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A Case Study Balancing Predetermined Targets and Real-World Constraints to Guide Optimum Urban Tree Canopy Cover for Perth, Western Australia

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Abstract: Trees in urban settings are becoming increasingly important as mediators to emerging challenges that transect social, environmental, and economic factors. Trees provide shade; absorb and store atmospheric carbon and other pollutants; reduce local temperature fluctuations; provide essential inner-city fauna habitat; assist in reducing over-land stormwater flow; provide amenity; and provide many more social, environmental, and economic benefits. To secure these benefits, tree canopy cover targets are commonly employed by land managers; however, such targets are rarely quantified against the characteristics and limitations of individual urban centers. Through the generation and interrogation of qualitative and quantitative data, this case study of Perth, Western Australia presents a new conceptual tool that integrates eleven factors found to influence the capacity and opportunity for a city to support urban tree canopy cover. This tool is designed to capture and causally weigh urban tree canopy considerations based on individual city characteristics, collective values, and identifiable constraints. The output of the tool provides an "optimum" tree canopy cover result (as a percentage of the urban fabric) to better inform canopy cover targets and recommendations for urban tree strategic planning and management. This tool is valuable for urban land managers, city planners, urban designers, and communities in effective planning, management, valuation, and investment regarding urban trees as a sub-set of urban green infrastructure.

Keywords: urban greening; urban forest management; green infrastructure; urban resilience; nature-based solutions

1. Introduction

Industrial and residential development associated with the densification and growth of cities frequently requires clearing of remnant, restored, and exotic vegetation [1]. This clearing of vegetation adversely impacts urban centers. Examples of impacts include reduced elemental protection for inhabitants, loss of fauna habitat and food opportunities, reduced local biodiversity, and reduced opportunities for carbon sequestration and natural air purification [1]. Further, permeable surfaces are often converted to impermeable surfaces. This conversion takes the form of roads, roofs, paving, and paths that reduce the opportunity for water to naturally percolate through the ground, thereby creating a higher flood propensity [2–7]. In addition, these surfaces can reflect and embed solar heat, exacerbating local temperature increases and the urban heat island effect [2–7].

Urban expansion to accommodate growing populations often results in the removal of trees for densification and new construction; the upgrade and widening of road networks in support of higher traffic volumes and public transport options; and the installation of power lines, service lines, and drainage assets that impose restrictions on shape, size, and volume of tree canopy [1,6,7].

In addition to the pressures on trees due to population increase, the threats posed by climate change, extreme weather events, and declining human health in cities also require immediate and meaningful action [8–10].

Green infrastructure (GI) is a concept attached to human-made or human-influenced nature-based infrastructure, designed and installed for the purpose of easing environmental pressures, such as climate change, flooding, or extreme temperature fluctuations. As such, GI is a broad-ranging concept that comprises networks of public open space, urban tree canopies, wetlands (natural or constructed), biofiltration systems, green walls, and green roofs among others [11–13]. This case study examines urban trees and urban canopy cover as a subset of GI.

Trees are becoming increasingly important in the urban fabric as mediators of emerging challenges. A large volume of research confirms that urban trees improve our physiological health (cardiovascular, sympathetic nervous system), mental health (improving outlook on life, reducing anxiety and depression, and restoring cognitive fatigue), productivity, and social capital, and accelerate human physical healing processes [14–17]. The presence of urban trees can reduce the prevalence of crime and antisocial behaviour under some conditions [18–20], generate economic rewards through reductions in heating and cooling costs [21], and increase property values [22,23]. Other services delivered by urban trees include those of an environmental and ecological foundation, which reduces local climate temperatures, provides green linkages, increases local biodiversity, absorbs atmospheric carbon, and supports habitat transitionary corridors [23–28].

Within this case study, canopy cover is defined and treated as a collective asset that is made up of a mix in vegetation species' foliage mass over the height of three meters [23,25,26]. With respect to approaches in ascertaining the percentage of tree canopy cover, it is posited that standard approaches to mapping, classifying, and measuring canopy are undertaken in full-leaf season.

Tree species composition and individual characteristics must be carefully considered within this "collective asset" [29]. The variance in "trees" is enormous and expansive. For instance, trees can vary in height between three meters and over fifty meters [29]. Trees may be narrow in form, or expand over tens of meters in width [29]. Tree canopy may remain all year, or defoliate during winter of hibernation periods. Individual differences among species and the relationship these have to "canopy cover" as a collective are imperative in the discourse of greening urban centers [30].

Investigation, and a thorough understanding of urban forests, is essential in properly considering the use and management of this asset in order to gain access to the established benefits [30]. Land managers and planners are urged to consider the respective vegetation complexed with particular regard to

1. Foliage retention: the impact this may have on the relationship between this GI asset and local urban needs [31].
2. Water dependance/drought tolerance: species demand on water and the variance within the urban forest [31].
3. Species robustness: how species react to harsh and changing conditions and how this relates to urban center canopy needs [31].
4. Interspecies interactions: competition within the urban forest that may impact the way in which canopy cover is pursued and managed [30].
5. Invasive/weed species: the impact this may have on the productivity and impact of vegetation mass on an urban center [32].

The conceptual model presented in Figure 1 proposes three high-level categories (zones) that can be used to describe the status of tree canopy cover that is currently held by an urban center. As described above, the zones treat all vegetation species' foliage mass, in excess of three meters, as a collective asset (canopy cover). The terminology proposed for these zones are "opportunity", "optimal", and "saturation". Opportunity suggests that there is lack of canopy cover resulting in an opportunity for improvement. Optimal suggests an ideal balance between canopy cover and existing benefits. Saturation suggests that the canopy cover has surpassed a point of positive returns and adverse impacts will be experienced. The purpose of displaying these conceptual zones on a bell curve (below) is to express the nature of the relationship between canopy cover and derived benefits.

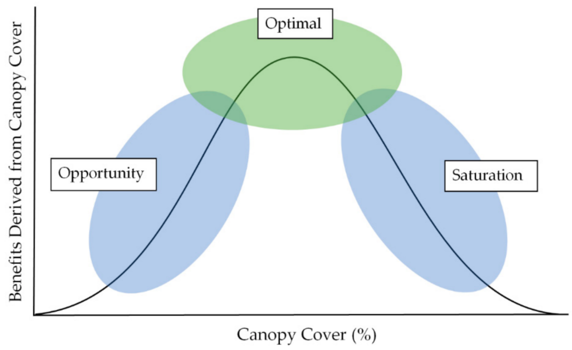

Figure 1. Relationship between canopy cover benefits and percentage of canopy over.

While quantifiable benefits accrue from the presence of trees in the urban fabric, the limitations and potential loss of amenity must also be considered. Urban trees require water, particularly during establishment and regular maintenance (pruning, assessment, and specialized treatment). Trees generate litter through debris drop (leaf, branches, and bark), which can impact drainage networks, damage infrastructure and services (protruding roots and falling limbs), and be perceived as generally unpleasant by some residents and managers [33,34].

Considering the interplay between economic, social, and environmental factors, this case study hypothesizes that an optimum canopy capacity is inherent for tree canopy cover within an urban landscape at a point before saturation of the potential canopy space begins to occur. It is postulated that the identification and understanding of this capacity will be aided by application of the proposed GI tool in decision making for future urban strategic planning and management.

Based on the research that underpins the development of this case study, it is believed that such calculation methods have not yet been reported in current published literature. The purpose of this case study is, therefore, to present a novel approach to calculating optimal urban tree canopy cover percentages and make it globally applicable. This case study deploys the mixed-method approach to data collection, tool creation, tool validation, and application, in a case study simulation.

2. Materials and Methods

2.1. Case Study Site

In demonstration of the tool output, a case study was undertaken in the city of Perth, on the west coast of Australia. Perth is home to around 2.14 million people, with a metropolitan area covering around 6400 km^2 [35]. Perth is located within the Mediterranean climate band and is characterized by long, hot summers and mild, wet winters [35].

Perth's urban forest varies in structure, quality, performance, and vegetation cover. Many Perth Local Government Authorities seek to establish percentage-based tree canopy cover targets [6,7]. Current canopy cover percentages vary significantly across the metropolitan area, ranging from as little as 5% up to 40%.

Perth is home to a growing volume of GI research, and research pertaining to the impact and necessity of integrated responses to emerging challenges [8,9,35].

2.2. Determination of Factors Influencing Tree Canopy Cover

A mixed-methods approach was employed in this research for the collection and analysis of the data from the literature review and focus group stages [36]. A systematic scoping review was undertaken to identify and assess a broad range of literature (see Supplementary Material) that informed the unbiased identification of factors suitable for consideration and incorporation into the assessment tool [37]. This stage was undertaken because of the lack of consolidated research that is currently available. Informed by the scoping review, a rapid review of pertinent literature was undertaken to qualify, quantify, and benchmark criteria for each factor identified (See Supplementary Material) [38]. A multidisciplinary focus group of invited practitioners and community representatives known to the authors were consulted to review and inform the proposed factors and measurement criteria used in the construction of the tool.

Incorporating the information gathered in the literature reviews and feedback from the focus group, a simulated application of the tool is provided to demonstrate how urban tree canopy cover can be optimized considering the social, ecological, and political constraints of the urban fabric of Perth, Western Australia.

2.3. Tool Refinement by Focus Group

While focus groups are accepted as a self-contained method [39,40], this technique was employed to supplement the scoping and rapid literature reviews to leverage the added power of mixed methods research (See Supplementary Materials). The focus group was undertaken over the duration of five hours under the guidance of, and adherence to, Curtin University Human Ethics Permit Number HRE2019-0451. The primary objective of the focus group was to revise and advise on a prototype of the tool developed from the initial findings of the literature reviews [41]. While beyond the scope of this case study, in the future there is potential for focus group participants to act as "agents" for the research outcomes, which is a common strategy when undertaking research crossing complex social, cultural and/or political fields [42], p. 104. The focus group was undertaken in the latter stages of the research process (See Supplementary Materials), which is a method supported by researchers such as Kitzinger [43].

To minimize any potential bias in the data collected from the focus group, an independent facilitator was employed. A range (n = 15) of practitioners, academics, and industry experts were selected for the focus group. Each participant possessed expert knowledge in at least one of the eleven factors. The profile of each participant is displayed below in Table 1. Group discussion was generated using a structured set of questions (Table 2) to ensure balanced discussion among the participants and to avoid any persons or factor or aspect dominating focus group discussion.

Table 1. Focus group participant profiles.

Participant No.	Capacity of Participation	Field of Expertise	Length of Experience (Years)
1	Professional Practitioner	Arboriculture	30+
2	Professional Practitioner	Arboriculture	10+
3	Elected Community Representative	Local Government Councilor	10+
4	Professional Practitioner	Public Open Space Management	30+
5	Professional Practitioner	Environmental Management	25+
6	Professional Practitioner	Planning and Development	25+
7	Community Stakeholder	Community Environmental Volunteer	15+
8	Community Stakeholder	Community Environmental Volunteer	15+
9	Community Stakeholder	Community Environmental Volunteer	20+
10	Professional Practitioner	Urban Sustainability and Green Space Management	20+
11	Elected Community Representative	Local Government Councilor	10+
12	Academic	Biophilic Green Architecture	15+
13	Professional Practitioner	Engineer	15+
14	Professional Practitioner	Urban Planning	5+
15	Academic	Urban Ecology and Sustainability	10+

Table 2. Questions considered by focus group for each factor and measurement criteria utilized by the tool.

Aspect	Question
1	Based on the background information provided, do you have questions about the application and quantification of the factor?
2	Based on the background information provided, do you have questions about the measurement criteria of the factor?
3	Do you think this factor is important in determining optimum canopy cover?
5	Do you have any suggestions to enhance the contribution of the factor within the canopy cover tool?

In reflection of the groups combined professional input, the weightings and criteria of several factors were amended accordingly.

3. Factor Exploration and Confirmation

There is currently no standardized method for quantifying an optimum cover of tree canopy that can be supported within urban centers. Many factors affect the viable and desirable volume of tree canopy cover commensurate to local characteristics and context such as need, desire, natural and built environment constraints, climate, and ability of the urban center to manage and maintain urban trees through ongoing financial investment. Little research has been undertaken to understand the individual and inter-factor relationships that impact on the ability of a city to support tree canopy cover. Developed through the identification and modelling of influencing factors, the proposed approach can be used to help urban planners and land managers calculate local scale optimum canopy capacity. This information can then be used when determining urban tree investment requirements and can enhance resource allocation processes.

Consideration must also be given to the number of significant and diverse threats faced by urban trees. The most apparent threats are land development, climate change, adverse community perceptions/desire, pest and disease attack, poor management, and inadequate resourcing. Ultimately, the way in which urban centers respond to these threats will determine the success of this approach to GI as a mediator, on a local level, to overcome the various challenges emerging across urban centers today.

Globally, many local, state, and national government authorities have proposed varying canopy cover percentage targets [6,7]. However, the scoping and rapid review revealed that these broadly applied targets are based on limited robust scientific and/or technical information. This being the case, urban centers may be significantly over-supplying or under-supplying tree canopy cover across their communities. Without robust knowledge and rationalization of targets, resource attempts may fall short of efficacy and may not demonstrate the best use of a GI dollar [33].

3.1. Determining Factors of Optimum Tree Canopy

Refer to Appendix A for further details surrounding the criteria assessment structure when considering the below.

3.1.1. Water Resource Availability

Urban trees generally require a significant volume of water to aid establishment, and depending on species, soil water-holding capacity, site factors, and climate conditions, trees may require ongoing supplementary water in order to thrive. Water sources utilized for watering urban trees include shallow superficial aquifer supplies, deep aquifer supplies, dams, lakes, potable water sources, and treated waste water [44]. In some extreme cases, water source options may extend to desalination and other more energy intensive types of treated water [44].

Water resource availability can vary significantly, depending on factors such as underground geology, rainfall patterns, water abstraction patterns, human interventions to aid asset recovery (such as aquifer recharge), and superficial injection [44]. Pertinent to this factor is the ability of the water resource to recover in volume, either annually or within a cyclical pattern. A surplus to recovery (asset recovery in excess of abstraction) is considered desirable based on anticipated climate change implications, population increases, and other competing demands. Factors that may affect the water resource availability considerations for land owners/manages include the following:

1. Population growth predictions;
2. Volume of water able to be abstracted that can support sustainable recovery;
3. Water efficiency opportunities;
4. Alternative water source options (i.e., desalination);
5. Social behavior and values (i.e., unauthorized bore installation and usage).

3.1.2. Cost of Water

Depending on the water source and security, cost implications vary [43–46]. Cost differentials between water sources depend on a number of factors, including geographical location; geological and hydrological conditions; the frequency, distribution, pattern, and volume of local rainfall; the scarcity of water sources; and quality markers across water assets [43–46].

3.1.3. Soil Characteristics

Trees depend upon a soil profile that provides oxygen, retains water, allows excess water to drain from the root zone, and possesses a cation exchange capacity in order to draw in and hold nutrients to be absorbed by the roots [47]. Hence, the balance and dominance of soil characteristics influence tree growth and performance. Individual differences among tree species play a part in the impact of soil character. Globally, there are recognized locale specific optimal soil conditions for urban trees such as the ability of the profile to provide oxygen, make nutrients available, and hold water. Informed local practitioners and community representatives need to consider these characteristics in the application of the tool.

3.1.4. Financial Investment

Trees incur a capital cost typically comprising the tree, stakes, fertilizer, planting labor, equipment, fuel, and consumables. In addition, annual costs are incurred comprising periodic pruning, watering, and minor maintenance activities, pertinent to establishing trees in urban environments.

Post-establishment, tree management is likely to include pruning (formative, strategic, clearance, and safety), specialized assessments, disease control, watering, fertilizing, and surrounding weed control. Trees in public areas bring risk, in terms of damage to people or property through branch or tree failure. This may translate into higher demand for management, insurance premiums, and other associated legal/settlement costs for accidents and/or injuries. Urban trees also increase demand on associated services, i.e., high densities of deciduous trees may increase the required frequency of street sweeping to avoid blockage of drainage systems. Additional costs may also be incurred through infrastructure damage from roots and expanding root crowns and basal stems.

3.1.5. Community Desire

Two main aspects must be considered when expending public money. Firstly, the extent of the benefit to be gained from the expenditure. Secondly, which sector of the community will the expenditure directly benefit. However, those who most benefit and those who do not receive direct benefit are both important stakeholders and thus entitled to express their opinions towards the planning and installation phases.

In a democratic political system, community desire is highly relevant within decision making processes. For this reason, community desire is a significant factor in pursuit of an urban forest integrated with the built environment.

3.1.6. Shade Requirements

Shade requirements from canopy can vary according to presence and abundance of other surrounding landscape features that may provide shade. Extent of shade is impacted by size of buildings, sun angle, solar azimuth, cloud cover, and surrounding landscapes and streetscape formations [17]. Communities and societies that commonly utilize outdoor spaces and public communal areas in cities with higher temperatures may require more shade than those with lower temperatures that tend to encapsulate themselves in their homes and workplaces [17].

3.1.7. Biodiversity/Ecological Demand

Trees provide refuge, habitat, and food sources for fauna. Variable across species, fauna require a volume of tree canopy to support their health, protection, and continuing habitation within the urban fabric [26]. Tree canopy that is sufficient, or slightly in excess, is desirable to support and provide protection from the ecological demands of a location.

To be carefully balanced, biodiversity of flora and fauna is equally important [26]. The higher the biodiversity, the higher (in most cases) the resilience of a region or location.

3.1.8. Political Influence

Political influence, in this context, is referring to two driving aspects. Firstly, the positive perception of and desire for canopy cover, and secondly the level of influence that the political forces hold over decision-making in this space. While a relatively subjective factor to consider due to the need for individual classification and reporting, it is worth capturing.

3.1.9. Climate

Climate characteristics include temperature, wind patterns, rainfall patterns, and extreme weather events. Urban canopy cover provides protection for people and property against many adverse climate characteristics and as such is linked to, and can drive, the need and desire for canopy cover [33,34,48]. The more adverse climate conditions experienced, the more suitable it may be for increasing canopy cover.

3.1.10. Extreme Weather Events

Extreme weather events are observed cross-element and include events such as flooding, fire, prolonged heat waves, sporadic extreme temperatures, intense storms, and combinations thereof [49,50]. Extreme weather events can be devastating in human, financial, and ecological terms, and with an increase in occurrence projected under climate change, measures should be taken to mitigate the potential effects of these events [49,50]. Trees and tree canopy can buffer the impacts of extreme weather events through diffusing heavy rainfall, providing heat reductions through shade, providing protection from strong winds, reducing erosion, and assisting in localized temperature regulation [49,50].

3.1.11. Zoning

Zoning and living density regulations affect the amount of land available to support urban trees. Changes in zoning, often in the form of increasing density, drive development, subdivision, and as a result vegetation clearing. Urban trees require free land, which is directly affected and influenced by zoning. The higher the zoning density, the lower the likely opportunity for tree planting and tree support [51].

Moving away from a general account of how zoning is likely to influence tree canopy, alternative options exist. Trees may be housed in road/footpath cut outs, pots, medians, roundabouts, and other infrastructure installations [51]. While this is a genuine possibility, the cost of such pursuits needs to be considered, along with the viability of those assets in such conditions.

4. Results

4.1. Framework for Optimum Tree Canopy Assessment

Each identified factor was analyzed to determine the direction of relationship and type of influence held to canopy cover reported in the literature. The relationship and influence of each factor were converted to ordinal parameters (Appendix A) that were quantified by the application of a fivefive-point Likert Scale [52].

It is recognized that not all eleven identified factors will influence tree canopy capacity uniformly. To adjust to this recognition, the five-point scale operates to standardize the influence as well as capture the type of influence (i.e., positive or negative). For a number of factors, the scale has been inverted. The five-point scale provides a simple way that these factors can be captured and applied for the generation of the optimal tree canopy cover percentage output. Appendix A shows the criteria assessment structure in detail, supplementing Table 3.

Table 3. Factors identified as influencing the ability of an urban center to support and require tree canopy cover with scaling criteria.

Factor	Scale	Criteria
Water Resource Availability	five-point Likert Scale	Major surplus of water for sustainable recovery (+110%)
		Minor surplus of water for sustainable recovery (+105%)
		Adequate supply for sustainable recovery (100%)
		Minor short fall of water for sustainable recovery (−95%)
Cost of Water	five-point Likert Scale	No cost—supported by rain only ($0 kL)
		Low ($0–$2 kL)
		Medium ($2–$4 kL)
		High ($4–$6 kL)
Soil Characteristics	five-point Likert Scale	Very high in all desired factors
		High in all desired factors
		Moderate in all desired factors
		Low in all desired factors
		Very low in all desired factors
Financial Investment	five-point Likert Scale	Very high investment ($)
		High investment
		Moderate investment
		Low investment
		Little to no investment
Community Desire	five-point Likert Scale	Strong desire
		Mild desire
		Neutral
		Mild opposition
		Strong opposition
Shade Requirements	five-point Likert Scale	Very high (7–8 factors present)
		High (5–6 factors present)
		Medium (3–4 factors present)
		Low (1–2 factors present)
		None (0 factors present)

Table 3. *Cont.*

Factor	Scale	Criteria
Biodiversity/Ecological Demand	five-point Likert Scale	Within a biodiversity hotspot
		High biodiversity
		Moderate diversity
		Low diversity
		Void of biodiversity
Political Influence	five-point Likert Scale	5 × 5 grid
Climate	five-point Likert Scale	Tropical
		Mediterranean
		Temperate
		Arid
		Mountains
Extreme Weather Events	five-point Likert Scale	5 × 5 grid
Zoning	five-point Likert Scale	CBD
		Inner city
		Metropolitan
		Outer metropolitan
		Semi-rural

The tool is based on entering a score from one to five into an interactive spreadsheet to describe how the urban center fits within the pre-established criteria for each factor. The criteria are expressed in explicit ordinal form to assist in decision making and reduction of subjectivity and conscious or unconscious bias. Once the scores have been entered, the influence of each factor is weighted to the total possible canopy coverage to arrive at a percentage that reveals the optimum canopy cover percentage. It is expected that it may take around twenty minutes for delegates to enter the information into the interactive spreadsheet to obtain the optimum canopy cover percentage.

4.2. Focus Group Enhancement of the Tool

The tool was tested via the focus group to assess the proposed factors and the measurement criteria for each factor. Both prior to the focus group, and after the completion of the focus group, participants were requested to nominate on a scale of one (not applicable) to nine (highly applicable) the suitability of the ordinal criteria in the assessment of each factor.

Table 4 displays the scores from the participants as taken prior to the focus group, and after the focus group. For ease of assessment, the net difference between both scoring efforts is included.

In order to determine if there was a significant overall net difference between the pre and post scoring efforts, a Paired Two Sample *t*-Test for Means was undertaken. The *t*-Test revealed that there was a significant difference between the scoping efforts ($p = 0.024$).

The most noteworthy changes occurred for the factors titled Cost of Water, Water Resource Availability, and Political Influence. In these three cases, the scoring increased between 0.7 and 1.6. This is understood to mean that extra discussion that occurred during the focus group aided in the understanding and overall determining of relevance and confidence in the factors and criteria.

In the cases of the factors titled Extreme Weather Events, Biodiversity/Ecological Demand, and Community Desire, these results decreased modestly (−0.3 to −0.1). This is understood to mean that after discussion of those factors, some participants felt less certain in the appropriateness and confidence of the factors and criteria. For those factors and others, some changes were made to the criteria to reflect the feedback from the focus group participants.

Table 4. Focus group participation factor scoring.

Factor	Participant Confidence Measurement (Pre-Focus Group)	Participant Confidence Measurement (Post-Focus Group)	Net Difference
Water Resource Availability	7.6 (n = 13)	8.4 (n = 10)	0.8
Cost of Water	6.9 (n = 13)	8.5 (n = 10)	1.6
Soil Characteristics	8.0 (n = 14)	8.5 (n = 10)	0.5
Financial Investment	7.4 (n = 13)	7.8 (n = 10)	0.4
Community Desire	7.9 (n = 14)	7.8 (n = 10)	−0.1
Shade Requirements	8.3 (n = 14)	8.8 (n = 10)	0.5
Biodiversity/Ecological Demand	7.6 (n = 13)	7.5 (n = 10)	−0.1
Political Influence	6.3 (n = 13)	7.0 (n = 10)	0.7
Climate	7.9 (n = 13)	8.2 (n = 10)	0.3
Extreme Weather Events	6.5 (n = 13)	6.2 (n = 10)	−0.3
Zoning	7.4 (n = 13)	7.7 (n = 10)	0.3

Participants were also asked to assign a strength of relationship to each factor on a three-point scale from being Low to High (See Table 5). The participants ranking of the strength of the relationships was then used in the form of 0.3 (High), 0.2 (Moderate), or 0.1 (Low), which was then applied to the selection of the five-point factor nomination.

Table 5. Focus group participation relationship scoring.

Factor	Strong Relationship (Value = 0.3)	Moderate Relationship (Value = 0.2)	Weak Relationship (Value = 0.1)	Mean Result ($\sum$nV/$\sum$n)	Assigned Factor Weighting
Water Resource Availability	$n = 9$	$n = 5$	$n = 0$	0.26	0.3 Strong
Cost of Water	$n = 7$	$n = 6$	$n = 0$	0.25	0.3 Strong
Soil Characteristics	$n = 6$	$n = 4$	$n = 3$	0.22	0.2 Moderate
Financial Investment	$n = 6$	$n = 7$	$n = 1$	0.24	0.2 Moderate
Community Desire	$n = 8$	$n = 6$	$n = 0$	0.26	0.3 Strong
Shade Requirements	$n = 9$	$n = 4$	$n = 0$	0.27	0.3 Strong
Biodiversity/Ecological Demand	$n = 6$	$n = 4$	$n = 4$	0.19	0.2 Moderate
Political Influence	$n = 7$	$n = 4$	$n = 4$	0.22	0.2 Moderate
Climate	$n = 9$	$n = 3$	$n = 1$	0.26	0.3 Strong
Extreme Weather Events	$n = 2$	$n = 8$	$n = 1$	0.21	0.2 Moderate
Zoning	$n = 6$	$n = 5$	$n = 2$	0.23	0.2 Moderate

4.3. Demonstration of the Tool

Two practitioners, with a combined 40 years of experience, entered the information for Perth into the tool. The information input can be seen in Figure 2, which shows the relationship of each factor to canopy cover capacity; the inter-factor relationships; the assigned score for each factor based on the criteria and application of Perth conditions and characteristics; the score after the relationship has been weighted; and the total aggregate score that is assessed against the physical ceiling imposed within the tool (60%) to reveal the optimum tree canopy cover percentage, which in this case is 40%.

Factor	Strength of Relationship to Tree Success	Water resource availability	Cost of water	Soil characteristics	Financial investment	Community desire	Shade requirements	Biodiversity/ecological demand	Political influence	Climate characteristics	Extreme weather events	Zoning	Perth Case Study	Score After Weighting		
Water resource availability	0.30		0.3	0.2	0.2	0.1	0.1	0.1	0.2	0.3	0.3	0.1	2	0.6		
Cost of water	0.30			0.1	0.3	0.1	0.1	0.1	0.1	0.3	0.3	0.1	3	0.9		
Soil characteristics	0.20				0.1	0.1	0.1	0.2	0.1	0.1	0.1	0.1	4	0.8		
Financial investment	0.20					0.3	0.3	0.2	0.3	0.2	0.2	0.2	3	0.6		
Community desire	0.30						0.2	0.2	0.3	0.1	0.2	0.2	4	1.2		
Shade requirements	0.30							0.1	0.2	0.3	0.3	0.3	4	1.2		
Biodiversity/ecological demand	0.20								0.1	0.1	0.2	0.2	3	0.6		
Political influence	0.20									0.1	0.2	0.2	3	0.6		
Climate characteristics	0.30										0.3	0.1	4	1.2		
Extreme weather events	0.20											0.2	3	0.6		
Zoning	0.20												3	0.6		
Sum of Factor Weightings	13.50												**Aggregate Score**	**8.9**		
													Aggregate Score Divided by the Total Potential	**65.93**	**Optimum Canopy Capacity**	**39.6**

Figure 2. Snapshot of the tool.

5. Discussion

5.1. Learnings of Case Study

Exploring and quantifying an optimal urban tree carrying capacity extends our understanding of the intricate, yet seemingly essential, impact of trees and on human wellbeing within urban centers in terms of how we should face the threats of climate change, extreme weather events, and increasing populations. Knowledge and understanding are the cornerstones of progress, as they bring about rational, measured, and verifiable methods that ensure appropriate decision making.

Setting a percentage target for urban tree canopy cover, produced through rigid methodology, has the ability to transform current industry practice. The tool offered in this case study provides a novel approach as a first step in improving current sub-par approaches to investments and operations of urban forests based on arbitrary targets. The tool provides clarity surrounding the optimum tree canopy percentage. The tool also facilitates the planning and forecasting of resources required to implement and manage the geographically supportable urban forest by quantifying the restrictions, opportunities, and impacts of projected canopy.

Conceptually, tree canopy and the associated benefits therein derived in an urban center can be thought of as a bell curve. The benefits increase as the canopy grows, eventually reaching an optimum level before producing declining returns where planting more trees generates various adverse outcomes. This occurs because too heavy a canopy cover (saturation) begins to result in competition of trees, overshadowing of other vegetation complexes, forced changes to existing and endemic ecosystems, and other associated issues with excessive shading (Figure 1).

Resource allocation and distribution is a heavily contended and contested processes, usually. Obtaining adequate resources for ventures and pursuits often requires tactful use of research, backing, and a sound business case. GI is multifaceted. Urban trees are only one form. From a budgetary and resourcing perspective, it is essential to determine the cost benefit rations of other GI examples in order to get the best financial return on investment.

From an investment–return perspective, urban trees (when considering their benefits) offer a solid case for substantial and sustained investment. This is not an entirely new concept; however, it is far from mainstream within the relevant industries, particularly in an operational sense. A GI example that has proven abilities to deliver urban centers with relief to social, environmental, and economic pressures that can provide an investor with a net-positive gain is beyond desirable; it is the epitome of urban planning and management excellence, and is something that should be executed with high priority.

5.2. Assumptions and Limitations of the Tool

The tool operates on the basis that the inputting practitioner has local and informed knowledge of each of the factors, as well as the relevant city characteristics. Assumptions are made that when the inputting practitioner does not have this information, this information is sought out, or consultation with a range of experts is undertaken (i.e., focus group) to obtain confident when inputting the information.

An assumption also exists that modifications are made to the tool as the inputting practitioner sees fit. It is expected that this would occur to the measurement criteria only, and that the tool would remain in-tact for other users as a basis for inquiry.

A limitation of the tool, and something deserving of further inquiry, is the impact upon species composition and how this causally impacts the accuracy and output values of the tool. It may be the case that with further research and case studies, the identification of species composition may play a valuable role in further refining the output value.

It is noted that among urban forests, species composition can play a major role in the ability of an urban center to support tree canopy cover. It is strongly suggested that individual species characteristics and complex formations are considered. As a starting point, the following considerations are advisable:

1. Foliage retention;
2. Water dependance/drought tolerance;
3. Species robustness;
4. Interspecies interactions;
5. Invasive/weed species.

5.3. Future Research

Green infrastructure research within the urban environment is lacking across the board. This lack of research is likely one factor in the broad lack of consideration of the underutilization of GI in urban centers. Increasing the quantification and qualification of GI assets will, in part, address this issue. This case study demonstrates how this can be achieved using the proffered tool for urban trees.

Future research may include case studies for the application of this tool undertaken in various cities varying in characteristics. Further inquiry may also follow a similar process considering other examples of GI assets to assist in better quantifying and qualifying needs, benefits, opportunities for mediation of challenges, indicators for further asset requirements, and so on. In order to reduce the ambiguity surrounding financial implications and returns of GI, research could be undertaken to better account for the tangible and intangible components and GI outcomes.

As mentioned above, further research into tree species composition may be found to be extremely valuable in the improvement of the tool's output figures, as well as facilitate a better understanding of canopy cover modelling.

6. Conclusions

Green infrastructure has the ability to make significant contributions to current challenges relevant to urban centers. As populations increase, densification is preferred to house the said growing population; the climate continues to change, which results in adverse impacts, and intervention is needed urgently. Current intervention methods and techniques are broad ranging, which vary in efficacy and success. GI has demonstrated a place in response approaches; however, it may be considered underutilized as an asset stratum.

Considering the above, it is seen that great opportunity exists in the GI remit. To realize these opportunities, barriers must be addressed and removed. A major barrier identified in GI consideration and implementation is seen as being the lacking quantification and qualification of GI asset subsets. In order to address this, in part, this case study demonstrates how measures can be taken to reduce this gap (perceived and real). Through the development and demonstration of this tool, it is thought similar endeavors are equally possible for the overall increase in efficiency, efficacy, and confidence for the multitude of other GI sub-sets.

Placement and application of GI sub-sets vary depending on the currency of challenges, opportunities, and barriers. Many urban centers are under threat from new and emerging challenges. Climate change, based on current modelled data, begun occurring decades ago. In the next few decades, we are facing ecological, social, human, infrastructure, economic, and sustainable development challenges that will require new-age solutions and thinking. These solutions are required to provide protection and security to urban centers. In order for land managers to make informed management decisions, enact community desire, and answer to global environmental obligations when considering the particular GI sub-set of urban trees, further modelling of optimum tree canopy cover is required.

Urban trees are accepted assets that assist in mediating things such as urban heat island effect, flash flooding, extreme temperature fluctuations, crime, social incohesion, and more. One major issue surrounding urban tree research and implementation is the paucity science and rigor behind the calculation methods that inform city-scale canopy cover percentage targets. This paper addresses this, in part, by identifying eleven major factors that influence a city's requirements for, and ability to, support canopy cover. By utilizing the tool as described in this paper, a custom canopy cover percentage can be calculated based on the assessment criteria for each of the eleven factors.

Supplementary Materials: Method for Scoping and Rapid Review. The following are available online at http://www.mdpi.com/1999-4907/11/11/1128/s1, Figure S1: Sequence of data collection methods., Table S1: Search terms used to identify papers included in the literature review.

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Appendix A

Table A1. Finer detail on criteria assessment structure.

Factor	Criteria	Assessment Structure
Water Resource Availability	Major surplus of water for sustainable recovery (+110%)	Likert-Scale score 5
	Minor surplus of water for sustainable recovery (+105%)	Likert-Scale score 4
	Adequate supply for sustainable recovery (100%)	Likert-Scale score 3
	Minor short fall of water for sustainable recovery (−95%)	Likert-Scale score 2
	Significant short fall of water for sustainable recovery (−90%)	Likert-Scale score 1
Cost of Water	No cost—supported by rain only ($0 kL)	Likert-Scale score 5
	Low ($0–$2 kL)	Likert-Scale score 4
	Medium ($2–$4 kL)	Likert-Scale score 3
	High ($4–$6 kL)	Likert-Scale score 2
	Extreme ($6+ kL)	Likert-Scale score 1
Soil Characteristics (high CEC, water holding capacity, free draining, good aeration)	Very high in all desired factors	Likert-Scale score 5
	High in all desired factors	Likert-Scale score 4
	Moderate in all desired factors	Likert-Scale score 3
	Low in all desired factors	Likert-Scale score 2
	Very Low in all desired factors	Likert-Scale score 1
Financial Investment	Very high investment ($/100 m^2 $1200–$1500)	Likert-Scale score 5
	High investment ($/100 m^2 $900–$1200)	Likert-Scale score 4
	Moderate investment ($/100 m^2 $600–$900)	Likert-Scale score 3
	Low investment ($/100 m^2 $300–$600)	Likert-Scale score 2
	Little to no investment ($/100 m^2 $0–$300)	Likert-Scale score 1
Community Desire	Strong desire	Likert-Scale score 5
	Mild desire	Likert-Scale score 4
	Neutral	Likert-Scale score 3
	Mild opposition	Likert-Scale score 2
	Strong opposition	Likert-Scale score 1

Table A1. *Cont.*

<table>
<tr><th>Factor</th><th>Criteria</th><th colspan="6">Assessment Structure</th></tr>
<tr><td rowspan="5">Shade Requirements
(High foot traffic, high car traffic, wide road, wider verge, orientation E/W, low infrastructure)</td><td>Very high (7–8 factors present)</td><td colspan="6">Likert-Scale score 5</td></tr>
<tr><td>High (5–6 factors present)</td><td colspan="6">Likert-Scale score 4</td></tr>
<tr><td>Medium (3–4 factors present)</td><td colspan="6">Likert-Scale score 3</td></tr>
<tr><td>Low (1–2 factors present)</td><td colspan="6">Likert-Scale score 2</td></tr>
<tr><td>None (0 factors present)</td><td colspan="6">Likert-Scale score 1</td></tr>
<tr><td rowspan="5">Biodiversity/Ecological Demand</td><td>Within a biodiversity hotspot</td><td colspan="6">Likert-Scale score 5</td></tr>
<tr><td>High biodiversity</td><td colspan="6">Likert-Scale score 4</td></tr>
<tr><td>Moderate diversity</td><td colspan="6">Likert-Scale score 3</td></tr>
<tr><td>Low diversity</td><td colspan="6">Likert-Scale score 2</td></tr>
<tr><td>Void of biodiversity</td><td colspan="6">Likert-Scale score 1</td></tr>
<tr><td rowspan="6">Political Influence</td><td rowspan="6">5 × 5 grid</td><td></td><td>very strong support</td><td>neutral</td><td>strong opposition</td><td>very strong opposition</td><td>neutral</td></tr>
<tr><td>very strong influence</td><td>5</td><td>4</td><td>3</td><td>2</td><td>1</td></tr>
<tr><td>strong influence</td><td>4</td><td>4</td><td>3</td><td>2</td><td>1</td></tr>
<tr><td>moderate influence</td><td>3</td><td>3</td><td>3</td><td>2</td><td>1</td></tr>
<tr><td>weak influence</td><td>2</td><td>2</td><td>2</td><td>2</td><td>1</td></tr>
<tr><td>no influence</td><td>1</td><td>1</td><td>1</td><td>1</td><td>1</td></tr>
<tr><td rowspan="5">Climate</td><td>Tropical</td><td colspan="6">Likert-Scale score 5</td></tr>
<tr><td>Mediterranean</td><td colspan="6">Likert-Scale score 4</td></tr>
<tr><td>Temperate</td><td colspan="6">Likert-Scale score 3</td></tr>
<tr><td>Arid</td><td colspan="6">Likert-Scale score 2</td></tr>
<tr><td>Mountains</td><td colspan="6">Likert-Scale score 1</td></tr>
</table>

Table A1. *Cont.*

Factor	Criteria	Assessment Structure					
Extreme Weather Events (heavy rainfall, localised flooding, extreme temperatures, strong winds)	5 × 5 grid		10+ times per year	7 to 9	4 to 6	1 to 3	never
		Experiences all extreme weather events	5	4	3	2	1
		Experiences most extreme weather events	4	4	3	2	1
		Experiences some extreme weather events	3	3	3	2	1
		Experiences	2	2	2	2	1
		Experiences none extreme weather events	1	1	1	1	1
Zoning	CBD	Likert-Scale score 5					
	Inner city	Likert-Scale score 4					
	Metropolitan	Likert-Scale score 3					
	Outer metropolitan	Likert-Scale score 2					
	Semi-rural	Likert-Scale score 1					

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