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Trees on Buildings: A Tree Selection Framework Based on Industry Best Practice

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Highlights:

What are the main findings?

- A four-stage tree selection framework is proposed to increase implementation success;
- Planting strategies, microclimate analysis and maintenance planning are essential for success;

What are the implications of the main findings?

- Soil volume selection should be evidence-based and suitable for trees at maturity;
- A balance between exotic and native species in green roof settings at the city scale is needed.

Abstract: Trees on buildings have received increased interest, and installations have multiplied over recent years, yet there is limited literature and policies guiding the successful implementation of projects relating to trees on buildings. This study investigates the tree selection process for implementation on buildings, using a survey and follow-up interviews with experienced experts to reveal current worldwide industry best practice, and provides a systematic framework for selecting the most appropriate tree species. A tree selection framework is proposed that consists of four stages: identifying the purpose of the tree; analysing the site context and its conditions; evaluating the risk of implementation; and investigating the characteristics of the candidate trees. Decision-makers can use the developed framework to inform design, implementation, and policy development of trees on buildings to reduce implementation risks. In addition, this paper provides useful insights to inform future research about trees on buildings.

Keywords: trees on buildings; tree selection; green roof; city policies; framework

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1. Introduction

Green infrastructure has received increasing attention over the last decade to mitigate the negative impacts of urbanisation and climate change [1]. Diverse types of plants with different implementations define the current types of green infrastructure systems available, including green roofs and green walls. Of the existing vegetation and plant types, trees show higher environmental and thermal performance [2] through air pollution reduction [3], urban heat island mitigation [4], increased shading and biodiversity [5], and improved thermal comfort [6]. However, trees on buildings have received less attention in green infrastructure studies [7] compared with low canopy vegetation. The few existing articles investigating trees rarely mention tree species or provide a holistic overview regarding their selection, although research application is broad (e.g., it might concern thermal performance, health, wildlife, etc.). For example, in their study regarding bird and butterfly diversity, Wang et al. [8] inventoried 126 plant species, tree height and tree crown, but since tree species are not mentioned, it is difficult to evaluate the benefits of one type of tree. The same phenomenon is observed in Tian and Jim [9] and Mohammadi and

Calautit [10] although the latter investigate the impact of tree configuration on the areo-thermal performance of the sky garden. As a result, conclusions of the investigations, albeit interesting, fail to inform on which trees to choose. One noticeable exception is provided in the study of Law, Hui, Jim and Ma [7], which specifically details tree species composition, planting space design and management, and tree health. In summary, this is surprising knowing that several green roof settings such as rooftop gardens, sky garden arrangements [6], intensive green roofs [11] and individual tree box planters having the capacity to support trees on a roof [7] are exist.

Several reasons explain the limited scholarship, such as the complexity of investigating trees, as it requires expertise across multiple disciplines; long-term investigations, or high upfront cost and maintenance [12,13]. Another substantial reason is that trees on buildings are exposed to extreme environmental conditions [7], such as wind loading pressures and strong sunlight exposure [6]. These conditions significantly affect tree stability and health, and therefore, tree species need to be critically chosen to withstand these conditions, as failure might pose a danger to people and property [14]. In addition, trees on buildings are grown in planters rather than natural ground, and this context includes it's own design challenges. Law, Hui, Jim and Ma [7] define a tree's growing space into three types: tree pit, raised planter, and sunken planter. The tree pit has no hard edges, while the raised planter has edges taller than 40 cm, and the sunken planter has edges shorter than 40 cm (Figure 1). Tree pits can only be within the ground level with no confinement for tree root growth. Only raised and sunken planters are suitable for trees on buildings to prevent building structure damage [15].

Figure 1. Planter types for implementing trees on buildings. (**A**) = sunken planter and (**B**) = raised planter.

The paucity of literature regarding tree selection and installation practice for trees on buildings plays an essential role in hindering their expansion and implementation [14]. Therefore, this study focuses on this gap by investigating two questions. First, what are the technical requirements and challenges for utilising trees on buildings? Second, what systematic procedures are needed to select the most appropriate tree species?

This paper is divided into five sections that present the literature review, the research method, the results and the discussion prior to the conclusion.

2. Literature Review

This section provides a broad literature review on tree selection requirements, underlining four important factors (site considerations, planter and substrate settings, native versus exotic species and wind load). It also reviews policies regarding tree implementation on buildings, with the example of Australia where the authors are located.

2.1. Site Considerations

Planting trees on buildings differs from planting into natural ground, as on buildings there may be structures below or above that impede both roots and crowns, potentially restricting the growth of the trees. Depending on the tree location, there might be limited access to sunlight, rainfall, and nutrients in the soil, which could all impact the process of photosynthesis, thereby reducing growth in the long term [16]. However, on buildings, conditions can be harsher. For example, Wang [17] has shown that illumination intensity can be 3300 lux stronger on rooftops than on ground levels, including 5% lower relative humidity, 6 °C higher temperatures and 0.6 m/s faster wind velocities in the middle of a sunny day.

Despite these constraints, there is no evidence that planting trees at a higher elevation leads to poorer tree health. Some trees, such as palms, might grow better at a higher elevation [7], as is reflected in many successful examples worldwide [18–22]. In fact, modifying building roofs to provide a suitable environment for trees might result in a better growing environment for tree growth than other on-ground locations, which might suffer from blocked sunlight and wind tunnels due to nearby buildings [7]. Therefore, it is essential to consider the environmental factors that could affect tree health and especially protect them from excessive wind and heat to increase success in this type of artificial planting [23].

2.2. Planter and Substrate Settings

Preparing an appropriate planter, whatever its size (box or intensive roof), to contain roots and ensure tree stability is necessary. However, there is no ideal planter suitable for all tree species, as trees have different needs. Furthermore, tree growth indexes, such as growth height, leaf length, leaf width, root length, and the number of lateral roots, could be reduced by the planter size due to limited soil thickness and volume [24]. Another study that observed sky garden tree species in Hong Kong conducted by Law, Hui, Jim and Ma [7] reported that planter type directly influences tree growth indexes. They noticed that palms perform better in raised planters, which have greater soil depth, while woody trees perform better in sunken planters with a shallower soil depth. To design the appropriate planter type and sufficient growth space for tree roots, it is important to understand the root habits of individual plant species, as root systems participate in tree stability and growth. For example, a common misconception is that below-ground root systems mirror the above-ground trunk and branches. However, most large roots responsible for structural support are in the upper 60 cm of the soil [25]. Trees self-optimise the distribution of their roots to support their needs [26,27], while mechanical control and hydrotropism play key roles in their growth [28,29].

Once the type of planter has been determined, the available scholarship shows that other important criteria include the selection of soil and its characteristics, as well as planter size. Soil needs to have sufficient void-spaces between particles to provide aeration and enable the movement of gases, especially oxygen and carbon dioxide, which support the vitality of the roots. Soil must have sufficient chemical qualities for plant nutrition and water retention to improve root health, thereby reducing their need to produce a larger but less efficient root system [25,30,31].

Allocating a suitably sized confined area for the root system is essential in managing tree growth over time and to a sustainable or appropriate size, as varying this area alters the root volume of the plants [32]. Plants stimulate their canopy and root growth according to the planter shape and size in which they are planted [33]. When planted in conditions with confined root areas, they undergo many physiological and morphological changes, that affect root and shoot growth, photosynthesis, biomass accumulation and partitioning, as well as leaf chlorophyll content, hydrotropism, nutrient uptake, respiration, and flowering [32,34]. As planter size increases, plant leaf area, shoot biomass and root biomass also increase [24,35]. Furthermore, in highly restricted planters, shoot biomass and root biomass can be increased by 43% by doubling planter size [32,33]. Roots rely upon plant aerial portions for photosynthates and various hormones, while plant aerial portions rely on the roots for water, nutrients, support, and hormones [30].

Lastly, to reduce risk of failure and increase safety, existing literature explains that planters should be designed to prevent trees growing as much as they would in under unconstrained natural conditions [36]. International practices for growing plants in containers and planters generally recommend a range from 8:1 to 10:1 for the ratio rootball diameter: trunk diameter. This range allows the rootball to provide a quality root system [37–39]. However, some city councils require the use of 0.6 × canopy projection at tree maturity as a minimum soil volume to increase implementation success [40].

2.3. Tree Selection Considerations

Since trees on buildings create new ecosystems [7], using the native plant species list is usually a good place to start to select trees that are well-adapted to the local climate. However, the unique setting may require consideration beyond the native plant lists to select traits that are well-adapted to the site conditions [41,42] including increased elevation and exposure. Usually, trees with sparse canopies, flexible stems, and high tolerance to heat, perform better on buildings [23], and smaller-sized, slower-growing trees are preferrable as they could limit maintenance and reduce wind resistance [43,44]. However, scholarship about the evolution of trees on buildings shows the recent shift to favouring canopy trees with broad leaves as they have higher ecological value and greater positive influence on the environment from various perspectives, including enhancing the microclimate and increasing biodiversity [7,45].

Sjöman and Nielsen [46] proposed tree selection criteria for urban paved and confined sites, that are also relevant to trees on buildings, as they mostly concern site conditions. These criteria include:

- The context of planting
- The adaptability of the selected trees to the conditions in urban paved sites
- The availability of the trees locally and testing of trees in similar environments
- Consulting local planting specialists and specifying site types and conditions
- Extend the selection to the full range of tree species suitable to the climatic region

The authors emphasise that, in all cases, tree selection must prioritise stress tolerance above aesthetic appeal and functional aspects [46]. Therefore, experts other than architects and landscape architects should participate in the selection process, and this may include horticulturists, arborists, bushfire experts, and environmental engineers [21,40,44]. It should be considered that trees show considerable variation in the shape and size of their crowns, height, trunk diameters, and leaf characteristics. These characteristics are determined by inherited tendencies that may change depending on the environment in which the trees grow [47]. The size of a tree canopy and its height above the ground determine the total amount of shade cast on the planted and surrounding surfaces and its impact on the microclimate [48]. The tree trunk needs to be of sufficient size and strength to withstand the forces acting on it, including the weight of the tree and the wind load. A careful assessment of wind load is needed as, experimentally, wind load is much more important than weight in determining the necessary tree trunk thickness [47].

2.4. Wind Load

Wind load is an important factor in ensuring the stability of trees on buildings. Tree anchorage to resist wind load relies upon the soil to resist fracture and handle the compression from the tree weight and the collected wind load by its canopy. In addition, windward roots, leeward roots, and roots in cross-sections must be strong and anchored to withstand pulling, buckling, and shearing [29]. The collected wind load by tree leaves and branches causes a high bending force at the tree trunk, which is distributed over the roots (the mechanically active roots) into the soil [49]. To cope with wind loads, trees naturally form their roots to ensure even load distribution with longer and stronger roots on the tension side (windward side), and stronger roots on the other (leeward) side to reinforce the soil, anchor the tree, and distribute the compression [49,50]. In addition, the tree root system acts as an anchor. The tree uses the root system to distribute the gained loads by wrapping around or hooking onto surrounding structural elements such as foundations, walls, and pipes. As planting trees in a planter with limited soil restricts tree root growth, most policies require adding an anchoring system to support tree roots and stabilise trees on buildings [21,40,44]. In addition, other structural elements that the trees can use to anchor can be incorporated into the designed planter structure. To understand wind loads on trees and consider these loads in the planter design, Coder [29] and Koizumi et al. [51] provided the following equation:

$$F = 0.5 \times WV^2 \times AD \times \left(\left(\frac{DC \times \ CL \ \times CW}{2} \right) \times \left(TH + \frac{CL}{3} \right) \right)$$

Note. F = wind load force on the treetop; WV = wind velocity; AD = air density; DC = drag coefficient; CL = crown length; CW = crown width; and TH = trunk height.

Two and a half times the force (2.5 × F) is concentrated on the windward roots and an equal amount of the force on leeward roots. The force centred on windward roots is 1.5 × F of the force centre on leeward roots [29] as per Figure 2. It is essential to design the planter to withstand these loads and the anchorage system to handle the upward forces to increase the implementation success. Figure 3 illustrates different types of recommended anchoring systems for the implementation of trees on buildings [21].

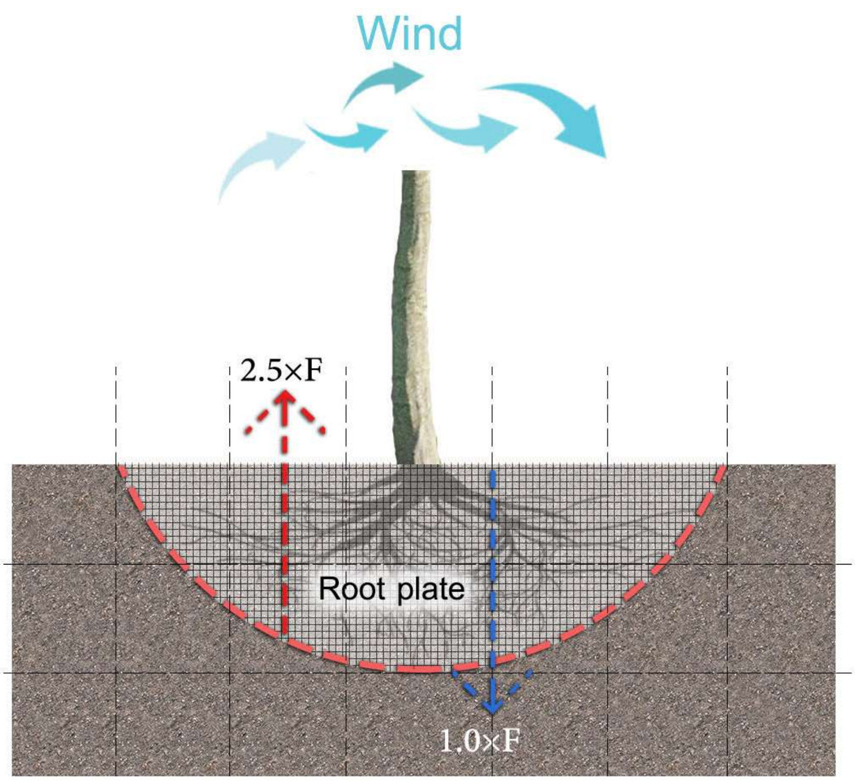

Figure 2. Wind loading and gravity impact of trees.

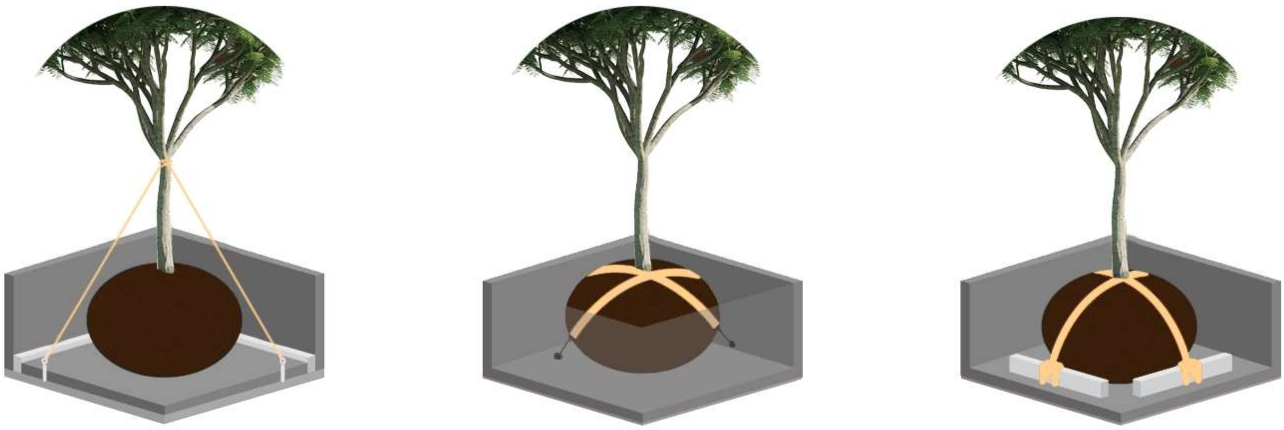

Figure 3. Different anchoring system types, illustrated based on the Melbourne guidelines [21]. (**A**) = plate anchorage system, (**B**) = rootball anchorage to planter wall, and (**C**) = anchor straps and 'dead man' system.

Note. Wind loading and gravity act as a combined load wheel, which responds to tree failure in the case that the root anchorage is not sufficient outside the load wheel. Illustration based on Coder [29]. F = wind load force on the treetop.

2.5. Policy Review

A review of the policies relevant to trees on buildings for five major Australian cities was conducted including Brisbane in Queensland; Sydney in New South Wales; Adelaide in South Australia; Melbourne in Victoria and Perth in Western Australia. In general, green infrastructure and green roof policies predate policies related to trees on buildings. Brisbane introduced a green roof policy in 2007 [52] followed by Sydney, Melbourne, and Adelaide in 2014 [21,53,54], while no policies for green roofs have been implemented in Perth yet [55]. Some cities have more progressive policies and incentives than others, which has inspired the establishment of a national body to enhance policies across the country via the *Roadmap for Green Roofs, Walls and Facades in Australia's Urban Landscapes 2020–2030* [56].

Whereas Sydney and Melbourne have established holistic guidelines for tree selection and implementation in urban areas, such as the Urban Forest Strategy in Sydney [57] and Melbourne [58], only Melbourne and Brisbane have developed guidelines for tree implementation on buildings as part of green roof guidelines. The Melbourne guidelines were introduced in 2014 [21], and largely adopt the German Landscape Research, Development and Construction Society (FLL)-Green Roof Guidelines, particularly for trees on buildings [59]. In addition, trees are included in Melbourne's Green Factor tool that encourages new buildings to be environmentally friendly and include green infrastructure. Melbourne's tree implementation guidelines provide specific guidance around the calculation of tree weight loadings based on tree size and require at least 1 m soil depth for trees and a root anchoring system to prevent windthrow. The planter is required to be wide enough and deep enough to host the trees lateral root growth as part of ensuring successful tree establishment [21]. The Freshwater Place Green Roof, Southbank, Victoria, is a good example of adopting these guidelines. This project included 30 established trees growing in the green roof garden beds [21].

The Brisbane guidelines regarding tree implementation on buildings include deep artificial planting on buildings, including podiums and intensive green roofs with strict requirements on planter dimensions. Specific constraints include a minimum internal depth of 1.2 m. Based on that the planting media must be 0.6 m^3 $\times$ canopy projection at tree maturity; minimum soil depth of 0.8 m for small trees (<5 m height at maturity) or minimum soil depth of 1.2 m or rootball depth plus 0.2 m, whichever is greater for taller trees (>5 m) over an area of 1.5 m $\times$ 1.5 m [40]. A planting scheme that demonstrates the suitability of trees to planter type, size, and location is also required. It also includes an in-ground anchoring system, irrigation system (which must be from a non-potable source and should be designed using sub-surface irrigation spears), a structural design and report to the suitability of the planter weight for the building, a fire safety certification, and a one-year of establishment period maintenance program [16]. An example of where these guidelines have been adopted is the Treehouse apartment by ARIA Living in West End, Brisbane. This project includes more than 100 established trees in building balconies and green roof garden beds [22].

Although the above-mentioned policies provide a good basis for guidelines about tree implementation on buildings, there are still some challenges that need to be covered to ensure tree implementation success. The main aspects to consider while designing and implementing trees on buildings have been highlighted in the literature review. However, the paucity of both the sources and case studies are evidence that there are still many unmet challenges and knowledge to produce, including tree selection and installation practices on buildings.

3. Methodology

This study used a qualitative approach based on survey and follow-up semi-structured interviews with experts in implementing trees on buildings, as illustrated in Figure 4.

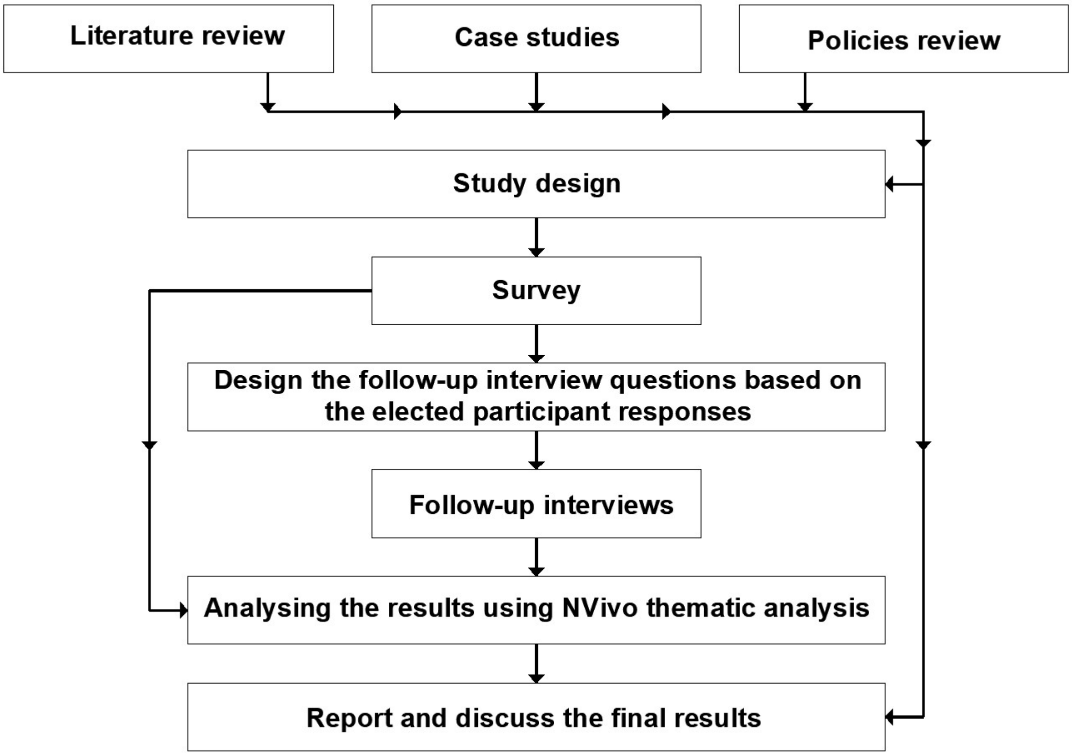

Figure 4. Research framework.

3.1. Study Design

The design of the survey and interviews was based on a review of the international literature and Australian policies on trees on buildings, sky gardens, green roofs, rooftop gardens, and tree selection in general to cover the missing knowledge and to facilitate trees implementation on buildings.

The survey explored trees on buildings from the experts' point of view, where an expert was defined as a person with experience in designing, constructing, maintaining, or regulating trees on buildings. The features of the survey and the interviews were as follows:

- The first section of the survey included closed-ended questions concerning the background of the experts (discipline, geographic location, role in the design, and implementation process) to classify the results of the study in the context of expert knowledge of tree selection and implementation on buildings.
- The second section of the survey consisted of open-ended questions focusing on the tree selection process and the implementation requirements for trees on buildings. It also investigated:
  - The designs and construction requirements of trees on buildings;
  - The process of preparation;
  - The barriers;
  - The existing policies;
  - The current techniques and risks;
  - The areas of improvement;
  - The required knowledge;
- Follow-up semi-structured interviews were conducted with those experts who expressed an interest in providing more information through the survey. The aim was to expand upon the themes presented in the survey questions in richer detail.

3.2. Data Collection

The survey was conducted using Google Forms. An identical survey was created using Microsoft Forms for dissemination in countries where Google Forms is restricted, specifically in China. The survey was promoted through the authors' social media, including Facebook, LinkedIn, ResearchGate, and Academia. Expert participants were also identified by a web search of projects that implemented trees on buildings and directly emailing their designers and developers. The survey remained open for four months (4 March to 4 July 2021) and was completed by 61 experts from various backgrounds, dominated by architects (29 participants) and landscape architects (10 participants), and locations worldwide, with an emphasis on the Australian context (43% of experts), while the rest of the experts were 36% Asian, 17% European, and 4% North American.

Eighteen experts participated in the semi-structured interviews (69% of the 26 experts invited). The average time of the interviews was 32 min. The interviewees were four landscape architects, two architects and horticulturists, an agricultural engineer, a tree grower, a developer, an installer, a maintenance expert, an arborist, a plant health expert, a policymaker, a fire engineer, and an academic.

3.3. Data Analysis Protocol

The transcripts from the surveys and interviews were analysed to identify the main themes using NVivo Word Frequency query and Word Tree. NVivo 12 is commonly used to analyse unstructured written data [60]. It helps to index the text inside the documents, search for words and phrases, and then link them to themes, contexts, and categories [61]. The survey data were exported to MS Excel from Google Forms and Microsoft Forms. The recorded interviews were automatically transcribed using Otter.ai and then edited manually for accuracy. The data were coded, categorised, and analysed based on the identified themes presented in Table 1. Participant responses were given unique S-number (S01–S61) identifiers for survey responses and I-numbers (I01–I18) for interview responses. The research questions and relevant theoretical concepts guided the initial coding process. The coded themes emphasised the emerging relationships between the analysed data, which were used then to categorise the results section.

Table 1. Coding themes of the survey results using NVivo showing the number of the participants and references in each theme.

Theme	Number of Participants	Number of References
Selection rationale		
Enhance the environment	61	121
Enhance building aesthetics	37	66
Enhance air quality	32	36
Enhance building users' health	20	37
Increase building energy efficiency	18	33
Enhance users' lifestyle	18	33
Marketing strategy	15	32
Enhance the thermal comfort	13	22
Increase roof usage	14	23
Increase building financial value	11	19
Climate change mitigation	12	19
Increase the biodiversity	9	14
Increase the shade on the roof	8	13
Stormwater delay and water harvesting	6	9
Increase building sustainability	6	6
Decision influencing factors		
Maintenance requirements	54	131
Trees selection and planting	33	67
Cost	23	41
Design team	22	52
Climate considerations	17	36
Location and Cross shading	10	18
Survival and establishment	9	19
Building theme	4	7
Implementation requirements		
Planter design	44	93
Irrigation	24	59
Soil media	18	37
Tree anchoring	17	25
Drainage layer	13	26
Planting techniques	8	11
Implementation risk		
Wind and storms	29	59
Water proofing	25	47
Roots	28	49
Weight and building structure	25	45
Dropping parts	17	26
Fire risk	10	29
Plant disease	10	20
Tree characteristics		
Growth rate	11	19
Size	11	15
Climate adaptation	8	12
Tree form	7	9
Wind and storms resilience	7	10
Trees stock	3	7
Longevity	2	4

4. Results

The findings can be categorised under four main themes. These relate to the design intention, the current and future environmental and design conditions, the risk assessment and the desired characteristics of trees on buildings.

4.1. Purpose of Installing Trees

All of the participants confirmed that implementing trees on buildings provides many benefits, which encompass a variety of economic, health, and wellbeing attributes: "*[the benefits] might be direct or indirect . . . [] . . . [for instance, they could] add value to the building and help sell the project . . . [] . . . attract customers . . . [] . . . provide a nice environment to work in and help the employees work better . . .* " (S06). Participants also noted that there needs to be a rationale for selecting tree species that enhances the targeted benefits of their implementation, which should "*depend on what exactly we're trying to achieve . . . [] . . . [is it] to just look better, or to absorb more carbon from the air, or to produce more oxygen for the world, or to supply food for that particular building?*" (I10). The following sub-sections propose a classification of the purpose of implementing trees on building into three categories.

4.1.1. Environmental Considerations

Most participants (70%) considered implementing trees on buildings for positive environmental outcomes. For instance, S51 mentioned that "*we have run out of green spaces in cities*". Therefore, "*implementing trees on buildings gives us the chance to return the ecological balance*" (I12), and "*increase the green coverage in the built environment*" (I15). Installing trees on buildings helps "*[mitigate] climate challenges*" (I05), "*reduce heat gain and increase heat stability*" (I16) which help in creating more "*habitat for animals*" (S58), "*balance the carbon footprint*" (S37), "*clean the air and capture dust*" (S04), "*minimise the rush of stormwater . . . [] . . . and for water purification*" (I01), and to "*re-connect people with nature*" (S52).

Participants also noted that the careful selection of trees could contribute to achieving several benefits. Examples of these included: "*using trees with a high rate of photosynthesis to produce oxygen and remove toxins*" (I06) and "*[trees with] high carbon fixation to increase carbon sinks*" (I06). Others suggested that a tree that could "*host and store water in its phloem and roots*" (I01) and, with "*high stomatal conductance and transpiration rate*" (I07), a tree could participate in stormwater delays and enhance the water cycle. Some focused on the flora and fauna aspects, noting that a tree "*attracts and brings insects and brings birds, and it brings bugs, bees, and spiders*" (I09), which "*promote biodiversity, and that can be by choosing native species and avoid using exotic species*" (I07). In all cases, "*a careful assessment of the environmental impact of the proposed rooftop garden is needed*" (I18), to ensure that "*the selected trees and their influence on the environment matched with the overall city strategy in maintaining an appropriate ecological balance*" (I17).

4.1.2. Building Design Considerations

Many participants (67%) agreed that trees on buildings are essential to enhancing building design and urban lifestyles. For instance, S06 stated that "*It's aesthetically appealing, and it breaks the rigidity of the architectural work creating a soft environment both for the direct user-user of the building and the indirect user-anyone who passes by the street if we look at in an urban context*". I08 added "*our [rooftop] garden is something that is not a static environment . . . [] . . . it's changing and evolving and becoming different all the time*". I09 emphasised that "*adding trees to a building makes buildings more attractive, as a connection to the ground and a connection to the landscape . . . [] . . . that is something that can't be replicated in any other way*". It is also considered a marketing approach, as "*it increases the attractiveness of the project in terms of a selling point*" (S61), and "*increases the value of the building*" (I15), as trees on buildings within a roof garden arrangement "*act as a recreational asset*" (I13) which "*increases the wellbeing of the users*" (S28), "*emotionally and physically*" (I14).

Participants reported that these added values could be gained by "*implementing species that have great aesthetics following the project theme*" (I06). For example, for recreational benefits and to enhance cultural memes, evergreen trees are preferred: "*customers don't like to see deciduous trees in winter, so sometimes you have to plant evergreen trees*" (I06), and "*maybe grow some citrus plants because we have this Eastern restaurant . . . [] . . . as they have this aroma, nice smell, and these waxy leaves . . . [] . . . Olive trees for an Italian restaurant, or some bamboo for a Thai restaurant*" (I12). For some projects, "*such as healing gardens or when we* *want the users to engage with the garden, we might add fruit trees or other trees that could help in this engagement*" (I01).

4.1.3. Thermal Considerations

Trees have an essential influence on enhancing thermal comfort and reducing the energy consumption of buildings, as emphasised by about 52% of participants. For example, I12 noted that "*trees affect the whole atmosphere including the microclimate . . . [] . . . and of course, the building*", while I13 stated that they "*provide shade and . . . [] . . . an informal, soft kind of impact*". Others mentioned that trees participate in "*providing some natural cooling*" (I09) and noted that when "*the trees are cooling down buildings, you won't require as much energy to keep the building cool . . . [] . . . and in the long-term, they reduce the impacts of urban heat islands and climate change*" (S17). The shade of trees also helps in "*reducing the effects of harmful ultraviolet and infrared rays on building products*" (I01) and provides an insulative effect by "*[reducing] the variation of temperature between the day and the night . . . [] . . . [which] affects the materials that are installed up there [on the roof]*" (I12).

When trees are selected for thermal performance, the participants emphasised selecting canopy trees "*that have a great shading and cooling effect*" (I06). These trees usually have "*dense foliage and spreading canopy*" (I07), "*their ability to evaporate water is high*" (I04), the characteristic of their leaves is also important "*they should have high reflectivity and stomatal conductance*" (I06). If the climate has a cold winter, "*we tend to select deciduous trees to increase the sun exposure on the building*" (I07) and "*use some fence and columnar trees to break the wind and cold air*" (I06).

4.2. Existing and Predicted Conditions of the Tree Context

Selecting trees for implementation on buildings differs from selecting trees at ground level. The latter usually follows long-established or specific guidelines. For trees on buildings, participants noted that it is "*site-specific*" (I04), and "*case by case*" (I11), and each tree should be selected based on the site context and its location conditions, "*there isn't a guidebook out there that says which plants you should plant, and there shouldn't be. It's not about guidebooks, it's about [tree] context and local context*" (I13). The following sub-sections classified the tree context conditions into three categories that provide considerations for tree selection.

4.2.1. Microclimate Considerations

Each building has its own microclimate, and there is a need for "*understanding the location of the building in context to weather*" (S21), as "*there are a lot of microclimates occurring on buildings*" (I04), and each "*building would have completely different environments, each face, and that will stipulate what trees you would specify*" (I13). Some trees, even if well adapted to other similar climates, may fail to grow properly if "*they were too exposed*" (I07, I16). Therefore, the selected trees "*have to be climatically and microclimatic responsive*" (I01) and "*able to handle a difference between significant rainfall and quite dry conditions and quite windy conditions at times*" (I05). It's important to choose resilient trees based on prior experience. "*Species that we know [are] really robust, and they can handle really terrible environments*" (I09). There is also a need to consider the predicted future conditions "*what the climates are likely to be? . . . [] . . . moving into a hotter climate with more periods of heavy rain, and then drought?*" (I01). After analysing the building microclimate, trees should be selected that "*will survive and thrive in the conditions that you place it in*". The propagation source of the selected trees should be investigated, particularly for the climatic characteristics, as the highly variable conditions on a building may cause undue stress and these conditions are becoming more extreme with climate change: "*we're looking at issues of dealing with temperatures that aren't similar to what were the temperatures in that place before*" (I01).

4.2.2. Planter Design and Location

Planter design and location on the building can provide essential guidance for selecting the correct tree species. The planter dimensions have a direct influence on the selected species "*we have to deal with soil volume . . . [] . . . if they want to have certain size trees, they have to provide appropriate soil volume*" (I01). The tree selection should consider "*the tree rootball size and the availability of the soil volume for the tree to reach its mature size*" (I06). If the planter does not provide the needed soil depth for the selected tree, several strategies can be used to compensate, for example to increase the soil depth, "*we had to find a way where we could get more substrate in, and we did that by creating mounding, so . . . [] . . . wherever there was a tree, we had to raise the mound up*" (I13). In addition, the size of the tree could be controlled to adapt to the planting conditions by "*regularly pruning the tree branches in a similar way to the Bonsai mechanism*" (I16).

One of the biggest challenges is the "*wrong tree in the wrong place*" (S51). The physical location and the environmental influence of that location need to be considered. For the location, it's important to "*make sure that your designs and structures don't wind up choking the base of the tree or causing adverse interactions between the trees and hard surfaces . . . [] . . . you need to avoid pavement heating or chafing at the root . . . [] . . . [avoid dark] colours, glass reflection, and all those sorts of things to make sure that the trees are healthy and well*" (I14). In addition, consider the "*proximity to the edge of the building*" (I02), "*how to access them safely*" (I02), and their location on the building, specifically if there is a "*structure above the tree*" (I15). One participant noted that decision-makers must "*select tree species that are going to produce healthy compact specimens for the light and wind conditions for the planter/roof garden location*" (I13). "*When you talk about all four sides, that means at least two of those sides are going to be susceptible to wind events and need to be designed accordingly. Then, of course, the south side [in Australasia] is going to a very low light period . . . [] . . . then it's a matter of balance and [that the planter] sits far enough away [from the shade] that there's enough reflected light coming back off the building uniform leaf development rather than lopsided*" (I08).

4.2.3. Planting Strategy

Selecting trees for the implementation on buildings should be part of a long-term vision that reaches beyond installation and must include the "*understanding of plant biology or tree sciences*" (I10) and "*the tree's lifespan*" (I01) and their expected size when "*grown to maturity*" (I14). Additionally, an understanding of "*the life-cycle helps in maintaining the trees, knowing when and how to prune them*" (I07). Therefore, "*a range of expertise is needed in the selection process, including the input of horticulturists, trees growers, and arborists*" (I17). Although "*increasing the variety and proximity of the plants is important to promote biodiversity*" (I08), at the first stage of the planting, it is important to "*avoid plant proximity to each other and mainly with trees . . . [] . . . [as] trees might face stress during the establishment period*" (I06) and "*plants proximity will increase this stress . . . [] . . . because over planting takes nutrients . . . [] . . . you can sacrifice the full look for the first year as the second year you'll be right up to where you are wanting to be*" (I07). In addition, "*it is preferable to plant trees for at least six months before planting shrubs and ground covers in the same planter to increase the trees' success*" (I18). Participants also mentioned it is important to assess the purpose of the trees and the surrounding environment, such as "*the connectivity of the sky garden with other green spaces whether on the ground or other green spaces*" (I08), as "*sometimes the trees [on buildings] are isolated, and that leaves them more vulnerable . . . [] . . . means that birds and things like that which might eat insects in the trees, don't have other trees to rest in or to nest*" and are therefore less likely to visit (I05). After selecting the trees, "*it would be better for the tree's health to place them for some time in a nearby location to adapt with the project environmental condition and ensure the availability of the tree stock before planting them*" (I06), as "*often clients want this big instant tree . . . [] . . . that's not available, and we get that for the scenario that what we ended up with is often trees that are available and look good*" (I01). It is also important to "*[avoid] poor quality stock and to maintain unity*" (I14), as "*sourcing from two different nurseries . . . [] . . . [might] looks like two completely different plants*" (I07).

4.3. Risk Evaluation

Trees on buildings are at risk from the surrounding environment, and they can also be a source of risk for the building if it is not properly considered. For example, one participant said that tree implementation "*can be risky with inappropriate tree selection, poor planter and substrate design and poor maintenance. Trees may fail; may become flammable; may drop limbs; may blow over; may damage infrastructure*" (S48). Assuming the planter is well-designed, the following sub-sections cover the main risks that need to be considered to ensure that the correct trees are selected and their ongoing stability after installation is maintained.

4.3.1. Risk of Failure

Trees, in general, can easily survive and flourish on a building. However, "*when they start to deteriorate in health, they can become seriously unstable. I've seen trees withstand quite large amounts of wind and storms, but as soon as they become weak, they just start to wriggle like this in the soil*" (I07). The biggest risk to tree health is "*definitely the establishment period*" (I02), and the tree "*on the rooftop of a building, it's going to need three years to establish . . . [] . . . the bigger the tree, the longer the establishment period . . . [] . . . the establishment period really determines what's going to live and what's not*" (I07). Therefore, "*you should ensure that you've got root development all the way through the profile, and everything's performing as naturally would occur*" (I08). In addition, "*during the establishment period, extra attention and maintenance plans for trees is needed to increase their success*" (I17).

Disease and pests have been identified as the second major risk by the participants. The environment on the roof is harsher than on the ground, which may cause tree stress, "*when trees are stressed, they are vulnerable to insect and pest damage, insect and fungal damage*" (I05). However, "*if you choose the species of tree well, you can probably reduce your risk of pests and disease problems*" (I06), as "*when the trees have a disease that can cause a lot more leaf drop, it can also cause sap drop from the leaf phloem, and this can get onto pavements and pool areas*" (I05). "*The disease could [also] transfer to other trees and plants and cause a serious problem in the roof garden*" (I16). In addition, it is important to monitor nutrients and select the appropriate growing medium to suit the selected trees, because "*as soon as they're nutrient deficient, they're prone to disease and pests once you've got disease and pests, it's really hard to get rid of it*" (I07) also, "*if you over fertilise, you can create good growth, but often the high nutrient leaves are attractive to insects. It can increase your insect attack and stripping of foliage*" (I05). "*Some tree species are highly attractive to insects and these species should not be selected*" (I17), as these trees "*need so much spraying . . . [] . . . and easily get mould and rust*" (I12). Mostly, "*exotic trees are more resistant for local disease and insects, while native species attract them . . . [] . . . to reduce risk of disease in the local environment, try to invite more exotic trees*" (I08).

4.3.2. Risk of Root Damage

Tree roots can place risk on the building structure, specifically "*when trees are exposed to torque and tension from the wind, that will motivate the trees to develop stronger roots*" (I06). Therefore, some trees need to be "*anchored to withstand these conditions and to reduce the risk of developing more aggressive roots*" (I06). Selecting the appropriate anchorage system is very important, as it might have an "*impact on the trees itself . . . [] . . . I have great fears when it goes below soil level that there will be issues . . . [] . . . and might cause damage to the rootball, tree trunk, and planter structure, specifically waterproofing*" (I01). In some cases, "*choosing trees with strong or aggressive roots can be a good solution to withstand these conditions [at the roof]. However, the planter setting should be adjusted to match with these roots*" (I06), even though "*trees with aggressive roots should be avoided because, after a few years, we will remove them if they cause structural problems to the planter, which may lead to sky garden [trees] failure*" (I14). It should be considered that "*sheltering trees on roof gardens from wind could reduce their need to establish strong roots*" (I15), and "*the tree form is also important; for instance, columnar trees have less aggressive roots than canopy trees*" (I18).

4.4. Characteristics of Candidate Trees

4.4.1. Size and Form Considerations

Tree size and form are essential criteria for the tree selection process. A few participants (16%) agreed on selecting small to medium tree sizes to avoid failure risk and improve the planting results. For instance, S38 argued that "*the trees grown on top of a building shouldn't be very tall*", and I13 added, "*we had to specify trees that were quite short species that probably didn't grow to more than about 10 m*". Large trees need more consideration during the planting process and increase the implementation complexity. For instance, I08 stated, "*if you're going to plant a tree greater than three meters in situ, you need to anchor it . . . [] . . . depends on its leaf volume and rootball size*". However, if the context design requires large trees, these trees still need "*growth control, [to avoid their failure] . . . [] . . . because of the climate there [on rooftop], [as] you don't have any shelter from the wind*" (I12). In addition, it is preferable to avoid planting mature trees as they need a longer time to adapt to the harsh environment on the roof, "*trees do much better if they're planted small, in the long run, in a couple of years, I think you'll find that this [smaller] tree will be doing better than a large tree . . . [] . . . The establishment period is quicker, it adapts faster, there's no shock, because it doesn't adapt to thriving somewhere else*" (I07).

Regarding the tree's form, I14 stated that if the selected trees "*are proved to be able to stay in a structurally stable form, in terms of growth rate and volume, still, you're going to . . . [] . . . be guided by their form*", and I05 added, "*wind velocities high on the building can be considerably higher than the ground, and this places a lot of torque and tension on the trees, especially if they have a broad canopy with a lot of leaf surface area that is available to catch the wind*". Therefore, a few participants (7%) prefer to select columnar trees, even I04 specifying, "*we've found through experience [that] palms are better on rooftops*" this might be because "*they have less leaf area, so they catch less wind and they're less exposed to the sun compared to large canopy trees*" (I06). Additionally, their "*root system being fibrous is better suited to constraints within planter boxes . . . [] . . . [and their] size, growth and habit [are easily be predicted]*" (I04).

4.4.2. Growth Considerations

Although knowledge of tree growth rates and life cycles is essential for developing a green roof planting strategy, understanding other tree suitability factors for implementation on buildings is also required. Some participants (18%) discussed tree growth and life cycle as selection criteria. However, all of them agreed on selecting trees with a slow growth rate and high longevity, with I14 specifying, "*there's going to be certain species which are well suited and certain species that aren't suitable at all. Obviously, a tree which grows very fast, very tall, is probably not going to be an option on a building*", and I01 added, "*they [fast growing trees] are very unstable . . . [] . . . when a storm comes along, they simply completely collapse . . . [] . . . as fast growth produces poor limb structure, and quality wood. It's not worth your investment . . . [] . . . [unless they are sheltered, that] might be fine because they're very unlikely to be affected. But if we're in exposed situations, we want stronger trees*". S61 added that the implementation of trees on buildings *could be risky* "*without a true understanding of the tree needs and life cycle*".

For maintenance aspects and form stability, the participants mentioned they prefer slow-growing trees as well, with I07 even specifying, "*they [our maintenance teams and facility managers] mentioned that they love the slow growth trees*", as fast growth trees "*are aggressive, they grow fast . . . [] . . . with their roots and the branches, they require heavy pruning*" (I07). The participants mentioned that they prefer trees that have great longevity, which generally can handle cyclones and storms such as the tropical and subtropical forest species, as "*they tend to have trees that basically are designed to handle storms and heavy wind, so there are the trees that have great longevity. When there are cyclones, they put a lot of energy into their structure and into their branching and into their wood, and often, they're slightly slower growing because there's this big investment into time and building something that's incredibly well braced and strong*" (I01).

4.4.3. Maintenance Considerations

The maintenance of trees is vital for their health and success. Most of the participants (89%) emphasised the importance of regular tree maintenance to check "*the structure of the branches*" (S04), clean the "*leaf litter or the fallen branches*" (I02, and I05), and "*control their size and shape*" (I02 and I06). Due to the high cost of regular maintenance, about 65% of the participants prefer to choose low maintenance trees for their projects. For instance, I01 stated, "*from planting design point of view, we were looking at plants that are low maintenance*", I12 added "*you should avoid the trees that they need so much spraying . . . [] . . . and maintenance*", and S08 confirm that it is better to "*use native low maintenance trees*". It is also essential during the selection process to "*take on board maintenance team feedback*" (S51) and "*urban farmers recommendation about the required maintenance of the selected trees*" (I06). This collected information can help in estimating the suitability of the trees considering the appropriate maintenance methods and requirements, such as the correct "*mechanisms to deal with loose limbs . . . [] . . . how to prune them . . . [] . . . and how to safely access to maintain them*" (I07). In addition, "*how to maintain the trees if they extend or affect other apartments*" (I04) and to "*maintain structural balance in the tree*" (I08).

5. Discussion

This paper investigated the implementation of trees on buildings with a survey and semi-structured interviews to uncover the current approach of industry when selecting tree species and the best implementation practices. In general, it was found that there are no established guidelines or criteria to select trees for implementation on buildings in either the literature or policies. Therefore, a few participants who have already implemented trees on buildings developed their own criteria based on adapting urban tree selection frameworks, their experience, and existing precedence. Although this approach sounds promising, they tend to repeat the selection of a limited portfolio of species in most of their projects. This has similarly been reported by Law, Hui, Jim and Ma [7], where they found that a limited number of tree species were used across various projects in Hong Kong's commercial sky gardens. The above-mentioned approach might add another barrier to tree selection. When one of the limited number of species fails in a project, it creates a negative precedent, and oftentimes the tree is eliminated from future selection, resulting in fewer available options. This phenomenon has been observed for selecting tree species on paved surfaces by Sjöman and Nielsen [46], who recommended expanding the list of suitable tree species to avoid this limitation. Another finding was that most of the participants are hesitant to try new tree species as they are not aware of a systematic approach to evaluate the suitability of trees. Therefore, they prefer to stay in their "comfort zone" using the limited choices known to be successful. Additionally, four main challenges were identified throughout the tree selection process, as discussed in the following paragraphs.

Implementing any tree species on a building could be considered beneficial as trees generally bring a number of positive influences to buildings and the surrounding environment [14]. However, these positive impacts could be increased by understanding the purpose of adding trees and selecting the species that match this purpose, which also has been emphasised by Nagendra and Gopal [45]. Many of the participants were unaware of all the different characteristics of trees and the impacts that these characteristics have on their environmental, cultural, or thermal performance. Generally, they considered that all trees were the same in these regards, differing only in their form and aesthetics. In some cases, even if the implementation was successful, some tree species might negatively impact or reduce the ecological added value due to inappropriate plant selection for the particular bioregion, as also highlighted by Sjöman and Nielsen [46]. For instance, implementing trees that promote biodiversity and attract different types of insect pests and fungus might not be suitable for implementing in the context of a hospital or recreational activity. Implementing exotic trees for their aesthetic value in an ecological context might have a negative impact on biodiversity, as the local fauna have not evolved with the exotic trees. Implementing evergreen canopy trees on a building that is in a cold climate could have a negative influence on thermal performance, due to the unwanted evaporative cooling and shading effects. Therefore, specifying the rationale and the context of tree implementation is an essential factor when selecting the right tree. This is also critical for typical green roof plant selection [62].

The location of a tree on a building, its proximity to physical elements and other species, the site characteristics, and the local microclimate, particularly wind and light, all play a role in determining the most appropriate tree form, size, structural strength, and ease of implementation. The analysis of all these elements needs to consider both the establishment period and the tree at full maturity. Chell et al. [63] showed that green infrastructure plant communities can be hugely dynamic over time, which applies equally well to trees. The lateral and vertical aspects of the location considering the current and future influence these trees will have on buildings, such as shading, view lines, accessibility, and aesthetics must also be considered, to avoid any negative outcomes once the trees are fully established. The absence of these considerations will increase the risk of tree failure, building damage, higher maintenance costs and the loss of user amenity [44]. Some of these characteristics have been covered in tree selection for urban spaces, for instance, Urban Forest Strategy [58], and Trees on Rooftops: Guidelines and Planting Considerations [44]. Trees on buildings are primarily implemented in locations high above the ground, and in some cases with limited maintenance access. In hard-to-reach locations, the failure of the tree could result in considerable cost and effort to replant or become a danger to the building and users if they are not removed or secured after failure. The risk increases if trees are located on building edges, resulting in them or their parts falling to the ground, creating severe hazards. Therefore, an assessment of tree locations and their characteristics is critical to avoid these risks, highlighted in the Guidelines for Planning, Construction and Maintenance of Green Roof [59], and required as an essential element for green roofs approvals in Singapore [44]. An example where these requirements are adequality applied is the Bosco Verticale [64]. The effect of tree roots also needs to be well considered. Species should be selected with rootball characteristics that suit the planter settings, especially the allocated soil volume should be adjusted to suit the selected tree. Restricted root growth and the inadequate sole volume may lead to stress, changing their life cycle and longevity, and reducing their ability to anchor, leading to their failure and uplifting in severe wind conditions, which Jim [43] has also emphasised.

Plant proximity, particularly the space between trees, is also a vital consideration, as close proximity will result in an undesirable level of shading, affecting growth and form as plants seek more light, resulting in undesirable forms and proportions [65]. On the other hand, increasing the distance between plants will increase solar heating of the soil, possibly reducing plant health and green roof aesthetics as mentioned by the participants. Therefore, a balance is needed with respect to plant density to maintain green roof sustainability, plant health and aesthetics. A few successful examples by WOHA architects followed these criteria in Singapore, such as Park Royal Collection Pickering, Kampung Admiralty, and Oasia Hotel [18–20].

Other factors influencing tree selection within the planter including water availability, irrigation regime, and the plant water requirements within the substrate volume. Plant inherent adaptations to water availability strongly influences tree selection. For instance, trees with high drought tolerance are more suitable for dry climates, and trees with high water uptake are more suitable for wet climates. However, natural disasters greatly disturb existing conditions, thus complexifying the optimal water-related features that a tree should offer [66,67]. More research is also needed to understand tree resilience to climate change effects to further enhance tree selection.

In addition, some city councils restrict using potable water to irrigate the integrated green infrastructure on buildings [4]. Therefore, water quality needs to be considered including the type of water and its effect on the health of the selected trees to increase success. The co-planting of trees with low canopy plants in the same planter also could affect water relationships and competition for water resources within the planter, specifically if the irrigation system relies on surface watering. Therefore, the irrigation system type and plant design in the planter could also provide insights into the selected trees based on their water requirements and vice versa.

After analysing all the influential factors on trees, the second stage will be to select a tree that has suitable form, size, growth rate, and maintenance requirements for the green roof. These characteristics are critical to the success of trees on buildings. This also will increase the tree choices and increase the canopy trees implementation as many participants present their interests in choosing columnar trees and specifically palms as there are many successful examples of palms on buildings. However, recent studies have shown that other species with broad canopy limit wind load [7]. Applying the aforementioned measures leads to better installation of canopy trees as they are needed for their higher ecological values [45]. However, a balanced and a better understanding of site and design requirements are essential before selecting the candidate trees. Some of the requirements might be contradictory, such as canopy trees which would increase wind load capturing and which will be problematic in locations with high exposure to wind load. On the other hand, columnar trees usually have faster growing rates than canopy trees, which would be detrimental in other locations on buildings and may affect the quality or the strength of the tree trunk and its ability to resist winds. City councils also need to conduct studies on the biodiversity and ecosystems at city scale to provide sufficient guidelines for the designers to follow, which will influence tree selection for their projects.

5.1. Tree Selection Framework for Implementation on Buildings

This study reveals that the industry approach of selecting appropriate tree species for implementation on buildings does not contradict existing frameworks for tree selection in urban paved sites (e.g., for street trees) but includes more specific analyses and requirements to adapt to the implementation context. Therefore, based on the above, this section aims to synthesise the approaches of the participating experts to guide a successful and safe tree selection for implementation on buildings. As a result, a tree selection framework was developed based on current industry best practices (Figure 5). The framework consists of four sequentially mandated stages:

- Identifying the purpose of the tree;
- Analysing the site conditions;
- Evaluating the implementation risks;
- Investigating the characteristics of the candidate trees.

In the first stage, designers need to prepare a brief explaining the purpose of implementing trees on buildings. This needs to be informed by the design brief of the specific buildings. The second stage includes studies and analyses to evaluate the conditions of the planter contexts, including the current and future microclimate and the planting strategy incorporating the available infrastructure. During the second stage, an estimate of the form and size of the trees needs to be determined to allow an evaluation of the implementation risks in the third stage, which is a risk assessment that includes the risks to the trees and the risks to the planters and building structure. The last step includes preparing a list of the candidate trees, their characteristics and their applicability for implementation based on the studies and analyses in the first three stages. This also needs to consider the impact of the candidate tree species on biodiversity and ecosystem services to ensure the ecological balance is maintained where these trees are implemented. This process could be repeated to ensure that the selected trees comply with all the requirements and context and have minimal risk to the building and the success of the trees on building. The authors recommend the proposed framework as a starting point to systematising tree selection and implementation on buildings.

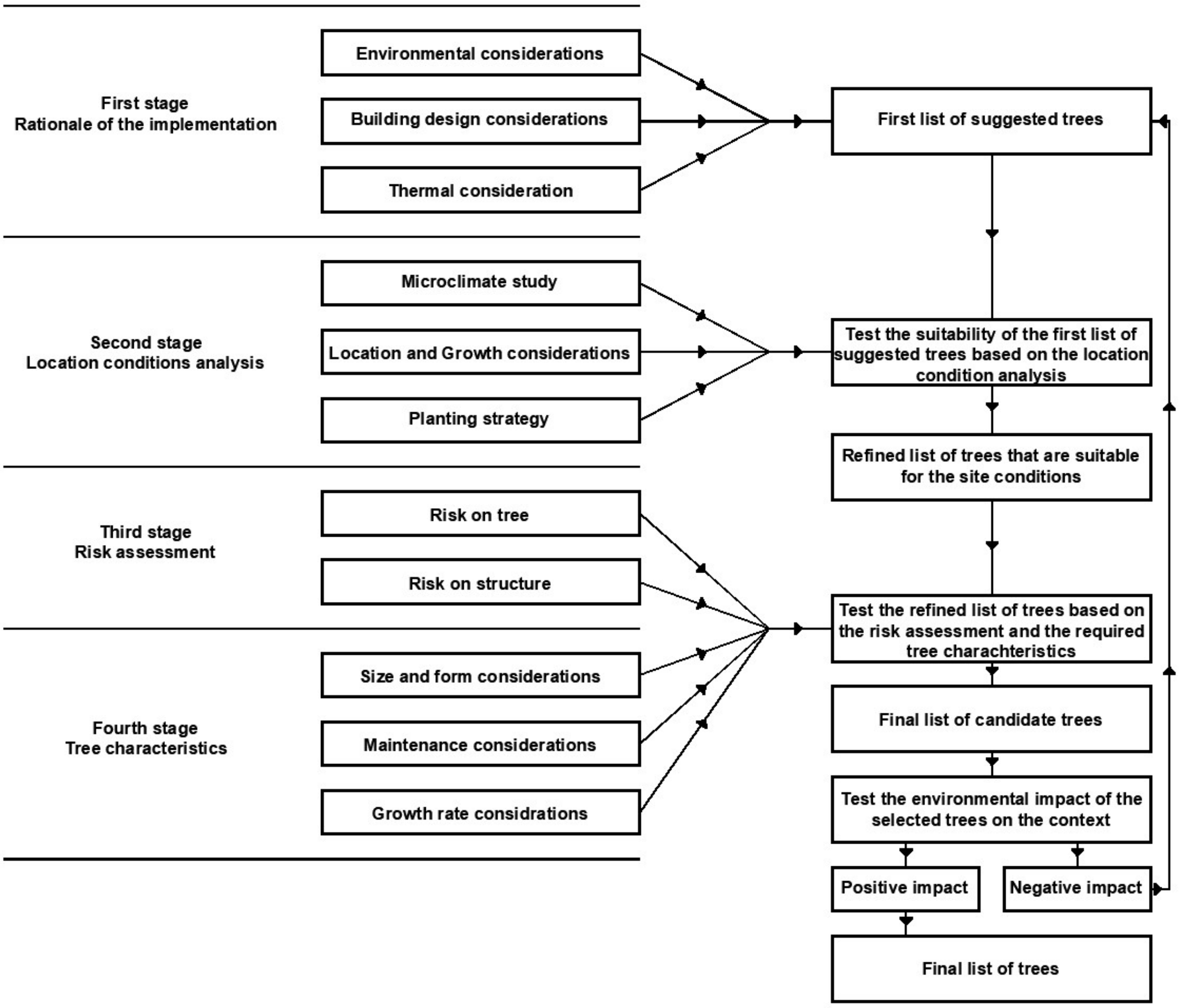

Figure 5. Proposed tree selection framework for implementation on buildings.

5.2. Policy Considerations

Tree species play an essential role in maintaining the ecological balance of cities, which has motivated many city councils to establish guidelines for implementing trees within the urban environment, emphasising increasing the diversity of tree species in some locations, while including some restrictions on planting or avoiding specific tree species in other locations. The same approach could be followed as a start with the implementation of trees on buildings, which could be enhanced by establishing a record of existing plantings and reporting their performance, as their implementation interest is escalating. Increased guidelines, initiatives and incentives could support greater tree implementation on buildings. It should be considered that incentive policies are critical to facilitating implementation, as implementing trees on buildings requires high installation and maintenance costs. These incentives could include tax reductions, financing, construction permits, sustainability certification, obligations by law and agile administrative processes [13]. Singapore presents a good example in their policies in this regard, as they provide early guidelines [44] and funding schemes up to 50% of the implementation cost of green roof settings that host trees [68], which significantly increases the implementation of trees on buildings. Unfortunately, to date the emphasis has been on exotic species [69] while native trees have been neglected. Buildings integrated green infrastructure designs need to prioritise utilising native tree species which provide greater ecological benefits [70]. City councils should collaborate with industry partners of these types of green infrastructure (e.g., architects, installers, developers) and research institutions to establish a comprehensive list of preferred exotic and native tree species with room to expand this list over time as more information comes to hand, and with capacity to show success via performance trials if a new species is proposed. This also could serve to resolve the stock shortage of the current limited range of suitable tree species for implementation on buildings. In addition, testing the selected trees for implementation on buildings against the required ecosystem and biodiversity in the built environment is essential to maintain the ecological balance within the city overall.

Tree failure could cause considerable risks to buildings, public amenities, and human health. Therefore, development assessors should require architects and developers to provide a microclimate analysis, a tree selection report, installation procedures and maintenance plans before approval can be given. Some city councils required these studies, Brisbane and Melbourne for instance [23,40], but still, the guidelines are insufficient. The lack of baselines to compare these studies increases the workload of designers and might even present some bias on issuing the approval of these developments, as is also reported by the participants in this study. The installation procedures should provide evidence for the proposed soil volume, not depth only. Some existing policies, relating to the relationship between soil depth and tree heights, or a specific soil volume based on the mature size of the tree in ground level. These policies should be revised to accommodate plant species requirements which are planned to be implemented on buildings, taking into consideration the limitation on tree growth as trees growth rate and size on buildings differ from on ground planting. In addition, it must be considered that trees could follow a restricted maintenance plan to limit the size of the tree to suit the planter and its context. Some trees will also naturally grow to a reduced height without maintenance due to the soil volume limitations of the planter. For instance, a tree that could reach 10 m canopy projection at tree maturity on the ground might reach only 5 m based on the planter size where it is implemented, following regular pruning and maintenance. Therefore, a tree that typically needs 6 m^3 of soil in natural planting on the ground level, might only need half of this soil volume in planter plantation as the maximum size of the tree will be limited and controlled. Adjusting these requirements by requiring a reasonable soil volume based on the expected or planned size of the trees on buildings will boost the implementation and reduce the cost, design and installation efforts associate risk on buildings.

5.3. Limitations and Future Studies

The existing literature regarding trees on buildings is limited, and the proposed framework provides tree selection guidance based on current industry best practice. Most participants in this study had limited knowledge of tree science and tree performance, however, they all had direct experience with tree selection and installation on buildings. Therefore, most of their information on tree growth indexes and their impact on buildings and the surrounding environment was limited. Due to their extensive experience, they were, however, able to provide substantial information about the requirements and anticipated risks of tree implementation. Future studies could benefit from focussing on the perspectives of disciplines with more knowledge on plant science, such as horticulturalists, arboriculturists, agricultural engineers, urban farmers, ecological engineers and urban ecologists. This study has provided a tree selection framework that synthesises industry best practice and available knowledge in both grey and academic literature. It is important that future studies validate and iteratively improve these stages over time to expand the quality of tree selection and implementation on buildings. At this stage of the industry's development, particularly in Australia, the industry would benefit from investing in performance monitoring of existing trees on buildings to establish a database of the currently used tree species to influence tree selection for future implementation.

This study investigated best practice design based on several contexts including climatic conditions, geographic locations, and the background of the designers and experts in the field. To collect information about tree selection and implementation in different climates and contexts, and the invitation to participate was open worldwide. However, the exclusive use of English might have prevented non-English speakers from participating and may have limited the comprehension of some experts. As a result, participation in the survey was from a small number of countries, with a predominance of Australian responses. Future research might emphasise other parts of the world, notably Asia, which was underrepresented in the survey and where the practice of implementing trees on buildings is widespread.

Finally, most of the participating architects in the study strongly support the implementation of trees on buildings. However, they do not focus on the implementation of tree requirements, the available implementation techniques, and the knowledge of how to avoid the anticipated risks of the implemented trees, which was also reported by the landscape architects and installers' responses. Future studies should investigate this point further to identify any knowledge gaps that architects may have regarding tree implementation, which might enhance the education channels and increase future tree implementation on buildings.

6. Conclusions

This study investigated the selection of trees for implementation on buildings and provided a tree selection framework to guide the selection process systematically based on the points of view of experts in the field. The research emphasised that selecting the correct tree species for implementation on buildings can significantly reduce implementation risk and maintenance requirements, thus enhancing positive outcomes. The authors suggest that designers and decision-makers adopt the proposed tree selection framework to guide their decisions regarding tree selection and implementation on buildings. The framework consists of four stages: identifying the purpose of the trees; analysing the site conditions; evaluating the implementation risks; and investigating the characteristics of the candidate trees. In addition, this paper discussed the limited existing tree selection policies and literature. Three main recommendations for policymakers resulted from this study. Firstly, regulation of the process of tree implementation on buildings is needed to maintain the balance between native and exotic tree species in cities to enhance the ecological balance, as the industry is largely focused on exotic species. Secondly, developers must undertake all the required studies for approval of buildings that integrate trees, including a microclimate analysis, a tree selection report, the installation procedures and a maintenance plan. Finally, the existing soil depth mandates for trees must be reconsidered and replaced by evidence-based soil volume considerations for each species, from early establishment through to maturity, based on the planter conditions and anticipated tree growth size.

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