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澳大利亚植物园中的城市生物多样性设计与保护策略

Design and Conservation Strategies for Urban Biodiversity in Australian Botanic Gardens

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摘要: 由于景观起源、物理环境条件和社会经济发展的差异, 在南北半球, 学术界对城市生物多样性及其与生态设计方法的相互作用有着不同的理解。数千年来, 澳大利亚本土植物群落在这片大陆繁衍生息, 形成了生物多样性极高的独特景观。植物园融合自然和人造元素, 具有科研和保育功能, 其设计与规划反映了科学知识随时间变化的动态特征, 也为研究不同社会群体在过去如何利用和重视植物提供了独特视角, 植物园的生态设计方法反映了重视和保护生物多样性的新愿景。以澳大利亚为例, 研究并回顾了植物园在保护生物多样性方面的益处, 讨论了为展示生物多样性植物园设计重点的变化, 分析了澳大利亚植物园的设计历史、澳大利亚本土生物多样性以及以生物多样性为重点的设计解决方案。为了解澳大利亚当地生物多样性和制定植物园示范保护与策略提供研究框架, 为重新思考和加强植物园设计中的“生物多样性”提供新视角。

关键词: 风景园林; 生态设计; 野生动物友好设计; 城市生物多样性; 本土植物保育; 原始残存植被

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Abstract: Due to the differences in landscape origins, physical environment conditions, and socio-economic development, there are different approaches to understanding urban biodiversity and the way it intersects with ecological design approaches in the Northern and Southern Hemisphere. Australian native plant communities have thrived in this continent for millennia and formed a unique landscape of very high biodiversity. Botanic gardens are venerable institutions that have evolved through the years, adapting to cultural and social demands. The planning and design of botanic gardens are affected by political, economic and social perceptions as well as by individual designers. Botanic gardens reflect the dynamic character of scientific knowledge, and changes in the aesthetic expressions of human cultures over time. Botanic gardens therefore offer a unique vision of how different social groups have used and valued plants in the past. The recent ecological design approaches of botanic gardens reflect a new vision of valuing and protecting biodiversity. This paper reviews the biodiversity benefits of botanic gardens. It discusses the changes of design focus to demonstrate biodiversity, using case studies in Australia. The design history of Australian botanic gardens, Australia's native biodiversity, and biodiversity-focused design solutions are discussed and analysed. It offers a framework for understanding local biodiversity and developing designing strategies for demonstration preservation strategies in botanic gardens. The research outcomes of this paper provides a new angle which allows to rethink and reinforce "biodiversity" in designing a botanic garden.

Keywords: landscape architecture; ecological design; wildlife friendly design; urban biodiversity; conservation of native plants; remnant vegetation

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0 引言

澳大利亚的生物多样性对于其国家内部的民族认同及可持续发展（生态、经济与生活质量）而言不可或缺^[1]。在澳大利亚，超过80%的植物与动物物种为特有种（不仅为澳大利亚本土种，且仅在澳大利亚自然存在）^[2]，其中约90%的维管植物为特有种。这些植物不仅是澳大利亚景观的重要组成部分，且占全世界植物种类的10%^[3]。被澳大利亚原住民（最早居住在澳大利亚大陆的居民）在日常使用中并分类的约16 000种本土植物是居民维持生计（食物和医药）的关键。分布在澳大利亚南部的块根植物、在干旱地区采集到的种子以及热带地区的果实均为澳大利亚原住民的主要食物来源^[4]。

澳大利亚的植物区系的高丰富度及特有种的高比例，主要归因于澳洲大陆与其他大陆的长期地理隔绝^[5]。约5 000万年前，澳大利亚从南半球的超级大陆——冈瓦纳古大陆中分裂出来，南美洲、非洲、印度和南极均为冈瓦纳古大陆的一部分^[6]。澳大利亚开花植物的主要科为豆科（金合欢属）、桃金娘科（桉属）、山龙眼科（班克木属和银桦属）、菊科（澳大利亚本土维菊属）以及禾本科（澳大利亚本土草本）植物^[7]。这种植物特有种的高度地方性现象也可以在冈瓦纳古大陆的其他板块中体现，例如南非（69%的维管植物为特有种）^[8]和新西兰（约80%的维管植物为特有种）^[9]。

不同于本土生物多样性，城市生物多样性在很大程度上取决于建成环境的规划、设计与管理。城市生物多样性的综合定义是“在人类住区及其边缘发现的生物多样性及丰富性（包括遗传变异）和栖息地多样性”^[10]。城市生物多样性由外来物种和本地物种共同组成。城市生物多样性不仅存在于人为设计的景观（公园、私人花园、植物园和街景）中，还存在于城市区域内受保护的原始残余植被和农业景观中，包含了棕地和其他城市群落中自生植物^[11]。

澳大利亚独特的本土生物多样性当今主要受到3个因素的严重影响：持续的土地及植被清理、外来杂草的入侵（自1788年以来已

超过3 000种）和气候变化^[12]。本土生态系统受到威胁并面临消失这一现状，使得人们注重保育本土植物及其回归城市环境并形成强烈的愿景，具体措施包括湿地和溪流的植被恢复项目、种植本土植物的街边及绿化带花园以及在私人花园和公园中使用本土植物进行设计。

21世纪初，全球越来越多的植物园开始专注于发掘和应用对生物多样性更加友好的生态设计方法。在全球范围内的本土植物物种和植物群落的破坏迫使许多植物园开展教育计划，强调植物作为所有生命赖以生存的主要生物单位的重要作用。强调与突出保育地球的重要性是大多数植物园中植物展示的首要目标^[12]。20世纪后期至今，打造“保育花园”已成为当代植物园设计目标^[13]。

当前学术界对澳大利亚植物园保护的研究日渐兴起。Moskwa与Crilly^[14]分析了澳大利亚植物园的3个主要功能——娱乐、教育和保育，并将其与园区维护管理的初始目标进行比较。Virtue等^[15]对墨尔本、霍巴特和珀斯3座澳大利亚城市中植物园中的100种杂草进行调研，并针对这些植物园中的杂草率与杂草现状进行评估与分析。Hardwick等^[16]以澳大利亚植物园为例，展示并描述了植物园在保护过程中的多元方法。例如，澳大利亚国家植物园建立了一个持续更新的本土植物数据库，协助园区的管理、研究和保护。

然而，目前尚未有研究从景观的角度对澳大利亚植物园的本土生物多样性及其保护方案进行全面综述与分析，例如根据不同园林风格，对园内的空间与植物配置进行相应的组织与划分。若要了解澳大利亚植物园生物多样性的设计方案，应当从研究当地的环境历史和澳大利亚植物园的设计与发展历史着手。本研究首先简要概述澳大利亚殖民时期植物园的发展，分析其造园风格对植物收藏的布局和组织设计的影响，同时反映了在19世纪时人们对植物园作用的普遍看法。强调为应对21世纪生物多样性危机和气候变化，澳大利亚植物园在设计和教育策略方面的变化。进而讨论在澳大利亚植物园中，如何恰当地运用景观设计原则，以达到生物多样性

友好的设计目的，例如野生动物友好设计和蜜蜂旅馆。本研究旨在向中国学者提供一个澳大利亚解决生物多样性丧失问题的措施概览。

1 研究方法与研究问题

本研究的研究方法以文献综述为主。以学术书籍、政府政策及行动指南、学术论文，以及澳大利亚植物园的官网作为综述的主要资料来源。本研究围绕3个主要研究问题，分别是：1）澳大利亚植物园的设计是如何随着时间而发展？植物园设计风格如何影响本地生物多样性及如何理解其在社会中的作用？2）澳大利亚植物园对本土植物和外来植物的态度如何改变？它们在保护生物多样性方面的作用有哪些？3）澳大利亚植物园在保护生物多样性方面的措施有哪些？

2 澳大利亚植物园的设计历史与园林风格

2.1 植物园的历史概述

建造植物园的哲学思想之一是重建伊甸园^[17]，其任务是收集来自世界各地的不同植物，并将它们带回一个花园，以重建地球上的天堂。这种信念不仅影响了16世纪第一批当代植物园的发展，也为维多利亚时代植物园的建立奠定了精神基础。

植物园的发展沿革经历了3个阶段：16—17世纪欧洲的药用植物园，18—19世纪的殖民时期植物园（以英国、美国、澳大利亚、印度、新西兰等国家为代表），以及20—21世纪在全球范围内建立的以保育为主要功能的植物园^[18-19]（表1）。

2.2 澳大利亚植物园的分布与设计布局

资本主义、殖民主义、植物分类学及以卡尔·林奈的“二项命名法”和亚历山大·冯·洪堡的《植物地理学论文集》为代表的地理学理论的发展是18—19世纪时期建造植物园的主要驱动力^[20]。18世纪时人们对自然和园艺的态度发生了较大的转变，尤其体现在英国，这种改变也同时影响了澳大利亚早期定居者对于园艺的看法^[21]。澳大利亚的植物园尤其受到邱园的影响。早期建立澳大利亚植物园的主要原因是复制欧洲开发公

表 1 植物园的作用与功能变化^[18-19]
Tab. 1 The changing roles of botanic gardens^[18-19]

发展阶段 Stages	设计重点 Focuses	植物园案例 Examples
16-17 世纪欧洲: 药用植物园 16th and 17th century: "physic" gardens	在高校中以教育为目的, 种植药用植物 Growing medicinal plants with educational purposes in universities	意大利帕多瓦植物园 (1545 年) 荷兰莱顿植物园 (1590 年) 法国巴黎植物园 (1635 年) The Orto Botanico di Padova in Padua, Italy (1545) The Hortus Botanicus in Leiden, Netherlands (1590) The Jardin des Plantes, Paris, France (1635)
18-19 世纪: 维多 利亚时代的殖民时 期植物园 18th and 19th century: Victorian colonial botanic gardens	18 世纪, 植物的经济价值成为植物园选种 的重点; 19 世纪, 园艺成为一种流行的休闲活动, 科学和经济作用与审美作用相融合, 反映 了人们对异国情调的热爱 The economic values of plants became an important aspect during the 18th century; In the 19th century, gardening became a popular leisure activity, and the scientific and economic role blended with the aesthetic one, reflecting a love of the exotic	英国皇家植物园邱园 (1759 年) 澳大利亚悉尼皇家植物园 (1816 年) 澳大利亚塔斯马尼亚皇家植物园 (1818 年) 澳大利亚墨尔本皇家植物园 (1846 年) 澳大利亚阿德莱德植物园 (1857 年) The Royal Botanic Gardens, Kew, England (1759) The Royal Botanic Gardens, Sydney, Australia (1816) The Royal Tasmanian Botanical Gardens, Hobart, Australia (1818) The Royal Botanic Gardens Victoria, Melbourne, Australia (1846) Adelaide Botanic Gardens, Australia (1857)
20-21 世纪: 保育植物园 20th and 21st century: conservation gardens	保育和教育是植物园应对气候变化和生物 多样性损失的 2 个主要功能 Conservation and education are the two main functions of botanic gardens in response to climate change and the loss of biodiversity	澳大利亚国王公园与植物园 (1965 年) 澳大利亚国家植物园 (1970 年) 澳大利亚克兰伯恩皇家植物园 (2006 年) Kings Park and Botanic Garden, Australia (1965) Australian National Botanic Gardens, Canberra, Australia (1970) The Royal Botanic Gardens Victoria, Cranbourne, Australia (2006)

表 2 植物园中风景如画式和花园式风格的园林设计特征^[21]
Tab. 2 Design features of the Picturesque and the Gardenesque styles^[21]

风格类型 Style	设计特征 Design features
风景如画式 Picturesque	1) 如画的风光, 视觉上的远景; 2) 创造一个“理想的”自然; 3) 不规则的布局, 弯曲的路径, 粗糙的岩石和丛生的树木; 4) 偏爱使用绿色及本地物种 1) Picture-like landscapes, visually navigated vistas; 2) Creation of an "ideal" nature; 3) Irregular layout, curvy pathways, rough rockwork, and clumps of trees; 4) Green colour and preference of native species
花园式 Gardenesque	1) 艺术与植物学的结合; 2) 将乔木和灌木作为植物学标本展示; 3) 不同方法和风格的混合 (折衷主义和复兴主义), 几何路径、花坛和花毯结合曲线路径以及“自由” 配置灌木种植; 4) 色彩鲜艳, 植物种类繁多 1) A combination of art and botanical science; 2) Display trees and shrubs as botanical specimens; 3) Mixture of different approaches and styles (eclecticism and revivalism). Geometric pathways, flowerbeds and flower carpets in combination with some curvy pathways and "free" configuration shrub plantings; 4) Bright colours, many variety of plant species

共休闲空间的做法, 并测试植物的经济潜力。

澳大利亚的植物园最开始是作为引进观赏植物和培育农业和园艺品种的中心出现。最早的澳大利亚植物园是由约瑟夫-班克斯爵

士在悉尼 (悉尼皇家植物园, 1816 年) 和霍巴特 (塔斯马尼亚皇家植物园, 1818 年) 创建的, 具备系统的植物收藏与收集体系。到 19 世纪 50 年代末, 墨尔本、布里斯班和阿德莱德

的植物园均建造完毕, 将科学功能与公共休闲空间相结合^[22]。至 2001 年, 澳大利亚约有 100 多个植物园^[18]。至 2021 年, 根据“生物多样性公约秘书处”(SCBD) 提供的公开文件, 澳大利亚约有 137 个植物园和树木园, 分布在南澳大利亚州 (14 个)、北领地州 (3 个)、昆士兰州 (34 个)、新南威尔士州 (39 个)、西澳大利亚州 (10 个)、维多利亚州 (28 个)、澳大利亚首都地区 (3 个)、塔斯马尼亚州 (5 个) 以及诺福克岛 (1 个)。记录在案的活体植物数量超过约 25 万株, 植物物种数量约为 1.5 万种^[23]。

植物园中传统的植物种植布局主要基于科学的植物分类学、植物的形态分类 (乔木、灌木、草本植物), 以及植物所在的地理和气候区域进行配置。例如, 墨尔本皇家植物园尝试了根据植物所在的地理区位进行种植设计。悉尼皇家植物园对自然式布局 (模仿自然界中的自由形状, 而非追求对称布局) 和林奈分类学的布局 (使用正式的几何花坛) 都进行过尝试。除以上的传统布局方法外, 还有一种更为生态的方法来发展“栖息地种植”。“栖息地种植”法模仿并依据适合植物生长的自然环境中土壤与气候条件分区种植。例如新南威尔士和昆士兰的雨林植物种植区、澳大利亚的湿地和干地硬叶植物收藏区, 以及卧龙岗植物园的旱地植物收藏^[18]。

2.3 澳大利亚植物园的造园风格

澳大利亚的城市景观和植物园设计首先受到 18 世纪英国“风景如画式”(Picturesque) 和维多利亚时代 (1837—1901 年) 的“花园式”(Gardenesque) 风格的深刻影响^[24] (表 2)。在澳大利亚, 维多利亚时代的殖民时期植物园的设计与规划, 通常被认为是一个驯服和适应荒野的过程^[19]。

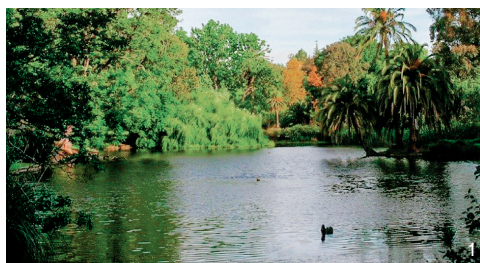
作为英国风景园林风格的一部分, “风景如画式”指“如画般”。它由绘画理论演变而来, 展示对自然的崇拜, 将艺术和自然风光 (和植被) 结合在一起。不规则的布局、弯曲的小路、粗糙的岩石和丛生的树木是“风景如画式”风格的核心元素。如诗如画的先决条件并不取决于它是经过改造的还是自然的, 而是其是否具备成为风景画的能力。“殖

民时期的风景如画”这一概念被用来描述澳大利亚的风景足够如画，而不需要任何人工的改进^[19]。因此，尽管许多“风景如画式”的园林由人为设计，而非自然之作，但不可否认，这种风格直接促进了人们对荒野与自然不可替代的欣赏态度^[4]。

值得一提的是，上文的“自然”特指英国的“自然”。在澳大利亚，“风景如画式”的设计原则适用于澳大利亚的自然环境中。Jacky Bowring以新西兰为例，将这种类型的“风景如画”定义为“皮钦-风景如画式”(Pidgin Picturesque)。她以语言为隐喻，把“母语”比作“英国的自然环境”，把“本土语言”比作殖民地的“自然环境”。“皮钦-风景如画式”是英国“风景如画式”风格和殖民地的本土环境的结合。这种语言的变化源于当地的建筑、地形和植被^[25]。与新西兰极为相似，澳大利亚的“风景如画式”风格同时具有“进口的风景如画式语言”及“基于自然环境的本土语言”的特质^[25]。这种“舶来品”与“本土环境”之间的交流是“风景如画式”风格的核心，其最突出影响体现于墨尔本皇家植物园部分区域的设计(图1)。

“花园式”风格于1832年由苏格兰园丁John Claudius Loudon提出^[26]。“花园式”的核心是运用博物馆展览的方式和折衷主义的原则来展示外来植物，以热带及亚热带物种为主。“花园式”风格认为群植使植物争夺光线和空间，从而限制它们的生长。因此，与“风景如画式”的植物群植偏好不同，“花园式”的特点是单株种植而非大规模种植^[27]，成为维多利亚时代植物园展示新外来物种的流行形式^[28](图2)。1857年，查尔斯·摩尔在悉尼皇家植物园减少了植物种植面积，以实现种植更有规律地长期发展^[4]。“花园式”风格植物园的愿景是基于几何路径，将游客引向散落在草坪上的异国情调的乔木和灌木或通向花毯和池塘。尽管在澳大利亚仍然存在少量的建于19世纪的完整的“花园式”园林，在澳大利亚植物园中依旧可窥“花园式”风格的影响。

植物园设计的要求主要集中在植物的分类展示和植物收藏上。这一目标在很大程度上



1 墨尔本皇家植物园中的“风景如画式”风格
Picturesque in the Melbourne Botanic Gardens
2 墨尔本皇家植物园中的“花园式”风格
Gardenesque in Melbourne Botanic Gardens

上符合“花园式”对外来植物、几何和对称布局的特殊偏好，以及尝试多种观赏物种的愿望。例如，悉尼皇家植物园和阿德莱德植物园就是“花园式”布局的典范^[4]。

澳大利亚的植物园和公园受到人们对观赏性园艺的偏爱和对自然特征的追求的影响，融合并推进了“风景如画式”和“花园式”2种风格，这种融合也是对艺术和自然热爱的结合^[29]。装饰特征(不寻常的颜色、形式和质地)与植物群落的“自由”(非几何)配置相结合。阿德莱德植物园使用了“花园式”的元素，配有花坛和花圃。其布局既非几何也非自然，被称为“不规则对称”布局^[21]，也就是说轴线的两侧无须具备相同的大小或形状的植物组团，两侧植物组团的根据功能和实际设计需要而变化。

在澳大利亚的众多殖民时期的植物园中，可以看到很多热带和亚热带植物自然群植的例子，它们作为一般近景，并与以水体(例如湖泊)为视线焦点的远景相结合。由于澳大利亚部分地区位于亚热带地区，随着19世纪中叶亚热带植物的流行，澳大利亚的植物园逐渐开始注重对亚热带植物的栽培。悉尼皇家植物园的Charles Moore提出了使用“自



3 悉尼皇家植物园对棕榈树和蕨类植物的“自然式群植”
The cultivation of groves of palms and tree ferns with
“naturalistic grouping” in Royal Botanic Gardens, Sydney
4 阿德莱德植物园中的“花园式”风格
Gardenesque in Adelaide Botanic Gardens

然式群植”的方法种植棕榈树和蕨类植物^[19](图3)，这种自然式群植方法同样表现为植物在同质化的草坪上进行的自由排列(图4)。

2.4 植物园设计风格对本土生物多样性的影响

深受人类文化审美表达方式变化的影响，园林设计风格对植物园的园林布局、设计元素和植物选择有至关重要的影响，并进一步影响植物园生物多样性以及向公众展示生物多样性的方式。

植物园设计的核心是向公众展示植物。19世纪，澳大利亚的植物园同时使用“风景如画式”和“花园式”风格的元素。他们对植物收藏的方式并非旨在保护生物多样性，而是取决于这2种风格如何在视觉上更好地展示植物。在墨尔本皇家植物园中，“风景如画式”风格通过远景创造视觉效果，“花园式”用于展示植物群落。在澳大利亚的植物园中，2种风格的运用对本土植物和外来植物均有选择，故在当时植物园中的植物多样性由外来和本土植物组成。从20世纪中叶至今，新的“本土风格”的设计方法更加强调本土生物多样性。植物园往往利用现有的原生残留丛林来作为植物收藏的一部分，将其保留并未做



5 20—21 世纪澳大利亚植物园中对本土植物重视的时间线

Timeline of the development of the appreciation of native plants used in botanic gardens in Australia, in the 20th and 21st century

任何进一步的设计或修改。例如在国王公园，大面积的残余原生植被构成了植物园不可替代的一部分。在保护本土生物多样性方面，“本土风格”设计方法比“风景如画式”和“花园式”风格更适用于澳大利亚植物园。

关于设计风格对本地生物多样性的影响的研究主要集中在植物种类的选择上。大多数物种依赖植物群落的特定特征来满足它们的栖息地条件，不仅限于觅食，还包括构筑筑巢和庇护所^[60]。动物的物种丰富度主要依赖于植被的多样性和复杂性^[11]。在植物园中，植被的复杂性包括乔木、灌木（林下）、草本（地被）植物、藤本（攀缘）植物和水生植物。原则上，大面积的植物群落可能包含更多样的植物物种，从而促进群落生境的多样化^[31]。也有学者认为，城市植被结构中的本土和外来植物物种都可以为本土野生动物的生存及保育增加价值，因为一些外来植物可吸引高度多样化的动物群（包括鸟类和无脊椎动物）^[32]。以蜜蜂为例，在植物园种植一定数量的外来植物，对于那些只对一种或几种本土开花植物觅食的本土蜜蜂物种来说是有益的。因为这些外来的开花植物既可吸引欧洲蜜蜂（*Apis mellifera*），又可吸引一部分澳大利亚本土蜜蜂物种。从而减少欧洲蜜蜂与那些觅食结构较单一的本土蜂种在本土蜜源植物上的竞争。因此，在澳大利亚，尽管本土动物更适应它们的本土栖息地，但将外来植物纳入植物园，对于保护生物多样性也是有益的。

3 澳大利亚植物园的生态设计

生态设计原则从 20 世纪 60 年代开始发展成为澳大利亚风景园林设计的一个关键组

成部分，一定程度上受到美国风景园林师伊恩·麦克哈格的《设计结合自然》一书的影响^[21]。当今的生态设计原则强调本土性及其与当地环境的紧密联系，创造“地方感”以及植被的动态特征^[33]。这些原则主要包括保护地方性植被和当地植物群落以及恢复退化的本地生态系统。

3.1 澳大利亚植物园对本土和外来植物侧重点的变化

从欧洲人定居到现在，澳大利亚植物园对本土和外来植物的态度发生了巨大变化。在澳大利亚植物园使用外来植物的最初原因是澳大利亚缺少满足欧洲移民口味与情感联结的欧洲本土作物。悉尼皇家植物园就是从种植谷物和其他可食用植物的土地上开始发展起来的。这些作物从英国和巴西里约热内卢被运送到澳大利亚^[19]。

除农业外，园艺栽培的植物选择也主要侧重于外来物种，其因有二：1）当时欧洲移民对澳大利亚本土植物群知之甚少；2）“花园式”风格对外来植物的偏爱影响了澳大利亚植物园的植物选择。但墨尔本皇家植物园是一个例外，出于科研目的，为了收集植物标本和种子并将其送至欧洲，需要首先在澳大利亚种植并培育本土植物，因此在墨尔本皇家植物园中种植了 2 000 多个澳大利亚物种^[19]。

由于外来植物的兴趣及当时对澳洲植物难以种植的固有认知，在澳大利亚的大多数植物园中，本土植物仍旧处于无足轻重的地位^[34]。直到 1950 年，澳大利亚才开始在堪培拉的一个新植物园（现为澳大利亚国家植物园）中集中种植澳大利亚本土植物（图 5）。

珀斯国王公园和堪培拉的澳大利亚国家



6 澳大利亚“Bush”——珀斯典型的班克木林地

Australian Bush: A typical Banksia woodland in Perth

植物园的设计和植物选择均受到生态设计的启发，极大地促进了对澳洲及当地本土植物的认识、欣赏和保护^[19]。澳大利亚国家植物园拥有最大、最全面的澳大利亚本土植物群的活体收藏。国王公园专注于西澳大利亚植物群的种植和展示，园中的原生植物群已具备非常重要的生态意义。

从 20 世纪 80 年代开始，澳大利亚的主要植物园开始相继开设用于种植本土植物的卫星植物园。例如于 1988 年正式开放的悉尼皇家植物园的安南山植物园，是澳大利亚最大的植物园，植物收藏均为本土植物。园内的主题分区以展示澳大利亚最具代表性的植物属为特色^[18]。

如今，基于对本土植物的日益重视，本土植物与外来植物的结合在澳大利亚的植物园中得到较好的平衡与广泛的接受^[35]。例如，本土的地被植物开始与草坪结合，共同承担地被植物的功能。花型与叶型的多样性得到了更广泛的认可。更重要的是，公共植物园设计与管理中体现的生态保护意识，使公众逐渐了解到保护本土植物群的重要性。

3.2 “Bush”在澳大利亚的特殊含义

提到保护澳大利亚本土植物群，就必然要提到在澳大利亚具有独特含义的“Bush”，它被视为国家身份的象征^[36]（图 6），是早在欧洲殖民者定居前，存在于澳洲大陆上千年的景观^[4]。在澳大利亚，它包含 2 种含义：1）“自然”^[37]指未受干扰的植被，如森林、林地和灌木丛；2）不同于城市文化的“荒野”^[38]。在欧洲人定居后，由于深灰绿色的叶子缺乏季节性变化，本土植物物种不受欢迎，没有被广泛用于私人花园和公共公园^[19]。直到

19世纪末和20世纪初，“Bush”才被视为园林的一部分。自20世纪中期以来，一些“Bush”中的本土物种才开始在城市园林中种植。在农村地区，由于具备相似的自然环境，“Bush”逐渐成为园林的一部分。

“丛林花园”（Bush Garden）的概念由Betty Maloney和Jean Walker在1966年提出，是鼓励完全使用本土植物的设计理念^[39]。模仿丛林（自然）的“丛林花园”是对自然的诠释，而非直接复制。“丛林花园”的特征是使用本土植物，采用自然和不规则的布局，不使用草坪，外来植物或花坛。“丛林花园”的设计与“植被复原”的概念相似，二者都强调种植当地本土植物与当地环境中濒危特有植物。

3.3 植物园在保护生物多样性方面的作用

植物园与树木园是集濒危物种的活体收藏，植物保护、种质资源的长期存档，植物展示、公众教育和科学研究为一体的科学机构^[40]。在澳大利亚已知的植物物种中，目前有7%是濒危物种，占世界濒危植物物种的15%^[9]。植物园也是外来植物物种保护的重要场所，因为它们为外来植物提供了适合其自然生长的栖息地，达到了迁地保护的效果。

植物园在保护生物多样性方面采取3种主要方法，即就地保护、迁地保护和基因库（或种子库）^[41]。就地保护是指在自然环境中保护物种，包括维护其自然栖息地。迁地保护（或异地保护）是指在其自然栖息地之外的场所保护物种^[42]。基因库是指储存种质资源（如种子、器官、组织、花粉或基因组）以保护遗传多样性的一种保护方法，也通常被当作原地保护的一种形式。澳大利亚的植物园已在保护生物多样性和应对气候变化方面采取了积极行动，主要体现在4个方面的优势。它们分别是：1）季节性研究是植物园的专长。植物开花时间的变化是气候变化的生物指标^[43]。开花时间的限制影响授粉，从而进一步影响生物多样性^[44]。在澳大利亚已经建立了一个城市和地区植物园网络及保护机构，通过制定计划，获得植物开花时间的长期数据，监测气候变化对生物多样性造成的影响。这些数据对南半球至关重要。2）澳大利亚的植物园拥有丰富的种子库、基因库和植物活

体收藏。活植物收集利于保护濒危种群，对植被修复至关重要。3）澳大利亚重视通过建立多网络和植物园组织在生物多样性保护（全国和区域范围内）方面的合作。例如，澳大利亚植物保护网络（ANPC）、澳大利亚植物园理事会（CHABG）、澳大利亚植物标本馆理事会（CHAH）及植物园和公园管理局（BGPA）是重要的合作网络。他们共享资源以保护植物园和植物标本馆的生物多样性。4）澳大利亚的植物园制定了志愿者计划，让公众和社区参与植物园的活动。志愿者被称为“植物园之友”，这些志愿者团体对于激发公众的兴趣和意识、启动项目以及支持澳大利亚植物园的保护和研究活动具有重要意义。

就地保护通过恢复计划在物种层面进行，旨在恢复本土物种的栖息地，并将栖息地中的目标种群恢复到无须人工干预即可维持的状态^[2]。这是澳大利亚植物园常用的针对栖息地丧失和物种减少的有效解决方案。迁地保护的包括濒危物种（不限于本土物种）、特有物种、作物野生近缘种和旗舰物种。迁地保护所提供的关于植物生理耐受性和本土植物适应性的研究资源，为就地保护的开展提供优先级和解决方案。

与此同时，植物园又被认为是潜在入侵植物物种的主要来源地之一^[45]。首先，有观点认为迁地保护是起因之一^[2]。其次，植物园在生物多样性热点地区中的分布与大多数环境杂草的入侵之间也存在联系^[46]。

植物保育与公众教育如今已经成为植物园的首要任务。园内的互动展示、导游、故事讲解和教育计划帮助植物园宣传植物保护的重要性^[47]。由于植物园中的维护频率较高，对杂草的控制也因此较为有效^[48]。因此，将外来植物引入植物园，其公众教育和保有种质资源的优势大于外来植物入侵的劣势。植物园在此的教育作用并非向公众推广入侵物种，而是可以帮助公众识别他们，以防止其在私家花园内种植。

4 澳大利亚植物园保护生物多样性的解决方案

从殖民时期至今，澳大利亚植物园的主

要功能和侧重点已经发生了变化。植物园的设计和植物配置由基于造园风格的公共设施转变为基于保育功能和科研的机构，其设计主要为满足其保育需求。

本节总结了澳大利亚植物园的主要生物多样性保护策略，其范围从应对气候变化的全国性战略行动计划，扩大到墨尔本皇家植物园的景观演替策略，再到植物园的野生动物友好型设计和教育项目。

4.1 全国性的行动计划

为保护和恢复生物多样性，澳大利亚已经提出了5个全国性的行动计划和指南^[49-53]（表3），受威胁的植物物种的数量仍在增加。造成这一结果的原因有栖息地损失、生物入侵，以及缺乏对特有植被的生态价值的认识^[2]。

4.2 《墨尔本皇家植物园景观演替策略2016—2036年》

气候变化正在威胁着生物多样性的各个层面——基因、物种、植物群落和生态系统。《墨尔本皇家植物园景观演替策略2016—2036年》为植物园顺利过渡到适应2090年气候和环境条件提供指导^[54]，同时“保留花园的遗产特征、景观品质和物种多样性。也是澳大利亚植物园的第一个为其他植物园应对气候变化规划的蓝图的决策”^[55]。该策略从5个主要维度提出，分别是：1）“积极管理墨尔本花园的景观和植物收藏”；2）“建立由多种分类群组成的混合年龄植物选择”；3）“最大限度地提高可持续水资源的可用性和使用效率”；4）“通过景观设计最大限度地发挥绿地和建筑环境的效益”；5）“增强气候变化对植物景观影响的理解”^[54]。该计划的愿景是保证景观质量和维持植物收藏多样性，并进一步发挥墨尔本皇家植物园的科学和文化价值^[55]。

4.3 澳大利亚植物园的野生动物友好设计和项目

植物园是野生动物（包括本地和受威胁的鸟类、哺乳动物和无脊椎动物）重要的栖息地。例如，位于克兰伯恩的维多利亚皇家植物园为袋熊、袋狸、鸭子和针鼹等野生动物提供了安全的栖息地^[56]（表4）。建造防捕食者围栏，以保护本地动物群南棕袋狸免受猫

表 3 全澳范围内促进植物园生物多样性的主要行动计划和指南^[49-53]
 Tab. 3 Major nationwide action plans and guides in promoting biodiversity for botanic gardens^[49-53]

名称 Guidelines	年份 Year	发布机构 Organisations	主要内容 Main contents
《国家生物多样性和气候变化行动计划 2004—2007》 <i>The National Biodiversity and Climate Change Action Plan 2004-2007</i>	2004	自然资源管理部长理事会 Natural Resource Management Ministerial Council	提供保护因气候变化而受到威胁的物种的行动计划，包括植物园中的濒危陆地物种 ^[49] Provides action plans for conserving threatened species due to climate change, including the endangered terrestrial species in botanic gardens ^[49]
《国家气候变化适应框架》 <i>The National Climate Change Adaptation Framework</i>	2007	澳大利亚政府委员会 Council of Australian Governments	为澳大利亚植物园的植物生物多样性保护提供气候风险管理框架 ^[50] Provides a climate risk management framework for Australia's botanic gardens for plant biodiversity protection ^[50]
《澳大利亚植物园在适应气候变化方面的作用的国家战略和行动计划》 <i>National Strategy and Action Plan for the Role of Australia's Botanic Gardens in Adapting to Climate Change</i>	2008	澳大利亚植物园负责人委员会 Council of Heads of Australian Botanic Gardens	概述可以促进澳大利亚植物园应对气候变化的战略和具体行动 ^[51] Outlines strategies and specific actions to promote and resource Australia's botanic gardens coping with climate change ^[51]
《澳大利亚 2010—2030 年生物多样性保护战略》 <i>Australia's Biodiversity Conservation Strategy 2010-2030</i>	2010	自然资源管理部长理事会 Natural Resource Management Ministerial Council	制定 2010—2030 年保护澳大利亚生物多样性的指导框架 ^[52] Sets a guiding framework on conserving Australia's biodiversity for 2010-2030 ^[52]
《澳大利亚自然战略 2019—2030 年》 <i>Australia's Strategy for Nature 2019-2030</i>	2019	澳大利亚自然中心和农业、水和环境部 Australia's Nature Hub and Department of Agriculture, Water and the Environment	该战略计划得到澳大利亚政府的认可，重点是寻找支持功能生物系统的创新方法 ^[53] Endorsed by the Australian government, this strategic plan focusing on searching for innovative approaches to support functioning biological systems ^[53]

表 4 澳大利亚植物园的主要野生动物友好解决方案^[56-59]
 Tab. 4 Major wildlife-friendly solutions in Australia's botanic gardens^[56-59]

野生动物友好措施 Wildlife-friendly Solutions	植物园及其相关机构 Botanic gardens or organisations	功能 Functions
专为本土动物群设计的防捕食者围栏和围栏上的特殊门洞 A predator-proof fence and special gates on fences designed for native fauna	克兰伯恩维多利亚皇家植物园 Royal Botanic Gardens Victoria, Cranbourne	保护濒临灭绝的南棕袋狸不被猫和狐狸捕食，同时为本地物种提供进入围栏的通道 ^[56] Protect the endangered Southern Brown Bandicoot from being predated by cats and foxes, while providing access to fences for native species ^[56]
野生动物隧道 A wildlife tunnel	克兰伯恩维多利亚皇家植物园 Royal Botanic Gardens Victoria, Cranbourne	确保袋熊、袋狸、鸭子和针鼹安全过街 Allow safe access for wombats, bandicoots, ducks, and echidnas when crossing the road
无脊椎动物野生动物园——第 1 阶段 Invertebrate Safari — Stage 1	悉尼皇家植物园 Royal Botanic Garden, Sydney	面向小学生的教育计划。学生可在植物园探索无脊椎动物的栖息地，并学习识别其身体特征及生计 ^[57] An educational program for primary school students. It allows students to explore habitats for invertebrates in the botanic gardens, and learn to identify their body features and living essentials ^[57]
生态侦探——第 2 阶段 Eco Detectives — Stage 2	悉尼皇家植物园 Royal Botanic Garden, Sydney	一项针对小学生的教育计划，旨在了解坎伯兰平原林地对本地物种的重要性。它还包括为猛鸮（澳大利亚东部的本地猫头鹰物种）规划足够的栖息地 ^[58] An educational program for primary school students to learn the importance of the Cumberland Plain Woodland for native species. It also includes planning adequate habitats for the powerful owl (a native owl species to eastern Australia) ^[58]
为设计鸟类友好花园提供园艺资源 Provide gardening resources for designing bird-friendly gardens	珀斯国王公园 Kings Park and Botanic Gardens, Perth	珀斯国王公园网站上向公众提供了一些关于设计鸟类友好花园的简单设计指南 ^[59] Some simple design guidelines are provided to the public on Kings Park's website on designing a bird-friendly garden ^[59]

和狐狸的伤害。此外，为改善野生动物的可达性，围栏上装有特殊设计过的门洞，并在公路下方建造隧道以为野生动物提供安全通道^[56]。

在澳大利亚，本土蜜蜂和欧洲蜜蜂对农业和生态环境都至关重要。欧洲蜜蜂于 19 世纪被引入澳大利亚，主要以本土植物为食，是蜂蜜的主要来源^[60]。目前，澳大利亚由养蜂

人管理的蜂箱约有 57 万个，野生蜂群数以万计，本土蜜蜂超过 1 700 种^[61]。澳大利亚拥有丰富的天然芳香（产蜂蜜）植物群，外来植物和本土植物都为这些传粉媒介提供了必不可少的觅食资源。例如，农村工业研究与发展公司（RIRDC）出版的《蜜蜂友好：欧洲蜜蜂和澳大利亚本土授粉者的种植指南》提供了

家庭花园和街景植物物种选择。蜜蜂旅馆已成为最常见的蜜蜂友好设计特征（建筑结构和周围开花植物的组合），不仅存在于植物园中，而且存在于公园和私人花园中。它们为本地蜜蜂和其他昆虫传粉者提供筑巢空间。空心树干组成单独的房间为本土蜜蜂创造了合适的栖息地。蜜蜂旅馆提升公众对本地蜜蜂在

表 5 澳大利亚植物园的主要蜜蜂友好解决方案^[62-64]
Tab. 5 Major bee-friendly solutions in Australia's botanic gardens^[62-64]

蜜蜂友好措施 Bee-friendly solutions	植物园及其机构 Botanic gardens or organisations	功能 Functions
本土蜜蜂旅馆 Air Bee “n” Bee	澳大利亚国家植物园 Australian National Botanic Garden, Canberra	蜜蜂旅馆为独居的本土蜜蜂提供房间，提供本土蜜蜂栖息地 ^[62] A bee hotel offers rooms to solitary native bees, providing native bee habitats ^[62]
欧洲蜜蜂“背包” “Backpacks” for European honey bees	悉尼皇家植物园 Royal Botanic Garden, Sydney	超小型 RFID 标签放置在单个蜜蜂的背上，跟踪蜜蜂的动作以了解蜜蜂的行为 ^[63] Ultra-tiny RFID tags are placed on individual bee's backs, tracking bees' movements to understand bee behaviours ^[63]
蜜蜂计划 Plan Bee	悉尼皇家植物园 Royal Botanic Garden, Sydney	面向小学生的教育课程，包括面对面的演讲、研讨会、花园散步和传粉媒介相关活动 ^[64] An educational program for primary school students. Face-to-face presentations, workshops, garden walks, and pollinator-related activities are included ^[64]

健康生态系统中的作用的认知，具有保护和教育双重作用（表 5）。

5 讨论与结论

本研究从 3 个主要角度讨论澳大利亚植物园的生物多样性保护：澳大利亚植物园设计历史和风格对生物多样性的影响；对澳大利亚植物园原生生物多样性的观点；保护本地生物多样性的解决方案。为了解当地生物多样性和制定植物园示范保护策略的设计策略提供了一个框架。该框架包括对当地环境历史和景观设计历史的理解，接纳随着时间的推移对生物多样性看法的变化，并整合当前当地的生物多样性条件。保护植物园生物多样性的解决方案应包括不同维度，从国家层面的宏观政策、植物园层面的开发和管理规划到园内详细设计原则。

植物园的生物多样性保护不仅需要植物知识，还包括尊重当地环境（地方感），适应城市化和气候变化，寻找保护物种和栖息地的策略，以及结合景观设计寻求最大的生态效益。保护城市环境中的生物多样性为其居民带来重大利益。植物园不仅为野生动物提供栖息地，而且其首先是为人类设计的。生态设计方法需满足人类在创造美观环境方面的需求。

此外，植物园与植物选择密切相关。尽管在当下，本土物种在植被组成中更受青睐（更适应当地土壤，通常对害虫的抵抗力更强），但重要的是选择符合条件的物种进行保

护。在澳大利亚，植物园是其他类型城市绿地的实验室，在设计城市植物群落（适当的生物多样性和可持续植物调色板）时为植物选择提供研究结果。植物园本土开花植物收藏的大多数植物物种广泛用于私人花园、街道边缘和环形交叉路口（交通岛），部分植物无法从市场上获取。

植物园的规划和设计随着时间的推移而变化，以反映功能的变化、科学和文化的变化。保护、研究、教育和娱乐都是现代澳大利亚植物园的积极追求。一方面，澳大利亚植物园反映了与其他英国殖民植物园相似的风格，例如邱园是澳大利亚植物园的主要灵感。另一方面，由于对澳大利亚独特的本土生物多样性丧失的关注日益增加，从 20 世纪中叶到现在，澳大利亚植物园的设计重点已转移到保护本土和当地生物多样性上。未来研究中的一项重要任务应为研究如何根据不同的原生栖息地要求，制定对原生野生动物友好的植物园原则。笔者的下一项研究将侧重于为西澳大利亚的蜜蜂友好植物园制定设计指南。

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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 endemism 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^[12]. 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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