中图分类号：P901
文献标识码：A
文章编号：1673-1530（2015）01-0052-18
DOI：10.14085/j.fjyl.2015.01.0052.18
收稿日期：2014-03-18
修回日期：2014-11-27

已建成项目的景观绩效：美国风景园林基金会公布的指标及方法对比

Landscape Performance of Built Projects: Comparing Landscape Architecture Foundation's Published Metrics and Methods

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摘要：风景园林学是一门循证的（evidence-based）专业和学科，因而需要充足的依据来指导未来的设计。为了推进可持续的设计实践，收集科学证据来支撑设计并体现绩效至关重要。美国风景园林基金会的景观绩效系列（Landscape Performance Series， 简称 LPS）是收集这类证据的一种尝试。LPS 建立在可持续三角（sustainability triad）架构上，通过研究者与从业者的合作，对在环境、经济、社会层面上景观方法运用的成果进行量化。

景观绩效的研究尚不成熟，在评价指标和方法上还存在着许多空白。本研究有两项主要任务：一是将现行的景观绩效指标与其他度量系统进行对比，找出差别，为完善将来的景观绩效的指标提出建议；二是检验和探讨景观绩效量化通用方法的可靠性和有效性。

关键字：可持续性；绩效评估；绿色能源与环境设计先锋认证；可持续场所倡议

Abstract: Landscape architecture is an evidence-based profession and discipline, in which creditable evidence is used to guide future design. In order to promote sustainable design practice, scientific evidence that supports design and presents performance needs to be collected. Landscape Architecture Foundation's Landscape Performance Series (LPS) is one of the efforts that attempt to collect this evidence. Built upon the sustainability triad, LPS is intended to quantify outcomes of applied landscape solutions in environmental, economic and social aspects through a collaboration of researchers and practitioners.

Landscape performance research is still in its infancy. There exist a number of gaps in its metrics and methods. This study includes two major tasks. The first is to compare the currently used metrics of landscape performance with other measuring systems in order to identify gaps and make recommendations on improving future landscape performance metrics. The second is to examine and discuss the reliability and validity of the methods that are frequently used in landscape performance quantification.

Key words: Sustainability; Performance Evaluation; LEED-ND; SITES

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1 引言

自世界环境与发展委员会(World Commission on Environment and Development)首次提出可持续发展以来，该理念在过去 30 年中得到了广泛的发展。可持续发展强调保护环境、促进经济发展和推进社会公平三方面的平衡（WCED，1997；坎普贝尔，1996）。大量规划和设计思想都在追求这一平衡，如新城市主义、精明增长、以公共交通为导向的开发及混合使用开发等。与此同时，对可持续设计策略的研究和实践也层出不穷，如低影响开发技术、使用本土物种、采用可再生能源及材料再回收等。

风景园林学是一门循证的（evidence-based）专业和学科，因而需要充足的依据来指导未来的设计。为了推进可持续的设计实践，收集科学证据来支撑设计并体现绩效至关重要。现有的研究已经在收集这种证据上进行了多方面的努力，如社区开发项目绿色能源与环境设计先锋认证(Leadership in Energy and Environmental Design for Neighborhood Development，简称 LEED-ND）、可持续场所倡议(Sustainable Sites Initiative, 简称 SITES)以及景观绩效系列（Landscape Performance Series，简称 LPS）。

LEED-ND 和 SITES 都属于评估体系，由针对可持续性不同方面一系列的指标组成。每个指标都具有一定分值，参评项目通过各项指标来检验是否可以得到这些分数。这些评价体系对景观项目的可持续性进行了认证，且在一定程度上促进了可持续设计的实践。

LPS 由美国风景园林基金会（Landscape Architecture Foundation，简称 LAF）发起，作为“一套在线互动的资源，为设计师、咨询机构和倡导者展示景观绩效的价值，提供评估绩效的工具，并给出可持续景观解决方案的理由。”不同于 LEED-ND 和 SITES，LPS 是一套回溯评估体系，它在项目建成后对绩效进行量化，而不是基于设计和施工文件进行估计或预测。

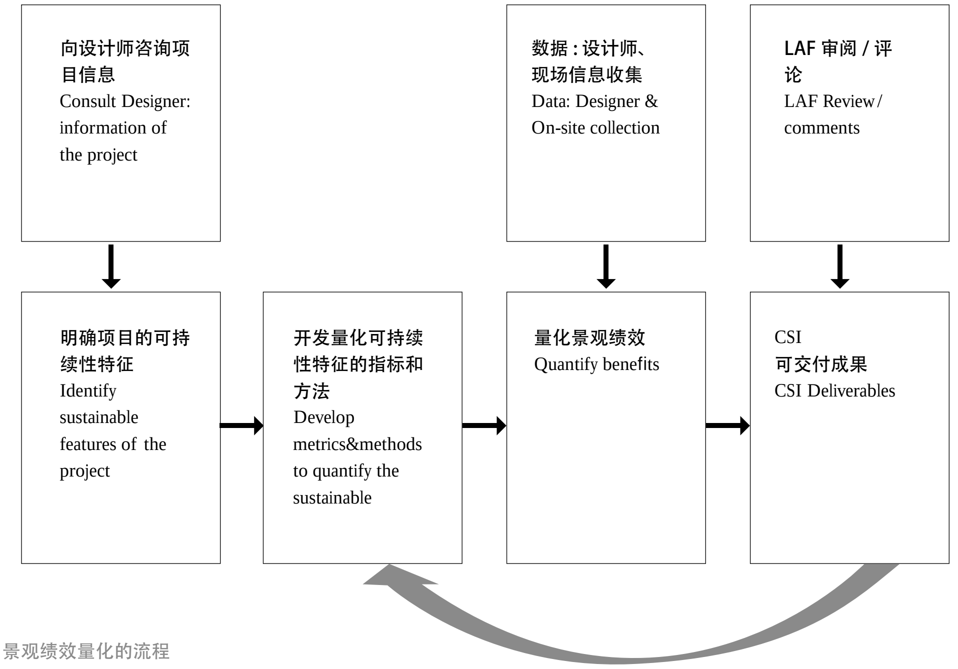
景观绩效的量化是通过案例研究调查计划（Case Study Investigation，简称 CSI）计划进行的，该计划由大学教授、学生和设计公司合作开展。对景观绩效的评估而言，确定测量哪些指标尤其重要，指标的选择往往取决于项目中运用了何种景观方法以及这些指标反映该方法的绩效的程度。量化方法也同样重要，如果量化方法不合适，结果会具有误导性。图 1 说明了案例研究调查计划的景观绩效量化流程。

本研究有 2 个目标。目标之一是将现行的景观绩效度量指标与生态系统服务、LEED-ND 指标以及 SITES 指标、建筑绩效指标进行比较，找出差别，为改进将来的景观绩效度量指标提出建议；目标之二是检验并讨论景观绩效中普遍使用的方法的可靠性及有效性。

2 方法

景观绩效评估的首要目的是指导未来设计的决策。如果不能正确评估绩效，误导性的结果将会导致错误的决策。因此，选择合适的指标和方法至关重要。景观设计创造并改变生态系统，所以景观绩效中一个关键性的评估是尝试对景观项目提供的生态系统服务进行评估。于是，我们将 CSI 指标和生态系统服务指标进行比较以找出区别。

除了景观绩效之外，还有一些其他重要的景观可持续性评估方式，包括 LEED-ND 和 SITES。LEED-ND 和 SITES 都属于评价体系，它们为可持续性景观设计树立了标杆。



1 景观绩效量化的流程
Procedure of Landscape Performance Quantification

1

于是我们也将 CSI 指标与 LEED-ND 和 SITES 的指标进行比较。

另外，因为景观绩效是从建筑营造绩效中衍生出来的，所以我们也将景观绩效指标与一套使用后评估的建筑指标进行比较。

景观绩效的研究尚不成熟，量化的方法也鲜有参考。在许多案例中，使用何种方法进行量化取决于所能得到的数据。我们采用佩德哈泽和舒麦金（佩德哈泽与舒麦尔金，1991）对信度与效度的定义作为标准对几种典型的指标及其量化方法进行检验。

3 结论和讨论

3.1 指标分析

LAF 将景观绩效指标分为环境、经济和社会 3 个类别（表 1）。这些指标系统性地评估了由景观项目创造或改变的生态系统服务，包括供应服务、调节服务、支援服务以及文化服务（千年生态系统评估，2005）（图 2）。在景观绩效的框架下，环境指标可度量供应服务、调节服务和支援服务，社会指标可度量文化服务，经济指标可度量与生态系统服务相关的货币收益。现行案例研究调查计划的环境效益指标涵盖了大部分供应和调节服务，除了气候调节、降低风速、人类疾病控制和暴雨防护（橙色部分）。社会效益指标涵盖了大部分文化服务，但未涉及生态旅游、灵感激发和社会关系这些内容（图 2）。因此，我们建议 LAF 将这几项补充到未来的案例研究调查计划中。例如，风速的降低可用风速仪测出，并表述为“风速降低 n 英里 / 小时”，或“一年中有 n 天是低风速”。再如，人类疾病的控制可通过医院的接待量来度量，表述为“职工或居民就医的平均次数每年减少了 n 次。”表 4 展示了如何将这些指标添加到 CSI 中，并举例说明它们的测量和表述方法。

表 1 景观绩效指标（按资料来源中的顺序排列）（来源：LAF，2014）
Table 1 Landscape Performance Metrics (Following the sequence in the source) (Source: LAF, 2014)

环境 Environmental	土地 Land	交通 Transportation 土壤保护 Soil preservation 形成 / 修复土壤 Soil creation/restoration 土地利用效率 / 土地保护 Land efficiency/preservation 海岸线保护 / 重建 Shoreline protection/restoration
	水 Water	雨洪管理 Stormwater management 节水 Water conservation 水质 Water quality 防洪 Flood protection 地下水补给 Groundwater recharge
	栖息地 Habitat	栖息地保护 / 创建 / 恢复 Habitat preservation/creation/restoration 恢复廊道连通性 Restore corridor connectivity 改善栖息地环境 Improve habitat quality 增加物种多样性 Increase biodiversity 提高生态完整性 Increase ecological integrity
	碳、能源和空气质量 Carbon, Energy & Air Quality	能源使用及排放 Energy use & emissions 空气质量 Air quality 温度和城市热岛效应 Temperature & urban heat island 碳储存和固定 Carbon storage & sequestration
	材料与废弃物 Material &Waste	再利用 / 再回收材料 Reused/recycled materials 乡土材料 Local materials 绿色垃圾 Green waste 减少垃圾 Waste reduction
经济 Economic		房产价值 Property values 建设节约 Construction savings 节约运行与维护费用 O&M savings 减少更换 Replacement avoidance 游客消费 Visitor spending 税收收入 Tax revenue 经济发展 Economic development 创造就业机会 Job creation 注册增长 Increase enrollment
社会 Social	公共健康和安全 Public health & safety	用户满意度 User's satisfaction 生活质量 Life quality 噪音抑制 Noise mitigation 锻炼 Foster play/exercise 可步行 Walkability 心理治疗 / 精神价值 Therapy/spiritual value 减少交通事故 Traffic accident reduction 降低犯罪率 Crime reduction
		娱乐及社会价值 Recreational & social value 教育价值 Educational value 食品生产 Food production 风景质量 / 视线 Scenic quality/views 文化遗产 Cultural heritage 创造场所 / 场所感 Placemaking/sense of place 公平 Equity

LEED-ND 和 SITES 与 LPS 在许多方面都有不同。首先，LEED-ND 和 SITES 在景观项目设计及建设的初期阶段进行评估，LPS 评估则针对景观项目建成和使用后。另外，这三者的组织框架不同。LEED-ND 根据不同尺度而组织：环境 / 区域，社区和建筑。SITES 根据项目的生命周期而组织：选址，概念设计，设计，建造和使用。LPS 根据可持续三角而组织：环境、经济和社会（图 3）。从度量项来看，LPS 是唯一从环境、经济和社会 3 方面综合评估景观项目的一个体系。LEED-ND 注重环境方面，并未强调经济和社会方面；SITES 侧重环境方面和部分社会方面，而未考虑经济方面。

LEED、SITES 和 LPS 中不同的侧重点和度量方法决定了他们评估的指标不同。LEED 由美国绿色建筑协会（U.S.Green Building Council，简称 USGBC）于 1999 年首次提出，旨在促进环境友好型绿色建筑的发展，遵循了 20 世纪 90 年代“发展对环境低影响”的要求。后来，人们意识到除非一栋建筑处于绿色大环境中，否则不可能完全实现绿色生态，所以 USGBC 开发了 LEED-ND，将对绿色建筑的评估扩展到对于建筑周边景观环境的评估（USGBC2014）。

SITES 于 2006 年提出，在美国植物园（U.S. Botanic Garden）、德克萨斯大学奥斯丁分校伯德 • 约翰逊夫人野花中心(Lady Bird Johnson Wildflower Center at University of Texas, Austin）以及美国风景园林师协会（American Society of Landscape Architects, ASLA）的共同努力下完成。SITES 突出了健康的生态系统的重要性，使用评价体系来促进更具弹性和稳定性的景观设计（SITES，2014）。USGBC 长期支持 SITES 的创建和开发，因此，LEED 和 SITES 在其评价体系中有一些相似的指标（SITES，2014）

供应服务
（从生态系统中获得的产品）
Provisioning Services (Products obtained from ecosystems)
——食物 Food
——水 Water
——材料 Materials
——能源 Energy
——生物多样性 Biodiversity

调节服务
（从生态系过程调节功能中获得的收益）
Regulating Services
(Benefits obtained from regulation of ecosystems processes)
——空气质量维护
Air quality maintenance
——气候调节 Climate regulation
——碳封存 Carbon sequestration
——温度调节
Temperature regulation
——海岸线稳定
Shoreline stabilization
——雨洪管理
Stormwater management
——风速降低 Wind reduction
——控制侵蚀 Erosion control
——水体净化 Water purification
——垃圾治理 Waste treatment
——人类疾病防控
Regulation of human disease
——暴雨防护 Storm protection

文化服务
（从生态系统中获得的非物质效益）
Cultural Services
(Nonmaterial benefits obtained from ecosystem)
——精神的和宗教的
Spritual and religious
——娱乐和生态旅游
Recreation and ecotourism
——美学价值 Aesthetic values
——灵感 Inspiration
——教育价值 Educational values
——场所感 Sense of place
——文化遗产 Cultural heritage
——社会关系 Social relations

配套服务
（为所有其他生态系统服务产品带来必要的服务）
Supporting Services
(Services necessary for the production of all other ecosystem services)
——土壤形成 Soil formation ——养分循环 Nutrient cycling ——初级生产 Primary production

2

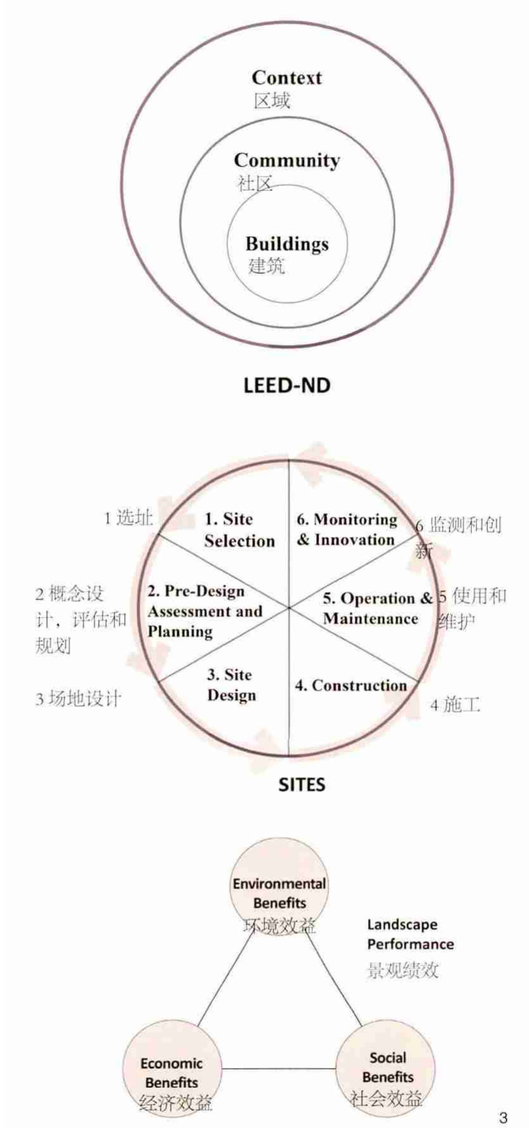
LEED-ND 和 SITES 中使用的评价体系是基于较早的研究及专家的估测而创建的，自 20 世纪 70 年代人们意识到可持续发展的重要性后，生态友好型设计就引起了人们极大的关注，大量阐释开发对环境影响的研究得以开展。但是，对项目使用者的态度的研究较为缺乏，这在某些程度上解释了为什么社会效益没有被包含在 LEED-ND 和 SITES 的评价体系中。另外，LEED-ND 和 SITES 的评估过程主要依赖预测，由于缺少相关专业知识技能以及受制于社会经济背景的多样性，设计专家很难通过估测为 LEED-ND 和 SITES 提供社会和经济的评估标准。这些原因导致了 LEED-ND 和 SITES 评价体系中社会和经济指标的缺失。

LPS 创建于 2010 年，晚于 LEED 和 SITES。此时，使用者视角和经济效益的重要性正逐步被人们所认识到。由于可持续开发项目的成本常常高于传统开发项目的成本，另外，某些传统的景观也更加受到使用者的青睐（比如人工草坪相对于野生草地），因此，业主和使用者有时并不喜欢可持续开发项目。意识到这一点后，LAF 在可持续三角的基础上提出了 LPS，每一个项目都需要通过可持续

2 与景观项目相关的生态系统服务 (在千年生态系统评估与特威尔等人的基础上改编)
Ecosystem Services Related to Landscape Projects.
(Adapted from: Millennium Ecosystem Assessment &Twill et al., 2011)

表 2 LEED-ND 评价体系列表（按资料来源中的顺序排列）（来源：USGBC, 2009）
Table 2 LEED-ND Rating System Checklist (following the sequence in the source) (Source: USGBC, 2009)

巧妙的选址与连接性 Smart Location and Linkage	巧妙的选址 Smart location
	濒危物种和生态群落 Imperiled Species and Ecological Communities
	湿地和水体保护 Wetland and Water Body Conservation
	农田保护 Agricultural land conservation
	避开河漫滩 Floodplain avoidance
	择优选址 Preferred locations
	棕地再利用 Brownfield redevelopment
	减少汽车依赖的选址 Locations with Reduced Automobile Dependence
	构建自行车网络和站点 Bicycle Network and Storage
	居住和工作临近 Housing and Jobs Proximity
	陡坡防护 Steep slope protection
	栖息地、湿地及水体保护的场地设计 Site Design for Habitat or Wetland and Water Body Conservation
	栖息地、湿地及水体的恢复 Restoration of Habitat or Wetlands and Water Bodies
	栖息地、湿地及水体的长期保护管理 Long-term Conservation management of Habitat or Wetlands and Water Bodies
邻里模式和设计 Neighborhood Pattern and Design	适合步行的街道 Walkable Streets
	紧凑发展 Compact development
	连接和开放的社社区 Connected and open community
	混合使用社区中心 Mixed-use neighborhood centers
	收入来源多样的社区 Mixed-income diverse communities
	减少停车占用的空间 Reduced parking footprint
	街道网络 Street network
	交通设施 Transit facilities
	交通需求管理 Transportation demand management
	连接市民公共空间 Access to civic and public spaces
	连接娱乐设施 Access to recreation facilities
	参与性和通用设计 Visitability and universal design
	社区外延和公众参与 Community outreach and involvement
	本地食物生产 Local food production
	绿树成荫 Tree-lined and shaded streets
	社区学校 Neighborhood schools
绿色基础设施 Green Infrastructure	认证的绿色建筑 Certified green building
	建筑节能 Minimum building energy efficiency
	建筑低耗水 Minimum building water efficiency
	施工污染防治 Construction activity pollution prevention
	注册绿色建筑 Certified green building
	建筑节能效率 Building energy efficiency
	建筑用水效率 Building water efficiency
	景观用水效率 Water-efficiency landscaping
	现有建筑再利用 Existing building reuse
	历史资源保护和利用 Historic resource preservation and adaptive use
	最小的干扰场地设计 Minimized site disturbance in design and construction
	雨洪管理 Stormwater management
	减弱热岛效应 Heat island reduction
	太阳方位 Solar orientation
	现场可再生能源利用 On-site renewable energy resources
	区域供热和降温 District heating and cooling
	基础设施能源利用效率 Infrastructure energy efficiency
	废水管理 Wastewater management
	废旧基础设施回收 Recycled content in infrastructure
	固体垃圾管理基础设施 Solid waste management infrastructure
	减少光污染 Light pollution reduction
创新与设计过程 Innovative and Design Process	创新和示范效益 Innovation and exemplary performance
	LEED 认证专业 LEED accredited professional
优先进行区域范围考虑 Regional Priority Credit	优先进行区域范围考虑 Regional priority



3

3 LEED-ND、SITES 和 LPS 的框架比较
Comparison of Frameworks between LEED-ND, SITES, and LPS

发展的 3 个方面来评估，即环境、经济和社会。此外，LPS 的评估在项目建成和使用后进行，因而能够有效评估经济效益并获取使用者的反馈意见。以上因素解释了 LEED-ND、SITES 和 LPS 评价体系的指标差异。

尽管 LEED-ND、SITES 和 LPS 存在差别，但三者都在评估景观的可持续性。因此，研究 LEED-ND 和 SITES 的得分体系的分类，从而找到景观绩效案例研究项目中可能存在的问题，这是很有价值的。

LPS 与 LEED-ND 及 SITES 对比的结果表明，三者在环境效益方面有许多相似之处，如土地保护，土壤保护 / 改良，节水，防洪，栖息地保护及修复，节能，减少碳排放 / 碳封存以及材料的回收再利用等内容。因为 LEED-ND 和 SITES 的评估包括项目的区域环境和生命周期，所以包含了几个现行 LPS 中没有的指标（表 2 及表 3 中橙色部分）。例如，LEED-ND 与 SITES 中都提到了巧妙的选址，评估项目的位置是否与现有交通体系紧密联系、是否能减少景观使用者对于机动车的依赖。这个指标可以补充到 LPS 中并表述为“降低了 n% 的机动车使用率”或“减少了 n% 的停车空间”。再如，在 SITES 中有这样一个指标——“考虑拆除的设计”，这个指标评估设计是否考虑了景观项目在生命周期结束并需要被拆除时的回收。这一指标可以补充到 LPS 中并表述为“减少了 n 磅垃圾”或“减少了 n 量运输垃圾的卡车的需求量，等于节省了 n 美元成本”。表 4 总结了 LEED-ND 与 SITES 中含有而 LPS 中没有的指标，并给出度量和表述的例子。

需要指出的是，LEED、SITES 和 LPS 需要互相配合。LEED、SITES 及 LPS 评估的都是项目在可持续性和设计策略上的有效性，LEED-ND 与 SITES 侧重于前瞻性预测，而 LPS 侧重于回溯性的量化，这两种分析类型互为补充。LEED 与 SITES 记录一个项目的详细信息，如基线数据和策略运用，然而现行的案例研究调查计划存在一个问题——项目的基线信息非系统性地收集，由此限制了项目的前后对比。LEED 与 SITES 中记录的数据有利于 LPS 的量化，并更好地指导未来的设计。另一方面，因为 LEED 与 SITES 是在预测项目的绩效，因此结果是不准确的。LPS 可以帮助完善现有的评价体系，并提升未来项目认证的准确性。

因为 LPS 是从建筑营造绩效衍生而来的，我们也参考了建筑营造绩效评估指标。特威尔（Twill）等人宣称绿色建筑中有 10 项可以量化的生态系统服务；这些生态系统服务与社会效益、经济效益共同组成了建筑营造绩

绿色建筑的生态系统测评服务体系
Measurable Ecosystem Services for Green Building
—碳封存 Carbon sequestration
—空气质量 Air quality
—防洪 Flood protection
—水储存 Water storage
—水过滤 Water filtration
—能量代谢 Energy consumption or generation
—雨水排放 Stormwater conveyance
—生物多样性 Biodiversity
—气温（热岛效应）Temperature (heat island effect)
—材料生命周期 Materials life-cycle

社会效益
Social Benefits
—人类健康 Human health
—劳动生产率 Worker productivity
—舒适度 Comfort
—满意度 Satisfaction
—幸福感 Well-being
—多样化交通 Transportation options
—场所营造 Placemaking
—亲近自然 Biophilia
—美学价值 Aesthetic values
—精神价值 Spiritual values
—娱乐价值 Recreational values
—科普教育价值 Scientific and educational values
—生态旅游机会 Ecotourism opportunities

经济激励机制 Economic Incentives
—能源激励机制 Energy incentives
—减少交通需求的激励措施 Transportation demand reduction incentives
—材料提供 Materials provision
—食物供给 Food provision
—碳信用 Carbon credits
—水调节激励机制 Water regulation incentives
—雨洪管理激励机制 Stormwater regulation incentives
—废物吸收分解激励机制 Waste absorption and breakdown incentives
—生物多样性与栖息地营造激励机制 Biodiversity and Habitat incentives
—土壤与养分激励机制 Soil and nutrient incentives
—室内空气质量激励机制 Indoor air quality incentives
—环保材料激励机制 Healthy materials incentives
—劳动生产率激励机制 Worker productivity incentives
—舒适度激励机制 Comfort incentives
—满意度激励机制 Satisfaction incentives
—幸福感激励机制 Well-being incentives
—多样化交通激励机制 Transportation options social incentives
—场所营造激励机制 Placemaking incentives
—亲近自然的激励机制 Biophilia incentives
……

4

4 建筑评价指标（来源：特威尔等人，2011）
Building Evaluation Metrics (Source: Twill et al., 2011)

表 3 SITES 评价体系列表（按资料来源中的顺序排列）（来源：SITES，2009）
Table 3 SITES Rating System Checklist (following the sequence of the source) (Source: SITES, 2009)

场址选择 Site Selection	指定为基本农田、特殊农田及全州重要农田的土壤限制开发 Limit development of soils designated as prime farmland, unique farmland, and farmland of statewide importance
	保护泛洪区功能 Protect floodplain functions
	保护湿地 Preserve wetlands
	保护濒危物种及栖息地 Preserve threatened or endangered species and their habitats
	选择棕地或荒地作再开发用地 Select brownfields or greyfields for redevelopment
	选择现有社区内的场地 Select sites within existing communities
	选择鼓励非机动车交通和公共交通的场地 Select sites that encourage non-motorized transportation and use of public transit
设计前评价和规划 Pre-Design Assessment and Planning	开展场地设计前评估并探索场地可持续发展的可能性 Conduct a pre-design site assessment and explore opportunities for site sustainability
	运用综合的场地开发流程 Use an integrated site development process
	鼓励场地设计中的使用者和其他利益相关者参与设计 Engage users and other stakeholders in site design
场地设计 - 水 Site Design – Water	将景观灌溉用水的使用量从现有基准值下降 50% Reduce portable water use for landscape irrigation by 50% from establish baseline
	将景观灌溉用水的使用量从现有基准值下降 75% 以上 Reduce portable water use for landscape irrigation by 75% or more from established baseline
	保护并修复河岸、湿地与海岸缓冲区 Protect and restore riparian, wetland, and shoreline buffers
	恢复消失的河流、湿地与海岸线 Rehabilitate lost streams, wetlands, and shorelines
	场地雨洪管理 Manage stormwater on site
	保护并提升场地内水源及回收水的质量 Protect and enhance on-site water resources and receiving water quality
	雨水 / 暴雨适应型设计，突出景观舒适性 Design rainwater/stormwater features to provide a landscape amenity
	节约用水及其他资源 Maintain water features to conserve water and other resources
场地设计 - 土壤和植物 Site Design – Soil and Vegetation	控制和管理场地内入侵性植物 Control and manage known invasive plants found on site
	运用合适的、非入侵性植物 Use appropriate, non-invasive plants
	创建土壤管理计划 Create a soil management plan
	在设计建设中最小化对土壤的干扰 Minimize soil disturbance in design and construction
	保护标志性植物 Preserve all vegetation designated as special status
	保留或恢复场地中适量的植物生物量 Preserve or restore appropriate plant biomass site
	运用乡土植物 Use native plants
	保留生态区域内的乡土植物群落 Preserve plant communities native to the ecoregion
	恢复生态区域内的乡土植物群落 Restore plant community native to the ecoregion
	运用植物降低建筑排放热量 Use vegetation to minimize building heating requirements
	使用植物满足建筑降温需求 Use vegetation to minimize building cooling requirements
	减轻城市热岛效应 Reduce urban heat island effect
	降低灾难性大火风险 Reduce the risk of catastrophic wildfire
场地设计 - 材料选择 Site Design – Material Selection	不使用濒危树种木材 Eliminate the use of wood from threatened tree species
	保持场地构筑物、硬质景观及优美风景 Maintain on-site structures, hardscape, and landscape amenities
	考虑拆除的设计 Design for deconstruction and disassembly
	再利用回收材料及植物 Reuse salvaged materials and plants
	使用回收材料 Use recycled content materials
	使用认证木材 Use certified wood
	使用乡土材料 Use regional materials
	使用挥发性有机化合物排放量低的胶粘剂、密封胶、涂料、涂层 Use adhesives, sealants, paints, and coating with reduced VOC emissions
	支持植物保护可持续实践 Support sustainable practices in plant production
	支持材料制造可持续实践 Support sustainable practices in materials manufacturing

场地设计 - 人类健康和福利 Site Design – Human Health and Well-Being	促进场地平衡开发 Promote equitable site development
	促进场地平衡利用 Promote equitable site use
	加强可持续意识和教育 Promote sustainability awareness and education
	保护和保持特殊文化和历史场所 Protect and maintain unique cultural and historical places
	提供最适宜的场地可达性，安全性和指示性 Provide for optimum site accessibility, safety, and wayfinding
	提供户外体育活动场所 Provide opportunities for outdoor physical activity
	提供植物认知和户外精神疗养的安静场所 Provide views of vegetation and quiet outdoor spaces for mental restoration
	提供户外社交场所 Provide outdoor spaces for social interactions
	减少光污染 Reduce light pollution
施工建造 Construction	控制建设施工污染 Control and retain construction pollutants
	恢复施工中受干扰的土壤 Restore soils disturbed during construction
	恢复先前开发中受干扰的土壤 Restore soils disturbed by previous development
	清理拆除的材料垃圾 Divert construction and demolition materials from disposal
	植物、石材、施工后土壤的再利用及回收 Reuse or recycle vegetation, rocks, and soil generated during construction
	减少温室气体排放 减少施工中局部空气污染 Minimize generation of greenhouse gas emissions and exposure to localized air pollutants during construction
使用和维护 Operation and Maintenance	制定可持续场所维护计划 Plan for sustainable site maintenance
	提供储存和收集回收场所 Provide for storage and collection of recyclables
	回收场地使用和维护中产生的有机物质 Recycle organic matter generated during site operations and maintenance
	减少的所有景观使用中的户外能源消耗 Reduce outdoor energy consumption for all landscape and exterior operations
	景观用电使用可再生能源 Use renewable sources for landscape electricity needs
	减少环境院草烟雾 Minimize exposure to environmental tobacco smoke
	减少景观维护中产生的温室气体和局部空气污染 Minimize generation of greenhouse gases and exposure to localized air pollutants during landscape maintenance activities
	较少排放并提倡高效节能车辆的使用 Reduce emissions and promote to use of fuel-efficient vehicles
监控和创新 Monitoring and Innovation	可持续设计实践的监控效益 Monitor performance of sustainable design practice
	场地设计创新 Innovation in site design

效评估的指标（图 4）。景观绩效可以借鉴这些建筑营造的指标。例如，工人工作效率可以补充到 LPS 中并表述为“提高了 n% 的工人的工作效率”或“增加了 n% 的公司的年收入”图 4 总结了可以补充到 LPS 中的建筑营造评价指标。

3.2 对现行方法的评估

景观绩效系列（LAF）将景观绩效定义为“对景观实现其预设目标以及为实现可持续发展做出的贡献的衡量指标。”（LAF, 2014）。正如佩德哈泽和舒麦尔金于 1991 年提出的，度量的质量通常取决于度量方法的信度（Reliability）和效度（validity）。信度包括内部一致性、可重复性与稳定性，用于确定实验结果是否一致并可重复；效度用于判断一种仪器是否或者在多大程度上度量了我们需要度量的东西，它可以被进一步分为 3 个主要方面：内容效度、效标效度和结构效度。

3.2.1 CSI 计划使用的主要方法

CSI 计划主要用于支持设计和多功能景观评估。由于每一个 CSI 项目都是独特的，研究团队又通常分开工作，所采用的定量方法和记录的景观效益都彼此有别。在我们看来，所有调研方法都有一个共同的缺点，即它们都是“一次性观测”。当然，“一次性观测”能够表达可持续景观所创造的效益的一个横截面，它们也有利于对可持续发展和传统发展的对比研究。但如果我们的目标是准确量化景观绩效，许多方法的可靠性和有效性都有待推敲。

海恩斯 - 杨（Haines-Young, 2000）提出，景观是一个动态过程而不是一种固定状态。因此，一次性观测并不能展现可持续性的所有维度。景观的可持续性取决于持续提供生态系统服务的能力、产生新的效益能力和降低相

表 4 对未来 CSI 指标的建议
Table 4 Recommendations on Metrics for Future CSI

有利资源分类 Benefit Categories		指标 Metrics	如何评测与报道 How can it be measured and reported?
环境效益 Environmental	土地 Land	巧妙选址 Smart location（LEED-ND & SITES）	降低停车面积达 n% Reduced parking footprint by n% 降低机动车依赖达 n% Reduced automobile dependence by n%
	水源 Water	建筑活动污染防治 Construction activity pollution prevention（LEEN-ND）	阻止污染物进入水源达 n% Prevented n% of pollutants from entering the water system.
		暴雨防护 Storm protection （千年生态系统评估 Millennium Ecosystem Assessment）	降低飓风 / 巨浪的损害达 n% 或 $n Mitigated the damage of hurricane/large waves by n% or $n
	碳 Carbon 能源 Energy 空气质量 Air Quality	气候调节 Climate regulation（千年生态系统评估 ）	减少极端降水达 n% Reduced extreme precipitation by n% 每年减少干旱天数达 n reduced drought days by n per year
		风调节 Wind reduction（千年生态系统评估）	降低风速达 n mph Reduced wind speed by n mph 每年减少多风天数达 n Reduced windy days by n per year
	材料 & 废弃物 Material & Waste	拆除及分解设计 Design for deconstruction and disassembly（SITES）	降低废物运输需求达 n% Reduced the demand for waste transportation by n% 减少废物产生达 n% Reduced waste by n%
		使用经过认证的木材 Use certified wood（SITES）	减少某种木料消耗达 by n%, 节约成本达 $ n Reduced consumption of n wood by n, saving $ n in cost
		使用低有机化合物挥发的材料 Use materials with reduced VOC（SITES）	减少暴露于空气污染或挥发性有机化合物达 n% Reduced exposure to air pollution/VOC by n%
经济效益 Economic		对可持续策略的激励机制 Incentives due to sustainable solutions（Twill et al.）	由于某种做法从成本 n 中节约 $n Obtained $n from n because of n 由于采用某种可持续策略节约税收 $ n Reduced $ n tax due to applied sustainable solutions
社会效益 Social 光污染减少 Light pollution reduction（LEEN-ND & SITES） 灾难性大火 Catastrophic wildfire（SITES） 劳动生产率 Worker productivity（Twill et al.）		人类疾病 Human diseases（千年生态系统评估）	降低居民与病原体接触达 n% Reduced residents' exposure to pathogens by n% 降低探病率达 n Reduced hospital visit by n
		降低光污染达 n% Reduced light pollution by n% 降低由于光污染引发的交通事故达 n% Reduced car accident by n% through light pollution prevention n% 调查对象反映光污染减弱 n% of respondents who surveyed express that the light pollution is reduced	
		降低灾难性大火产生的风险达 n% Reduced the risk of catastrophic wildfire by n%	
		提高雇佣者的劳动生产率达 n% Increased productivity of employee by n% 增加公司年收入达 $n Increased company's annual revenue by $n	
		幸福感 Well-Being（Twill et al.）	每年降低的医疗费用达 $n Reduced medical spending by $n every year 降低探病次数达 n% Reduced hospital visit by n%
		舒适感 Comfort（Twill et al.）	全年创造舒适环境天数达 n（舒适范围内的温度和风） Created comfort environment (temp. wind in a certain range)for n days in a year. n% 调查对象反映舒适度提升 Improved comfort for n% of respondents who surveyed
		经济价值 Ecotourism values（Twill et al.）	共为 n 名游客提供生态旅游 Provided opportunity of ecotourism to n visitors 因生态旅游提高收入达 n Increased revenue income by n due to ecotourism opportunities

关成本的能力。如果效益定量方法能够表达景观的这些能力，我们就可以判定该景观方案正在实现其目标并且对于可持续性有贡献。下面我们将深入讨论一些被广泛提及的指标和定量方法。

3.2.2 生境保护和丰富生物多样性的方法

在2011年开展的39个景观绩效案例研究中，有23个案例提到了“生境保护、创建和恢复”的功能。由于动植物数量的统计十分消耗时间与成本，因此大多数研究援引了他人的研究成果。比如，阿瓦隆公园与保护区（Avalon Park and Preserve）案例引用了一项阿瓦隆公园与保护区的研究，并将其与自然资源库（Inventory of Natural Resources）中拉夫金（Revkin，2009）以及金、高和权（Kim, Koh & Kwon， 2009）关于清溪川恢复工程的两项研究的数据进行了对比，而老柯里尔高尔夫俱乐部（Old Collier Golf Club）案例引用了奥杜邦国际（Audubon International）的研究成果。

在生物多样性方面，有3个项目运用了植被管理指标（Plant Stewardship Index，简称PSI）对比他们的项目场地在景观建设前后的生物多样性变化（阿瓦隆公园与保护区 Avalon Park and Preserve，库桑诺教育中心 Cusano Educational Education Center 和救世军克罗克社区活动中心 Salvation Army Kroc Community Center）。

发表的研究成果均经过了同行的评审，因而具有良好的效标效度，但其可靠性和内容效度值得商榷。景观会随着时间而改变和发展，所引用的研究都是在景观绩效评估之前完成的，然而随着时间的推移，研究区域内的生物多样性很可能已经随着景观的发展和人类的活动而改变。因此，引用的研究不能充分代表景观绩效研究开展时场地的状态。另外，内容效度也是有待商榷的，因为先前由其他人进行的相关研究并不能涵盖生物多样性的各个方面。比如，在23个被报道生物多样性有所提升的研究中，大多数只有鸟的种类增加的数据。在同一时期，我们并不能排除如小型哺乳动物、鱼类、两栖类生物种类都减少的可能性，以此推断景观项目提升了该区域的生物多样性是片面的。至于PSI，这是一项经过检验的生物多样性度量方法，因此在宾夕法尼亚和新泽西山麓地带运用PSI的那些案例研究的标准效度和可靠性都是很好的。

对比这2种方法，援引他人研究成果的优势在于节约时间和成本，缺陷在于数据并不是专门为景观绩效量化而收集的，降低了其内容效度。PSI在效度和可靠性方面都有所保障，但只适用于一些特定范围，不能广泛应用于不同区域项目之间的比较。

3.2.3 雨洪管理（径流与下渗）

雨洪管理的测量有很多方法。比如美国风景园林师协会总部屋顶绿化运用流量计和雨量测量计来检测水质和水量。马利布木材厂报道了工程师的生态滞留设计参数，假设它会依照设计预期工作。洛杉矶港威尔明顿海滨公园运用国家林木效益计算器（the National Tree Benefit Calculator）估算树木截留的雨量。其他项目如黎明社区和克雷斯吉基金会（Daybreak and Kresge Foundation Headquarters）则引用了前人的研究。

运用流量计和雨量测量计监测雨水总量和质量的方法保证了景观绩效定量研究的第一手数据能够被地收集起来，在信度和效度方面都是令人信服的。这种方法的缺点在于，当研究场地较大时成本十分高昂。另外，为了保证数据普遍适用和可靠，研究团队还需要进行长时间的数据收集，费时费力。因此，这一方法仅适用于类似屋顶花园这种边界明确、只需要少量测量仪器就能完成数据收集的小场地研究。

只有在难以获得实际数据的情况下才能考虑使用设计参数作为替代，进行景观绩效的预测。比如，如果项目开始后没有降雨，则可以用设计参数来替代实际降雨量。显然，这并不等同实际测量。CSI的目标是实际测量景观绩效，并与设计意图进行对照，用参数带入的预测并不能达到该目标，因此在任何情况下都不推荐使用。

然而，运用LAF绩效工具包评估景观绩效的方法是不同的。iTree（国家树木效益计算器）广泛应用于CSI项目，尤其常运用于计算碳封存。该工具是由美国农业部林务局等多家合作伙伴开发的，经过同行评议的软件，其标准有效性和可靠性都有所保障。值得一提的是，这种工具只提供了对树木绩效的概算，不具有准确的科学价值。因此结论可能与真实数值有出入，特别是当其应用于美国以外的场地时。尽管如此，它仍被认为是测算树木绩效的最好工具。

3.2.4 节水

39个项目中，有26个项目记录了景观项目的节水功能。其中，有9个项目通过种植乡土树种或耐旱品种减少了灌溉需求；6个项目通过安装节水型水管装置和灌溉设备减少了水资源浪费。这些景观绩效都是根据水量计读取的，具有真实有效性。

然而，文献表明种植乡土植物品种往往会引起用户的不满。例如戴维斯等人（戴维斯等，2004）宣称乡土品种在城市里的成功很大程度上取决于人们的观感，再如纳绍尔（纳索尔，1993）发现人们更喜欢较为传统、有序的景观。大多数CSI项目都是在5年内建成的，乡土物种的长期绩效取决于人们在多大程度上能够接受富有“野趣”的景观设计。如果人

们并不欣赏这种“野趣”，设计很可能将被改回传统样式，景观节水的绩效将因此丧失。

此外，虽然使用再生水灌溉用可以节约饮用水，但这种做法对于植物生长和人类健康和满意度的影响尚未明晰。这种方法节水的实际效果还须通过长期监测才能判定。

3.2.5 材料与废弃物

虽然材料回收再利用和废弃物减少包含于景观绩效的环境类别中，但它的价值有时是通过节约施工成本的经济价值来体现的。比如，根据洛杉矶港威尔明顿滨水公园（the Port of Los Angeles Wilmington Waterfront Park）的报道，经托运公司计算，公园建设中通过回收水泥和沥青降低运输成本约 97 500 美元。然而波特治湖滨与散步道（Portage LakeFront and Riverwalk）引用了另一家公司准备的 LEED 评估文件，指出 75% 的废弃物得到回收再利用。尽管两个研究团队都表明材料回收和再利用是经济的，但他们使用的方法是不全面的，在内容效度上存在问题。

洛杉矶港威尔明顿海滨公园考虑了避免运输节约的成本，但忽视了在建筑材料项目上的成本节省。而波特治湖滨与散步道仅关注材料成本的节省，忽视了运输成本的节约。此外，这两个案例都没能认识到，材料回收再利用可能需要消耗额外的劳动力和技术，这可能同样昂贵。另外，回收和再利用材料有可能存在耐久性较差、生命周期较短的问题。这些被忽略的因素降低了评估的有效性。

3.2.6 经济发展

由于在数据收集和变量选择上具有一定困难，经济发展的量化颇为困难。许多经济数据经由市、郡、地区和国家层面采集，基于这些数据难以确定某个特定景观项目对经济增长究竟有多大贡献。清溪川恢复工程对比了项目所在区域与首尔市中心区的商业和劳动人口增长量。千禧公园则通过公园周围区域 6 年内居住单元和旅游业的增长量来证明商业的增长。

这两种方法都运用了对比的方法：清溪川恢复工程在项目区域和城市中心区之间做了横向比较，而千禧公园则纵向比较了一段时间内项目周边区域的变化。这种比较排除了其他变量的影响，提高了信度和效度。当具备项目区域内的历史数据时，纵向比较可以用于展现当地经济如何随时间增长。如果掌握了某个时间几个不同区域的经济数据，横向比较可以用于观察景观项目所在区域的经济是否优于其他区域。

3.2.7 公共健康与安全

与经济发展相似，公共健康和安全也很难量化。目前 CSI 中的相关指标是“居民 / 雇员满意度”“步行适宜性”和“噪声等级”。其中，噪声等级的降低常以定点测量或专家估算予以量化。与运用流量计或雨量计来监测雨洪相似，运用设备测算噪音等级的方法有不错的信度和效度。居民 / 雇员满意度和步行适宜性则更多通过调研或采访的形式来评估，其信度和效度取决于调查或采访是如何计划与进行的。由于采访问卷通常并不公开，在此我们不探究其信度和效度。

本文通过将现行的景观绩效指标与生态系统服务、建筑营造绩效评价指标、LEED-ND 和 SITES 中的指标进行对比，对景观绩效指标进行了考察。同时本文也探讨了其中几个广泛运用的方法的信度和效度。

与其他评价体系相比，景观绩效是唯一一个在总体框架上包括可持续性 3 方面的评价体系。LEED-ND 从大到区域环境、小至建筑的多种尺度评估景观项目。SITES 则通过生命周期评估。这 2 种不同的评价体系的视角能使景观绩效指标更为详尽。另外，建筑绩效评估和使用后评估比景观绩效更加成熟，其中有许多指标值得借鉴，对现行景观绩效的指标进行补充。可以补充至景观绩效的指标如下：

（1）环境效益：

① 巧妙选址

② 施工活动污染防治

③ 暴雨防护

④ 气候调节

⑤ 风调节

⑥ 考虑拆除的设计

⑦ 使用认证木材

⑧ 运用低挥发性有机化合物的材料

（2）经济效益：

① 可持续设计的激励机制

（3）社会效益：

① 人类疾病控制

② 光污染控制

③ 防止灾难性大火

④ 劳动生产率

⑤ 幸福感

⑥ 舒适感

⑦ 生态旅游

景观绩效的研究尚在起步阶段，对环境效益、经济效益和社会效益进行量化的经验是很有限的。在某种程度上，研究团队是根据数据的易得性及其研究者的专长来选择指标和研究方法的。因此采用的研究方法在不同项目之间往往不一样，难以保证研究方法和研究成果的可靠性和有效性。我们建议制定标准化的数据收集准则以减少研究对数据易得性的依赖。此外，随着景观绩效系列数据库的扩大，我们建议发展标准的量化方法，这不仅可以增加研究结果的信度和效度，同时也将方便不同研究之间的对比。

1 Introduction

Since being first put forward by the World Commission on Environment and Development, sustainable development has been developing expansively over the past thirty years. It emphasizes balancing sustainability's three aspects: preserving the environment, boosting the economic development, and improving equity (WCED, 1987; Campbell, 1996). Numerous planning and design practices, such as new urbanism, smart growth, transit oriented development, and mixed-use development, emerged to pursuit this balance. Moreover, research and practice on sustainable design strategies bloom, such as low impact development techniques, native species, renewable energy resources, and recycled materials.

Landscape architecture is an evidence-based profession and discipline, in which creditable evidence is used to guide future design. In order to further promote sustainable design practice, scientific evidence that supports design and presents performance needs to be collected. Various efforts have been made to collect this evidence. Examples of these efforts include Leadership in Energy and Environmental Design for Neighborhood Development (LEED-ND), Sustainable Sites Initiative (SITES), and Landscape Performance Series (LPS).

LEED-ND and SITES are rating systems. They consist of a series of metrics addressing different aspects of sustainability. Each metric is associated with a certain number of points. Design documents of participating projects are examined by the metrics to decide whether the projects can earn the points of the metrics. These rating systems recognize landscape projects' degree of sustainability and to some extent promote sustainable design practice.

LPS was initiated by Landscape Architecture Foundation (LAF). It is "an online interactive set of resources to show value and provide tools for designers, agencies and advocates to evaluate performance and make the case for sustainable landscape solutions (LAF, 2014)." Unlike LEED-ND and SITES, landscape performance is a backward evaluation system. That is, it quantifies performance of landscape solutions after a project is constructed rather than estimating or predicting outcomes based on design and construction documents.

Landscape performance quantification was conducted through a Case Study Investigation (CSI) program, a collaboration of faculty, students and design firms (LAF, 2014). For landscape performance evaluation, to decide what to measure (metrics) is especially important. Metrics are often selected based on what landscape solutions have been applied in a project and how well the metrics can reflect the performance of the solutions. Equally important to the metrics are the methods. If the quantification methods are not appropriate, the results would be misleading. Figure 1 shows the procedure of CSI program's landscape performance quantification.

This study includes two objectives. The first is to compare the currently used metrics of landscape performance with ecosystem services, checklists of LEED-ND and SITES, and building performance metrics to identify gaps and make recommendations on improving future landscape performance metrics. The second objective of this study is to examine and discuss the reliability and validity of the methods that are frequently used in landscape performance quantification.

2 Methods

The overarching goal of measuring landscape performance is to inform future design decision-making. If performance is not measured correctly, the results will be misleading, and problematic decisions will follow. Therefore, selecting appropriate metrics and methods is important. Landscape design creates and modifies ecosystems. One critical assessment in landscape performance is an effort to evaluate the ecosystem services provided by landscape projects. With that being said, we compared the CSI metrics against ecosystem services to identify gaps.

Besides landscape performance, other significant efforts in assessing sustainability of landscape projects include LEED-ND and SITES. LEED-ND and SITES are both rating systems, providing performance benchmarks for sustainable land design. We compared the CSI metrics against the checklists of LEED-ND and SITES to identify gaps.

Further, since landscape performance is derived from building performance, landscape performance metrics were also compared against a set of post-occupancy evaluation metrics of buildings to identify gaps.

Landscape performance research is still new. There are few guidelines on quantification methods. In many cases, readily available data determine what methods would be used. We selected several typically reported metrics and discussed their quantification methods. The examination standards are reliability and validity as defined by Pedhazur and Schmelkin (1991).

3 Results and Discussion

3.1 Analysis of Metrics

LAF classified landscape performance metrics into the environmental, economic, and social categories, as shown in Table 1. These metrics systematically evaluate ecosystem services that are created or changed by landscape projects. Ecosystems include provisioning services, regulating services, supporting services and cultural services (Millennium Ecosystem Assessment, 2005) (Figure 2). Under the landscape performance's framework, environmental metrics measure provisioning, regulating, and supporting services. Meanwhile, social metrics measure cultural services, and economic metrics measure monetary benefits associated with ecosystem services. Compared to the ecosystems services shown in Figure 2, environmental benefit metrics of the current CSI program address most provisioning and regulating services except for climate regulation, wind reduction, regulation of human disease, and storm protection (highlighted with red dash lines). Social metrics cover a majority of cultural services except for ecotourism, inspiration, and social relations. Therefore, we suggest LAF include these metrics in its future CSI programs. For example, wind reduction can be measured using an anemometer and reported as "reduced wind speed by n mph" or "reduced windy days by n days per year." For another example, regulation of human disease can be measured by counting hospital visit and reported as "reduced employee/residents' average number of hospital visit by n times per year." Table 4 shows how the metrics can be added to the CSI benefit metrics and some examples of how these metrics can be measured and reported in CSI.

LEED-ND and SITES differ from landscape performance in a number of ways. First, LEED-ND and SITES evaluate landscape projects at the design and early construction phases, while landscape performance targets on landscape projects after they are built and occupied. Additionally, LEED-ND, SITES and the landscape performance metrics are organized differently. LEED-ND is organized according to scale: context/location, community pattern, and buildings. SITES is organized according to a project's life cycle: site selection, predesign, design, construction, and operation. Landscape performance is organized according to the sustainability triad: environment, economy, and society (Figure 3). In terms of items that are measured, landscape performance is the only one that evaluates projects in the three environmental, economic and social aspects. LEED-ND focuses on environmental aspects, without addressing economic and social aspects. SITES focuses on environmentaland part of the social aspects, without taking into consideration of economic aspects of sustainability.

The different focuses and measuring methods used in LEED, SITES and LPS determine that the items they measured are different. LEED was first initiated in 1999 by the U.S. Green Building Council (USGBC) to promote green buildingsthat are environmentally friendly, complying with the growing demand of reducing developments' impact on the natural environment in 1990s. Later on, it is realized that a building cannot be totally green unless it is located in a green context, so the USGBC developed LEED-ND to extend its evaluation to a building's surrounding landscapes (USGBC 2014).

SITES was created in 2006 by a collaborative effort of the U.S. Botanic Garden, Lady Bird Johnson Wildflower Center at University of Texas, Austin, and American Society of Landscape Architects. SITES highlights the importance of healthy ecosystems, using the rating system to promote landscape designs that are more resilient and stable (SITES, 2014). USGBC has been supporting the creation and development of SITES for a long time, and therefore, LEED and SITES share several similar credits in their rating systems (SITES, 2014).

The scoringsystems used in LEED-ND and SITES were developed based on previous research and experts' estimation. Since realizing the importance of sustainable development in 1970s, considerable attention has been paid to promoting environmentally friendly design practices and abundant research has been conducted to clarify theenvironmental impacts of a development. However, efforts dedicated to analyzing users' perspective on a development are not as much, somewhat explaining why social aspect is not covered in the rating systems. Additionally, the scoring process of LEED-ND and SITES are mostly based on prediction. It is often more difficult for design experts to estimate users' perspective and economic performance of developments due to a lack of professional knowledge, skills and various social-economic contexts. These reasons contribute to the result that social and economic metrics are not included in LEED-ND and SITES.

LPS was initiated in 2010 after LEED

and SITES, when the importance of users' perspective and a development's economic development was increasingly aware of. Sustainable developments normally cost more than conventionaldevelopments; plus, some conventional landscapes are more favored by users (e.g., lawn vs wild grasses). Therefore, clients and users sometimes do not prefer sustainable developments. With that being realized, LAF built LPS upon sustainability triad and requires every project to be assessed in the three aspects of sustainability, resulting in the environmental, economic and social metrics being included in LPS. Furthermore, LPS assesses a development after it is constructed and occupied, making it possible to evaluate its economic performance and obtain users' perspective. The factors above explain why the items measured in LEED-ND, SITES and LPS are different.

Despite their differences, LEED-ND, SITES and LPS all attempt to evaluate landscapes' sustainability. Therefore, it is valuable to study the scoring categories of LEED-ND and SITES to identify potential gaps existing in landscape performance case study programs.

The results of comparing landscape performance with LEED-ND and SITES indicate that they share many similarities in environmental benefits such as land preservation, soil preservation/restoration, water conservation, flood protection, habitat preservation/restoration, energy conservation, carbon reduction/sequestration and recycle and reuse of materials. Because LEED-ND and SITES evaluate the context and life cycle of a project, they include several metrics that landscape performance does not (as highlighted in bold red letters in Table 2 and Table 3). For example, both LEED-ND and SITES have a smart location category, which evaluates whether projects' site locations are close to existing transit systems/ development and reduce users' dependence on automobiles. This metric can be added to landscape performanceand represented as "reduced average autotrips by n%" or "reduced parking footprint by n." For another example, SITES has a metric, "design for deconstruction and disassembly." This metric examines whether landscape projects plan for recycling and salvage when theyneed to be demolished at the end of their life cycle. It can be added to LPS and reported as "reduced waste by n lbs." or "reduced the demand for waste transportation by n trucks, equals cost saving of $ n." Table 4summarizes the LEED-ND and SITES metrics that are not included in LPS and provides examples of how to measure and report them.

It is also worth noting that there is a demand for LEED, SITES and LPS to collaborate. LEED, SITES and LPS all evaluate the effectiveness of sustainable development and design strategies. LEED-ND and SITES focus on prospective predicting, while LPS focuses on backward quantification. These two types of analysis complement each other. LEED and SITES document a project's detailed information such as baseline data and strategies applied, while, one problem of the current CSI program is that projects' baseline information is not collected systematically, limiting the before and after comparison of a project. The documented data in LEED and SITES can benefit landscape performance quantification and better inform future design. On the other hand, since LEED and SITES predict a project's performance, the result is not as accurate. LPS can help confirm the rating systems and improve their accuracy for future project certification.

Since landscape performance is derived from building performance, we also referred to building performance for metrics. Twill et al. (2011) claimed that for green buildings, there are ten potentially measureable ecosystem services; these ecosystem services, together with the social and economic benefits they provide, compose building performance evaluation metrics (Figure 4). Landscape performance can borrow some of these building metrics. For example, worker productivity could be added to landscape performance and reported as "increased employee's productivity by n%" or "increased company's annual revenue income by $n." Table 4 includes the building evaluation metrics that can be added to LPS.

3.2 Evaluation of the Currently Used Methods

LAF defines landscape performance as "The measure of efficiency with which landscape solutions fulfill their intended purpose and contribute toward achieving sustainability." (LAF, 2014)As Pedhazur and Schmelkin (1991) argued, the quality of measurement often depends on reliability and validity of the measuring methods. Reliability, as they claimed, also known as internal consistency reliability, repeatability and stability, is used to determine whether a study result is consistent and reproducible. Meanwhile, validity is used to determine whether or to what extent an instrument measures what it is intended to measure; it can be further divided into three main aspects: content validity, criterion validity and construct validity (Pedhazur & Schmelkin, 1991).

3.2.1 Major Method Used in the CSI Program

The CSI program is an effort to support design and assessment of multifunctional landscape. As every project of the CSI program is unique and research teams typically work separately, the documented landscape benefits and employed quantification methods vary from team to team. In our opinion, one drawback of the research methods is that almost all measurements are one time snapshots. Certainly, the cross-sectional snapshots evidence performance benefits created by sustainable landscape solutions. They also facilitate comparative study between sustainable and traditional developments. However, if our goal is to accurately quantify landscape performance benefits, the reliability and validity of many methods are questionable.

Haines-Young (2000) argued that landscape is a dynamic process rather than a state. Therefore, snapshots could not demonstrate the full spectrum of sustainability. Sustainability of landscapes depends on their ability to continue to provideecosystem services in the future and their capacity to generate new types of benefits and reduction of associated cost (Haines-Young, 2000). If the benefit quantification methods can address such ability and capacity of a landscape, we believe that the landscape solutions are fulfilling their purpose and contributing toward sustainability. Next, we will discuss some widely reported metrics and their quantification methods in detail.

3.2.2 Methods for Habitat Preservation / Biodiversity Increase

Out of the 39 landscape performance case studies published by the 2011 CSI program, 23 reported "habitat preservation, creation and restoration." Animal and vegetation count is both time and cost consuming. Thus, mostresearch teams cited study results from others. For example, Avalon Park and Preserve cited an Avalon Park and Preserve survey and compared it with the baseline Inventory of Natural Resources, Cheonggyecheon Stream Restoration Project cited studies of Revkin (2009) and Kim, Koh& Kwon (2009), and Old Collier Golf Club cited study results of Audubon International.

In terms of biodiversity, three projects employedthe Plant Stewardship Index (PSI) to compare biodiversity of the study sites before and after construction (Avalon Park and Preserve, Cusano Educational Education Center, and Salvation Army Kroc Community Center).

Guaranteed by peer review, results of published studies have good criterion validity. However the reliability and content validity arearguable. Landscapes change and develop overtime; the cited studies were conducted before landscape performance was documented; as time goes by, biodiversity is very likely to change together with landscape development and human activities. For this reason, the cited studies cannot fully represent the situation when the landscape performance was conducted. In addition, content validity is also debatable, because these previous studies conducted by other people might not address all aspects of biodiversity. For example, among the 23 case studies that reported biodiversity increases, most only have evidence for bird species increases. It is possible that other species like small mammals, fish, amphibians all decreased;therefore, we cannot conclude that the landscape projects increase the biodiversity of the site. As for the PSI scale, it is an approved biodiversity measurement in the Piedmont of Pennsylvania and New Jersey; so its criterion validity and reliability are good.

Comparing the two methods, the strength of citing other people's research is that it saves time and cost. The weakness is that the data were not collected specifically for the purpose of landscape performance quantification, which undermines its content validity. The PSI scale is good for both validity and reliability. However it is only valid in particular areas and cannot be used broadly to make a comparison between projects in different regions.

3.2.3 Stormwater Management (Runoff, Infiltration)

Various methods are employed to measure stormwater management. For example, ASLA Headquarters Green Roof used flow meters and gauges to monitor water quality and quantity. Marlibu Lumber Yard reported engineer's design parameter forbioretention, assumingit would perform as designed. Port of Los Angeles Wilmington Waterfront Park used the National Tree Benefit Calculator to estimate stormwater captured by trees. Some other projects such as Daybreak and Kresge Foundation Headquarters citedprevious research.

The method of using flow meters and rain gauges to monitor stormwater quality and quantity is solid in reliability and validity. It allows first hand data to be collected specifically for the purpose of landscape performance quantification. The weakness of this method is that it could be costly when project sites are large. Further, in order to increase data's generalizability and reliability, research teams may need to collect data for a long time, which could be time-consuming and labor-intense. This method isapplicable for small sites like a roof gardenwhosestudy boundary is clearly defined and requires only a few measuring devices.

Using design parameters to predict landscape performance is only acceptable as a substitutewhen real world data could not be obtained. For example it never rains since the project was constructed. However this is not a real measurement. The goal of CSI is to physically measure landscape performance and compare it with designers' intention. The prediction here does not achieve the goal and is not recommended in any situation.

However, using LAF's Benefit Toolkit to assess landscape benefits is different. iTree (formally National Tree Benefit Calculator) is a widely used tool in the CSI program, especially for calculating carbon sequestration. The toolispeer-reviewed software developed by USDA Forest Service and a number of cooperators. Its criterion validity and reliability are guaranteed. However,it's worth mentioning that the tool only provides a generalestimation of tree performance rather than scientifically accurate value. Therefore, results might be different from true value, especially for project sites outside the US. Despite that, it is considered one of the best tools to measure tree benefits.

3.2.4 Water Conservation

Water conservation is another benefit that many projects documented (26 out of 39). Among the 26 case studies that documented this benefit, 9reported reducing irrigation demand by planting native species or drought-tolerant species; 6 reported reducing water wasting by installing water-conserving plumbing fixtures/low-flow irrigation d to quantify this benefit isreading water meters. It is reliable and valid.

However, literature indicates that native species often cause user's dissatisfaction. For example, Davies et al. (2004) claimed that the success of native species in urban areas largely depends on people's perception. For another example, Nassauer (1993) discovered that people prefer more traditional, orderly landscape. Most CSI projects were built within five years,the long-term benefits of native species depend on how well people accept the "wild" landscape design. If they do not appreciate it, it is possible that the landscape will be changed back to a conventional design and the benefit of water consumption will be lost.

Furthermore, although using reclaimed water for irrigation saves potable water, its influence on vegetation growth and people's health and satisfaction remain unclear. Long-term monitoring is necessary to ensure the benefit of saving water.

3.2.5 Material & Waste

Although material reuse/recycle and waste reduction is a benefit under environmental category, its value is occasionally represented through economic value by saving costs in construction. For example, the Port of Los Angeles Wilmington Waterfront Park reported that recycling cement and asphalt avoided hauling costs by $97,500 as estimated by a local hauling company, whereas, Portage Lake Front and Riverwalk cited the LEED document prepared by another company, indicating that 75% of the waste was recycled. Although both research teams demonstrated that materials recycle and reuse was economical, they used a more piecemeal approach, which is problematic in content validity.

Port of Los Angeles Wilmington Waterfront Park addressedcost saving in hauling deposit, but overlooked the cost saving in construction materials.Portage Lake Front and Riverwalk merely paid attention to cost saving in materials, ignoring cost saving in transportation. Additionally, both case studies failed to acknowledge that materials reuse and recycle might require extra labor and techniques which could be costly. Furthermore, reused and recycled materials might have less durability and shorter lifespan. These missing elements undermine the validity of measurement.

3.2.6 Economic Development

Economic development is challenging to quantify due to difficulties in data collection and variable selection. Many economic data are collected at city, county, region, and national levels, which makes it difficult to determine how much economic growth can be attributed to a particular landscape project. The Cheonggyecheoon Stream Restoration Project compared the number of increased business and number of increased working people in the project area with the downtown Seoul. Millennium Park used number of increased residential units/occupancy and tourism within a 6-year period to demonstrate business growth.

Both methods involved comparison; the Cheonggyecheoon Stream made a cross-sectional comparison between project area and the city downtown, while Millennium Park made a longitudinal comparison of the area close to the site over time. These comparisons factored out influence of other variables and increased the reliability and validity of the methods. When historical data of a project area are available, a longitudinal comparison can be conducted to demonstrate how local economy grows over time. When economic data in several different regions at a certain time are available, a cross-sectional comparison can be conducted to observe how the economy of a region where a landscape project is locatedexceeds other regions.

3.2.7 Public Health and Safety

Similar to economic development, public health and safety are also difficult to quantify. The metrics that are currently used in CSI include "resident / employee satisfaction," "walkability," and "noise level." Noise level reduction is normally quantified through on-site measuring or experts estimation. Similar to using flow meters and rain gauges to monitor stormwater, the reliability and validity of using devices to measure noise level on site are good. Resident/employee satisfaction and walkability are often measured through surveys or interviews. Reliability and validity of surveys and interviews usually depend on how surveys and interviews are designed and conducted. Since survey and interview questionnaires are often not published, we do not discuss their reliability and validity here.

This paper examines the currently used landscape performance metrics by comparing them with ecosystem services, building performance evaluation metrics and those in the checklists of LEED-ND and SITES. This paper also discusses the reliability and validity of several widely used methods in LPS.

Compared to other evaluation and rating

systems, landscape performance is the only one whose framework addresses three aspects of sustainability. LEED-ND assesses landscape projects from large scale (context) to small scale (building). SITES assesses landscapes throughout their life cycle. The different perspectives of these two rating systems can help improve the comprehensiveness of the landscape performance metrics. Furthermore, building performance evaluation and post-occupancy evaluation are more developed than landscape performance. Theyinclude quite a few metrics that can be borrowed to complement the currently used landscape performance metrics. The metrics that can be added to landscape performance include the following:

(1) Enviornmental:

a. Smart location

b. Construction activity pollution prevention

c. Storm protection

d. Climate regulation

e. Wind reduction

f. Design for deconstruction and disassembly

g. Use certified wood

h. Use materials with reduced VOC

(2) Economic

a. Incentivies due to sustainable solutions

(3) Social

a. Human disease control

b. Light pollution reuction

c. Catastrophic wildfire

d. Worker productivity

e. Well-being

f. Comfort

g. Ecotourism

Landscape performance research is still new. The experience in quantifying performance in the environmental, economic and social aspects is limited. Research teams often select metrics and methods according to the availability of data and researchers' expertise to some extent. As such, methods generally differ from project to project, which makes it difficult to guarantee the reliability and validity of methods and results. We recommend developing standardized data collection guidelines to reduce the dependence of methods on data availability. Moreover, as the database of the Landscape Performance Series expands, we suggest developing standardized quantification methods, which not only increasesthe reliability and validity of results, but also makes comparative study possible.

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