基于“海绵+”复合模式下校园景观改造研究——以北京市芙蓉小学为例

Research on Campus Landscape Reconstruction Based on "Sponge +" Composite Mode — Case Study of Furong Primary School in Beijing

韩元* 汪洋 陈茂福 吴昊

HAN Yuan* ，WANG Yang，CHEN Maofu，WU Hao

DOI: 10.12145/202003030

基金项目：国家水体污染控制与治理科技重大专项（项目编号：2017ZX07103-002）

北京市通州区科技计划项目（ 项目编号：KJ2019CX059)

摘要：海绵城市是生态城市文明建设中解决城市水环境问题的一项可持续建设模式。目前我国海绵城市建设处于起步阶段，尚未达到与景观生态环境建设、文化建设的高度融合。本文在大量调研国内校园海绵化建设案例基础上，从校园场地特征进行阐述，跨专业、综合性、创新性地提出了“海绵+”复合模式构建下校园景观改造程序及实施途径，通过构建科学的校园雨洪管理，以“海绵+景观”重构并提升校园空间形象，以“海绵+文化”塑造校园文化特色，有机融合构成一个完整的海绵城市建设体系。本文以芙蓉小学项目为例，探索校园海绵化改造、景观、文化要素相融合重塑的策略途径，以期为海绵城市建设研究与实践提供有益借鉴。

关键词：海绵化改造；雨洪管理；景观环境；文化教育

Abstract: Sponge city is a sustainable construction mode to solve the problem of urban water environment in the construction of ecological city civilization. At present, sponge city construction in China is in the initial stage, which has not yet reached a high degree of integration with landscape ecological environment construction and cultural construction. Based on a large number of domestic campus sponge construction cases, this paper expounds the characteristics of the campus site, and puts forward the transformation procedures and implementation paths of

campus sponge under the construction of "sponge +" composite mode, which is interdisciplinary, comprehensive and innovative. Through the construction of scientific rain and flood management on campus, the campus space image is reconstructed and enhanced by "sponge + landscape", and the campus cultural characteristics are shaped by "sponge + culture", so as to organically integrate and form a complete construction system of sponge city. Taking the project of Furong Primary School as an example, this paper explores the strategic paths of the integration and reconstruction of campus sponge, landscape and cultural elements, in order to provide useful references for the research and practice of sponge city construction.

Key words: sponge transformation; stormwater management; landscape environment; cultural education

---

韩元/1988 年生/ 男/ 北控水务(中国) 投资有限公司高级工程师/ 研究方向：景观规划设计、海绵城市设计

通讯作者邮箱（Corresponding author E-mail）：495645241@qq.com

HAN Yuan, male, was born in 1988. He is a senior engineer in the Beijing Enterprises Water Group Limited. Research direction: landscape planning and design, sponge city design

汪洋/1983 年生/ 男/ 北控水务（中国）投资有限公司高级经理/ 研究方向：水环境治理

WANG Yang, male, was born in 1982. He is a senior Manager in Beijing Enterprises Water Group Limited. Research direction: water environment treatment

陈茂福/1982 年生/ 男/ 北控水务（中国）投资有限公司注册环保工程师/ 研究方向：水环境治理

CHEN Maofu, male, was born in 1982. He is an environmental protection engineer in Beijing Enterprises Water Group Limited. Research direction: water environment treatment

吴昊/1983 年生/ 男/WADI 设计（瓦地设计）总经理，荷兰注册景观设计师/ 研究方向：生态水环境、生态景观、海绵城市

WU Hao, male, was born in 1983. He is the general manager of WADI studio, and registered landscape architect in the Netherlands. Research direction: eco-water environment, landscape architecture and sponge city design

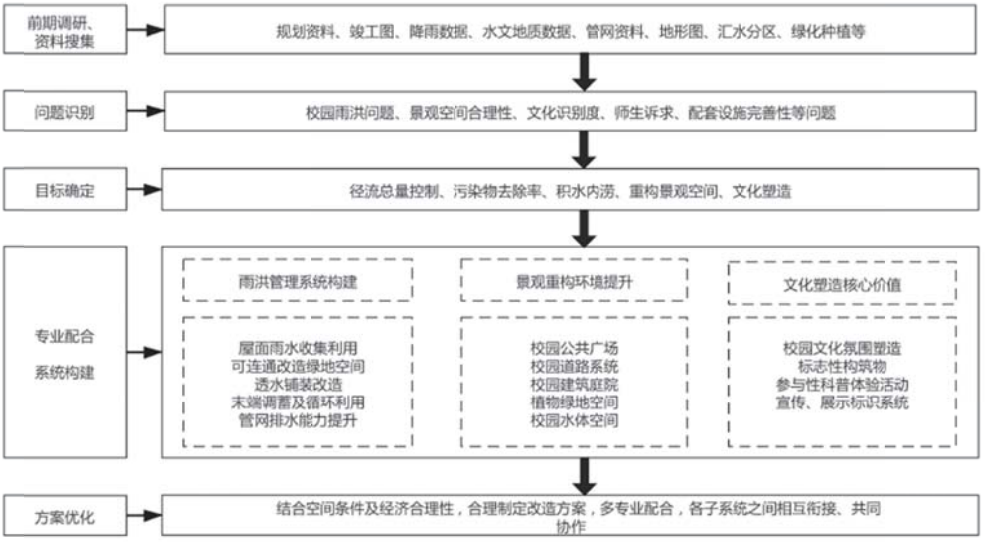
---

引言

近年来，针对我国城市建设中出现的积水内涝、径流污染严重、水资源短缺等一系列城市水生态、水环境、水安全和水资源方面的问题，中国亟须重新定位城市水系统的内涵并协调城市建设与水环境的关系，恢复和增强城市水系统的抵御力和恢复力[1]。2013 年，习近平总书记在《中央城镇化工作会议》的讲话中强调：建设自然存积、自然渗透、自然净化的“海绵城市”。海绵城市是以“渗、滞、蓄、净、用、排”为手段，通过“源头减排—过程控制—末端调蓄利用”多层次、多目标、系统性地解决城市水环境问题，在提升城市环境质量等方面成效显著[2]。

自 2015 年以来，国家先后启动两批次共 30 个海绵城市建设试点，北京城市副中心两河片区入选国家第二批海绵城市建设试点，具体内容包括已建成区海绵化改造和行政办公区及其他新建区的海绵化建设。根据《北京城市副中心控制性详细规划（街区层面）（2016 年— 2035 年）》要求，要把副中心建设成为绿色城市、森林城市、海绵城市、 智慧城市、人文城市、宜居城市，成为首都的一个新地标，成为新时代城市建设发展的典范。基于副中心高起点、高标准的要求，经过近三年实践探索，试点片区海绵城市建设初见成效，已形成一批可推广、可复制的示范项目。

北京市通州区海绵城市试点片区中建成区以公共建筑和住宅小区海绵化改造为主，其中学校面积占公建总面积的 72%。学校从安全角度考虑，并不适合做雨水外排压力的疏解环节。因此，若在校园内建立科学的雨洪管理系统可以有效缓解积水内涝、减轻雨水外排的压力等问题。“海绵校园”指整个校园像海绵一样，具有一定的弹性和适应环境变化的能力[3]。近几年国内出现一批校园海绵化改造优秀案例：清华大学胜因院景观环境改造项目跨学科提出了景观水文综合性设计理念，强调雨洪管理措施与历史景观环境融为一体[4]；昆山杜克大学以水环境保护为核心目标，通过绿色基础设施实现雨水径流在源头、过程和末端的全过程治理。将景观功能与水系统相结合，校园成为如“海绵”般能够调节水资源、空间、景观的大系统[5]；北京交通大学电气工程学院庭院生态节能改造，将光、电新能源与雨水花园相结合体现科技与自然的结合，成为节约型校园的示范等[6]。



1

基于“海绵 +”复合模式下校园景观改造程序

Procedures for Campus Landscape Reconstruction Based on "Sponge +" Composite Mode

由此可见，如何基于校园场地功能和环境需求，打造一个兼具生态和谐、景观优美、文化氛围突出、师生参与感和认同感强的校园空间成为海绵校园规划设计的难点与重点。本文基于跨学科方法和技术，创新性地提出了“海绵+”复合模式构建下校园景观改造程序及途径，并以芙蓉小学“ 海绵+”的创新实践为例，为城市已建成区校园海绵化改造提供相关实践参考。

1.“海绵+”复合模式校园景观改造程序与实施途径

“海绵+”复合模式校园景观改造是指在解决校园雨洪问题的基础上，以“海绵+景观”为途径重构校园空间形象，以“海绵+文化”为手段塑造校园文化特色，最终形成一个功能融合、系统完整的海绵校园环境。

1.1 “海绵+”复合模式校园景观改造程序

首先应用低影响开发技术对场地雨水进行控制和管理；其次基于师生的行为模式及对于校园活动空间多样化的需求构建“海绵+景观”模式，一方面要给师生提供多样化的户外活动空间，另一方面提升校园景观形象使其具有鲜明的、独特的审美特征和意义。同时挖掘校园文化内涵，构建“海绵+文化”模式，延续校园文脉，塑造良好的校园文化价值氛围，使其对学生产生潜移默化的教育影响。 “海绵建设生态基础”“景观重构空间环境”“文化塑造核心价值”，三者层层叠加、有机融合共同构成“海绵+”复合模式校园景观改造系统。

1.2 “海绵+”复合模式校园景观改造实施途径

（1）以问题为导向：搜集场地资料，对校园空间、构成要素、校园文化特色、教学理念等进行详细踏勘、调研，进行问题识别与梳理。

（2）以需求为依据：综合考虑师生行为、心理模式及对于多样化校园空间使用功能的需求。

（3）以目标为指引：定量指标根据《海绵城市建设绩效评价与考核办法（试行）》对年径流总量控制率、面源污染削减率、雨水资源利用率等要求确定[7]；同时定性指标方面，结合空间功能需求、景观审美需求、文化表现需求，协同各专业共同确定。通过大量实践与探索，提出“海绵+”复合模式下校园景观改造程序（图 1）。

综上所述，校园“海绵+”复合模式改造实施途径，在雨洪管理层面，按照源头减排、过程控制、系统治理的指导思想，坚持统筹协调、问题导向、因地制宜、灰绿结合的原则，以绿色 LID 源头减排设施的建设为主，综合采用渗、滞、蓄、净、用、排等措施构建场地雨洪管理系统。景观层面，通过空间序列、形象、比例、尺度、肌理、色彩、图案、文化符号等手法对环境与文化进行重构与提升。即通过确定改造的目标和功能定位，在科学的雨洪管理系统基础上突出校园各功能区域景观环境及文化特色，各系统之间统筹考虑，共同发挥综合性作用。

2. 芙蓉小学现状评价及问题识别

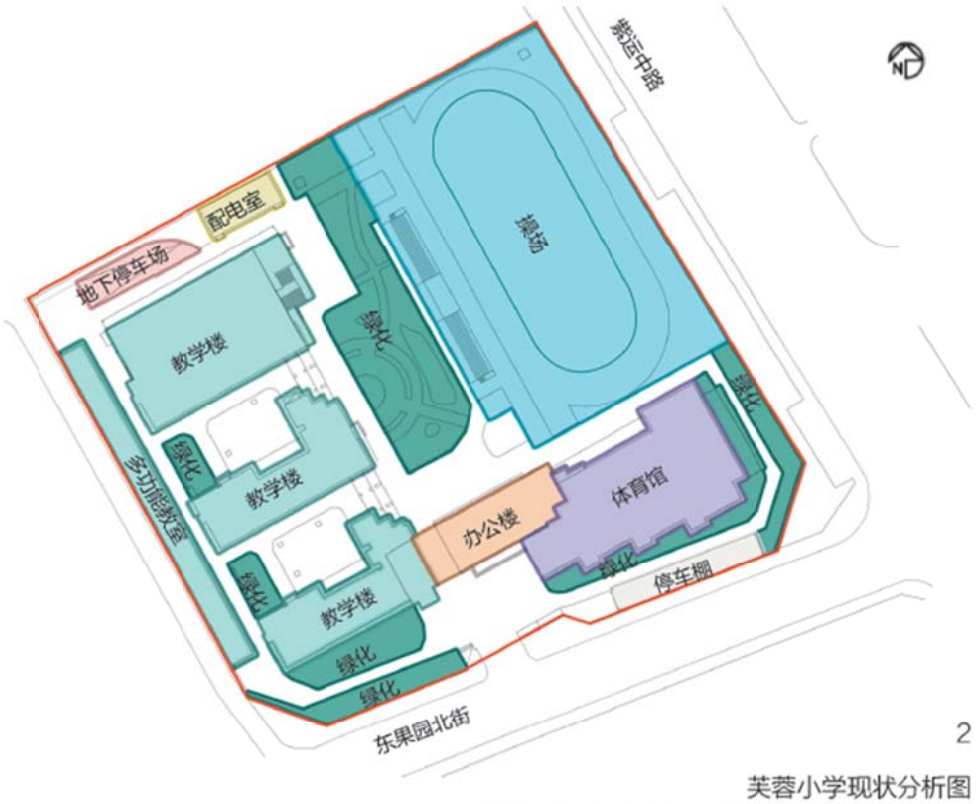
芙蓉小学建成于 2012 年 9 月，是一所倾心打造的区域名校，办学理念是“清新融通”。学校为师生营造了清新、和谐、大气、包容的文化氛围。根据北京市通州区海绵城市试点要求，在解决校园雨洪问题的同时通过场地更新提升校园景观环境品质，使旧的校园焕发新的活力。

2.1 自然条件分析

通州区属大陆性季风气候区，年平均降水量 585 mm，受冬、夏季风影响，降水时空分布不均，其中 65% 的降水集中在 7 月 —8 月份，经常发生春旱、夏涝。经勘测校园稳定地下水位埋深在 9.30 m — 13.50 m之间，土壤渗透系数满足海绵设施蓄水排空时间要求。

2.2 现状评价及问题识别

芙蓉小学占地面积 22 959 m2，详见校园平面图（图 2）。根据现场调研及资料收集，总结归纳校园空间构成要素和现状问题（表 1）。



2

芙蓉小学现状分析图

Status Analysis Chart of Furong Primary School

表 1　芙蓉小学现状要素分析评估及问题识别

Table 1 Analysis and Evaluation and Problem Identification of the Current Status of Furong Primary School

要素	现状要素评估及问题识别
建筑物	屋面荷载不满足屋顶绿化改造要求；建筑雨落管散排地面，降雨时造成地面湿滑，长时间冲刷浸泡造成散水功能严重破坏
硬化铺装	校园地势北高南低，高差 0.4 m；不透水砖和塑胶铺装，面层破损塌陷较多，地表排水不畅，积水点较多
绿化	绿地土壤裸露严重，绿地普遍高于道路，不利于雨水的收集和消纳；植物配置简单、层次单一，主要有麦冬、黄杨、小檗、白蜡、雪松、山桃、海棠、银杏、紫叶李等
排水体制	校园为雨污分流制排水系统，管线局部存在逆坡。局部区域雨水口数量较少且无截污设施
空间使用及文化特色	校园空间过于简单、开敞，无标志性设施及活动设施，难以满足师生对多功能空间的需求；学校特色文化及标识系统缺失，空间识别性不强
师生诉求	对校园破损、塌陷的铺装改造要避免给学生活动带来安全隐患，缓解学校目前户外活动空间不足的压力；中心绿地区增加休息连廊，满足师生休息、娱乐的需求

表 2 芙蓉小学“海绵 +”复合模式系统的构建

Table 2 Construction of "Sponge +" Composite Mode System in Furong Primary School

“海绵 +”复合模式构建	“海绵 +”复合模式构建策略
海绵化改造	通过因地制宜改造现存硬化铺装、绿地、雨水落管等，建设下凹式绿地、雨水花园、排水沟、地下蓄水池等 LID 措施，利用湿地水处理系统净化雨水并回用，强调校园内雨水的渗、滞、蓄、净、用、排等过程
“海绵 + 文化”	打造北京城市副中心生态海绵校园示范样板，深入结合校园自身文化和教育理念
“海绵 + 教育”	设计一套有趣且实用的教育展示系统，结合改造，进行互动，增强学生对 LID 技术的认识，如海绵大使评选活动、雨水收集及回用等的体验
“海绵 + 智慧”	将海绵监测、小气象站、海绵展示牌、小学课外创新活动结合起来，打造“智慧 / 智能校园”
“海绵 + 景观”	对校园空间重构，提升学校形象，布置上实现空间分区特色和技术多样，满足师生多用途空间使用的需求，突出校园海绵生态特色之美

3．基于“海绵+”复合模式下芙蓉小学海绵化改造

3.1 功能定位

综合考虑北京市通州区海绵城市建设试点整体要求，在绿色雨洪管理系统构建的基础上，努力做到通过对场地和基础设施的更新，给老师、学生、家长提供理想的环境，使校园环境成为小学生成长中的重要一环。因此，本方案在海绵化改造的同时力图融入体验、启发和教育三大功能，为学生建设一座参与和体验式的“海绵校园”和自然课堂。

（1）体验功能：看得见、听得到、摸得着的水、空气、土壤、花草。

（2）启发功能：充分发展学生的感知、欣赏、独立思考能力、审美能力以及积极参与实践的技能。

（3）教育功能：激发学生保护环境责任感，帮助学生初步形成良好的环境价值观和行为方式，并以自己的情感和行为去关心他人、关心生命、关心自然。

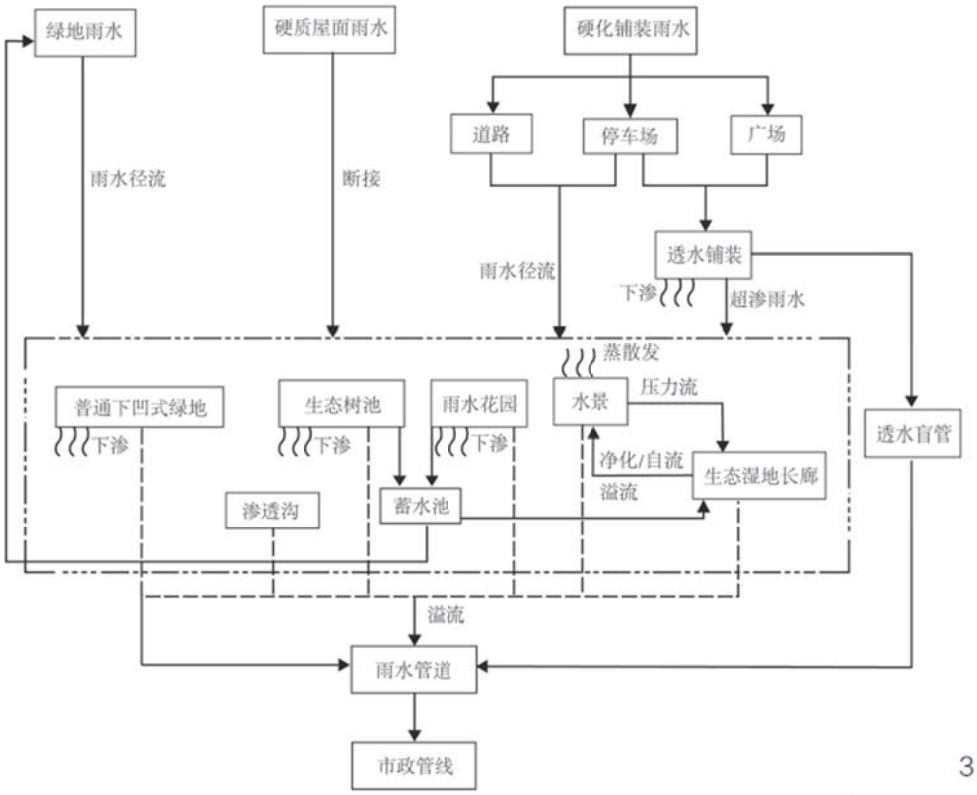
3.2 芙蓉小学“海绵+”复合模式构建

将海绵化改造结合创新型设计，综合多专业创新构建 “海绵+”复合模式系统（表 2），使学生充分体验海绵科技和文化，与水进行互动，寓教于乐，打造北京市通州区第一个“海绵+”校园。

3.3 芙蓉小学“海绵+”复合模式下校园空间改造策

雨洪管理层面，依据校园空间布局，结合场地竖向及周围区域雨水设施的衔接需求，本着雨水径流“源头—过程—末端”全过程控制原则，系统制定“海绵+”校园雨洪管理系统技术路线（图 3），明确低影响开发措施布局（图 4）。景观层面，以中心入口为主要景观轴线，将校园划分四片景观空间格局（图 5—图 6），分别为“缤纷校园入口区、活力校园核心区、主题科教内庭院、动静皆宜体育场”。

（1）校园主入口是展示学校特色与形象的区域。校园入口大面积不透水硬化铺装，因破损严重改造为彩色透水混凝土，并通过道路竖向调整及路牙石开孔，将雨水导入周边绿地中进行消纳（图 7），超标雨水溢流排放至雨水管网。对硬化铺装周边绿地地形重新梳理，在保护长势较好的乔木的前提下，因地制宜布置植草沟、下凹绿地和雨水花园等设施。选择耐水湿、易维护植物，如萱草、鸢尾、马蔺、狼尾草、黑心菊、松果菊、血草、拂子茅、粉黛乱子草、细叶芒等，丰富植物配置组合。建筑外立面通过色彩搭配绘制“荷花”主题图案，并增加文化宣传和导视系统。校园入口区通过改造形成构图协调，色彩搭配统一，展示性强，突出清新、和谐、大气、包容的校园文化氛围（图 8）。



3

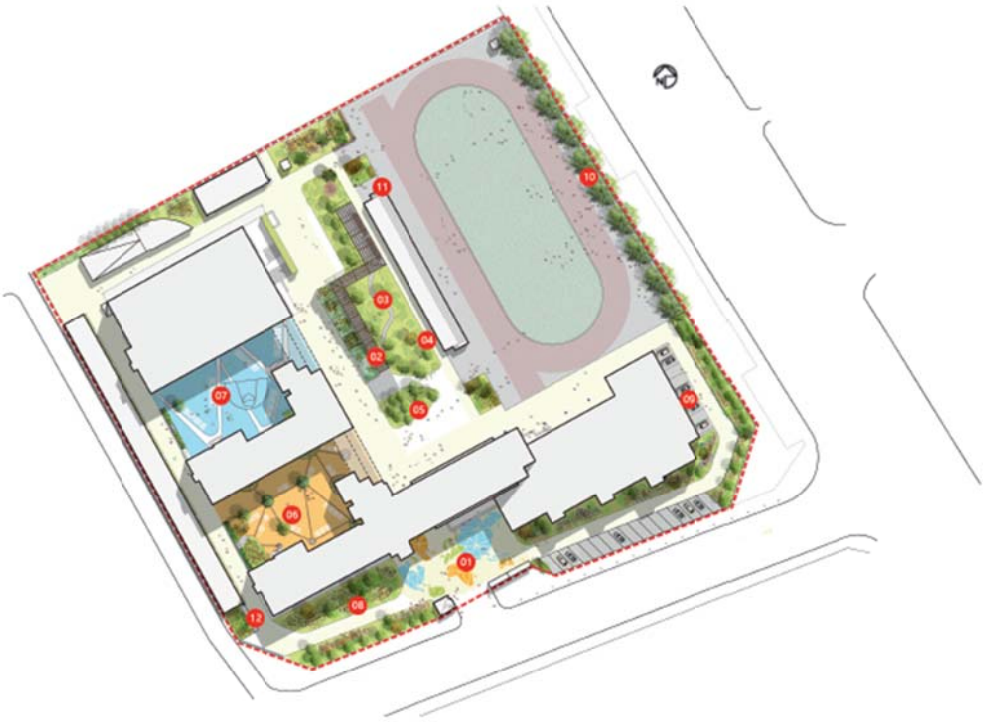
雨洪管理系统技术路线图

Technical Route of Rainwater Management System

4

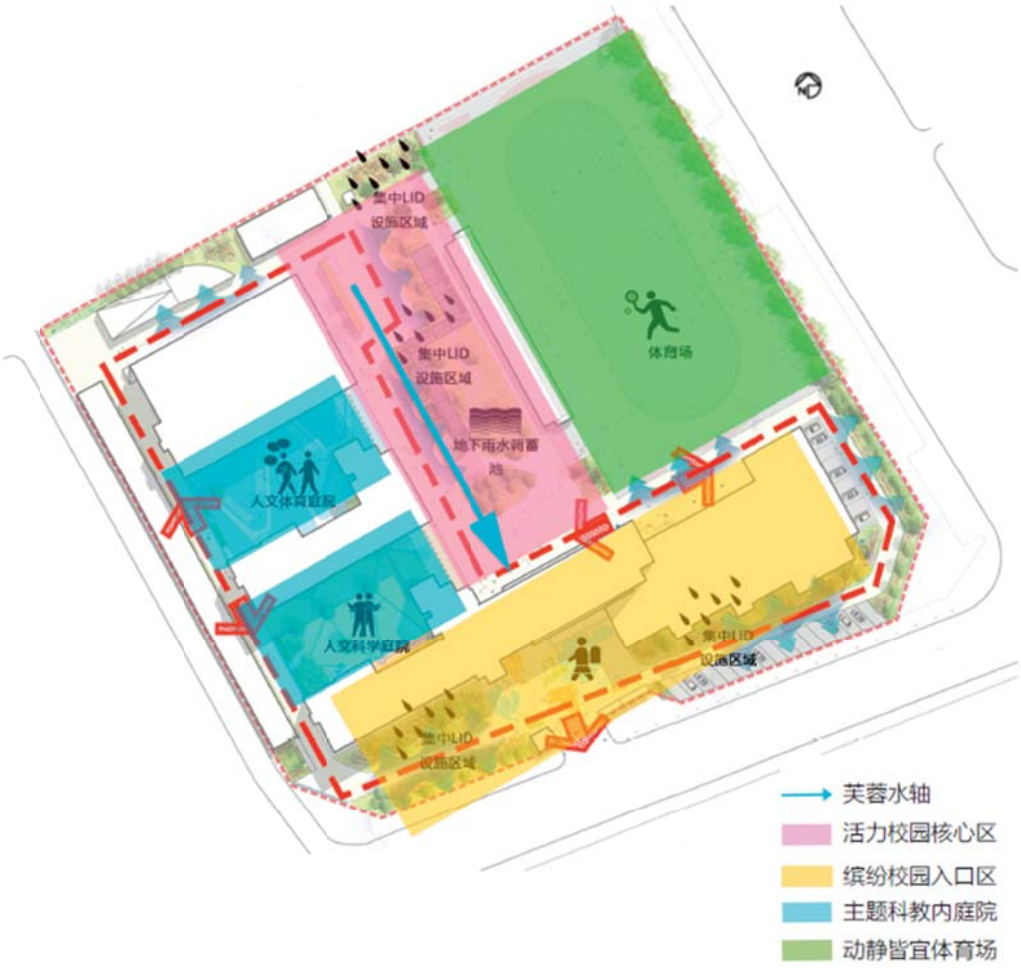
芙蓉小学海绵设施布置图

Sponge Facilities Layout of Furong Primary School



1. 世界拼图
2. 湿地水轴
3. 雨水连廊
4. 下沉草地
5. 树阵广场
6. 教育庭院
7. 体育庭院
8. 雨水花园
9. 生态停车场
10. 树下坐凳
11. 雨水观察台
12. 开心农场

芙蓉小学海绵化改造景观平面图
Sponge Renovation Landscape Plan of Furong Primary School



6

芙蓉小学海绵改造空间分布图

Sponge Renovation Space Division Map of Furong Primary School

道路周边下凹绿地改造
Transformation of Sunken Green Space

芙蓉小学入口改造
Entrance Reconstruction of Furong Primary School

（2）活力校园核心区是校园中心活动区。在原中心绿地处新建湿地雨水处理系统。该系统包括一套完整的地下雨水收集、处理、回用设施（图 9）。具体而言，收集的雨水径流经过前端旋流沉砂预处理后流入地下蓄水池。蓄水池中的雨水径流通过阶梯式潜流滤池中的填料、植物净化处理后（图 10）与灌溉系统相连用于绿化喷灌。该系统通过末端调蓄实现对雨水滞留、调蓄及回用的目标，从而减少场地外排雨量，发挥雨水资源循环利用、节约水资源的作用。湿地长廊作为校园核心景观，其中的生态滤池以荷花为主题搭配不同的水生、湿生植物造景（图 11）。池中亭亭玉立的荷花不仅突出了湿地生态水景而且更好地诠释了学校“思汇芙蓉，出于清水，秀之世界”的教育理念。生态滤池外立面用锈红钢板与绿色植物搭配，

形成了粗糙与细腻的肌理对比、厚重与明快的色彩对比。新建休闲观赏廊架设计有不同尺度的平台满足学生交流、聚会、休息等活动需求。场地保留了绿地中原有长势较好的乔木，通过林下空间补充花境，丰富视觉层次上的观景体验，为师生漫步林下提供和谐静谧的空间氛围（图 12）。此外，结合小气象站和海绵监测、海绵展示牌的布置，为小学生提供近距离观察、感知、参与学习水生态的知识场所（图 13），起到海绵城市科普宣传的作用。

（3）主题科教内庭院为师生课间活动场地。该区域采用建筑雨落管断接处理方式，引入雨水罐收集雨水，超标雨水则引入周边绿地的雨水花园中进行消纳。雨水花园中设置小型木栈道便于学生近距离观察雨水花园工作原理（图 14）。根据师生的诉求，将破损活动场地改造为彩色透水铺装（图 15），并保护场地大型乔木。方案通过色彩、图案划分塑造了自然科学庭院和人文活力庭园两部分，有效增加了场地的知识性和趣味性，解决了活动场地不足的问题。同时在教学楼墙面绘制海绵城市科普卡通宣传画，向学生普及环保知识。

（4）校园操场活动区内现存塑胶跑道较新，整体排水顺畅仅破损处存在积水问题。故在对破损处塑胶进行修补的同时在操场周边增加线性排水沟和雨水花园便于雨水排出、消纳。另将校区一角改造为菜园，与雨水收集罐、生态渗沟等收、排水措施结合（图 16）。学生在老师带领下可在这里亲近自然，在劳动中学习使用雨水收集罐，体验种植蔬菜的乐趣。

3.4 校园海绵化改造后指标分析

对芙蓉小学海绵设施规模计算见表 3，验证满足试点区海绵建设要求。经计算，当校园内雨水回用设施容积达 140 m 时，全年可实现雨水利用量 1579 m^3，相当于实现自来水替代率 60%。随着芙蓉小学“海绵+”模式充分落地，学校还举办了“海绵知识小课堂” “海绵大使评选”等活动，增强学生对 LID 技术、湿地雨水处理系统、雨水循环利用、智慧校园的体验和认知。芙蓉小学海绵化改造工程不仅解决了水环境问题，由于改造融合了环境教育的理念，还实现了环境认知和体验互动，受到师生以及家长的欢迎，也得到了行业专家的高度评价。

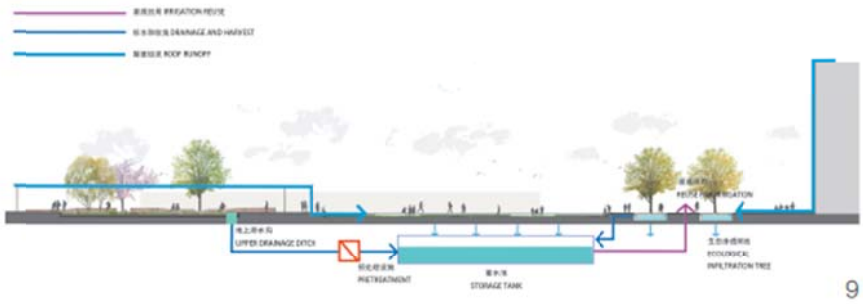
表 3 芙蓉小学海绵化改造后指标分析

Table 3 Index Analysis of Furong Primary School after Sponge Transformation

汇水总面积	总调蓄量	径流控制率	径流污染（SS）去除率	雨水资源利用率
22644 m^2	643.6 m^3	76.8%	60.7%	16.8%

4. 结语

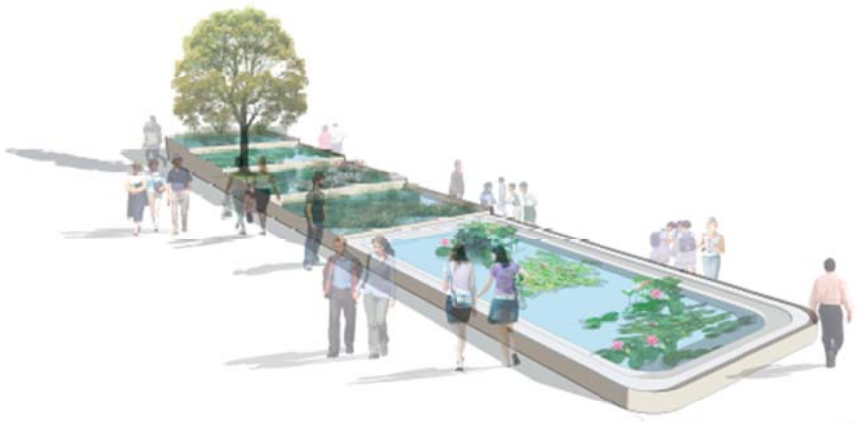
芙蓉小学海绵化改造项目是在城市高密度建成区复杂条件下解决城市雨洪问题、实现环境可持续发展的创新尝试。为应对海绵城市建设实践探索与需求，本方案提出了“海绵+”创新复合模式下校园景观改造体系，明确了多目标校园海绵化改造体系构建程序及实施途径，探索了雨洪管理与景观环境、文化塑造及学生科普体验有机融合的模式，使之成为“海绵+景观+文化”等多功能复合的校园新空间。其意义在于打破单一的工程目标，在解决水生态、水环境、水安全和水资源问题的同时，基于场地特色横向拓展、多专业协同，实现了水景观、水文化的融合。



9

校园雨水收集循环利用系统示意图

Schematic Diagram of Rainwater Collection and Recycling System in Campus



10

阶梯式潜流滤池示意图

Schematic Diagram of Stepped Underflow Filter

湿地长廊雨水处理系统
Rainwater Treatment System in a Wetland Gallery

林下空间改造
Space Transformation Under the Forest

学生近距离观察生态净化系统
Students Closely Observe the Ecological Purification System

庭院雨水花园改造实景图
Courtyard Rain Garden Reconstruction

主题庭院改造实景图
Theme Courtyard Reconstruction

校园一角菜园改造
Transformation of a Corner of Campus Vegetable Garden

Introduction

Aiming at a series of problems on city water ecology, water environment, water safety and water resources in city construction in recent years such as ponding and waterlogging, serious runoff pollution and water resource shortage, it is urgent for China to re-consider the connotation of city water system and coordinate relations between city construction and water environment, and to recover and strengthen the resistance and resilience of city water system [1]. As emphasized by General Secretary Xi Jinping in his speech Working Conference about Urbanization in 2013 ,

it is needed to construct the “sponge city” with natural storage, natural permeation and natural purification. Sponge city solves the problem of city water environment in a systematic way by utilizing multi-layers and multi-objectives with “source emission reduction – process control – tail end storage and utilization” by means of “leakage, retention, storage, purification, utilization and drainage”, with obvious effects on aspect of improving city environment quality [2].

Our country has set two batches including 30 experiment units for sponge city construction since 2015, in which Lianghe District, Sub-center of Beijing City, was selected into the second batch of the experiment units, including specific contents of the sponge-oriented reconstruction of the constructed districts as well as the sponge-oriented construction of the administrative areas and other newly constructed districts. According to the requirements in Regulatory Detailed Plan of the Sub-center of Beijing (street layer) (2016-2035) , the sub-center shall be constructed as a green city, a forest city, a sponge city, an intelligent city, a humanistic city and a livable city, and become a new landmark of the capital as well as the demonstration for city construction and development in the new era. Based on the requirements of the high starting point and the high standard of the sub-center, after practical exploration of 3 years, initial success has been made for sponge city construction of the experimental unit, forming a batch of promotable and reproducible demonstrative projects.

Most of the constructed areas of sponge city experimental unit in Tongzhou District of Beijing are sponge reconstruction of public buildings and residence communities, in which the school area occupies 72% of the total area of public buildings. Taking security into consideration, it is not suitable to utilize the dredging method for pressure of rain water discharge for the school. Therefore, scientific rainfall flood management system can be established in the campus to relieve problems such as ponding and waterlogging, pressure from rain water drainage and so on. The “sponge campus” means that the whole campus has certain resilience and environment change adaptation ability like sponge [3]. There has been a batch of excellent cases about campus sponge reconstruction in our country in recent years: The landscape environment reconstruction project of Sheng Yin College of Tsinghua University has proposed the comprehensive design idea about landscape hydrology, and lays integration of the rainfall flood management measures and historic landscape environment [4]; Kunshan Duke University takes water environment protection as the core objective, to realize whole-process governance of rainfall runoff in source,

process and tail end from the green infrastructure. It integrates landscape function and the water system, to make the campus a big system like “sponge” that can adjust water resource, space and landscape [5]; College of Electrical Engineering of Beijing Jiaotong University conducts ecological and energy-saving reconstruction to the courtyard, to integrate light, new energy and rainwater garden, and to embody integration between technologies and the nature, which is a demonstration for a conservation-oriented campus.

This shows that the building of a campus space integrated with harmonious ecology, beautiful landscape, prominent cultural atmosphere, strong sense of participation of teachers and students and sense of identity is the difficulty and the emphasis of planning and designing a sponge campus. Based on interdisciplinary methods and technologies, this paper creatively proposes the procedures and paths for campus landscape reconstruction under the “sponge+” composite mode. In addition, with the innovative practice of “sponge+” of Furong Primary School, it provides references for related practices for campus sponge reconstruction in the constructed areas.

1. Procedures and Implementation Paths for Campus Landscape Reconstruction of the “Sponge+” Composite Mode

The campus landscape reconstruction based on the “sponge+” composite mode means reconstruction of the campus space image by means of “sponge +landscape” and reconstruction of the cultural features of the campus by means of “sponge + culture” based on solving the problem of the rainfall flood in campus, so as to form a sponge campus environment with integrated functions and a complete system.

1.1 Procedures for Campus Landscape Reconstruction of the “Sponge+” Composite Mode

Firstly, control and manage rainwater in the field with low-influence development technologies; secondly, construct the “sponge + landscape” mode aiming at the demands of diversified activity spaces in the campus based on behavior modes of teachers and students. On one hand, provide teachers and students with diversified outdoor activity space; on the other hand, improve campus landscape image to provide it with distinct and unique aesthetic characteristics and significance. At the same time, explore the cultural connotation of the campus, construct the “sponge + culture” mode, and extend the context in the campus, so as to build good cultural value atmosphere of the campus and generate unconscious influence on students. “Constructing the ecological basis in a

sponge way" "reconstructing the space environment with landscapes" and "building core values with culture" are integrated and overlapped to constitute the campus landscape reconstruction system with the "sponge+" composite mode.

1.2 Implementation Paths for Campus Landscape Reconstruction of the "Sponge+" Composite Mode

(1) Take problems as the orientation: Search for data about the field, investigate and research the campus space, constituting elements, features of campus culture and teaching philosophy, and identify and arrange problems.

(2) Take demands as the basis: Take the demands on the diversified campus space using functions based on conducts of teachers and students and psychological pattern into consideration.

(3) Take the objectives as the guidance: Quantitative indexes are determined as per requirements, according to the Measures for Performance Evaluation and Assessment of Sponge City Construction (Trial) , such as the control rate of the annual runoff volume, the reduction rate of non-point source pollution and the rainwater resource utilization rate [7]. At the same time, on the aspect of qualitative indexes, they are determined jointly by combining demands on space functions, demands on landscape appearance and demands on cultural expression.

Based on practice and exploration, the procedures for campus landscape reconstruction of the "sponge+" composite mode have been proposed (figure 1). In conclusion, with respect to the implementation paths of the campus reconstruction based on the "sponge+" composite mode, on the layer of rainfall flood management, the guiding ideas of resource emission reduction, process control and systematic governance, the principles of overall coordination, questionorientation, adjusting measures to local conditions and combination between grey and green are observed. The rainfall flood management system is constructed with the principal of the construction of LID source emission reduction facilities, with measures such as leakage, retention, storage, purification, using and drainage. On the aspect of landscape, approaches such as space sequence, image, proportion, scale, texture, color, pattern and cultural symbols are adopted to reconstruct and improve the environment and the culture. That is to say, through the determination of the goals and functional orientation of the transformation, highlight landscape environment and cultural features of each functional area of the campus based on the scientific rainfall management system, and take overall planning among different systems, so as to play comprehensive roles.

2. Current Status Evaluation and Problem Identification of Furong Primary School

Established in September, 2012, Furong Primary School is a regional famous school. With the operating philosophy of “fresh and integration”, the school builds fresh, harmonious, generous and compatible cultural atmosphere for teachers and students. According to the requirements on the experimental unit of the sponge city in Tongzhou District, Beijing, it is needed to improve the campus landscape environment quality by means of field reconstruction at the same time of solving the problem of rainfall flood, to inspire the vitality of the old campus.

2.1 Analysis on Natural Conditions

Tongzhou District is situated in the area of mainland monsoon type climate, with average annual precipitation of 585 mm. Influenced by the winter and summer monsoon, it has non-uniform spatial and temporal distribution in rainfall, in which 65% of rainfall concentrates in July and August, with frequent spring droughts and summer floods. According to field investigation, the depth of the stable underground water level is between the ranges of 9.30 m~13.50 m, and the soil permeability coefficient can meet the requirements on time of water storage and drainage of sponge facilities.

2.2 Current Status Evaluation and Problem Identification

With a site area of 22,959 m2, Furong Primary School has the planar graph as follows (figure 2). According to field investigation and data collection, the spatial composition elements and the current problems are concluded (table 1).

3. The Sponge Reconstruction of Furong Primary School Based on the “Sponge+” Composite Mode

3.1 Function Orientation

By taking comprehensive overall requirements on experimental unit of sponge city construction in Tongzhou District, Beijing into consideration, based on the green rainfall flood management system, it is needed to provide teachers, students and their parents with ideal environment based on updating of fields and infrastructures, to make campus environment an important link for growing of primary students. Therefore, the scheme tries to integrate three functions of experiencing, enlightening and education into sponge reconstruction, to build a participatory and experiential "sponge campus" and natural classroom for students.

(1) Experiencing function: The water, air, soil, flowers and grass that can be seen, heard and touched;

(2) Enlightening function: Give full play to student abilities in perception, appreciation, dependent thinking and aesthetic judgment, participation and practice;

(3) Education function: Inspire students to protect the environment, and help them form good environment value system and conduct method and care about others, life and the nature with their emotions and conducts.

3.2 Construction of the "Sponge+" Composite Mode of Furong Primary School

The sponge reconstruction is integrated with the innovative design, and constructs the "sponge+" composite mode system in a comprehensive and multi-specialty way (table 2), so that students can experience the sponge technologies and culture and interact with water, to build the first "sponge+" campus in Tongzhou District, Beijing by teaching through lively activities.

3.3 Strategies for Campus Space Reconstruction of Furong Primary School of the "Sponge+" Composite Mode

On the rainfall flood management layer, according to space arrangement of the campus, in combination of the demands on connection between rainwater facilities in vertical and surrounding areas, the "sponge+" campus rainfall flood management system technical route is formulated with the full-course control principle of the "source-process-tail end" of rainwater runoff (figure 3) and clarifies the low-influence development measure layout (figure 4). On the landscape layer, the center entrance is taken as the main landscape axis, to divide the campus into four landscape space patterns (figure 5~figure 6), which are "entrance of colorful campus, core area of energetic campus, court of science and education themes and stadium area".

(1) The main entrance of the campus is a region showing the features and the image of the campus. The large areas of waterproof hardened pavement with great damages are reconstructed as colorful pervious concrete, and rainwater is led into the surrounding greenbelts for absorption through vertical adjustment of roads and holes on road traffic stones (figure 7). The excessive rainwater overflow is drained to the rainwater pipelines. The terrain of the greenbelts surrounding the hardened pavement has been re-constructed, and facilities such as grass ditches, concave greenbelts and rainwater parks are arranged according to practical conditions. Plants resistant to water dampness and easy for maintenance such as day lily, fleur-de-lis, iris ensata, Chinese

pennisetum, rudbeckia hirta, Echinacea purpurea, blood grass, calamagrostis epigejos, hairawn muhly and maiden grass are planted, to enrich the plant configuration and combination. are patterns of “lotus” with color matching, and cultural publicity and guide system are equipped. A whole set of fresh, harmonious, generous and compatible campus culture atmosphere is emphasized with unified color matching and strong exhibition performance (figure 8).

(2) The core area of the energetic campus is the central activity area in the campus. Wetland rainwater treatment system is added to the original green space. The system includes a set of complete underground rainwater collection, treatment and recycling facilities (figure 9). To be specific, the collected rainwater runoff flows through the front-end rotational flow sand pre-treatment and then flows into the underground reservoir. The rainwater runoff in the water storage pool is conducted with treatment of the padding in the stair-type undercurrent filter chamber (figure 10), and then connects with the irrigation system on the greening irrigation. The system realizes rainwater retention, storage and recycling through tail-end storage, so as to reduce rainwater drainage volume out of the field, and to play roles of recycled utilization of rainwater resource and saving water resource.

The wetland gallery is the core landscape of the campus, and the ecological filter chamber takes lotus as the theme, matched with different quantic and wetland plant landscaping (figure 11). The beautiful lotuses in the pool not only highlight the ecological water landscape of wetland but also explain the teaching idea of “showing in the world like lotus growth from clean water” of the school. The external facade of the ecological filter pool is made of rusted red steel plates and green plants, forming the comparison between roughness and fineness and between heaviness and lightness. The newly constructed gallery frame has platforms of different scales to meet demands of students in exchange, parties and rest. In addition, trees with good growing trend are left in the greenbelts, and flower border is supplemented in the space under forests, to enrich landscape experience on visual layer, and to provide teachers and students with harmonious and quiet space atmosphere (figure 12). Besides, in combination of small meteorological stations as well as sponge supervision and sponge exhibition plates, it provides primary school students with a site to observe, perceive and participate in water ecology knowledge in close ranges (figure 13), playing the role of propaganda for sponge cities.

(3) The internal court for theme scientific teaching provides teachers and students with site for

break activities. The building rainwater down pipe disconnecting treatment method is adopted for this region, to collect rainwater in the rainwater tank, and the excessive rainwater is introduced into the rainwater park in surrounding greenbelts for absorption. Small-sized wooden trestle is set in the rainwater park, so that students can observe the working principles of the rainwater park (figure 14). According to appeals from teachers and students, the damaged activity field is reconstructed as colorful permeable pavement (figure 15), which can also be utilized to protect large-scale trees in the field. The scheme creates the natural science garden and the humanistic vigor court with color and pattern division, to add knowledge and interests of the field, and solves the problem of insufficient activity field. At the same time, picture posters about sponge cities are drawn on walls of teaching buildings, to popularize environment protection related knowledge.

(4) The existing plastic track in the playground is relatively new, with smooth overall water drainage, and there is only the problem of ponding in some damaged places. Therefore, in addition to repairing the damaged plastic, it is only needed to add linear drainage ditch and rainwater garden around the playground for rainwater drainage and adsorption. In addition, a corner of the campus is reconstructed as a vegetable garden, in combination of water collection and drainage measures such as rainwater gathering tank and ecological sewer (figure 16). With leading of teachers, students can get close to the nature, learn to use rainwater collection tanks and experience happiness of vegetable planting.

3.4 Index Analysis of Sponge Reconstruction of the Campus

Please refer to table 3 for the sponge facilities scale calculation of Furong Primary School, to verify that it meets the requirements on sponge construction of the experimental unit. According to calculation, when the rainwater recycling facilities achieve the volume of 140 m3, it realizes rainwater utilization volume of 1579 m3 in the whole year, equivalent to realization the replacement rate of tap water of 60%. With the implementation of the “sponge+” mode of Furong Primary School, the “classroom for sponge knowledge” and the appraisal of “sponge ambassador” are held by the school, to strengthen the experience and cognition of primary school students to LID technologies, wetland rainwater treatment system, rainwater recycling and intelligent campus. The sponge reconstruction of Furong Primary School not only solves the problem of water environment but also realizes environment cognition and experience interaction due to integration with the idea of environment education. It is welcomed by teachers, students and parents; in

addition, it is highly appraised by leaders and experts in the industry.

4. Conclusion

The sponge reconstruction project of Furong Primary School is an innovative attempt to solve the problem of rainfall flood in cities and realize sustainable development of environment in the complex conditions of high-density constructed areas in cities. In order to respond to practical exploration and demands of sponge city construction, the “sponge+” composite mode is proposed in this scheme, clarifying the construction procedures and the implementation paths of multi-objective campus landscape reconstruction system, exploring the mode integrated with rainfall flood management, landscape environment, culture building and popularization of science for students, and making it a new campus space with multiple functions of “sponge + landscape + culture”. It breaks through the single project objective; at the same time of solving the problems related to water ecology, water environment, water safety and water resources, it conducts horizontal expansion and multi-specialty coordination based on field features, to realize integration of water landscapes and water culture.

参考文献（References）：

[1] 卫超，赵杨. 海绵城市：从理念到实践[M]. 江苏凤凰科学技术出版社,2018.

WEI Chao, ZHAO Yang. Sponge City: from concept to implementation [M]. Jiangsu Phoenix Science Press, 2018

[2] 住房城乡建设部, 海绵城市建设技术指南：低影响开发雨水系统构建(试行) [S]. 2014.10.

Ministry of Housing and Urban-Rural Development, Technical Guide for Sponge City Construction: Low-impact Development Rainwater System Construction (Trial)[S]. 2014.10.

[3] 邹萍秀，曹磊，王焱*，(美) 珍玛丽• 哈特曼，等. 海绵城市理念在校园风景园林规划设计中的应用—以天津大学北洋园校区为例 [J]. 中国园林，2019,35(08):72-76.

ZOU Pingxiu, CAO Lei, WANG Yan *, (U.S.) Jean Marie Hartman,etc. Tianjin University Peiyang Campus: Application of Sponge City Concept in Campus Landscape Planning and Design [J]. Chinese Landscape Architecture, 2019, 35(08): 72-76.

[4] 刘海龙，张丹明，李金晨，等. 景观水文与历史场所的融合——清华大学胜因院景观环

境改造设计[J]. 中国园林,2014,30(01):7-12.

LIU Hailong, ZHANG Danming, LI Jinchen, et al. The Merging of Landscape Hydrology with Historical Site—Reconstruction Design of Shengyinyuan, Tsinghua University [J]. Chinese Landscape Architecture, 2014, 30 (01): 7-12.2014, 30 (01):7-12.

[5] 章林伟，等. 海绵城市建设典型案例[M]. 中国建筑工业出版社.2017.ZHANG Linwei, et al. Sponge city case studies [M]. China Architecture & Building Press. 2017.

[6] 伍祯. 北京交通大学海绵校园景观规划设计研究[D]. 北京：北京交通大学，2018.

WU Zhen. Landscape Planning and Design based on Sponge Campus in Beijing Jiaotong University [D]. Beijing: Beijing Jiaotong University, 2018.

[7] 住房城乡建设部办，海绵城市建设绩效评价与考核办法（试行）[S]. 2015.7

Ministry of Housing and Urban-Rural Development, Sponge City Construction Performance Evaluation and Assessment Measures (Trial) [S]. 2015.7

（整理： 赵迪 译：王彤）