources. Effective access for community members to verge gardening resources (largely information and some gardening materials) was mostly facilitated by LGA incentives, community education events, and the Water Corporation Water Efficiency Program. Despite growing recognition and uptake by residents (Babington et al., 2023; Hughes et al., 2023; Hunt et al., 2022), verge transformation through gardening remains uncommon at the suburban street scale, with some residents unaware or unconvinced of the potential benefits (Doll et al., 2023; Hughes et al., 2023). Evidence of the prevalence of verge gardens is difficult to obtain, and to date, to the author's knowledge, there are only two studies quantifying the number of verge gardens within LGAs, both of which suggest a process of transition through increasing adoption: 8% of household verges in one LGA (Hunt et al., 2022) and approximately 2% of household verges formally adopted between 2013–2017 in another (Hughes et al., 2023). Our results highlight a significant role for residents and plant nurseries as occupying a significant knowledge brokerage role. This finding, along with the presence of social media, and champions of change in the top-listed knowledge brokers, provides some counterbalance to the analysis finding that brokerage is greatest among multi-level government and formal peak body groups. The comparatively small size and outer-connected position of the transformers community, which is associated with the physical implementation of verge transformation, aligns with the authors' observations and limited evidence that verge gardens are still uncommon across Perth.

Following social network mapping and revisiting our original conceptual mapping of the stakeholder landscape (Fig. 2), we found that we underestimated the 'influence' and knowledge brokerage role of peak bodies in the network. Indeed, of the four largest communities, three had influential peak bodies. Yet it may be of interest that the 'governance/enablers' community did not. The communities the peak bodies influenced may also highlight the context of the interviewee, in constructing their network map from their perspective, thus centring their own organisation's network. While this could be a potential source of bias, given that our respondent maps produced evidence of saturation (no new stakeholder groups were added), we are confident of a thorough and adequate representation of the system.

4.3. Unpacking verge greening communities: Transcending siloes

Within each of the network communities, there are well-established links that *transcend* traditional stakeholder role or sectoral siloes. The diversity of communities facilitating effective connections across Local and State Government, societal actors (government, not-for-profit, advocacy, peak bodies, consultancy businesses), and sectors, has likely increased the availability and sharing of information from multiple sources and contributed to the uptake and normalisation of verge greening as an accepted endeavour. The dominance of State Government agencies in the four most central and well-connected communities reflects the clear mandate of government and utilities in urban planning and development, and as a critical contributor to more formal water and greenspace actor coalitions. Implementing blue-green infrastructure depends on the governance conditions supporting that 'infrastructure' (Bixler et al., 2020). That peak bodies were also most substantially represented within these communities suggests they have close and effective connections to government and formal decision-making processes across the water, urban greening, planning and development sectors, at least as it pertains to street verge greening. Of most interest, however, is how well-balanced the diverse stakeholders are within the '*Governance enablers*' community. This may be a reflection of the network reaching a mature and effective stage of information sharing, where progressive Local and State Government, and private sector, have 'caught up' with the innovations of civil society and the water efficiency messaging, or arrived similarly at the need to enable governance that can support growing adoption of verge transformation practices. That the network reveals information flows across sectors and diverse social

actors is also likely a reflection of the long period of strong messaging from the public utility about water scarcity (over the last 30 or so years), biodiversity loss (last two decades), and more recently, public concerns about climate change driving urban heating and a growing population increasing pressure on urban greenspace. Effectively, recognition of the multiple, interconnected crises, i.e. the polycrisis (e.g. Hoyer et al., 2023), may well have influenced the emergence of this diverse network capable of transcending silos for more effective resource sharing.

Among the smaller network communities, many community-led groups and locally based research-to-practice initiatives are still 'on the periphery' of the network. They have links with key nodes and the highest degree centrality communities (see groups in Fig. 2B), but retain distance and probably a desire to do things 'their own way' (where verge gardening in many suburbs may still be seen as a rebellious practice and making a statement). However, the proportions of stakeholders in these groups really mirrors those most heavily driving the early adoption of verge greening practices (i.e. champions of change with media support, LGAs and environmental consultants, horticulturalists, landscape architects and progressive developers), particularly in attempting to implement innovative and place-based solutions. It provides further evidence of the need to have diverse stakeholders, often with traditionally divergent goals operating together in closely connected networks to drive the adoption of novel or unconventional sustainability practices.

During interviews, respondents from State and Local Government, utilities, and peak body organisations reported the major barriers to information sharing were having to navigate the siloed departments within government organisations (which was outside the scope of this network mapping), or for those operating across all of Perth, navigating multiple LGAs, each with their own policies and regulations. Navigating organisational boundaries for decision making was also reported as a major barrier by Bixler et al. (2020). Several of these respondents accessed committees with multiple department and peak body representation to help address this. Additionally, temporal aspects of information flows and communication were raised by many as barriers, where for example, information sharing could have been initiated earlier or more consistently throughout a multistakeholder verge management endeavour. Future work capturing and representing the efficacy and quality of resource flows between network nodes could be beneficial, to reveal nodes that may act as barriers and towards which interventions may be tailored. Ghose and Pettygrove (2014), for example, identified social networks as an important mechanism by which groups can overcome barriers, yet highlighting their political and uneven nature.

4.4. Learning from verge greening to promote novel sustainability practices

The uptake of verge gardening, from a form of 'guerrilla gardening' or unconventional practice to one actively promoted by not only civil society groups, but also by Local and State Government policy, demonstrates mainstreaming, even as it remains uncommon. Connections between diverse actors, such as champions of change, early adopters in Local Government, progressive urban developers, and State Government policies - arguably accelerated through the uptake of social media, demonstrate recognition of the social, cultural, and financial capital that can be made from fostering urban greening across the private–public interface. We posit that the normalisation of an uncommon urban greening practice on largely ignored or 'utilitarian' strips of land represents something larger than the phenomenon of an individual verge garden or streetscape itself. These physical spaces also act as civic intermediaries, connecting across the private–public threshold in multiple ways beyond mere physical access, but in expressions of governance and civic engagement, identity (of individuals, communities, and a city), social, psychological and environmental health, and in the growing recognition of nature-based solutions and green infrastructure within environmental economics (e.g. compensation or other provisions for tree removal/loss). These previously vacant, minimally managed strips of land are gaining traction as spaces that are important for deliberate urban planning and civic greening processes. In doing so, verges and their potential functions, act as a means, both physically and conceptually, of drawing together diverse interests in a co-produced process (after Wyborn et al., 2019) of generating transformational, social, and environmental change towards more sustainable outcomes.

There are many other situations where the uptake of uncommon or novel practices needs to happen across a diverse stakeholder network (including public and private actors) to affect the kinds of transformational change necessary for achieving more sustainable and equitable outcomes. These could include actions such as native vegetation retention policies on private land (e.g. Simmons et al., 2020) electric vehicle uptake and other forms of low emissions transport (Heidrich et al., 2017; Sharda et al., 2024), the shift to sustainable, equitable and nutritious diets (de la Haye et al., 2021), and the shift away from single use plastics (Schultz et al., 2024). Understanding the community structures within stakeholder networks may well assist in identifying ways of diversifying resource sharing, which may assist the adoption of these unconventional or novel sustainability solutions (Ernston et al., 2010).

Future work examining spatial and temporal scale of influence within the networks would be valuable to better understand the drivers and conditions facilitating adoption. For example, spatially, stakeholder groups work and exert influence at different (geographic) scales (Ernston et al., 2010). In this project, we were addressing the Perth Metropolitan Region, but some actors extended to national scale and some at streetscape scale. How might the influence of geographical scale, from small (household to street), medium (LGA scale), to large (city/state) be reflected in the shape of the network of resource flows and how might this shape governance aspects?

Additionally, understanding the timeline of uptake, policy change, and other context-specific drivers influencing adoption, as well as how actors connect in and over time to the verge greening network, could provide valuable insights to support the adoption of unconventional practices for advancing sustainability. Network-specific needs vary over time, as networks evolve (Bodin & Crona, 2009; Crona & Bodin, 2006). Here, for example, multiple context-specific conditions have coalesced to drive unconventional connections across scales or levels of influence in the actor network. These conditions include the prior lead-in time among horticulture research focusing on local native species and generating verge-appropriate native plants available commercially, having arrived at a time of great recognition of biodiversity loss in the southwest WA global biodiversity hotspot. The long lead-in time driven by the State Government water utility in recognising the drying climate and promoting public water savings, along with its success in public messaging in partnership with Local Government Authorities, was no doubt influential.

5. Conclusion

This study examined the social networks of diverse stakeholders with interests or influence in urban roadside verge management and verge gardening, in the Perth Metropolitan Area, Western Australia, through participant network mapping and network analysis. This was in response to policy shifts and the growth in the practice of transforming roadside verges with gardens, from one deemed 'illegal' or unconventional to one encouraged via mainstream local and state policy and programs. The resource flows of the network were dominated by almost 80% information flows. The major providers, recipients, and brokers were primarily Local Government Authorities and State Government entities (the water utility's Water Efficiency Partnership Program, roads management, and planning departments), along with a mix of other public, private, and advocacy entities. The four large and five smaller communities detected within the network were found to have distinct

roles or functions, illustrating a network that transcends traditional sectoral siloes and connects across physical scales (from individual verges, streetscapes, council to city-wide action). The dominance of information flows, the centrality and influence of governance actors (State and Local Governments), peak bodies, and water efficiency and green space 'hubs', together with the highly distributed networks of smaller 'change maker' actors, are all aspects of the network that are potentially contributing to the increasing verge transformation. This network case study of diverse stakeholders associated with innovative urban greening reveals the importance of multiple, diverse knowledge brokers transcending sectors and siloes to share resources, particularly information, in the adoption and uptake of an uncommon, yet transformational sustainability practice.

CRediT authorship contribution statement

E. Ligtermoet: Writing – review & editing, Writing – original draft, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **N. Pauli:** Writing – review & editing, Writing – original draft, Visualization, Supervision, Methodology, Investigation, Formal analysis, Conceptualization. **K. Martinus:** Writing – review & editing, Methodology, Formal analysis. **C. Ramalho:** Writing – review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.landurbplan.2025.105342.

Data availability

The data that has been used is confidential.

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