Design and Conservation Strategies for Urban Biodiversity in Australian Botanic Gardens

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0 Introduction

Australia's biodiversity is indispensable to the country's national identity and sustainable development (ecology, economy, and living quality)[1]. In Australia, more than 80% of plant and animal species are endemic (they are not only native but also only exist naturally in Australia)[2], with about 90% of vascular plants being endemic. These plants not only form a crucial part of Australia's landscapes but also comprise 10% of the plant species worldwide[3]. The 16,000 native plant species were key to the livelihood (food and medicine) of Aboriginal Australians, the first inhabitants of the Australian continent, who discovered and categorised the plant species from daily use. The tuberous root plants in southern Australia, the seeds collected in arid regions, and the fruits in the tropics were their main food resource[4].

Australia's high floristic richness and endemicity can be mostly explained by the isolation of the continent from other landmasses for a long time[5]. About 50 million years ago, Australia was split from Gondwana, a southern supercontinent that also included South America, Africa, India, and Antarctica[6]. The dominant families of flowering plants in Australia are the Fabaceae (acacias), Myrtaceae (eucalypts), Proteaceae (banksias, grevilleas), Asteraceae (daisies), and Poaceae (grasses)[7]. This high endemism can be also found in other formal Gondwanic lands, such as South Africa (69% of vascular plant species are endemic)[8], and New Zealand (approximately 80% of vascular plants are endemic)[9].

In the contrast to native biodiversity, urban biodiversity is largely dependent on the planning, design, and management of the built environment. A comprehensive definition of "urban biodiversity" is "the variety and richness of living organisms (including genetic variation) and habitat diversity found in and on the edge of human settlements "[10]. Urban biodiversity consists of exotic and native species. Urban biodiversity exists not only in designed landscapes (public and private parks and gardens, botanic gardens, and streetscape) but also in protected remnant vegetation within urban areas, as well as agricultural landscapes as well as spontaneously appeared plants in brownfields and other urban biotopes[11].

Australia's unique native biodiversity is now deeply affected by three main factors: continuing land clearing, invasion by exotic environmental weeds (more than 3,000 species since 1788), and climate change[2]. Threatening and disappearing of native ecosystems resulted in developing a strong vision on the importance of protection and returning native flora to the urban environment (revegetation projects of wetland and stream restorations, verge native gardens, and design with native plants in private and public parks).

At the beginning of the 21st century, more botanic gardens globally have started to concentrate on ecological design approaches that are more biodiversity-friendly. The worldwide destruction and extinction of native plant species and plant communities have forced many botanic gardens to undertake educational programs that stress the role of plants as the primary biological unit upon which all life depends. Conservation and the importance of safeguarding the planet is the subtext of nearly every display in most botanic gardens[12]. The 'conservation garden' concept has emerged as the new botanic garden of the late 20th century and gardens today[13].

There has been growing research interest in the conservation of Australia's botanic gardens. Moskwa and Crilley analysed three main functions of botanic gardens in Australia (recreation, education, conservation) and compared them with the initial goals of garden management[14]. Virtue et al. analysed 100 weed species in botanic gardens of Melbourne, Hobart and Perth, and assessed the level of weediness in different botanic gardens[15]. Hardwick et al. provided some examples in Australian botanic gardens to demonstrate various approaches of botanic gardens in the conservation process[16]. For example, Australian National Botanic Gardens has an updated native plants database to assist in their management, research and protection.

However, there has been no comprehensive review of native biodiversity and its conservation solutions from a landscape architecture point of view (e.g. spatial organisation of a space according to different garden styles, principles of structural organisation and planting design characteristics) in Australia's botanic gardens. To understand the design solutions for biodiversity in Australian Botanic Gardens, we should study the local environmental history and the history of the design and development of the Australian Botanic Gardens. This paper starts with a short overview of the development of colonial botanic gardens. Then we analyse the influence of garden styles, such as Picturesque and Gardenesque, on the design of layout and organisation of plant collections that also reflected the 19th century vision on the role of botanic gardens. The paper also emphasises the changes in botanic gardens' design and educational strategies mirrored the 21st century biodiversity crisis and climate change. We also discuss the application of appropriate landscape design principles for organising biodiversity-friendly exhibits (e.g. wildlife-friendly designs and bee hotels) in Australian botanic gardens.

1 Methods and Questions

This research is based on literature review. Books, Australian nationwide strategies and action plans, peer-review papers, and the official web pages of Australia's botanic gardens were the main

sources. This research consists of 3 main research questions: 1) How has the design of Australian botanic gardens developed throughout time? How are the botanic garden design styles impact the understanding of native biodiversity and its role in society? 2) How has the attitude towards natives and exotics changed Australia's botanic gardens? What are the roles of botanic gardens in preserving biodiversity? 3) What are the solutions to preserving biodiversity in Australia's botanic gardens?

2 Australia's Botanic Gardens: Design History and Garden Styles

2.1 An Overview of the History of Botanic Gardens

One of the philosophical ideas behind the creation of botanic gardens was to recreate the Garden of Eden[17]. The task was to collect different plants from around the world and bring them back into one garden to recreate paradise on earth. This belief not only influenced the development of the first contemporary botanic gardens in the 16th century but also formed a spiritual foundation for the establishment of botanic gardens in the Victorian era.

The development of botanic gardens has gone through three stages: the 'physic' gardens in the 16th and 17th centuries in Europe, the colonial botanic gardens in the 18th and 19th centuries (in England, USA, Australia, India, New Zealand), and the conservation gardens of the 20th and 21st centuries established globally[18-19](Tab. 1).

2.2 The Distribution and Design Layout of Botanic Gardens in Australia

The development of capitalism, colonialism, and plant taxonomic and geographic theories (particularly the *Binomial Nomenclature* by Carl Linnaeus, and the "*Essay on the Geography of Plants*" by Alexander von Humboldt) were the driving forces behind the establishment of botanic gardens during the 18th and 19th centuries[20]. There was a revolution in attitudes to nature and garden design in the 18th century, especially in Britain, the main source of Australia's early settler garden influence[21]. Botanic gardens in Australia were particularly influenced by the Kew Royal Botanic Gardens (Kew Gardens). The main reasons for the establishment of the early Australian botanic gardens were to duplicate the European practice of developing public spaces for leisure and to test plants for economic potential.

From the very beginning, botanic gardens in Australia served as centres of the introduction of ornamental plants and experimenting with species suitable for agriculture and horticulture. The earliest Australian botanic gardens were established by Sir Joseph Banks in Sydney (Royal Botanic Gardens, Sydney, in 1816) and Hobart (Royal Tasmanian Botanical Gardens in 1818), both engaging in the systematic collection of plants. By the end of 1850s, botanic gardens in Melbourne, Brisbane and Adelaide all established, combining the scientific functions with public spaces for leisure[22]. By 2001, Australia had more than 100 botanic gardens[18]. By 2021, according to the open-access document provided by the "Secretariat of the Convention on Biological Diversity (SCBD)", there are approximately 137 botanic gardens and arboreta across the country (SCBD, 2021), including South Australia (14), Northern Territory (3), Queensland (34), New South Wales (39), Western Australia (10), Victoria (28), Australian Capital Territory (3), Tasmania (5), and Norfolk Island (1). The estimated number of "living plant accessions recorded in these botanic gardens are more than 250,000". The estimated number of plant species in these collections is 15,000[23].

The traditional layout for plant collections is based on the scientific plant taxonomy (plant families and genera); plant life forms (trees, shrubs, herbaceous plantings), and geographic and climatic zones, inspired by the Kew Gardens. For example, Melbourne Gardens experimented with geographic regions. RBG Sydney (Royal Botanic Garden Sydney) tried with a "natural" approach (imitating free shapes as it is in nature instead of pursuing a symmetrical layout) and a "Linnean" layout (using formal geometrical flowerbeds).

Apart from the traditional collections classification methods, there is a more ecological way to develop "habitat plantings". This method mimics the natural environment with existing soil and climatic conditions. Examples of this approach are the rainforest collections of New South Wales and Queensland, the wet and dry sclerophyll forest collections of Australia, and the dryland collections of other countries in Wollongong Botanic Gardens[18].

2.3 Garden Styles of Botanic Gardens in Australia

Urban landscapes and botanic garden designs in Australia were deeply influenced firstly by English landscapes (picturesque) of the 18th century and the gardenesque style from the Victorian era (1837-1901)[24] (Tab. 2). Designing Victorian colonial botanic gardens in Australia were often considered as a process of taming while adapting the wilderness[19].

As a part of the English landscape garden style, picturesque means "picture-like", which was "strongly influenced by the idea of making landscapes in manners of pictures", notably the drawings of Claude Lorrain[21]. It evolved from the painting theory, showcasing its admiration for nature, and bonding art and natural scenery (and vegetation) together. Irregular layout, curvy pathways, rough rockwork, and clumps of trees are the core elements of the Picturesque style. The prerequisite of being Picturesque is not dependent on whether it's modified or natural, but its capability as a proper landscape picture. The concept of "Colonial Picturesque" was used to describe that the Australian landscape was Picturesque enough without the need for any artificial improvements[21]. Thus, although many Picturesque sceneries are designed, rather than the work of unassisted nature, this style has led to an "irreplaceable appreciation of wild nature"[4].

However, it is worth mentioning that this note of "nature" referred to the English wild nature. In Australia, Picturesque principles were applied and transferred to Australia's natural setting. Jacky Bowring used New Zealand as an example, defining this type of Picturesque as the "pidgin Picturesque". She used the language as the metaphor, comparing "mother tongue" to the "English Picturesque", and "indigenous language"

as the "natural environment" in colonies. Pidgin Picturesque is a combination or an adapted version of the English Picturesque and the colonies' indigenous environment. These variations in this language arose from the indigenous architecture, topography, and vegetation[25]. Quite similar to New Zealand, the Australian Picturesque shared qualities of both "imported language of the Picturesque and an indigenous language based in the natural environment"[25]. This communication between "imported conventions" with an "indigenous environment" is the core of the Picturesque. For example, the most prominent influence of Picturesque principles can be seen in the design of some areas in the Melbourne Botanic Garden (Fig. 1).

The gardenesque style was proposed in 1832 by a Scottish landscape gardener, John Claudius Loudon[26]. The Gardenesque style, at its core, was designed to display exotic plants (as well as tropical and subtropical species) using the principles of the museum's exhibits and eclecticism. Gardenesque believes that group planting allows plants to compete for light and space and thus limit their growth. Thus, unlike Picturesque's preference for planting group of plants, Gardenesque featured single plantings rather than mass plantings[27], which became a popular form of displaying new exotic species in the botanic gardens[28] (Fig. 2). In 1857, at the RBG Sydney, Charles Moore reduced the planting area for a more regular and long-term development[4]. The vision of a Gardenesque botanic garden is based on geometric pathways directing visitors to exotic trees and shrubs (scattering on the lawns) or leading towards flower carpets and ponds. Although few Gardenesque gardens built in the 19th century still exist in Australia, the influence of Gardenesque principles is visible in Australian botanic gardens.

The requirements of the botanic garden design mainly focus on the taxonomic displays of plants, and plant collections. This target largely fits with Gardenesque's particular interest in exotic plants, geometric and symmetry layout, and desire to try many varieties of ornamental species. RBG Sydney and Adelaide botanic gardens are the outstanding remaining examples of original Gardenesque layouts[4].

Botanic gardens and public parks in Australia blended and advanced both the Gardenesque and Picturesque styles. This mixture was largely affected by their favour of ornamental gardening, and the pursuit of natural features, in other words, a mix of the love of art and nature[29]. Ornamental features (unusual colour, forms and texture) were combined with the "free" (not geometrical) configuration of plant groupings. Adelaide botanic gardens used the elements from Gardenesque, with parterres and floral bedding. In 1864, its layout was neither geometric nor natural, it was called an "irregular symmetry" layout[19], which means there was no need for the sides of the axis to be in the same size or shape. The proportion of both sides varies based on functions and actual design needs.

Using naturalistic grouping methods for exotic tropical and subtropical plants in combination with creating vistas with focal points and use of water (e.g. lakes) can be seen in many colonial botanic gardens in Australia. As Australia's geographic location includes subtropical regions, with the popularity of subtropical plantings in the mid-19th century, botanic gardens in Australia began to focus on the cultivation of subtropical plants. Charles Moore in RBG Sydney pioneered the cultivation of "groves of palms and tree ferns" with "naturalistic grouping"[21] (Fig. 3). This naturalistic grouping method also means the free arrangements of plants on the compulsory lawn "canvas" (Fig. 4).

2.4 Botanic Garden Design Styles' Impacts on Native Biodiversity

Deeply influenced by changes in the aesthetic expressions of human cultures, garden design styles have a critical impact on the garden layout, design elements, and plant selections in botanic gardens, thus further impacting its biodiversity and the way this biodiversity is displayed to the public.

The core of the botanic garden design is the plant display to the public. In the 19th century, botanic gardens in Australia used elements of both the Picturesque and the Gardenesque styles. Instead of aiming to preserve biodiversity, the way they created the plant collections depended on how the two styles can display the plants visually. In Melbourne Botanic Gardens, the Picturesque style creates the vista, and the Gardenesque is used to display plant communities. In Australia, the two styles chose both natives and exotics to create plant collections. In essence, plant biodiversity was presented by a mixture of both exotic and native components in botanic gardens at that time. Starting from the mid-20th century until the present, new design approaches ("native style") had more emphasis on native biodiversity. The new plant collections in botanic gardens tend to use the existing remnants or bushlands to create botanic collections. These remnant areas are also parts of the botanic gardens, without any further design or modification. For example in Kings Park, a large area of remnant native vegetation constitute an irreplaceable part of the botanic garden. Thus we would argue that, in terms of preserving native biodiversity, the recent "native style" design approach is more applicable in Australian botanic gardens than the Picturesque and the Gardenesque styles.

Discussion of the impacts of design style on native biodiversity is mainly focused on plant selections. Most species are dependent on specific features of plant communities to satisfy their habitat essentials, not limited to foraging resources, but also nesting and shelter[30]. Fauna species richness and abundance predominantly rely on the diversity and complexity of vegetation[11]. In botanic gardens, vegetation complexity includes trees, shrubbery (understory), herbaceous plants (ground cover), vines (climbers), and aquatic plants. In principle, larger flora diversity supports more species, leads to a more diverse habitat[31]. It is also argued that both native and exotic plant species in an urban vegetation structure, could add value for native wildlife since some exotic plants attract a high diversity of fauna (including birds and invertebrates)[32]. For example, there are certain numbers of Australian native bee species forage on both indigenous and exotic plants with good quality pollen and nectar. For those Australian native bees who have a distinct taste in only one or several native flowering species, a right proportion area for exotic

plants in the botanic gardens would be also beneficial. Because these exotic flowering plants can attract the exotic European honey bees, thereby reducing their competition with native bee species on native flowering plants. Thus, in Australia, although native fauna are more adapted to their native habitats, an area of exotic plant collections seems feasible to be included in botanic gardens.

3 Ecological Design in Australia's Botanic Gardens

Ecological design principles started to develop as a key component in Australian landscape design from the 1960s, influenced in part by American landscape architect Ian McHarg's book *Design with Nature*[21]. Substantially, ecological design principles today emphasize nativeness and its powerful connection to the local context, in the creation of a "sense of place", as well as the dynamic character of vegetation[33]. These principles primarily include the conservation of endemic vegetation and local plant communities and the restoration of the degraded native ecosystems.

3.1 The Changing Attitude Towards Natives and Exotics in Australia's Botanic Gardens

Attitudes toward native and exotic plants for botanic gardens in Australia have changed dramatically from the time of European settlement till now. The initial reason for using exotic plants in Australia's botanic gardens is mainly due to the absence of European native crops for European settlers for reasons of both taste and sentiment. RBG Sydney started from a site planted with cereal seeds and other edible plants, collected from England and Rio de Janeiro[19].

In addition to agriculture, horticulture in gardens also mainly focused on exotic species, for two main reasons: 1) Australian native flora was largely unknown by European settlers at that time; 2) The love of exotics in the Gardenesque style affected the plant selections in Australia's botanic gardens. However, there is an exception. To collect and send herbarium specimens and seeds to European institutions, there was a need to cultivate Australian native plants in Australia first, thus over 2,000 Australian species were planted in the Melbourne Gardens[19].

Overwhelming interest in exotics and a perception that Australian plants were difficult to grow indicates the natives continued to be an insignificant component in most of Australia's botanic gardens[34]. It was not until about 1950 that Australia started to concentrate on native plant species in a new botanic garden at Canberra, now known as the Australian National Botanic Gardens (Fig. 5).

The design and plant choice of Western Australian Botanic Gardens in Kings Park, Perth, and Australian National Botanic Gardens (ANBG) in Canberra, were both inspired by the development of ecological principles and greatly contribute to the awareness, appreciation, and conservation of native plants[19]. ANBG holds the largest and the most comprehensive living collection of native Australian flora. The Western Australian Botanic Garden focuses on the cultivation and display of Western Australian flora. An area of remnant bushland in botanic gardens has started to be very ecologically important.

In the 1980s, other Australian states began to establish satellite sites of major botanic gardens for the cultivation of native plants, such as the Mount Annan Botanic Garden of the RBG Sydney. It is the largest botanic garden in Australia officially opened in 1988, planted with all native species. The collections are themed gardens, featuring the most representative of Australia's plant genera[18].

Nowadays, based on the growing emphasis on the indigenous plants to handle local conditions the blending of natives with exotics is well balanced and accepted in Australia's botanic gardens[35]. For example, there is a blend in the use of lawn and native groundcovers. The diversity of flower forms and foliage are more widely appreciated. Furthermore, the growing ecological consciousness in public Botanic gardens brings the importance of native flora and conservation to public attention.

3.2 Australian Bush

"Bush" is a very unique term in Australia, when it comes to the protection of native vegetation. It is regarded as a symbol of national identity[36] (Fig. 6). It has been an indigenous landscape for thousands of years, long before European colonisation[4]. It contains two interpretations. One equals "nature"[37] in Australia, referring to the undisturbed vegetation, such as forests, woodlands, and shrublands. One equals "wilderness", different than the culture of the city[38]. After European settlement, due to the perceived lack of seasonal changes in the dark grey-green foliage, native plant species were not very popular or widely available for cultivation in private gardens and public parks[21]. The bush was considered not a part of the garden until the late 19th and early 20th centuries. Some of the indigenous species from the bush were invited into gardens since the mid-20th century. While in rural areas, because of the similar natural environment, the bush has gradually become a part of the gardens.

The concept of "bush garden" was proposed in 1966 by Betty Maloney and Jean Walker, encouraging a design approach exclusively using native plants[39]. Bush gardens that mimic the bush (nature), are interpretations, rather than a direct copy. The main components of a bush garden are native plants, natural and irregular layouts, the absence of lawn, exotic plants, or flowerbeds. The design of bush gardens is quite similar to the concept of "revegetation", both of which emphasise the planting of not only the local native flora but also the endangered endemics to the local environment.

3.3 Roles of Botanic Gardens in Preserving Biodiversity

Botanic gardens and arboreta are scientific institutions with competently managed living plant collections that reinforce plant conservation, display, education, and scientific research[40]. Of the plant species known in Australia, 7% are currently considered endangered or vulnerable, accounting for 15% of the world's endangered plant species[3] Botanic gardens are important places of plant conservation due to their roles in providing spaces and resources (habitats) for plants away from their natural growing environment (ex-situ conservation).

They have adopted three major methods in the conservation of biodiversity, namely, in-situ conservation, ex-situ conservation, and gene banking (or seed banking)[41]. In-situ conservation refers to the conservation of species in their natural surroundings,

including the maintenance of their natural habitats. Ex-situ conservation (or off-site conservation) is the conservation of species outside their natural habitats[42]. Gene banking refers to a conservation method that stores germplasm resources (such as seeds, organs, tissues, pollen, or genome) to preserve genetic diversity. This is often considered as a form of ex-situ conservation. Botanic gardens in Australia have 4 main advantages in preserving biodiversity and coping with climate change.

1) Botanic gardens' expertise in seasonality studies. Changes of plants' flowering time are biological indicators of climate change[43]. Constraints on flowering time may impact pollination mutualism, which further affects biodiversity[44]. A network of city and regional botanic gardens, and conservation agencies have been established to develop programs to obtain long-term data on plant flowering times, monitoring the impacts on biodiversity causing by climate changes. These data are vital to the Southern Hemisphere.

2) Australia's botanic gardens have abundant seed banks, gene banks, and living collections. The living plant collections are essential by preserving endangered taxa and facilitating recovery after loss by reintroducing (revegetating) species into the wild.

3) Australia values cooperation in biodiversity conservation (nationwide and region-wide) through building multi networks and organisations of botanical gardens. For example, the Australian Network for Plant Conservation (ANPC), Council of Heads of Australian Botanic Gardens (CHABG), Council of Heads of Australian Herbaria (CHAH), and Botanic Gardens and Parks Authority (BGPA) are all important networks in collaboration and sharing resources to preserve biodiversity in botanic gardens and herbariums.

4) Australia's botanic gardens have developed volunteer programs in engaging people and communities in activities to botanic gardens. These are called "Friends of Botanic Gardens". These friends groups are significant to stimulate public interest and awareness, generate ideas, initiate projects, and support the conservation and research activities of botanic gardens in Australia.

In situ conservation is carried out at the species level through restoration plans. The main idea is to restore native species' habitats to restore the target population in their habitat to a state where they can sustain without human intervention[2]. It is an effective solution to habitat loss and population reduction, which are commonly applied in Australia's botanic gardens. Ex-situ conservation includes endangered species (not limited to natives), endemic species, crop wild relatives, and flagship species. It provides research resources on physiological tolerances of plants and the adaptation of our native plants, to advise priorities and solutions for in-situ conservation.

However, botanic gardens are also considered as one of the major sources of potentially invasive plant species[45]. Firstly, there is an opinion on whether ex-situ conservation is one of the causes[2]. Secondly, there's a connection between botanic gardens' most common locations in biodiversity hotspots and the early introduction of most environmental weeds[46].

Conservation and education of the public have come to the forefront in botanic gardens through various means. Interactive displays, guided tours, storytelling, and educational programs have helped botanic gardens communicate the importance of conservation[47]. Since weed control in botanic gardens is effective due to their high maintenance[48], introducing species to botanic gardens has more positive results (educating the public and keep germplasm resources) than its invasive potential. Rather than promoting locally invasive species to the public, botanic gardens can teach the public to recognise a plant to avoid its cultivation within their gardens.

4 Solutions in Preserving Biodiversity in Australia's Botanic Gardens

As can be seen from the above, the main functions and emphasis of botanic gardens have changed in Australia. Botanic gardens have shifted from public amenities whose designs and plant configurations are mainly based on garden styles to a conservation and research hot spot, designed mostly based on conservation needs.

This section concludes the main biodiversity conservation strategies in Australia's botanic gardens. It ranges from nationwide strategic action plans in coping with climate change, to Melbourne Gardens' Landscape Succession Strategy, to wildlife-friendly designs and educational programs in botanic gardens. This section aims to provide an overview to the Chinese scholars on how Australia is addressing the issue of biodiversity loss.

4.1 Nation-Wide Action Plans

Several nationwide action plans and guides have been proposed to protect and restore Australia's biodiversity[49-53](Tab. 3). But the results are still not satisfactory, as the numbers of threatened plant species continue to increase. Reasons include habitat loss, biological invasion, and the lack of awareness of the ecological values of the endemic vegetation[2].

4.2 *Landscape Succession Strategy – Melbourne Gardens 2016—2036*

Climate change is threatening all levels of biodiversity – genes, species, communities, and ecosystems. The Landscape Succession Strategy 2016—2036 for Melbourne Botanic Gardens guides the transition to a botanic garden suited to the projected climate and environmental conditions of 2090 while "retaining the Gardens' heritage character, landscape qualities, and species diversity"[54]. This is the first strategy in Australia's botanic gardens that proposed to become a blueprint for other botanic gardens' planning for coping with climate change[55]. The five strategies were proposed from five main dimensions, namely plant collections management, establishing a mixed-age plant selection to increase plant diversity, sustainable water usage, maximising and balancing the benefit and relationship between soft and hardscapes, and enhancing the education to the public on climate change[54]. The vision for this plan is to retain landscape qualities and plant collections diversity and to further draw on the cultural and scientific values of Melbourne Gardens[55].

4.3 Wildlife-Friendly Designs and Programs in Australia's Botanic Gardens

Botanic gardens are very important habitats for wildlife (including native and threatened bird species, mammals, and invertebrates). For example,

the Royal Botanic Gardens Victoria in Cranbourne provides safe and usable habitats for wildlife such as wombats, bandicoots, ducks, and echidnas (Tab. 4)[56-59]. A predator-proof fence was built to protect the native fauna, the Southern Brown Bandicoot, from cats and foxes. Also, to improve the accessibility for wildlife, special gates were designed in the fence to provide access suited to specific native species, and a tunnel was built under the road to wildlife provide safe access[56].

In Australia, both native bees and European honeybees are vital to agriculture and the ecological environment. European honeybees (*Apis mellifera*) were introduced to Australia in the 19th century, foraging mostly on native plants, responsible for most of the honey production[60]. At present, there are about 570,000 hives in Australia managed by beekeepers, along with thousands of feral bee colonies living in trees and other nesting sites. Australia is also home to over 1,700 native bee species of native bees[61]. Australia is rich in natural melliferous (honey-producing) flora. Both exotic and native plants provide essential foraging resources for these pollinators. An emphasis on bee-friendly design and educational programs is emerging in botanic gardens, initiated by the Australian government, research organisations, and botanic gardens themselves. For example, a published guide *Bee Friendly: A planting guide for European honeybees and Australian native pollinators* by Rural Industries Research and Development Corporation (RIRDC) provides a guide for people on plant species selections for both domestic gardens and streetscapes.

Bee hotels have become the most common bee-friendly design feature (combination of built structure and surrounding flowering plants) not only in botanic gardens but also in public parks and private gardens. They provide nesting spaces for native bees and other insect pollinators. The hotels' timber hollows and separate rooms create fitting habitats for native bees to establish multiple hives. Bee hotels have both conservation and education roles, by educating and raising public awareness of the role native bees' play in a healthy ecosystem (Tab. 5).

5 Discussion and Conclusions

This paper discusses the conservation of biodiversity in Australia's botanic gardens from three main angles: Its design history and styles' influence on biodiversity; the perceptions towards native biodiversity in Australia's botanic gardens; and the solutions for preserving native biodiversity. It offers a framework for understanding local biodiversity and developing designing strategies for demonstration preservation strategies in botanic gardens. This framework needs to include an understanding of the local environmental history and landscape design history, acknowledging changes in perceptions on biodiversity over time, and integrating current local biodiversity conditions. The solutions to preserving the biodiversity in botanic gardens should include different dimensions, from the national-level macro policies, the development and management plan at the botanic garden level, and the detailed design principles within the gardens.

Biodiversity conservation in botanic gardens requires not only plant knowledge but also includes respecting the local context (sense of place), adaptation to urbanisation and climate change, searching for strategies to preserve species and habitats, and seeking the maximum ecological benefits combined with landscape design. Conserving biodiversity in urban environments holds significant benefits for their inhabitants. Botanic gardens do not only provide habitats for wildlife but are first and foremost designed for humans. Ecological design approaches need to accommodate human beings' needs in the creation of an aesthetically pleasing environment.

Furthermore, botanic gardens are closely connected with plant selection. While native species today are much preferred in vegetation compositions (more adapted to local soil, and usually more resistant to pests), it is important to select eligible species for conservation purposes. In Australia, botanic gardens are laboratories for other types of urban green spaces, provide research results for plant selections when designing urban plant communities (an appropriate biodiverse and sustainable plant palette). Most of the plant species of the native flowering collections in botanic gardens are widely used in private gardens, street verges and roundabouts (traffic islands), while some plants in their collection are unavailable commercially.

The planning and design of botanic gardens have changed over time to reflect changes in function, changes in science, and culture. Conservation, research, education, and recreation are all active pursuits of modern Australian botanic gardens. On the one hand, Australian botanic gardens reflected styles similar to those used in other British colonial botanic gardens, especially the Kew Gardens, which were the main inspiration and influence for Australian botanic gardens. On the other hand, due to the rising attention given to the loss of unique native biodiversity in Australia, from the mid-20th century until the present, the design emphasis of Australian botanic gardens has been shifted to the conservation of native and local biodiversity. Another important task in future studies should be researching different native habitat requirements and formulating native wildlife-friendly botanic garden principles. Our next research will focus on developing design guidelines for bee-friendly botanic gardens in Western Australia.

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