

基于宫胁造林法的近自然城市森林数字化设计探索 ——以河北省绿博园邢台林为例

Digital Design Exploration of Nature-Approximating Urban Forest Basing on the Miyawaki Method: A Case Study of Xingtai Forest in a Hebei Green Expo Garden

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摘要

当下，中国城市森林的建设正处于高潮阶段，数字化技术的进步逐步推动着城市森林的发展。本文以近自然林业、潜在自然植被和新演替理论为理论基础，以“宫胁造林法”为实践基石，将经典理论与数字化技术结合应用，开展近自然城市森林的数字化设计探索。首先，文章梳理了近自然城市森林的发展历程，提出将数字化技术与近自然城市森林营建相结合的必要性。其次，借鉴“宫胁造林法”的相关步骤，提出近自然城市森林的数字化设计方法，包括“认知”“模拟”和“营建”三大步骤。最后，以河北省绿博园邢台林为例进行实证研究，分步解析近自然城市森林的数字化设计方法。具体的方法是：1）认知，通过植被调查研究自然群落特征，确定群落的关键参数；2）模拟，模拟自然群落构建目标群落，利用相关软件分析场地生境及划分目标群落类型，进行目标群落的类型设计和具体模式设计；3）营建，即数字化生成，利用Grasshopper结合Python脚本构建数字化生成运算集，代入关键参数的具体数值后即可生成种植设计图纸和相关苗木信息。该方法的建立为近自然城市森林的数字化设计提供了新的思路，能够推动更加科学、高效的城市森林建设。

关键词

风景园林；宫胁造林法；近自然城市森林；植物群落；数字化设计

ABSTRACT

Driven by digital technologies, urban forest development is at its height in China. Guided by the theories of nature-approximating forestry, potential natural vegetation and new succession, and by the Miyawaki Method, this paper explores the digital design of nature-approximating urban forest by innovatively applying widely-accepted theories with digital technologies. The paper reviews the evolution of nature-approximating urban forest and discusses why it is essential to introduce digital technologies into this type of forest's development. Based on the Miyawaki Method, this study proposes a three-step digital design approach to creating nature-approximating urban forest: cognition, simulation, and construction. Also, an empirical study on Xingtai Forest in a Hebei Green Expo Garden is conducted to analyze the digital design methods of nature-approximating urban forest. Steps include 1) cognition of plants to investigate characteristics of natural communities by collecting their key parameters; 2) construction of target communities by simulating natural communities, analyzing and classifying target habitats of designed communities by relevant software, and developing type and pattern designs of target communities; and 3) production of detailed construction schemes by utilizing Grasshopper and Python to generate digital generation clusters, after which planting design drawings and seedling information can be obtained by inputting values of key parameters. This method provides a new perspective on the digital design of nature-approximating urban forest, which helps facilitate urban forest development in an efficient way.

KEYWORDS

Landscape Architecture; Miyawaki Method; Nature-Approximating Urban Forest; Plant Community; Digital Design

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1 研究背景

1.1 近自然城市森林的发展

19世纪末, 欧洲的林学家面对人工林营建中出现的种种问题, 开始寻求森林的永续利用方法, 进行了近自然造林试验。由此产生了近自然林业 (nature-approximating forestry)^[1]、潜在自然植被 (potential natural vegetation)^[2]等相关理论, 促进了各国对近自然森林营建的研究。城市林业 (urban forestry)、城市森林 (urban forest)^[3]等相关研究首先在美国兴起。根据美国林学家罗伯特·米勒的定义, 城市森林指的是人类密集居住区所有木本植物及与之相关的植被的总和, 而城市林业则指对城市森林的营建和管护^[4]。1978年, 美国的《联邦合作林业法》明确指出, “在城市、郊区和乡镇内, 规划、营建、保护和管理树木及相关植物”^[4]。几乎与此同时, 日本全国范围内掀起了城市绿化高潮。20世纪90年代, 横滨国立大学教授宫胁昭提出的宫胁造林法 (Miyawaki Method) 已先后在日本、马来西亚、意大利、中国^[5]等国家和地区广泛应用并取得了相应成果, 被认为是一种较为可靠的近自然城市森林营建方法^{[6]-[8]}。宫胁造林法通过选择当地乡土树种, 应用容器育苗等“模拟自然”的技术和手法, 利用人工营造与后期植物自然生长的共同作用, 超常速、低造价地建造以地带性森林类型为目标、群落结构完整、物种多样性丰富、生物量高、后期完全遵循自然循环规律的少人工管理型森林^[9]。该方法通过人工参与, 适当改造土壤等环境条件, 直接种植顶极群落乔木层的优势种幼苗及灌木层的优势种幼苗, 可使演替时间缩短至原来的十分之一^[10]。

中国的城市森林研究起步于20世纪70年代末, 受到欧洲、美国和日本的影响, 出现了“生态园林”^[11]、“城市林业”^[12]等相关理念。近年来, 随着“国家森林城市”的创建, 城市森林的营建再一次广受关注。其主要目的是将森林引入城市, 在城市和城市周边营造森林, 协调城市与自然的关系。随着相关理论的发展, 城市森林的营建已不是单纯的林业活动。在参与主体上, 城市森林的营建融合了林学、生态学、风景园林学、园艺学等多学科的参与。在功能发挥上, 由于当下环境问题的日益频发, 以及娱乐交往等需求的增加, 人们愈发重视城市森林的生态效益和社会效益^[13], 而不仅仅是经济效益。要综合发挥城市森林的多重效益, 就需利用近自然的手法去营建城市森林, 中国颁布的相关规划曾多次强调这一点。例如, 《全国森林城市发展规划 (2018—2025年)》中明确指出, “在城市森林培育过程中……以种植乡土乔木树种

1 Research Background

1.1 Development of Nature-Approximating Urban Forest

At the end of the 19th century, European silviculturists began to explore the sustainable utilization of forests through nature-approximating afforestation experiments, aiming at addressing problems caused by traditional afforestation. Theories such as nature-approximating forestry^[1] and potential natural vegetation^[2] were therefore proposed, which have deepened related studies worldwide. Research on urban forestry and urban forests^[3] first appeared in the United States. According to Robert Miller, an American silviculturist, urban forest can be defined as “the sum of all woody and associated vegetation in and around dense human settlements,” while urban forestry refers to the cultivation and management of urban forests^[4]. The Cooperative Forestry Act (1978) of the United States clearly required to plan, establish, protect, and manage trees and associated plants within cities, their suburbs, and towns^[4]. Meanwhile, Japan launched a nationwide urban greening campaign. From then the Miyawaki Method proposed in the 1990s by Akira Miyawaki, professor from the Yokohama National University, has been widely and successfully applied in countries and regions including Japan, Malaysia, Italy, and China^[5]. Research has also proven the method’s effectiveness in creating nature-approximating urban forests^{[6]-[8]}. By selecting native species and using “nature simulation” techniques or measures such as container nursery, the Miyawaki Method encourages a synergy between artificial afforestation and natural succession of plants, which reinforces the role of nature in the later stages and establishes zonal forests with complete community structure, rich species diversity, and large biomass at a higher speed and lower cost^[9]. With proper human intervention on the environmental conditions (such as soil amelioration), this method can shorten the succession time by 90% by planting seedlings of dominant species in tree and shrub layers of the climax community^[10].

Studies on urban forests in China started in the late 1970s. Concepts such as “ecological gardens”^[11] and “urban forestry”^[12] emerged under the influence from Europe, the United States, and Japan. Along with the initiative of National Forest City, the construction of urban forest has once again come under the spotlight over the past few years. The initiative is to create forests in and around cities and to harmonize the city and the nature. Along with theoretical development, the construction of urban forest is now beyond an activity of creating forests. On the one hand, it involves multiple disciplines, such as Forestry, Ecology, Landscape Architecture, and Horticulture; On the other hand, scholarly attention is growingly on the ecological and social benefits of urban forests as the increase of severe environmental problems and people’s recreational needs^[13]. To maximize the overall benefits of urban forests, nature-approximating approaches should be introduced in practice. This has been promoted by relevant plans in China. For example, the National Forest City Development Plan (2018–2025) stipulated to foster nature-approximating urban forests by prioritizing the use of native tree

为主……培育近自然城市森林。”^[14]；北京市新一轮百万亩造林绿化行动计划（2019年度建设总体方案）中提到，“在大尺度的森林绿地中培育近自然的森林生态空间”^[15]。由此可见，近自然城市森林的营建在未来具有更为广阔的应用前景，而探索出一套适用于中国的快速高效的近自然城市森林营造方法，是本研究的核心内容。

1.2 近自然城市森林的营建与数字化技术的结合

在国内外数字化技术发展大潮的带动下，数字化技术也逐渐进入了风景园林专业中。在中国，蔡凌豪于2013年首次正式提出风景园林数字化规划设计概念，他认为，数字化设计强调的是一种并非被“预先设计”出来的环境，通过各种系统和元素在一个多元交互网络中动态建立完善的逻辑体系，因而具备相对的科学性和客观性^[16]。随着数字化时代的到来，数字化设计已成为有效提高景观设计科学性的主要方法，其运行平台、媒介、展示方式等都呈现出愈发多元发展的趋势。

在城市森林的营建过程中，数字化技术也逐渐发挥出更大的作用。如基于BIM平台构建植物信息模型数据库^[17]；利用GPS系统进行高精度定位和挖穴等。然而，这些技术大多适用于复杂程度较低的传统人工造林，由于近自然城市森林具有相当大的复杂性和随机性，目前鲜有学者或机构研究此类森林的数字化营建。在自然森林群落的水平结构中，最常见的是集群分布（clumped distribution），即种群个体分布极不均匀，常成群、成簇、成块或成斑状密集分布^[18]，形成不同的群落；从群落的垂直结构上来说，各层的郁闭度、植株高度、胸径大小也大不相同。鉴于自然森林的这些特点，若采用传统方式建设近自然城市森林，则面临着难以还原自然群落分布、效率低下等困境。而数字化设计可通过程序还原近自然森林的生成逻辑，通过参数控制群落的郁闭度、相对多度等关键指标，进而利用自然演替过程形成结构完整、功能完善的近自然城市森林。此外，群落设计中的大量重复操作及演算过程，可通过本研究原创的数字化生成运算集进行循环运算，方案若要调整，也可通过简单的参数调整快速生成设计方案，大大提高了整体设计效率。因此，有必要将数字化技术与近自然城市森林的营建相结合，探索其关键环节——近自然城市森林的数字化设计。

本研究借鉴“宫胁造林法”的相关步骤^[19]，提出了近自然城市森林的数字化设计方法，包括“认知”“模拟”和“营建”三大步骤：

1) 认知：通过植被调查研究自然植被群落的特征，提取树种信息、群落结构等关键参数。

2) 模拟：模拟自然群落，构建目标群落。首先，按照场地设计需求进行空间划分，划分出传统设计区域和数字化设计区域；其次，利用

species^[14]；Beijing's Overall Action Plan for a New Round of Planting One Million Mu of Trees (2019) also required to cultivate ecological nature-approximating forests within larger-scale green spaces^[15]. In this context, this paper aims to explore an efficient and applicable way to develop nature-approximating urban forests in China, facilitating its prospective promotion.

1.2 Nature-Approximating Urban Forest Construction With Digital Technology

Digital technology, seeing a rapid growth in recent years across the world, has been introduced in research and practice of landscape architecture as well. In 2013, Cai Linghao first proposed the concept of digital planning and design of landscape architecture in China, which, instead of building a “pre-designed” environment, dynamically establishes a sound logical mechanism in an interactive network formed by multiple systems and elements, with improved scientism.^[16] Today, digital design has become a main approach to encouraging evidence-based landscape design with diverse potential for development of the operation platform, media, display mode, etc.

Digital technologies are also prominently contributing to urban forest construction, such as building plant information model databases via BIM platform^[17] and utilizing GPS systems for high-precision locating and digging of tree pits. However, most existing techniques are suitable for traditional afforestation, while little research focuses on digital strategies for the construction of nature-approximating urban forests which faces with more complexity and unpredictability. A natural forest community usually forms a horizontal pattern of clumped distribution of species, i.e. individual species distribute densely and unevenly in groups, clusters, blocks or patches^[18]; Vertically, the crown density, height, and DBH of plants in each layer of the natural forest community vary greatly. In view of these characteristics of natural forest, the traditional way of forest construction faces difficulties in restoring the distribution of natural community and its low efficiency. However, digital design can construct a nature-approximating urban forest with complete structure and functions by programing key parameters (crown density, relative abundance, etc.) and leveraging natural succession. In community design, massive repetitive operations and algorithmic processes can be done through loop computation by digital generation clusters originally built in this study. Also, community design schemes can be easily altered by adjusting values of parameters, greatly improving the efficiency of design. This study demonstrates how to apply digital technologies into nature-approximating forest construction and explore relevant key steps.

Based on the Miyawaki Method^[19], this study proposes a three-step digital design approach to creating nature-approximating urban forest: cognition, simulation, and construction.

1) Cognition of plants is to investigate characteristics of natural communities by collecting data of parameters including species and community structure.

2) Simulation means to build target communities by simulating natural communities, specifically, dividing the site into traditional design areas and digital

相关软件科学分析场地生境并划分目标群落类型，进行目标群落的类型设计；最后，参照自然群落关键参数进行目标群落的具体模式设计。

3) 营建：即数字化生成，利用Grasshopper结合Python脚本构建数字化生成运算集，代入关键参数的具体数值后即可生成种植设计图纸和相关苗木信息（苗木数量、种植点坐标等），经校核后即可导出，用于指导施工。

本研究以河北省绿博园邢台林近自然城市森林的数字化设计为例进行实证研究。

2 近自然城市森林的数字化设计实践探索

2.1 研究区域概况

本研究以河北一处绿博园南部的邢台林为研究对象进行实践探索，研究时间为2019年9月至2020年7月。邢台林是绿博园中14片生态林之一，总面积约67hm²，以构建近自然城市森林为目标，以期实现生态、社会、景观和经济综合效益。

邢台林地处于河北北部（北纬39° 4′ —39° 4′ ，东经115° 53′ —115° 53′ ），位于大清河水系冲积扇上，属太行山东麓平原向冲积平原的过渡带，为缓倾平原，地势基本平坦，地面高程5~26m。土层深厚，地形开阔，土壤多为潮土，典型地带性植被为暖温带落叶阔叶林，植被覆盖率低，属暖温带季风型大陆性半湿润半干旱气候^[20]。

2.2 设计方法和过程

2.2.1 认知：潜在自然植被的调查和制图

潜在自然植被是未来设计目标群落的母本，需要通过调查寻找到典型的潜在自然植被并且确立关键参数以供目标群落的模拟构建。由于场地周边植被人工干预较大，已远离自然群落配置，需要寻找到植被条件良好的地点进行调查。

河北省邢台市老爷山坐落于河北平原西缘（北纬36° 50′ —37° 03′ ，东经113° 50′ —114° 40′ ），属太行山东麓，海拔500~1 437m。属暖温带大陆性半湿润气候^[21]。土壤多为褐土和潮土，植被类型丰富，种类繁多，多为灌草群落和次生落叶阔叶林群落。通过查阅相关文献及资料，发现太行山东麓平原地区常见树种有油松（*Pinus tabulaeformis*）、侧柏（*Platycladus orientalis*）、圆柏（*Juniperus chinensis*）、槐（*Styphnolobium japonicum*）、麻栎（*Quercus acutissima*）、臭椿（*Ailanthus altissima*）、构树（*Broussonetia papyrifera*）、山桃（*Prunus davidiana*）等，优势种为油松和侧柏；而

design areas as required, analyzing and classifying target habitats of designed communities by relevant software, and developing pattern designs of target communities with reference to the key parameters of natural communities.

And, 3) construction is to produce detailed construction schemes by utilizing Grasshopper and Python to generate digital generation clusters, after which planting design drawings and seedling information (numbers and coordinates) can be obtained by inputting values of key parameters. Upon verification, all these drawings can be used to guide the construction.

This paper represents an empirical study on Xingtai Forest in a Green Expo Garden in Hebei Province to explore digital design methods of nature-approximating urban forest.

2 Practice Exploration on Digital Design of Nature-Approximating Urban Forest

2.1 Study Area Overview

This study took Xingtai Forest in the south of a Green Expo Garden in Hebei Province as the example case, and the design spanned from September 2019 to July 2020. It is one of the 14 ecological forests in the park, covering an area of about 67 hm² and aiming at constructing a nature-approximating forest that could realize ecological, social, landscape, and economic benefits.

Xingtai Forest is located on the alluvial fan of the Daqing River Basin in northern Hebei (39°4′–39°4′ N, 115°53′–115°53′ E). The terrain is relatively gentle and open, 5 ~ 26 m in ground elevation, sitting in the transitional zone from the plain at the eastern foot of Taihang Mountains to the alluvial plain with deep fluvo-aquic soil layer. Under the warm temperate monsoon continental semi-humid and semi-arid climate, the site is dominated with typical zonal vegetation species which form a warm temperate deciduous broad-leaved forest, though the vegetation cover rate is low^[20].

2.2 Design Methods and Process

2.2.1 Cognition: Investigation and Mapping of Potential Natural Vegetation Species

The first step is to identify typical potential natural vegetation species, as the prototype for the designed community. An investigation is necessary to determine key parameters for target community construction. Since human intervention has largely changed the natural community structure of the surrounding areas, this study investigated an alternative area with similar vegetation conditions.

Laoye Mountain (36°50′–37°03′ N, 113°50′–114°40′ E) in Xingtai City of Hebei Province is located on the western edge of Hebei Plain. Sitting at the eastern foot of Taihang Mountains with altitudes of 500 ~ 1,437 m, it is featured with the warm temperate continental semi-humid climate^[21]. Cinnamon and fluvo-aquic soil is commonly found there, and the species of shrub-grass communities and secondary deciduous broad-leaved forest communities are rich. According

太行山山地地区常见树种有油松、麻栎、柿 (*Diospyros kaki*)、君迁子 (*Diospyros lotus*)、山杏 (*Prunus sibirica*)、山桃、臭椿、侧柏等, 优势种为油松和麻栎^[22], 两者在优势种和主要树种上有一定的相似性。

鉴于老爷山与邢台林同属于太行山东麓地带, 两者纬度相近, 气候相似, 且有较为典型的低山次生林植被, 在优势种、主要树种等方面具有一定的相似性。因此, 选择老爷山进行植被调查, 并结合邢台林场周边寺庙和古树名木等相关文献中记载的自然植被, 作为邢台林构建近自然城市森林的参考体系。

(1) 调查方法

本研究采用代表性样地法进行样方调查。运用光照、水分两个生境因子划分出了7个不同的群落生境类型——阴生、半阴生、半阳生、阳生、耐旱、中生、喜湿。研究团队在专家带领下进行实地勘测, 在老爷山针对不同的生境类型设置了7个20m × 20m的样地 (图1), 采用相邻格子样方法将每块样地划分成4个10m × 10m的乔木层样方, 在每个乔木层样地分别设置5m × 5m的灌木层样方和2m × 2m的草本层样方各一个。主要调查群落的生境、物种组成、多样性, 以及林分的水平结构和垂直结构 (图2)。

(2) 调查结果

将调查所得不同生境的群落资料进行整理, 计算各群落乔木层和灌木层的相对重要值, 确定优势种和伴生种等相关信息 (表1)。为了直观地表示种群 (尤其是乔木层) 在群落中的水平分布状况, 研究团队

to relevant documents, the dominant tree species in the plain region are *Pinus tabuliformis* and *Platycladus orientalis*. Other common tree species include *Juniperus chinensis*, *Styphnolobium japonicum*, *Quercus acutissima*, *Ailanthus altissima*, *Broussonetia papyrifera*, and *Prunus davidiana*. In the mountainous area, *Pinus tabuliformis* and *Quercus acutissima* are dominant species, and main trees include *Diospyros kaki*, *Diospyros lotus*, *Prunus sibirica*, *Prunus davidiana*, *Ailanthus altissima*, and *Platycladus orientalis*^[22], of which these two types of tree species are quite similar.

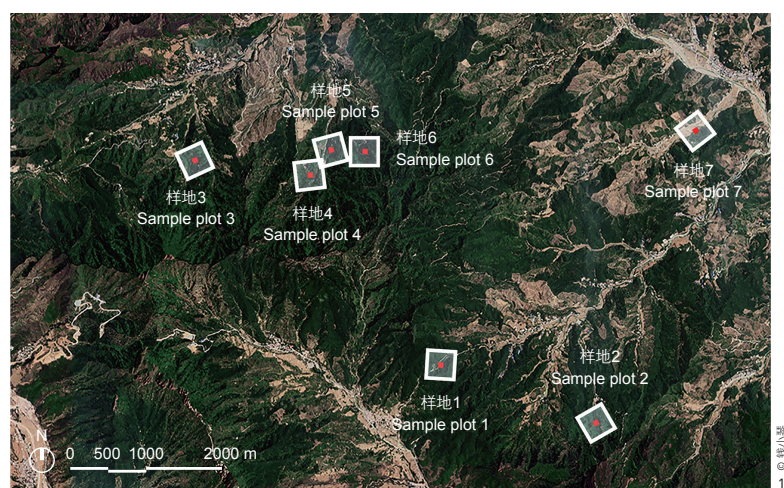
Considering the similarities between Xingtai Forest and Laoye Mountain in geography (east foot of Taihang Mountains), latitude, climate, as well as dominant and common tree species (typical low-mountain secondary forest vegetation), this research chose Laoye Mountain as a sample site for vegetation investigation. Document review on natural vegetation in surrounding temples, Fengshui Forests, as well as ancient and precious trees was also conducted to provide a guidance for the construction of nature-approximating Xingtai Forest.

(1) Investigation method

This study employed the quadrat survey method by selecting sample plots in Laoye Mountain. Seven community habitat types, i.e. skiophyte, semi-skiophyte, semi-heliophyte, heliophyte, xerophyte, mesophyte, and hygrophyte, were identified considering sunlight and moisture conditions. Guided by experts, the research team conducted a field survey on vegetation in Laoye Mountain. Seven 20 m × 20 m sample plots were set for different habitat types (Fig. 1), where each plot was divided into four 10 m × 10 m tree layer quadrats using the contiguous grid quadrat method. Then, a 5 m × 5 m shrub layer quadrat and a 2 m × 2 m herb layer quadrat were respectively set at the corner of each tree layer quadrat. Investigation objects included habitats, species composition, community diversity, and the horizontal and vertical structure of the forest (Fig. 2).

(2) Survey result

After sorting out the data of different habitats obtained from the field survey, the research team calculated relatively core values of tree and shrub layers of each community to determine the dominant species and companion species (Table 1). Additionally, projection of multi-layered crowns (especially tree layers) was mapped to visually represent the horizontal distribution of



1. 植被调查采样地地理位置示意
2. 样方调查航拍及现场

1. Map of sample plots for tree species investigation
2. Aerial and site photos of the quadrats

绘制了各样地的群落树冠分层投影图 (图3)。

调查结果显示, 多数样地乔木层种类较为丰富, 灌木层种类较少且以各乔木优势种的幼苗为主, 草本层相对简单; 各层优势种较为突出, 乔木层主要为油松、麻栎、刺槐、杏、楸, 灌木层主要为荆条和胡枝子, 草本层以野菊为主。

根据样方调查结果, 初步确定邢台林场地中树种的选择主要为乔木和灌木。在乔木层中, 拟定油松、麻栎、刺槐、杏、楸为优势种; 君迁子、臭椿、侧柏、梧桐、柿、酸枣、小叶杨、椴树、漆为伴生种。灌木层种类较少, 以荆条、胡枝子、臭牡丹为优势种。

various groups in all communities (Fig. 3).

Survey results reveal that in most quadrats, species of tree layers are richer than that of shrub layers, while the latter contained mostly seedlings of dominant tree species (e.g., *Pinus tabuliformis*, *Quercus acutissima*, *Robinia pseudoacacia*, *Prunus armeniaca*, *Catalpa bungei*). In addition, *Vitex negundo* var. *heterophylla* and *Lespedeza bicolor* in the shrub layer and *Chrysanthemum indicum* in the herb layer are the prominent dominant species.

According to the quadrat survey results, it was preliminarily determined to introduce trees and shrubs in Xingtai Forest. Dominant species of trees included

表1: 老爷山植物群落调查结果
Table 1: Species of each plant community in Laoye Mountain

序号 Code	群落名称 Community name	乔木层 Tree layer			灌木层 Shrub layer			草本层 Herb layer	
		郁闭度 Crown density	优势种 Dominant species	伴生种 Companion species	盖度 Coverage	优势种 Dominant species	伴生种 Companion species	优势种 Dominant species	伴生种 Companion species
1	阴生群落 Skiophyte community	0.80	油松 <i>Pinus tabuliformis</i>	麻栎 <i>Quercus acutissima</i>	0.28	刺槐 (幼苗) <i>Robinia pseudoacacia</i> (seedling)	椴树 (幼苗) <i>Tilia tuan</i> (seedling)	香青 <i>Anaphalis sinica</i>	青杞 <i>Solanum septemlobum</i>
			君迁子 <i>Diospyros lotus</i>	楸 <i>Catalpa bungei</i>					
			侧柏 <i>Platycladus orientalis</i>						
2	半阴生群落 Semi-skiophyte community	0.75	油松 <i>Pinus tabuliformis</i>	君迁子 <i>Diospyros lotus</i>	0.20	麻栎 (幼苗) <i>Quercus acutissima</i> (seedling)	臭椿 (幼苗) <i>Ailanthus altissima</i> (seedling)	茜草 <i>Rubia cordifolia</i>	三脉紫菀 <i>Aster trinervius</i> subsp. <i>ageratoides</i>
			麻栎 <i>Quercus acutissima</i>			胡枝子 <i>Lespedeza bicolor</i>	君迁子 (幼苗) <i>Diospyros lotus</i> (seedling)		黄花蒿 <i>Artemisia annua</i>
3	半阳生群落 Semi-heliophyte community	0.62	杏 <i>Prunus armeniaca</i>	臭椿 <i>Ailanthus altissima</i>	0.37	荆条 <i>Vitex negundo</i> var. <i>heterophylla</i>	/	唐松草 <i>Thalictrum aquilegifolium</i> var. <i>sibiricum</i>	/
			刺槐 <i>Robinia pseudoacacia</i>						
			麻栎 <i>Quercus acutissima</i>						
4	阳生群落 Heliophyte community	0.75	麻栎 <i>Quercus acutissima</i>	刺槐 <i>Robinia pseudoacacia</i>	0.35	刺槐 (幼苗) <i>Robinia pseudoacacia</i> (seedling)	胡枝子 <i>Lespedeza bicolor</i>	野菊 <i>Chrysanthemum indicum</i>	雀麦 <i>Bromus japonicus</i>
				侧柏 <i>Platycladus orientalis</i>					
				梧桐 <i>Firmiana simplex</i>					
5	耐旱群落 Xerophyte community	0.70	麻栎 <i>Quercus acutissima</i>	油松 <i>Pinus tabuliformis</i>	0.53	荆条 <i>Vitex negundo</i> var. <i>heterophylla</i>	/	野菊 <i>Chrysanthemum indicum</i>	青杞 <i>Solanum septemlobum</i>
			刺槐 <i>Robinia pseudoacacia</i>	臭椿 <i>Ailanthus altissima</i>					茜草 <i>Rubia cordifolia</i>
				酸枣 <i>Ziziphus jujuba</i> var. <i>spinosa</i>					

续表见下页 / Continued

根据对场地周边寺庙和古树名木的调查并结合相关资料发现, 寺庙内以柏木 (*Cupressus funebris*) 居多, 古树名木中以侧柏、榆树 (*Ulmus pumila*)、槐、刺槐、楸、君迁子、臭椿、毛白杨 (*Populus tomentosa*) 为主^{[23][24]}。

研究显示, 样方调查和场地调查的结果多有重合。就乔木层而言, 通过专家咨询, 本研究将场地调查中的侧柏、榆树、槐、君迁子、臭椿也归入优势种类别, 伴生种主要为柿、酸枣、小叶杨、椴树、漆等。此外, 由于调研所得的灌木层和草本层种类较为单一, 因此在专家指导下选取对场地适应性较强的相同科属或变种来丰富目标群落, 如穗花牡荆 (*Vitex agnus-castus*) (与荆条同属于马鞭草科)、紫穗槐 (*Amorpha fruticosa*)、多花胡枝子 (*Lespedeza floribunda*)、紫荆 (*Cercis chinensis*) (与胡枝子同属于豆科) 等。综合调查结果和专家意见, 建立了邢台林目标群落的参考物种库。

(3) 目标群落参数确定

以调查所得潜在自然植被群落为母本, 确立目标群落的一系列关键参数。需要指出的是, 由图3可知, 调研所得群落整体郁闭度较高, 且乔木层和灌木层已出现多层、相互之间覆盖重叠的现象。宫脇造林法的初期阶段主要利用“混合密植”的方法促进植株的生长, 从而达到自疏作用, 使得在竞争中获胜的植株将成为成熟森林的骨架, 而通常 $1/3 \sim 1/2$ 的苗木进入不了乔木层, 甚至死亡^[25]。因而, 在设计目标群落时, 设置的郁闭度 (或盖度) 为1.3~1.5倍的调研所得数值。此外, 对于造林初期的小苗而言, 其密度的控制是最为关键的, 也是宫脇造林法的核心控制要素。因此, 将相对多度作为控制目标群落个体密度的参数。为使计算更加简便, 植物冠幅选用调查所得的实际平均冠幅。综上, 确定目标群落的关键参数为树种名称、乔木郁闭度、灌木盖度、相对多度及平均冠幅。

2.2.2.2 模拟——构建目标群落

由于本次实践地点位于绿博园内, 既要保证近自然森林营建的科学性, 又要考虑到城市森林的景观需求。因此, 团队采用了大面积数字

Pinus tabuliformis, *Quercus acutissima*, *Robinia pseudoacacia*, *Prunus armeniaca*, and *Catalpa bungei*, and companion species of trees were *Diospyros lotus*, *Ailanthus altissima*, *Platycladus orientalis*, *Firmiana simplex*, *Diospyros kaki*, *Ziziphus jujuba* var. *spinosa*, *Populus simonii*, *Tilia tuan*, and *Toxicodendron vernicifluum*. Dominant species of shrubs included *Vitex negundo* var. *heterophylla*, *Lespedeza bicolor*, and *Clerodendrum bungei*.

According to document review on the surrounding areas of Xingtai Forest, it was found that *Cupressus funebris* was most commonly seen in temples; *Platycladus orientalis*, *Ulmus pumila*, *Styphnolobium japonicum*, *Robinia pseudoacacia*, *Catalpa bungei*, *Diospyros lotus*, *Ailanthus altissima*, and *Populus tomentosa* were the main ancient and precious tree species^{[23][24]}.

It can be found that result of the quadrat survey is similar to that of the site survey. Regarding the tree layer, this research team selected *Platycladus orientalis*, *Ulmus pumila*, *Styphnolobium japonicum*, *Diospyros lotus*, and *Ailanthus altissima* obtained from the site survey as dominant species, and took *Diospyros kaki*, *Ziziphus jujuba* var. *spinosa*, *Populus simonii*, *Tilia tuan*, *Toxicodendron vernicifluum*, etc. as companion species. For the shrub and herb layers, since the species diversity obtained from both surveys was low, this research introduced species of the same family/genus or varieties of the existing vegetation to enrich the target communities. For instance, *Vitex agnus-castus* (considering *Vitex negundo* var. *heterophylla*), and *Amorpha fruticosa*, *Lespedeza floribunda*, and *Cercis chinensis* (considering *Lespedeza bicolor*) that can well adapt to site conditions were considered. Finally, a reference species bank was created for target community construction in Xingtai Forest basing on both survey results and experts' suggestions.

(3) Determination of target community parameters

A series of key parameters to construct target communities were determined basing on the survey results of potential natural vegetation communities. Figure 3 indicates that the overall crown densities of the investigated communities were high, while the multi-layered tree and shrub layers had overlapped with each other. According to the Miyawaki Method, mixed and dense planting is mainly used in the early stage to facilitate vegetation growth and self-thinning, during which process the dominant species would form the skeleton of a mature forest, and one third to a half of the seedlings would hardly grow into tree layers, or even die^[25]. Thus, the crown density (or coverage) for target community construction was set 1.3 ~ 1.5 times the values obtained from the survey. Another critical step in the early stage is to control seedling density, which is also a key factor to the Miyawaki Method. The parameter of relative abundance was used to control the density in target communities. Moreover, the average crown width obtained from the survey was used to simplify calculation. To sum up, key parameters to construct target communities were species name, tree crown density, shrub coverage, relative abundance, and average crown width.

2.2.2 Simulation—Target Community Construction

The site of this practice in a Green Expo Garden requires that the construction of nature-approximating urban forest should be scientific and of landscape

化设计和少量关键区域传统设计相结合的方法,进行近自然城市森林的营建。

(1) 目标群落的类型设计

首先,将邢台林场地中的道路交叉口、重要节点周边等区域挑选出来作为传统设计区域,进行节点群落的设计。其次,明确数字化设计区域,分析场地生境条件(主要是光照和水分条件),划分生境区域。

就光照条件而言,场地受地形影响形成向阳面和背阳面,产生不同的光照时长和太阳辐射强度。本研究借助Rhinceros软件中的Sunflower插件进行光照时长分析,借助Grasshopper中的Heliotrope、Exposure等插件进行太阳辐射强度分析,综合两者分析结果得出基于光照条件的生境划分,确定目标群落的类型,即阴生群落、半阴生群落、阳生群落和半阳生群落。在本次设计中,由于场地在竖向设计上以微地形为主,因而光照时长变化不明显,主要参考太阳辐射强度来确定群落类型。由结果可知,场地应以阳生和半阳生群落为主。

影响水分因子的因素较多,包括降水量、灌水量、土壤蒸发量等,较合适的方式是依据现场测定的土壤湿度进行群落划分。在小尺度场地的生境类型划分中,刘晖等人通过对场地水源的分析与实地土壤湿度的测量,划分了湿地和旱地^[26]。但若将此方法应用于较大尺度的城市森林营建中,则工作量庞大,缺乏可操作性。本研究通过探究土壤水分平衡公式(1)(W_1 和 W_2 分别为某一时段开始和结束时土壤水分贮存量, R 为该时段的降水量, I 为灌水量, G 为地下水补给量, T 为植物蒸腾量, E_p 为土壤蒸发量, r 为地表径流量, B 为植物截流量, D 为渗漏量)^[27]发现,由于降水量和地下水补给量在设计场地范围地区内无明显变化、灌水量为人为设计因子,因而这三个变量在初期群落设计时先不予考虑;且由于小范围内的土质基本相同,土壤蒸发量和渗漏量差异可忽略不计;此外,设计场地最初为裸地,因而排除受植物因素影响的植物蒸腾量和植物截留量。综上所述,在本研究中,影响土壤含水量的主要因素是地表径流量。本研究利用Grasshopper插件进行径流模拟分析,依据径流线的密集程度辅助划分水分因子影响下的生境类型,分为喜湿生境、中生生境、耐旱生境。

$$W_2 - W_1 = (R + I + G) - (T + E_p + r + B + D) \quad (1)$$

结合光照因子分析下的生境类型划分,共确定了7种类型的生境——阳生、半阳生、半阴生、阴生、喜湿、中生、耐旱作为典型生境,按照这些生境类型对标上文中的代表性样地和群落调查结果。

aesthetics. Thus, a strategy combining large-area digital design with small-area traditional design was utilized.

(1) Community types

Firstly, road intersections and key nodes in Xingtai Forest were selected as traditional design area. Secondly, digital design areas were delimited in accordance with the habitat division, mainly considering sunlight and moisture conditions.

This study analyzed the sunlight durations of both sunward and shaded areas of the site by Sunflower plugin in Rhinceros and solar radiation intensity by Heliotrope and Exposure plugins in Grasshopper. The results of varied sunlight conditions then helped classify habitats and further delimit target communities, including skiophyte, semi-skiophyte, heliophyte, and semi-heliophyte communities. However, differences in sunlight duration were not obvious as the site terrain was mostly shaped by microrelief, which means determining community types by solar radiation intensity is more convincing. The results also showed that main community types on the site should be heliophyte and semi-heliophyte communities.

As many factors, such as precipitation, irrigation, and soil evaporation, may affect the site's soil moisture level, which was the accordance for the design of community division. Liu Hui et al. attempted to differentiate wet land and dry land by analyzing water sources and measuring soil moisture level^[26]. However, this method that is suitable for habitat classification in small-scale sites may be ineffective in large-scale urban forest construction due to the heavy workload and weak operability. In this regard, this design studied the equation of soil water balance (1), in which W_1 and W_2 are soil water storage amount at the beginning and end of a given period respectively, R is the precipitation amount during the period, I is the irrigation amount, G is the groundwater recharge amount, T is the plant transpiration amount, E_p is the soil evaporation amount, r is the surface runoff amount, B is rainfall interception by plants, and D is the leakage of soil water^[27]. In this case, variates of precipitation and groundwater recharge (due to no obvious change in the site), and irrigation amount (due to being man-made) were not considered in the early stage; while variates of soil evaporation and leakage of soil water (due to the similarity of soil texture in the given area) and plant transpiration and rainfall interception by plants (as the site was originally barren) were ignored. Finally, surface runoff amount, the main factor affecting soil moisture content in this design, was determined. On this basis, three types of habitats were classified, i.e. hygrophyte, mesophyte, and xerophyte, utilizing the Grasshopper plugin for runoff simulation to obtain results of runoff line density.

$$W_2 - W_1 = (R + I + G) - (T + E_p + r + B + D) \quad (1)$$

There were seven typical community habitat types classified altogether, i.e. heliophyte, semi-heliophyte, semi-skiophyte, skiophyte, hygrophyte, mesophyte, and xerophyte habitats. The classification result further contributed to matching representative sample selection and community mentioned above.

接着, 依据群落最小面积概念, 以常用取样样方面积反推目标群落面积。相关研究中中国北方暖温带常绿落叶阔叶混交林的样方面积一般为 400m^2 ^[28], 因此将本场地中目标群落的面积范围设为 $200 \sim 600\text{m}^2$ 。为了增强群落种类的丰富性, 同生境类型地场地可设置多种衍生群落。依据调研所得样方数据, 在总体树种构成种类和种间关系大致相同的情况下, 每个群落可设置优势种、伴生种不同的相对多度, 如阴生生境下可衍生出3种阴生群落A1、A2、A3。当调研所得样方数据较为复杂的时候, 同一生境下甚至可以衍生出4~5种目标群落。

综上, 形成邢台林的近自然城市森林目标群落构成(图4)。

(2) 目标群落的模式设计

在目标群落的模式设计上, 以半阳生群落C1为例(其现状如图5所示), 模拟“杏+刺槐+麻栎-荆条”群落, 还原其关键参数, 形成目标

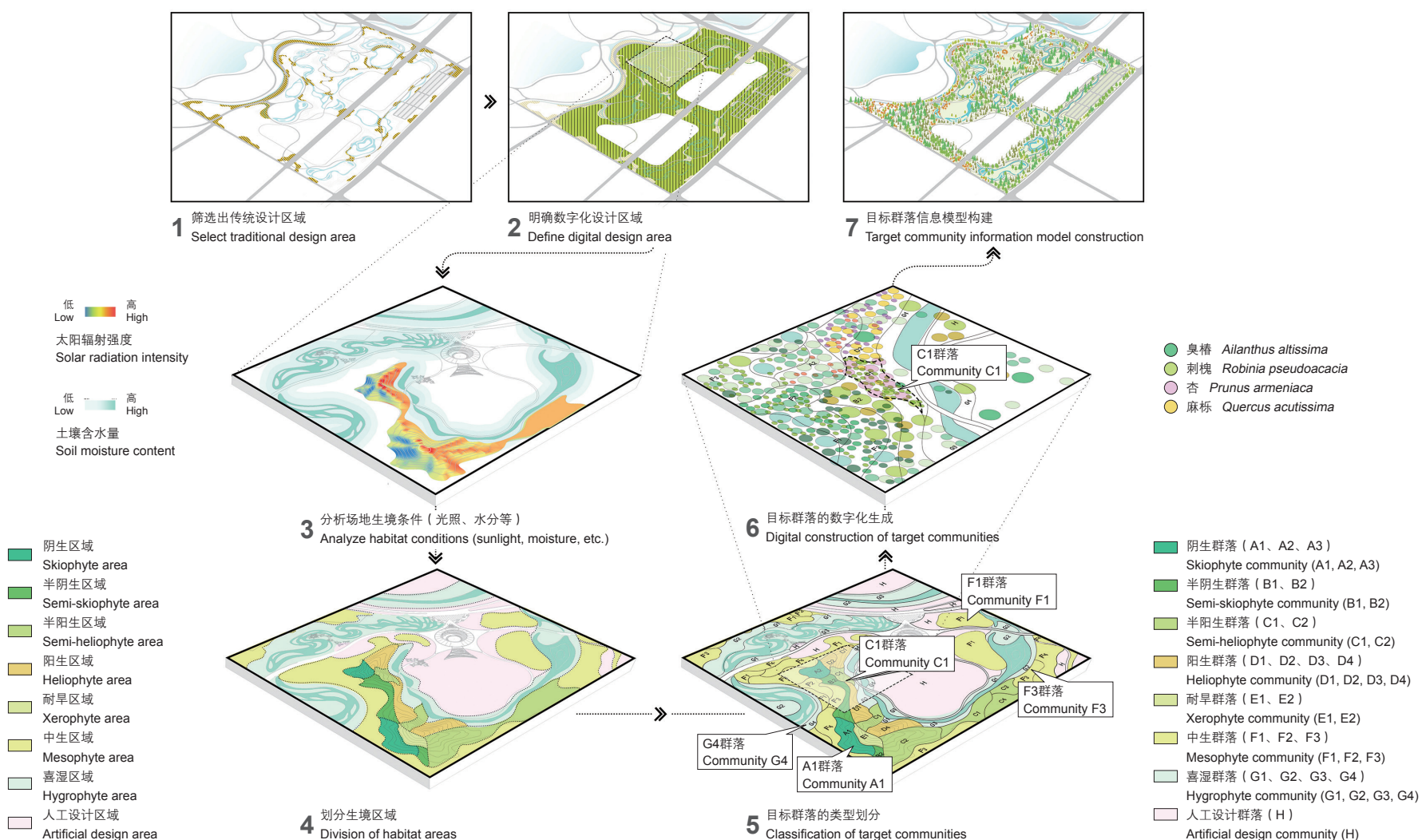
Furthermore, the size of target community was set according to the commonly-used sampled quadrat area under the concept of minimum community area. For instance, in this case, considering that the common quadrat area of evergreen deciduous broadleaf community in warm temperate zone is 400 m^2 , the community areas in this case were set as $200 \sim 600 \text{ m}^2$ ^[28]. Additionally, various community types were designed in the same habitat to enhance community diversity. Based on quadrat survey results, each community may adjust the relative abundance of dominant and companion species without changing the general tree species composition and interspecific relationship. For example, three types of skiophyte communities (A1, A2, and A3) can be developed in the skiophyte habitats. If the quadrat survey data indicate a more complex relationship, four or five types of target community might be developed from the same habitat.

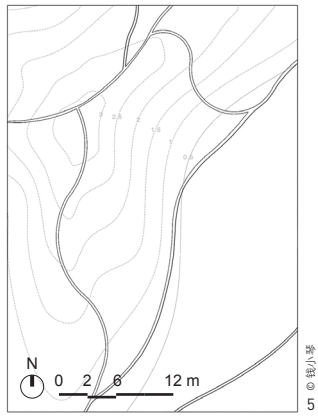
Upon the analytic results, target community types of a nature-approximating urban forest were determined (Fig. 4).

(2) Pattern design for target communities

As for the pattern design for target communities, for example, the plan of a case of semi-heliophyte community C1 is shown in Figure 5. Community C1 was

4. 目标群落构建过程示意
4. Process of target community construction





5. 半阳生群落C1现状测绘图
 6. 邢台林数字化生成步骤示意
5. Existing mapping of semi-heliophyte community C1
 6. Process of digital construction of the Xingtai Forest

表2: 半阳生群落C1组成
Table 2: Components of the semi-heliophyte community C1

层片 Layer	郁闭度 / 盖度 Crown density/ Coverage	植物名 Plant name	相对多度 Relative abundance	平均冠幅 (m) Average crown width (m)
乔木层 Tree layer	0.8	杏 <i>Prunus armeniaca</i>	0.52	3.0
		刺槐 <i>Robinia pseudoacacia</i>	0.26	2.0
		麻栎 <i>Quercus acutissima</i>	0.22	1.5
		臭椿 <i>Ailanthus altissima</i>	0.06	2.0
灌木层 Shrub layer	0.4	荆条 <i>Vitex negundo</i> var. <i>heterophylla</i>	1.0	1.0
草本层 Herb layer	/	唐松草 <i>Thalictrum aquilegifolium</i> var. <i>sibiricum</i>	/	/

群落(表2), 乔木层优势种为杏、刺槐和麻栎, 伴生种为臭椿; 灌木层基本为荆条; 草本层以唐松草为主。

2.2.3 营建——目标群落数字化生成

在确定目标群落具体构成后, 利用数字化技术自动生成每一个群落的种植设计图纸和相关苗木信息(包括种植点坐标、树种名称及数量), 同时构建目标群落信息模型(图4)。由于乔灌木层树种信息较为复杂, 草本层相对而言较为简单, 因此本次实践仅对乔灌木层进行了数字化营建研究, 未考虑草本层。

(1) 方法

Grasshopper是建模软件Rhino的内嵌参数化模块, 其自带的指令大都是基础的图形和数学运算, 在开展较为复杂任务的时候, 需要设计师将大量指令自行组合。而Python语言是一种编写起来相对简易的程

formed by controlling the key parameters of the target community (Table 2), which took *Prunus armeniaca*, *Robinia pseudoacacia*, and *Quercus acutissima* as the dominant species and *Ailanthus altissima* as the companion species in the tree layer, and the shrub layer and herb layer dominated by *Vitex negundo* var. *heterophylla* and *Thalictrum aquilegifolium* var. *sibiricum*, respectively.

2.2.3 Construction—Digitalization of Target Communities

Each community's planting design drawings and related seedling information (e.g. planting location coordinates, names, numbers of tree species) were automatically generated by digital technology after determining the structure and specific species of target communities. Then, the target community information model was constructed (Fig. 4). This study demonstrated the digitalized construction process of tree and shrub layers, which involves more factors and considerations compared with that of grass layers.

(1) Methods

This research combined two methods: Grasshopper, a visual programming language from Rhinoceros for parametric design with basic instructions of graphics and mathematical operation, and Python, a programming language that is easy for designers to compile scripts. Advantages of such a combination are that in complicated tasks, designers can form easy-to-understand design logic using their own language with the help of Python that exceeds the existing generation clusters in Grasshopper. In this way, by inputting specific parameter values (tree names, tree crown density, shrub coverage, relative abundance, and average crown width) with Python programming, the tree and shrub layers' design drawings of each target communities and related seedling information were obtained.

(2) Digitalization process

Shown in Figure 6, the first digitalization step is compiling the parameters of each community's tree crown density, shrub coverage, relative abundance, and average crown width (radius) into planting function $f(x)$ by using Grasshopper Python Script Editor. After that, specific parameter values of target communities were input into the model (Table 3). Then, tree species distribution layouts of each community could be automatically obtained, including planting CAD drawings and corresponding seedling and coordinate data.

(3) Digitalization principle

The principle of digitalization, i.e. planting function $f(x)$, consists of obtaining the number of trees and shrubs, and determining corresponding distribution layouts.

For obtaining the number of trees and shrubs, in Equation (2), (3), and (4), a certain species' number (N) is related to four parameters, i.e. the community's size (S), crown density or coverage (C), relative abundance (RA), and a species' average crown width (P). In this practice, the number (N) of each type of tree

序设计语言,设计师可通过自己的语言方式表达,形成容易理解的设计逻辑。将Python与Grasshopper相结合,设计语言可不受Grasshopper现有运算集的局限,设计逻辑也能够更加清晰地展现出来。研究结合两种技术,通过编写Python语言,将目标群落乔灌木层的各个参数(树种名称、乔木郁闭度、灌木盖度、相对多度、平均冠幅)的具体数值输入,得到各个群落的乔灌木设计图及相应的苗木表。

(2) 生成步骤

数字化生成的具体步骤为(图6):第一步,运用Python脚本运算器,将群落的乔木郁闭度、灌木盖度、相对多度及平均冠幅(半径)参数编译成种植函数 $f(x)$ 。第二步,输入目标群落各个参数的具体数值(表3)。第三步,计算机自动生成各个种植群落的树种分布,导出相关数据即可得到种植CAD图纸、苗木表及各种植点的坐标信息。

(3) 生成原理

数字化生成,种植函数 $f(x)$ 工作的原理可分为两大板块:得出乔灌木的数量和确定乔灌木的分布。

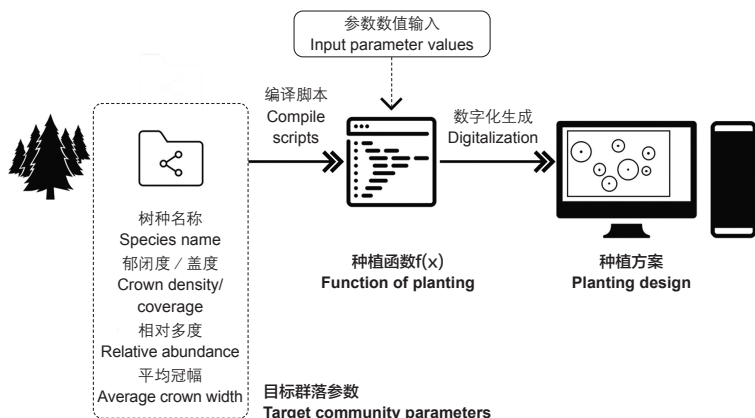
首先,得出乔灌木的数量。通过公式(2)、公式(3)、公式(4)可知,要求出某个种的数量(N),需要代入群落面积(S)、群落的郁闭度或盖度(C)、相对多度(RA)、某个种的平均冠幅(P)这4个参数,而某个种的数量(N)与其他参数间相关。本研究借助Grasshopper中的Square、Multiplication等运算器,结合Python脚本编译计算出闭合的群落斑块曲线的面积,从而得出每种乔(灌)木的数量(N)。

$$RA_i = \frac{N_i}{N_{\text{总}}} \quad (2)$$

$$S \times C = \sum_{i=1}^n (\pi \times P_i^2 \times N_i) \quad (3)$$

$$N_i = \frac{S \times C \times RA_i}{\sum_{i=1}^n (\pi \times P_i^2 \times RA_i)} \quad (4)$$

其次,确定乔灌木在平面上的分布。在同一层中,假定植物生长最好的生长状态是同层内树种相互不重叠,才能获得相等的光和热,来



(or shrub) was obtained by calculating the area of a target community patch delimited with the enclosed boundary and then utilizing operations of Square and Multiplication in Grasshopper and Python scripts.

$$RA_i = \frac{N_i}{N_{\text{sum}}} \quad (2)$$

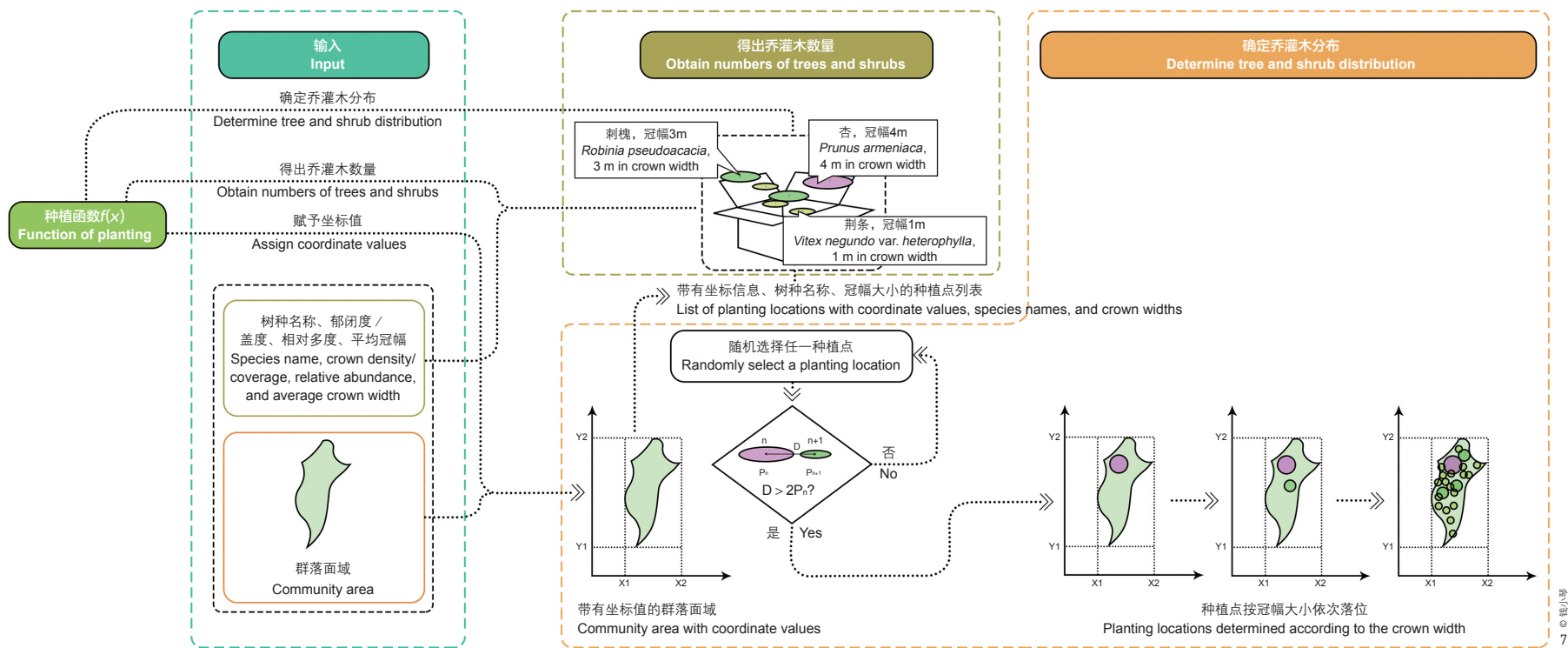
$$S \times C = \sum_{i=1}^n (\pi \times P_i^2 \times N_i) \quad (3)$$

$$N_i = \frac{S \times C \times RA_i}{\sum_{i=1}^n (\pi \times P_i^2 \times RA_i)} \quad (4)$$

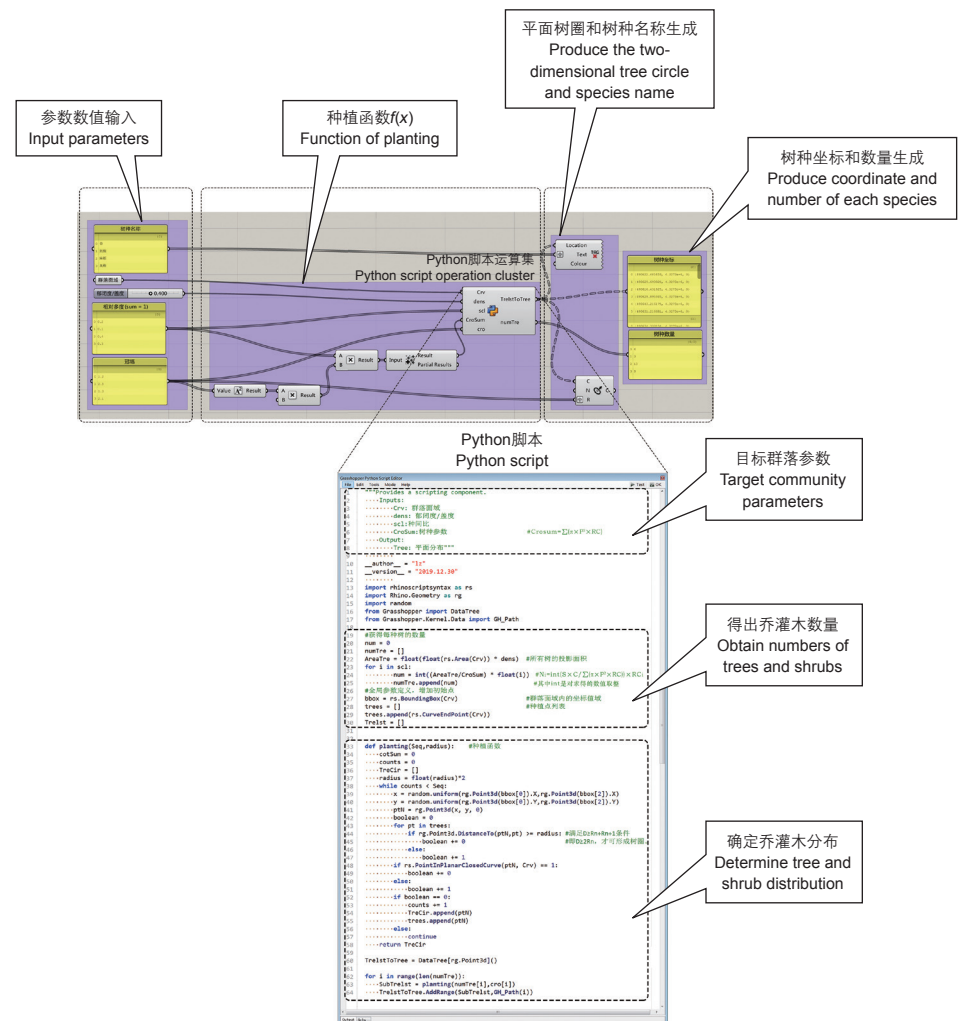
For determining the distribution layouts of trees and shrubs, this study first assumed that trees do not overlap each other in the same layer, creating an ideal condition for tree growth that facilitates dynamic self-thinning with suitable light and heat. A planting function $f(x)$ was designed to generate tree

表3: 目标群落参数信息及输入方式
Table 3: Parameters of target communities and input modes

目标群落参数 Parameters of target community	参数意义 Parameter description	输入方式 Input mode
树种名称 Species name	目标群落中不同树种的中文名称 Chinese names of species in a target community	文字输入 Text
郁闭度(C) Crown density	用于乔木层,是指单位面积上林冠对地面的遮盖比例,其总和为100%。 The coverage ratio of tree canopies to the ground per unit area, as an indicator to the measurement of tree layers; sum of the crown density of each plant species in a given area is 100%.	数值输入 Value
盖度(C) Coverage	用于灌木层,与郁闭度概念相近。指投影盖度,即植物地上器官垂直投影面积占样地面积的百分比。本文中的盖度为层盖度,即在同一地面上不同层的覆盖比例,其总和可超过100%。 The vertical projection area percentage of the aboveground parts of plants to the ground, as an indicator to measurement of shrub layers. In this research the sum of the coverage of each vegetation layer in a given area may exceed 100%.	数值输入 Value
相对多度(RA) Relative abundance	某种植物所占该层植物总数的百分比 The amount percentage of a plant among all plants in a given layer	数值输入 Value
平均冠幅(P) Average crown width	亦称平均树冠直径,即树冠投影面的平均直径。为了使得计算更为简便,本文中的冠幅均为平均冠幅的二分之一(即半径)。 Or average crown diameter, means the average diameter of a crown's projection. This research takes half of the average investigated crown width (i.e. radius) to simplify the calculation.	数值输入 Value
群落面积(S) Community size	指封闭的目标群落面积边缘线所形成的面积 The area formed by the enclosed boundary of a target community	拾取Rhino中设计的群落面积边缘线 Obtained the enclosed boundary of a certain community area from Rhino



7. 种植函数 $f(x)$ 工作原理 (以群落 C1 为例)
8. 数字化生成运算集及 Python 脚本
7. Operating flow of the planting function, taking community C1 for example.
8. Digital generation clusters and Python scripts



完成动态的自疏过程。因此，设计了种植函数 $f(x)$ 用于乔灌木层种植图的生成。种植函数 $f(x)$ 是借鉴官肋造林法中“混合密植”步骤，将带有树种信息的种植点随机分布，且保证同层内树种之间不会重叠的一种算法（图7）。在第一步得到乔灌木数量之后，通过自动设定群落面域内的某一点作为初始点，得到该群落面域内的坐标值域。在输入冠幅数值的时候，将其按照由大到小（即 $P_n > P_{n+1}$ ）的顺序进行输入（以便进行下一步的重叠判断）。由此，即相当于得到了一个带有坐标值域、树种名称、冠幅大小的种植点列表。接着，算法将随机选择列表中任一种植点进行重叠判断。只有当一个种植点与已形成树圈的种植点之间的距离符合 $D \geq P_n + P_{n+1}$ 条件（即 $D > 2P_n$ ）时，才可形成树圈输出，以保证同层树种之间不重叠。否则，返回种植点列表里再一次重新随机选择某一种植点，直到所有种植点均满足条件并输出树圈。至此，种植点的坐标得以确定（图8）。

9. 依据生境条件确定目标群落类型
10. 半阳生群落C1生成过程

9. Determine target community types according to habitat conditions
10. Construction of semi-heliophyte community C1

利用Grasshopper结合Python脚本的编译, 构建目标群落的设计逻辑, 不仅可以科学、高效地模拟宫胁造林法中“混合密植”的步骤, 而且可直接导出苗木表及各个树种的种植点坐标, 为之后的数字化施工打下基础。

2.3 设计成果

2.3.1 方案设计阶段

在方案设计阶段首先分析了场地的生境条件: 选取光照和水分两个因子, 定性地划分出不同的生境区域。以图9中所示场地为例, 进行光照条件和水分条件的分析, 确定了每个目标群落的类型。

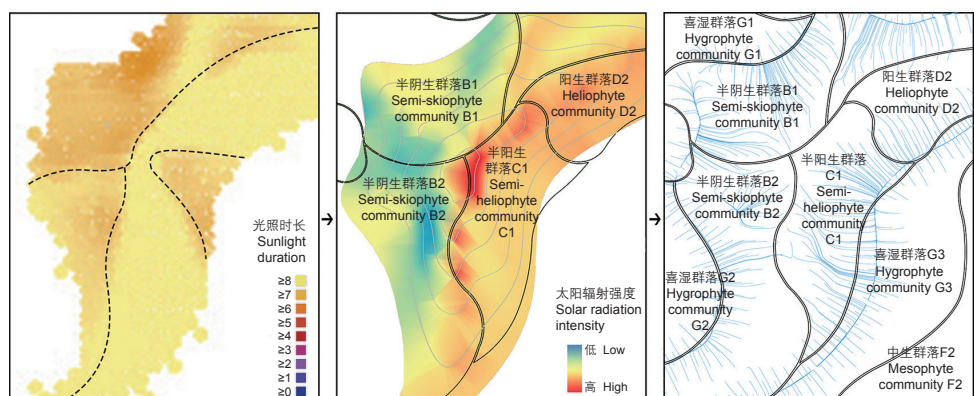
而后进行数字化生成。以半阳生群落C1为例, 进行目标群落的数字化生成(图10)及指标的校对。由表2可知, 设计的半阳生群落C1中, 乔木郁闭度为0.8, 以杏为主, 灌木盖度为0.4, 以荆条为主。在CAD软件中进行郁闭度和盖度的检验, 群落总面积为507.5m², 乔木总面积为386.3m², 郁闭度约为0.8, 灌木总面积为199.1m², 盖度约为0.4, 满足设计需求。

2.3.2 施工设计阶段

将生成的所有群落信息导入CAD软件之后, 即可获得种植施工平面图。仍然以半阳生群落C1为例, 将群落内的树种信息合并即可获得总苗木表及相应种植点坐标列表(图11)。数字化施工技术主要应用于放样和种植挖穴过程中。如利用GPS定位设备和基于BIM的操作控制系统, 使得平台能够自动提取苗木种类、种植点坐标、规格和供应商等。在BIM平台的Autodesk Revit软件中添加的苗木信息呈现在驾驶舱内的平板中, 系统将控制自动定位挖穴并记录每一次挖掘点(图12), 实现高精度的定位和高效的大规模挖穴过程。在实际施工过程中, 仅需要一位驾驶技术人员即可完成大片的城市森林建设, 大大降低了劳动成本, 同时也使得城市森林的营建更为准确和便捷。

2.3.3 后期管理养护阶段

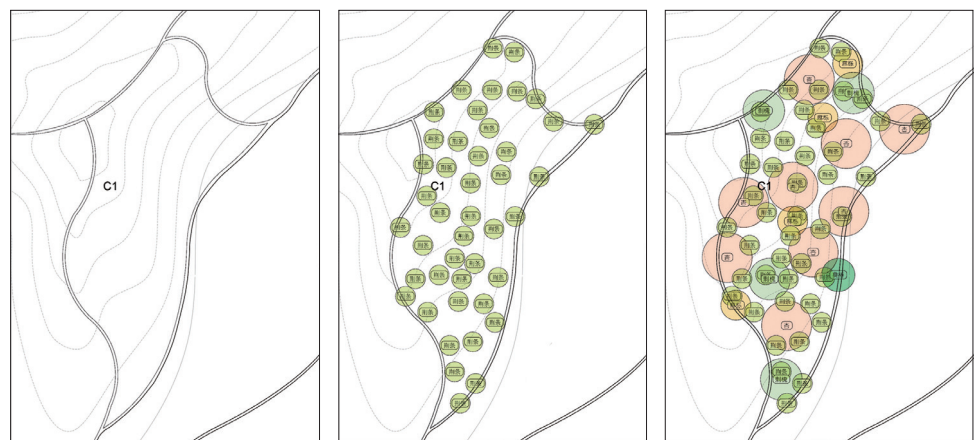
目前国内外已有较多园林植物数据库, 如中国植物图像库、网页版的《中国植物志》、英国植物科学图像库等。但是能在景观设计项目全生命周期中, 供设计、施工、养护管理等不同专业技术人员查询, 且应用了植物几何属性、非几何属性而建立的植物构件信息模型数据库却严重匮乏^[17]。本次实践基于PlantFactory软件构建了专属植物模型库^[29], 并展示了数字化生成群落的效果(图13)。此外, 通过Autodesk Revit软件添加植物名称、习性、苗源、价格等信息(图14), 补充了BIM平台中缺乏的植物信息, 可实现设计、施工和养护管理之间的信息交流^[30]。



依据光照时长初步划分
Preliminary division of community types according to sunlight duration

依据太阳辐射强度确定群落类型
Determine community types according to solar radiation intensity

依据径流模拟确定群落类型
Determine community types according to runoff simulation



半阳生群落C1场地
Site of semi-heliophyte community C1

灌木层生成
Shrub layer construction

乔木层生成
Tree layer construction

and shrub planting drawings. Referring to the idea of mixed and dense planting in Miyawaki Method, this study randomly distributed planting points with tree species information and ensured that no crown overlap exists in a same layer (Fig. 7). After obtaining the number of trees and shrub species, an initial point was automatically set in the target community area to obtain the coordinate value domain of all planting points. In the next step, values of crown width were input from large to small (i.e. $P_n > P_{n+1}$) to avoid overlap. Gradually, all planting points with coordinate value information, tree species name, and crown width were determined. Then, the algorithm randomly selected a planting point for overlapping test—Only when the distance between a given planting point and the previously determined ones met the condition that $D \geq P_n + P_{n+1}$ (i.e. $D > 2P_n$) to ensure no crown overlap occurs, could the given point be determined. Otherwise, the algorithm would return to the list of planting points to test again, until all the planting points met the conditions and output the tree circle (Fig. 8).

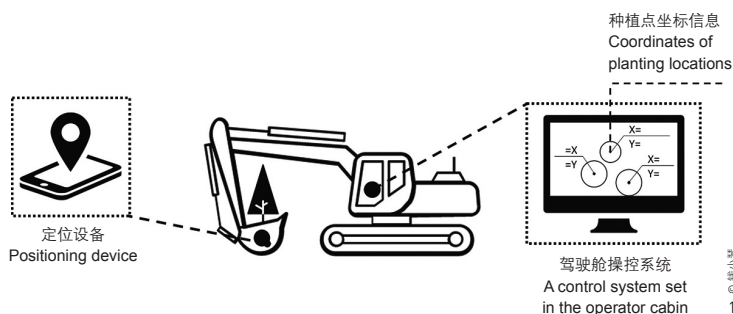
Employing Grasshopper and Python script compilation ensured the scientific process of mixed and dense planting in Miyawaki Method, helping directly obtain corresponding seedling information and planting coordinates of each tree species for further construction.

树种名称	树种数量	树种坐标
杏	0.10	0 (490669.20167, 4.3273e+6, 0)
刺槐	1.3	1 (490670.04804, 4.3273e+6, 0)
麻栎	1	2 (490662.60718, 4.3273e+6, 0)
臭椿	3.0	3 (490673.85247, 4.3273e+6, 0)
		4 (490673.72327, 4.3273e+6, 0)
		5 (490670.38995, 4.3273e+6, 0)
		6 (490662.72509, 4.3273e+6, 0)
		7 (490673.53345, 4.3273e+6, 0)

C1群落乔木层苗木表及种植点位
Seedling list and planting locations of the tree layer in community C1

树种名称	树种数量	树种坐标
荆条	0.17	9 (490670.88103, 4.3273e+6, 0)
		10 (490669.90357, 4.3272e+6, 0)
		11 (490666.52165, 4.3273e+6, 0)
		12 (490668.99488, 4.3273e+6, 0)
		13 (490674.86103, 4.3273e+6, 0)
		14 (490676.16721, 4.3273e+6, 0)
		15 (490681.46084, 4.3273e+6, 0)
		16 (490667.47649, 4.3273e+6, 0)

C1群落灌木层苗木表及种植点位
Seedling list and planting locations of the shrub layer in community C1



11. 半阳生群落C1苗木表及种植点位
12. 数字化施工示意

11. Seedling list and planting locations of species for semi-heliophyte community C1
12. Diagram of digital construction

3 总结

邢台林近自然城市森林的营建，是以潜在自然植被和新演替理论为理论基础，借鉴宫胁造林法关键步骤进行城市无林地造林的一次实践。在认知阶段，通过植被调查来确定场地的潜在自然植被类型，提取自然群落特征，确定群落关键参数。在模拟阶段，首先划分不同类型的设计区域，采用关键节点传统设计结合大范围数字化设计的方法，既可满足城市森林对景观效果的需求，也可提高设计的效率、降低设计成本。其次，以调研所得的潜在自然植被为参考，划分场地的生境类型，细化目标群落的类型和模式设计。在营建阶段，利用数字化技术自动生成每一个目标群落的种植设计图纸和相关苗木信息，实现所有苗木的具体落位。

本次实践创新性地将数字化技术融入到城市森林的营建过程中，实现了经典理论和数字技术的融合。在设计阶段，借助Sunflower、

2.3 Design Results

2.3.1 Conceptual Design

The habitat conditions of sunlight and moisture of the site were analyzed in this phase to divide habitat areas. Target community types could be determined based on the site analysis results as shown in Figure 9.

The next step was the digitalization of target communities. The semi-heliophyte community C1 (Fig. 10) as an example here to demonstrate the digitalization process and the calibration of indicators. Table 2 shows that in community C1 the tree layer was dominated by *Prunus armeniaca* with a crown density of 0.8, and the shrub layer was dominated by *Vitex negundo* var. *heterophylla* with a coverage of 0.4. Calibrated with CAD, these figures were proved to meet the design requirements with a total community area of 507.5 m², tree area of 386.3 m², and shrub area of 199.1 m².

2.3.2 Construction Design

Detailed planting drawings could be obtained after importing all the generated target community information into CAD. By summarizing data, a final list of corresponding seedling with the sum of each tree species and coordinates of planting points was obtained (Fig. 11). At present, digital construction technology is mainly used in planting point setting-out and planting well digging. For example, GPS positioning devices and BIM-based operating control systems can assist in information extraction of tree species, coordinates, specifications, and suppliers. After inputting the plant information into Autodesk Revit in BIM displayed on a tablet in the cockpit of the excavator, the system will control the automatic positioning and hole digging and map the location of each digging point (Fig. 12), achieving high-precision positioning and high-efficiency digging of large tree wells. In practice, only one driving technician is needed to complete the construction of a large urban forest, which extremely reduces labor costs and improves the accuracy and efficiency of urban forest construction.

2.3.3 Management and Maintenance

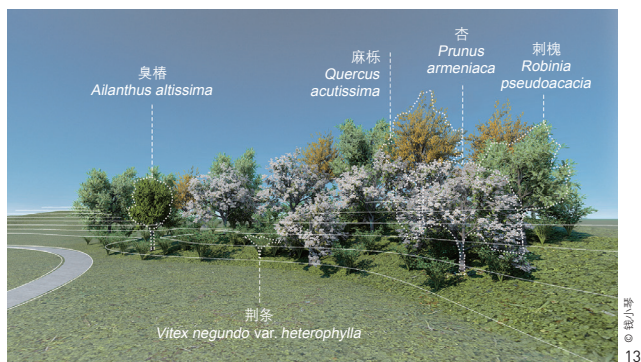
At present, there have been many landscape plant databases, including Plant Photo Bank of China, Flora Reipublicae Popularis Sinicae, and Plant Science Image Database website. However, plant structure information model databases that include geometric and non-geometric attributes of plants to serve professionals and technicians in design, construction, maintenance, and management in the whole process of landscape architecture are still absent^[17]. This research built a specialized plant model library based on PlantFactory^[29] that can display the rendering images of simulated communities (Fig. 13), but also supplement more information including plant name, habit, seedling source, and price that is not included in BIM platform through Autodesk Revit (Fig. 14), improving the exchange among design, construction, maintenance, and management^[30].

Grasshopper等相关插件进行科学的生境条件分析，模拟潜在自然植被的特征构建目标群落类型，保证了设计过程的科学性。在营建阶段，进行目标群落的数字化生成。利用Grasshopper结合Python脚本的编译构建设计逻辑，模拟宫胁造林法的关键步骤“混合密植”。关键算法的编译能够更精准地建立目标群落的各参数关系，免去人为操作，在减少主观因素干扰的同时也大大提高了设计效率。在施工中，由于施工单位不具备数字化施工技术，该进程未能实现通过GPS实现高精度的定位和高效率的大规模的挖穴。在后期管理中，有望基于BIM平台构建植物信息库进行精准管护。

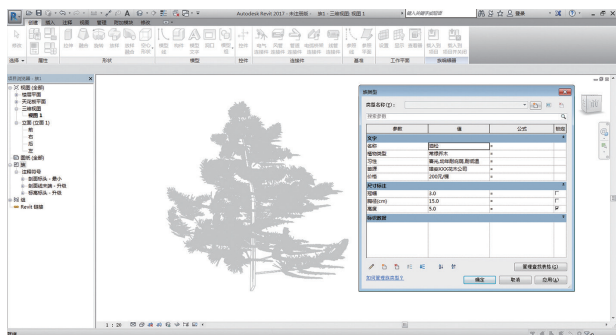
值得一提的是，本次实践利用数字化技术，通过生境选择、比例控制等手段，进行初期的混合密植，可提高目标树种的竞争力，促进目标群落的快速形成。然而，当前的研究过程存在一定的局限性：在场址生境条件分析阶段，尚处于单因子定性分析阶段，未能对所有影响因子进行准确的定量分析；在数字化生成阶段，群落整体结构与潜在自然植被类似，但树种均为随机分布，需要经过一定时间的自然演替，通过自疏和竞争等过程，才能形成成熟的自然群落的集群分布状态，达到较为理想的效果。如何通过数字化设计实现对成熟群落集聚分布特点的充分模拟，团队尚在研究中。此外，本次研究和实践止步于设计阶段，缺乏10~20年后对实践场地的造林成果检验，难以反映出造林存在的实际问题，需进行后期的持续追踪观察和监测（图15）。LAF

13. PlantFactory植物模型应用效果展示
14. 通过Autodesk Revit添加植物信息

13. Rendering generated from PlantFactory
14. Add plant data via Autodesk Revit



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3 Conclusions

Under theories on potential natural vegetation and new succession, and with the Miyawaki Method, this paper explores the digital design of Xingtai Forest, a nature-approximating urban forest. The research team first determined the potential natural vegetation types in the site via vegetation investigation, and then determined key community parameters upon the extracted natural community characteristics. At the simulation stage, the overall community design combined large-area digital design with small-area artificial design. This combined scheme can create an urban forest with landscape effects while improving design efficiency and reducing costs. Also, upon the investigation results of potential natural plants, habitat type classification and target community type and pattern design were conducted. At the construction stage, digital technology was used to generate planting design drawings and related seedling information automatically, facilitating the construction of target communities.

This study innovatively applies widely-accepted theories with digital technologies in the construction of an urban forest. At the design stage, the habitat conditions were analyzed with plugins such as Sunflower and Grasshopper, and the target community types were identified upon the characteristics of potential natural vegetation, ensuring the scientism of design process. After that, the target communities were generated through digitalization by Grasshopper and Python scripts. This design logic simulated the mixed and dense planting steps in the Miyawaki Method. Key algorithms in varied script editors helped establish the relationship among parameters of the target communities more accurately, thus minimizing manual operations and remarkably improving the design efficiency. However, high-precision positioning and efficient large-scale well digging supported by GPS was not realized because the construction contractor was incapable to implement digital tasks. In management and maintenance phase, plant databases supported by BIM platform are expected to be introduced.

With aid of digital technologies and by controlling habitat selection and ratio, the initial mixed and dense planting was realized that enhances the competitiveness of target tree species and promotes the rapid formation of target communities. Still, there are limitations in this research. First, simply single-factor qualitative analysis of habitat conditions was made in this study, lacking quantitative analysis of more affecting factors. Second, at the stage of digital construction, though the overall community structure mimicked the potential natural vegetation, varied tree species distributed randomly, which means that the natural succession, self-thinning, and competition of plants before developing into mature clusters of natural communities would possibly take a long time. Thus, further research should focus on how to better simulate the distribution pattern of mature communities via digital design. Also, as this research only explored the design of urban forests and has not tested the afforestation results in 10 to 20 years, follow-up observation and monitoring is therefore needed (Fig. 15). LAF



15-1
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15-2
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15. 建设完成的邢台林
15. Completed Xingtai Forest

致谢

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