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景观绩效

多功能景观的度量和评估

Landscape Performance

Measurement and Assessment of Multifunctional Landscapes

撰文：（美国）克里斯托弗·D·埃利斯 （美国）权炳淑 （美国） 莎拉·阿尔瓦德 （美国）罗宾·伯克
翻译：李璇
校对：刘京一
Text by: Christopher D. ELLIS (US) Byoung-Suk KWEON (US) Sarah ALWARD (US) Robin L. BURKE (US)
Translation: LI Xuan
Proofreading: LIU Jing-yi

摘要：景观绩效以量化的方式衡量了景观设计的效益。每一个景观都是独一无二的，因此需要用截然不同的方式来度量绩效。在确定绩效类别时，景观的多功能性就会显现出来。通过对这些问题的讨论以及 2 个景观绩效案例的研究得出结论。其中一个案例研究探讨了一个旨在促进可持续和健康生活的非盈利性组织总部设计的环境、社会和经济的效益。另一个案例研究揭示了市中心的交通环岛同时也是当地社区中心的聚集空间的环境、社会和经济效益。虽然这 2 个景观都提供了可持续性的重要度量方式，但是它们各自的度量方式都是根据其独特的问题和解决方式而专门制定的。

关键词：景观绩效；多功能景观；度量；评估；可持续发展

Abstract: Landscape performance measures the quantifiable benefits of designed landscapes. Each landscape is unique and subsequently requires distinctly different approaches to performance measurement. In the process of identifying appropriate performance categories the multifunctional nature of a landscape is revealed. This paper discusses these issues and presents two landscape performance case studies to help illustrate the conclusions. One case study examines the environmental, social and economic benefits of design foor a non-profit organization headquarters that seeks to promote sustainable, healthy living. The other case study reveals the environmental, social and economic benefits of design for a downtwn traffic circle that also serves as a central gathering space for the local community. Although both landscapes support important measures of sustainability, they do so in ways that are exclusively tailored to their unique set of design problems and solutions.

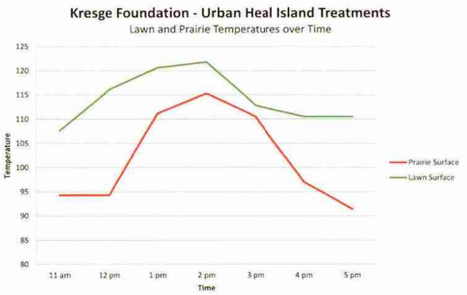
Key words: Landscape Performance; Multifunctional Landscapes; Measurement; Assessment; Sustainable Development

1 引言

景观绩效研究是风景园林行业一个新的热点。它汇集了广泛的科学方法，包括对多功能土地管理的认识和可持续发展的目标。景观绩效通过与以往建立的标准进行对比，考察了设计过的景观对非生物系统、生物系统和文化系统的影响。美国风景园林基金会（Landscape Architecture Foundation, LAF）从 2010 年开始对景观绩效展开案例研究，到现在已经发布了近 100 项关于景观设计在世界各地产生多重效益的研究。

景观绩效的优势在于使用了系统化、严谨、可量化的方法。方法包括基本统计、建模、监控、使用后评价和一系列其他适合已确定绩效类别的方法，包含定性和定量 2 个方面。根据生物地理区域、社会经济状况和当地的

作者简介：
克里斯托弗·D· 埃利斯 / 注册风景园林师 / 马里兰大学副教授 / 风景园林教育委员会前主席 / 风景园林基金会（LAF）研究委员会成员
权炳淑 / 注册风景园林师 / 马里兰大学副教授 / 《景观研究档案》主编 / 风景园林基金会（LAF）研究员
莎拉·阿尔瓦德 / 密歇根大学风景园林硕士生 /2011 年风景园林基金会（LAF）景观绩效研究助理
罗宾·伯克 / 贝洛伊特学院环境学学士 / 密歇根大学风景园林硕士生 / 美国遗产土地保护机构土地保护协调员
译者简介：
李璇 /1992 年生 / 女 / 湖南人 / 北京林业大学园林学院硕士生（北京 100083）
校对简介：
刘京一 /1989 年生 / 男 / 江苏人 / 北京林业大学园林学院硕士生（北京 100083）



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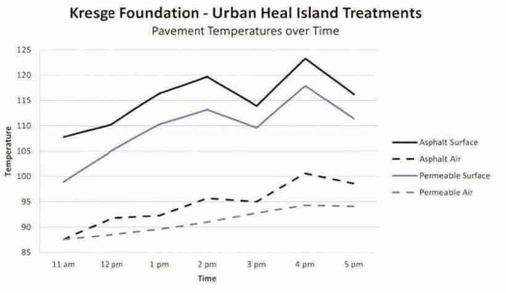

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1 草坪和牧草的热岛效应
Lawn and prairie heat island treatments.
2 沥青和透水铺装的热岛效应
Asphalt and pervious paver heat island treatments.

环境系统的不同，绩效的类别也有所不同。这些因素综合作用，导致设计场地具有独特的复杂属性，使得景观绩效的度量不可能有一种普适性的分析方法。然而，也许更重要的是先确定景观的绩效分类，然后在每个分类中选择相应的绩效度量和评估方法。

景观绩效的评估依赖于现状条件的基线数据和标准化的指标。现状或开发前状况的基线数据可用于前后对比，以确定设计实施后状况是否有所改善，而标准化指标为设计想要达到或超过的目标设定了门槛。基线数据分析可能是分析中最有效和最精确的分析方法，但也是实际操作中难度最大的。其原因有很多，其中一种解释是，很少有客户为基线数据的收集或开发后的评估买单。而指标分析可能是最容易实现的，因为设计师大都知道或者很容易得到特定设计要素的现行指标（如停车场的材料和施工方法）。当然，确定设计超出标准程度也需要一定成本。一些机构要求对某些具体设计元素进行绩效评价，如水质和径流量。或者，客户可能会因为宣传目的选择绩效评估。虽然越来越多的设计开始寻求可持续性认证（如美国 LEED 绿色建筑认证，可持续场所倡议），但度量的绩效仍较为局限，并且认证的场地与建筑的数量也只占很小的一部分。

景观本身是多功能的，它们支持多样的系统（非生物系统、生物系统、文化系统）以及在时间和空间上的土地利用（普利姆斯等，2004；罗登伯格和内甘普，2004）。某些功能，例如水文系统、生态系统和气候效应是先于人类活动而存在的。其它功能，如农业生产和交通运输系统是由于人类使用而存在的，并倾向于作为单一功能的景观。景观绩效承认多功能土地管理的价值，并尽可能寻求度量最广泛的绩效类别（或景观功能）。通过这种方式，景观绩效可以促进景观的功能多样性和可持续性。

最后，景观绩效与可持续发展的目标相一致（联合国，1987）。通过度量多功能的景观特征，景观绩效试图运用三重底线的思想（《经济学人》，2009 年 11 月 17 日）和广泛的可持续发展的原则（特纳，2005；《生活在同一个星球》，2014）。如果“你所度量的就是你所达到的”可以成立（《经济学人》，2009 年 11 月 17 日），那么确定并度量景观独特的功能特性就至关重要，这有助于定义这块场地的可持续性。

在过去 5 年里，景观绩效已经发展成为一个研究领域，很多论文在知名期刊上发表或在国际会议上宣读，高校开始开设景观绩效的课程。尽管如此，案例研究仍是景观绩效的基本工具和方法。下面的 2 个案例阐释了景观绩效是如何度量和分析的；高绩效的景观在功能多样性和可持续性方面有何种表现。第一个案例是密歇根州特洛伊市的克雷斯奇基金会总部，由保护设计论坛（Conservation Design Forum）设计（埃利斯，权，奥尔沃德，伯克，2011a）。它是一个挑战传统景观材料，维护和设计的案例。第二个案例研究是位于伊利诺伊州的诺马尔上城区环岛和街景，由霍尔·肖特（Hoerr Schaudt）景观设计事务所设计（埃利斯，权，奥尔沃德，伯克，2011b）。这是以城市广场为中心解决经济发展、雨水管理、交通安全和社区开放空间的案例。

2 案例研究

2.1 克雷斯奇基金会案例研究

获得了 LEED 白金认证的克雷斯奇基金会总部设计是一次可持续景观实践的探索，它实现了可持续发展的核心价值之一：环境保护。可持续策略包括屋顶绿化、雨水收集、人工湿地池塘、多孔路面和本土景观，具有补充地下水、减少饮用水使用、节约能源、创造栖息地以及提高工作环境满意度的功能。结合了新建筑与现存农舍的历史保护以及当地生态系统的恢复，形成了一个不同寻常且十分成功的策略，该策略反映了基金会的使命，即创造一个可持续发展的未来。这个由保护设计论坛设计的项目获得了众多设计奖项，如 AIA 芝加哥环境设计奖和密歇根州 ASLS 奖。

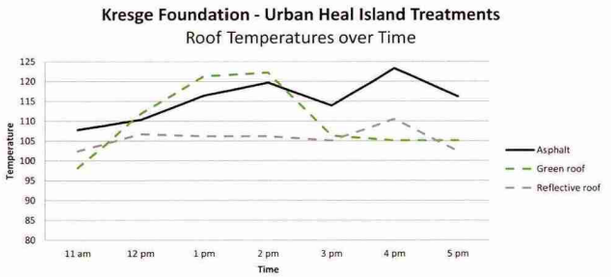
这个项目有许多引人注目的景观环境绩效。例如，通过减少 88%的草坪区域（从平面图测量为 64 537 平方英尺（约 5 995.68m^2），每年节省超过 100 万加仑（约 3 785m^3）灌溉用水和 6 400 美元。而在设计前，重要的草坪区域在生长季节需要每天灌溉。密歇根州立大学推广服务部(Michigan State University Extension Service)的弗兰克和莱曼(2011)估算了一个冷季型草坪每周的耗水量为 0.5-1.5

Biography:
Christopher D. ELLIS is an associate professor at the University of Maryland and is a licensed landscape architect. He serves on the Landscape Architecture Foundation Research Committee and is also Past-President of the Council of Educators in Landscape Architecture.

Byoung-Suk KWEON is an assistant professor of landscape architecture at the University of Maryland and is a licensed landscape architect. She serves as co-editor of Landscape Research Record and is a Landscape Architecture Foundation Research Scholar.

Sarah ALWARD has a Master of Landscape Architecture from the University of Michigan. She served as Landscape Performance Research Assistant for the Landscape Architecture Foundation in 2011.

Robin BURKE has a Bachelor of Environmental Studies from Beloit College in Wisconsin and a Master of Landscape Architecture from the University of Michigan.



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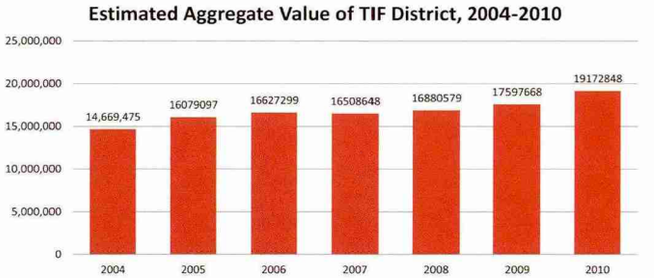

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英寸(0.0127-0.0381m)[每个生长季约2.16英尺（约0.658m）]。现在，新的设计已经完成，72%的场地覆盖本土植物，减少了灌溉的需求。密歇根州特洛伊市的饮用水价格是每100立方英尺（约2.832m^3）4.59美元，因此总共节省了约6 400美元[4.59美元×（64 537平方英尺×2.16英尺/100立方英尺]。

此外，通过用本土植物替代草坪，该项目恢复了1.76英亩（7 122m^2）的本土植被，其中包括在2010年5月场地植物调查中（戈因斯，2011）确定的53种本土草本植物。陆地栖息地的面积计算包括了牧场、草地、观赏圃以及湿地的面积。景观展示了多种生境类型，包括林地、高草草原、湿草甸、混合草原、海岸线、消落区和开放的水域。这些景观吸引了狐狸、大蓝鹭、加拿大鹅、麝鼠、臭鼬、花栗鼠和条纹鹰等动物的栖息。

与相同面积的传统多年生花园相比，本土景观每年节省了30 500美元的灌溉和维护成本。2011年，RS Means公司做了对比，灌溉多年生花园的成本为64 134美元，减去本土景观维护的实际费用33 340美元，就得到了节省的数字——30 500美元。此外，由于机动化设备、每周的手工除草工作和每年的焚烧工作都已不在需要，该设计每年分别减少了15.1磅(约6.85kg)碳氢化合物和488.2磅(约22.44kg）一氧化碳的排放。除了沿街市属地段之外都用本地植物替代了草坪，减少了每周割草的需求。所有其他的景观维护工作都通过人工完成，从而消除了空气污染和噪音。

克雷斯奇的设计通过使用牧草植物代替草坪[图1：平均减少12.1 °F（6.72°C）]，浅色透水路面砖代替沥青[图2：平均减少5.4 °F（3°C）]，以及屋顶绿化和高反射率的白色屋顶代替传统的屋顶表面等方式[图3：与沥青相比，平均分别减少4.7 °F（2.6°C）和10.5 °F（5.8°C）]减少当地地表温度。为了测量克雷斯奇的表面和空气温度，我们使用00782号Acu-Rite无线室内外数码温度计，放置在7个不同的地点，并在2011年6月30日上午11点到下午5点之间每小时读表1次。表面温度通过直接在地面或屋顶表面上的放置传感器进行测量，而空气温度在离地面2英尺(0.6m)以上的木制柱子上放置传感器来测量，并用一片木头以避免阳光直射。

通过在现场安装雨水管理系统，包括人工湿地池塘，生态水渠，屋顶绿化，透水停车场，以及18 000加仑(约981.37m^3)的雨水蓄水池，这个项目储存了64%的年均降雨量，即1700 000加仑（约6 435.2m^3）的雨水，并通过下渗补偿地下水。这个场地在24小时内可以渗透所有降水量（0.86英寸，约0.02m）。重新安排的停车场减少了铺装的面积，从而为植物和本土景观提供更多空间。4个屋顶绿化区域为建筑提供保温、并可吸纳雨水，与周围景观相融合，且并延长了屋顶使用寿命。

此外，项目回收了当地约318吨的混凝土碎块做成石笼墙，只在建筑表皮采用高质量的岩石，由此避免了11 000英里（约1 770km）的运输里程和73.6t的碳排放量。办公楼27%的建筑材料为可再生材料，76%的建筑材料采购于不超过场地方圆500英里（约804km）的区域，有效降低了运输成本和碳排放量。

2011年，美国加州大学伯克利分校（戈因斯，2011）通过调查问卷的形式对克雷奇基金会总部建筑的使用进行了评估，结果显示87%的员工对包括广场、景观和室外休息区在内的室外空间设计表示满意。克雷斯奇总部旨在为所有员工的办公桌前提供景观。然而，由于未预料到员工人数增加，新入职的16名员工在新地点工作，不能直接欣赏到景观。

克雷斯奇每年有200名参观者（克雷斯奇是一家科研资助机构，通常不向公众开放）。通过向他们介绍场地内的本土植物和雨水管理活动，克雷斯奇实现了环保意识和管理工作的推广。植物标签让参观者了解密歇根州的草原本土植物，标识牌则帮助人们关注本地植物群落和雨水管理的实践。此外，每年的控制焚烧除了能够有效控制外来物种入侵，鼓励本地植物群落的传播，同时也创建了一个功能性的生态系统，为社会提供教育的机会。

2.2 诺马尔上城区环岛与街景案例研究

上城区重建计划的核心地段是一个新的环岛和城镇绿地，它集雨水管理和公共娱乐活动为一体，是一个充满活力的聚会场所。2条街道的径流量被截留、存储，并通过水的回收使得雨水管理变成一个可见的公共便利设施。圆形的场地减少了交通事故，有助于人类健康和安全。街景中的特色树池使用未压实的

She currently serves as Land Protection Coordinator for the Legacy Land Conservancy.
About the Translator:
LI Xuan, born in 1992, is a MLA Candidate at Beijing Forestry University
Proofreading:
LIU Jing-yi, born in 1989, is a MLA Candidate at Beijing Forestry University

3 沥青、高反射屋顶和绿化屋顶的热岛效应
Asphalt, reflective roof, and green roof heat island treatments
4 诺马尔上城区房地产总价值
Aggregate property values within the Uptown Normal TIF district

土壤，使蓄洪能力增强，并能延长树的寿命，增加碳封存。环岛和街景是对重建可持续城市承诺的功能性阐述。

设计将原本不便的十字路口用环岛代替，相较于传统的 4 路交叉口减少了 75% 的冲突点，从而减少了 35%的交通事故。这个大体的估计通过测量交通量、以往发生的事故、交通管制以及机动车车道的数量和设置（农村或城市）计算得出。经过前后比较提供了减少的百分比值。

这个项目也节约了饮用水灌溉的成本。58 800 平方英尺（约 5 463m^2）的面积可以收集 1 400 000 加仑（约 5 299.58m^3）的雨水，将其重新利用在水景和灌溉上，每年能为城市节约 7 600 美元。通过计算不透水铺装表面产生的雨水径流，乘以年降雨量即得到全年存储在蓄水池的降雨量。这些水的使用取代了城市饮用水，将其乘以市政供水公司收取的每加仑水费[2011 年每 1 000 加仑（约3.78m^3）收费 5.40 美元] 即得出了前面的数值。除了可以为灌溉节省资金，消纳和回收一年的雨水量也减轻了市政排水系统的负担。

交通环岛内的喷泉通过一系列的过滤器不断循环收集雨水。雨水经过沙子、紫外线和沼泽过滤系统的处理，去除了 91%的悬浮固体（TSS），79%的磷（TP）以及 64%的氮（TN）。这些值由对沙子过滤器的测试和植物湿地系统过滤能力的科学研究而得出。鉴于当喷泉工作时，水通过过滤器不断回收，这些数据被认为是保守估计的，实际数值可能更高。

为了尽量减少土壤板结，沿着新植树的人行道设置了特殊的地下结构。这些结构有望将行道树的寿命延长 3 倍（从 13 年增加到 50 年）。这样在相当长的一段时间内将不用购买和栽植新的树木，可以节约树的更换成本约 61 000 美元。当然这个结构相对于传统方法要昂贵一些，因此节约的实际成本可能并没有那么多。

美国农业部林务局（USDA Forest Service）开发的 i-Tree 软件可用于模拟单棵树的碳封存，模拟需要输入树的种类、大小、气候区和附近的土地使用类型。新种植的 104 棵树估计每年封存至少 10 790 磅（约 4 894kg）的碳。如果树木能达到预测的 50 年寿命，那么诺马尔上城区收集和储存碳的总量将超过 227t。

经济绩效包括增长的房产价值和税收。上城区的税收从 2009 年至 2010 年增长了 9%（150 万美元），2004 至 2010 年增长了 31%（图 4）。额外的 68 万美元收入在诺马尔举行的上城区重建会议中产生。虽然环岛广场和喷泉并不是经济效益的唯一驱动力，但它们作为重建工作的核心取得了成功。

3 结论

这些案例研究表明了任何场地的景观绩效都有其独特性，景观绩效的度量方式根据不同的场地现有功能、社会环境和客户对绩效方式的需求而专门定制。例如，克雷斯奇基金会总部通过测量各种表面温度来确定热岛效应。它还采用调查问卷的方式了解员工对不同景观的看法。诺马尔上城区环岛和街景用水文模型来确定水的回收利用量和污染物减排量。它还要求与当地企业和机构进行面谈，以确定设计对房产价值和当地经济的影响。为了准确地测定特定场地的景观绩效，度量方式的选择必须基于场地和项目的特征，没有一种可以应用到所有场地的度量方式。

这些案例研究还说明了景观绩效的多功能特性。对于克雷奇基金会总部，设计通过减少城市热岛效应、减少雨水径流、节约灌溉饮用水体现了环保的功能。在生态上它利用本地植物和多样化的生境条件，在高度城市化的背景下吸引了多种野生动物；在社会功能上，它让在办公室工作的员工欣赏本土的栖息地，而非传统的草坪和花园式的景观。

同样，诺马尔上城区环岛和街景通过回收雨水径流、减少使用管道用水、提高树木健康和增加碳封存来体现设计功能的环保性；通过提高房地产价值和刺激经济活动体现功能的经济性；通过提升交通安全，提供社会活动中心来体现功能的社会性。

这 2 个案例说明了景观在功能上实现经济、环境和社会效益多方面的平衡，努力实现可持续功能的适当组合。但是，由于没有两个景观在各方面都是一样的，它们的绩效度量方式也必须是不同的。这是景观绩效的挑战，是可持续景观设计的目标：一个解决社会、环境和经济效益平衡并可用一系列工具和方法进行评估的独特景观。景观绩效系列（Landscape Performance Series）表明这是可能的（美国风景园林基金会，2010-2014 年）。下一步骤是推进景观绩效的评估作为度量可持续景观设计的标准。

1 Introduction

Landscape performance is a new focused area of research in landscape architecture. It brings together a broad range of scientific methods, recognition of multifunctional land management, and the goals of sustainable development. Landscape performance examines the effects that designed landscapes have on abiotic, biotic and cultural systems by comparison against studied baselines or established norms. The Landscape Architecture Foundation began developing case studies in landscape performance in 2010 and today has published nearly 100 studies that document multiple benefits of landscape designs to communities around the

world.

The strength of landscape performance lies in the use of systematic, rigorous and quantifiable methods. Methods include basic statistics, modeling, monitoring, post occupancy evaluation and a range of other qualitative and quantitative methods that fit identified performance categories. Performance categories differ based on biogeographic region, socioeconomic circumstances, and local environmental systems. These factors, in combination, result in unique blends of characteristics for designed sites making it difficult to define an all-inclusive standard set of analytical methods for measuring landscape performance. Instead, it is perhaps more important to first identify the appropriate performance categories for a given landscape and then choose corresponding methods to measure and evaluate the performance in each identified category.

Evaluation of landscape performance is dependent on baselines of existing conditions or standard benchmarks. A baseline of existing or predevelopment conditions enables before and after comparisons to determine whether conditions have improved based on an implemented design. Standard benchmarks set thresholds for which implemented designs hope to meet or exceed. The baseline approach is perhaps the most effective and accurate method of analysis but is also the least likely to be completed in practice. The reasons for this vary but one explanation is that clients rarely pay for baseline data collection or post development evaluation. The benchmark approach might be the easiest to achieve because most designers are aware of, or have easy access to the current standards for certain elements of design (e.g., parking lot materials and implementation methods). However, there is still a cost to determining the extent to which a design exceeds the standards. Some institutions require performance evaluation for specific elements of design such as water quality and runoff. In other cases, clients may choose to evaluate performance for promotional purposes. While these numbers might be growing as shown by the number of entities seeking sustainability certification (e.g., LEED, Sustainable SITES Initiativ™), the required performance areas are narrow in scope and the number of certified sites and buildings are still a fraction of the total.

Landscapes are inherently multifunctional meaning that they support a diversity of systems (abiotic, biotic, cultural) and land uses over time and space (Priemus et al., 2004; Rodenburg & Nijkamp, 2004). Some functions such as hydrologic systems, ecosystems and climate effects are present regardless of human intervention. Other functions such as agricultural production and transportation systems are managed for human use and tend toward monofunctional landscapes. Landscape performance recognizes the value of multifunctional land management and seeks to measure the broadest range of performance categories (or landscape functions) possible. In this way, landscape performance promotes functional landscape diversity and sustainability.

Finally, landscape performance is aligned with the goals of sustainability (United Nations, 1987). By measuring a broad range of functional characteristics, landscape performance attempts to address the ideas of a triple bottom line (*The Economist*, 2009, November 17) and an extensive set of sustainability principles (Turner, 2005; *One Planet Living*, 2014). If "what you measure is what you get" (*The Economist*, 2009, November 17), then it is important to identify and measure the unique functional characteristics of a landscape that helps to define sustainability for that place.

Over the past five years landscape performance has developed as a field of study. Papers are being published in notable journals, presented at international conferences and courses in landscape performance are being taught at major universities. Still, the primary vehicle for communicating the tools and methods for landscape performance is the case study. Below are two case studies that illustrate how landscape performance is measured and analyzed, and how high performance landscapes are multifunctional and support sustainability. The first case study, the Kresge Foundation headquarters is located in Troy, Michigan and the landscape was designed by Conservation Design Forum (Ellis, Kweon, Alward, & Burke, 2011a). It is an example of rethinking an organizational image by challenging the traditional landscape materials, maintenance and design. The second case study, the Uptown Normal Circle and Streetscape is located in Normal, Illinois and was designed by Hoerr Schaudt (Ellis, Kweon, Alward, & Burke, 2011b). It is an example of solving economic development, stormwater management, traffic safety and community open space all centered around one urban design plaza.

2 Case Studies

2.1 Kresge Foundation Case Study

The grounds of the Kresge Foundation's LEED-platinum headquarters explore sustainable landscape practices that allow it to realize one of its core values: environmental conservation.

Sustainable strategies include green roofs, rainwater collection, constructed wetland ponds, porous pavements, and native landscapes, which function to recharge groundwater, reduce potable water use, save energy, create habitat, and foster workplace satisfaction. The combination of new construction, historic preservation of existing farmhouses, and native ecosystem restoration results in an unusual and highly successful mix of strategies that reflect the Foundation's mission to create a sustainable future. This project, designed by Conservation Design Forum, received many design awards such as AIA Chicago Environmental Design Award and Michigan ASLA Award.

This project has many compelling environmental landscape performance benefits. For example, by reducing the lawn area by 88% (64,537sfas measured from site plans), the potable water saving for irrigation was more than 1 million gallons and $6400 per year. The significant turf area before the design change required daily irrigation during the growing season. Frank and Lyman (2011) at Michigan State University Extension Service estimates a cool-season lawn turf requires 0.5 to 1.5 in of water per week (about 2.16 feet deep per growing season). Now that the new design is implemented, 72% of the site is covered with native plants, reducing the need for irrigation. The cost of potable water in Troy, Michigan is $4.59 per 100 cubic feet bringing the total savings to about $6400 ($4.59 x (64,537 sf x 2.16 ft / 100 cf)).

Also, by replacing lawn with native plants, this project restored a total of 1.76 acres of native vegetation, which includes 53 native herbaceous plant species identified in a May 2010 site-wide plant survey (Goins, 2011). The area of terrestrial habitat was calculated by adding together the areas of prairie, grasses, ornamental beds, and wetland areas. The landscape showcases a variety of habitat types, including woodland, tall grass prairie, wet meadow, mixed prairie, shoreline, emergent, and open water areas. These have attracted a fox, great blue heron, a nesting pair of Canada geese, a muskrat, skunk, chipmunks and a sharp-shinned hawk.

Native landscapes save $30,500 in irrigation and maintenance costs each year, when compared to maintaining the same area as a traditional perennial garden. RS Means 2011 was used to perform cost calculations for a comparable perennial garden with irrigation coming to a total of $64,134. The actual maintenance cost of $33,340 of the native landscapes was subtracted from the comparison total resulting in a savings of $30,500. Also, the design reduces annual hydrocarbon and carbon monoxide emissions by 15.1 pounds and 488.2 pounds, respectively, by replacing motorized landscape equipment with weekly hand weeding and annual prescribed burns. Replacing lawn with native plants has reduced the need for weekly mowing, with the exception of the city-owned easement along the street. All other landscape maintenance is done by hand, eliminating air and noise pollution.

The Kresge design reduces local surface temperatures by using prairie plantings instead of turf grass (Figure 1: average decrease of 12.1°F), light-colored permeable pavers instead of asphalt (Figure 2: average decrease of 5.4°F), and green roof and high reflectance white roof instead of traditional roof surfaces (Figure 3: average decrease of 4.7°F and 10.5°F respectively, as compared to asphalt). To measure surface and air temperatures at Kresge, Acu-Rite Wireless Thermometer #00782 indoor/outdoor digital thermometer pairs were set up at seven different locations and read once per hour between 11 am and 5 pm on June 30, 2011. Surface temperature was measured by placing the sensor directly on the ground or roof surface; air temperature was measured by placing the sensor 2-feet above the ground on a wooden post, shaded from direct sunlight by apiece of wood.

By installing on-site stormwater management systems including constructed wetland ponds, bioswales, green roofs, permeable parking lot, and an 18,000-gallon stormwater cistern, this project stores and recharges groundwater by infiltrating 64% of the average annual rainfall or 1.7 million gallons. The site can infiltrate all water from storms up to 0.86 inches in 24 hours. Relocating the drive and parking lot reduced the amount of paved area, creating more space for plants and native landscape. Four green roof areas provide building insulation, absorb stormwater, blend into the surrounding landscape, and extend the life of the roof.

This project also avoided 11,000 vehicle miles and 73.6 tons of carbon emissions by recycling approximately 318 tons of locally-sourced crushed concrete within gabion walls, using higher-quality trap rock stone only as a facade. The LEED-platinum office building incorporates 27% recycled materials, with 76% of all construction materials sourced within 500 miles from the site, reducing transportation costs and emissions.

Based on a post-occupancy evaluation of the Kresge Foundation Headquarters by the University of California Berkeley (Goins, 2011), 87% of Kresge employees reported that they are satisfied with the design of the exterior grounds, including plazas, landscape, and outdoor seating areas. The

Kresge Headquarters was designed to provide views to the landscape from all 52 employee desks. However, due to unanticipated staff increases, an additional 16 employees are working at new work stations, which do not have direct views to the landscape. The post-occupancy evaluation was conducted by a questionnaire that was distributed to Kresge workers in 2011.

Environmental awareness and stewardship is promoted by introducing Kresge's 200 annual visitors to the site's native plantings and stormwater management practices (Kresge is a research funding organization and is not normally open to the public). Plant labels introduce visitors to Michigan's native prairie plants and interpretive signs help to educate people about native plant communities and stormwater management practices on the site. Also, Annual controlled burns are effective in controlling invasive species, encouraging the spread of native plant communities, and creating a functional ecosystem while providing educational opportunity for the community.

2.2 Uptown Normal Circle and Streetscape Case Study

At the heart of the Uptown Redevelopment Plan is a new roundabout and "town green" that incorporates stormwater management and public recreation into a vibrant gathering space. Runoff from two streets is captured, stored, and recycled through a water feature that makes stormwater management a visible public amenity. The roundabout further contributes to human health and safety by reducing traffic accidents. The streetscape features tree wells with uncompacted soils that add to stormwater storage and prolong tree life, increasing carbon sequestration. The circle and streetscape are a functional statement of the community's commitment to sustainable urban redevelopment.

The design is expected to reduce traffic accidents by 35% by replacing an awkward intersection with a roundabout containing 75% fewer points of conflict than a conventional 4-way intersection. This general estimate was calculated by measuring factors such as the traffic volume, crash history, number of legs, number of drive lanes and the setting (rural or urban). A before and after comparison provides the percent reduction values.

Also considered was the cost savings in potable water use for irrigation. By capturing 1.4 million gallons of stormwater from a 58,800 sf area and reusing it in the water feature and for irrigation the city saves $7,600 annually in potable water costs. This value was calculated by measuring the area of impervious surface creating stormwater runoff, multiplying this by the annual depth of rainfall to get the total annual volume of stormwater stored in the cistern in one year. This volume-which replaced the use of city drinking water-was multiplied by the cost per gallon of water charged by the municipal agency in charge of the city's water supply ($5.40 per 1000 gallons in 2011). In addition to saving money for irrigation, the burden of moving stormwater through the municipal system was lowered by removing and recycling this annual stormwater volume.

A fountain inside the traffic circle recirculates the captured stormwater continuously through a series of filters. The filter system removes an estimated 91% of total suspended solids (TSS), 79% of total phosphorous (TP), and 64% of total nitrogen (TN) from stormwater with each pass through the sand, UV, and bog filter system. These removal estimates are drawn from scientific studies that tested the removal capabilities of sand filters and vegetated wetland systems. Given that the water is recycled through the filters continuously during fountain operation, the estimates are thought to be conservative or that the removal rates are probably higher than reported.

Special underground structural cells designed to minimize soil compaction were installed along sidewalks where new trees were planted. These structures are expected to triple the lifespan of street trees from 13 to 50 years. The savings in tree replacement costs comes to about $61,000 by avoiding the purchase and installation of new trees over time. The structures themselves were additional costs over traditional methods so the actual savings might be slightly lower.

The USDA Forest Service developed i-Tree software that can be used to model carbon sequestration down to the individual tree level. The model input includes species, size, climate zone and nearby land use. The 104 new trees that were planted are estimated to sequester at least 10,790 pounds of carbon annually. If the trees live up to the maximum predicted lifetime of 50 years then Uptown Normal could expect to capture and store over 227 metric tons of carbon total.

Economic benefits include increased property values and revenue generation. The Uptown tax increment financing district estimated through appraisal a 9% ($1.5 million) increase from 2009 to 2010 and a 31% increase from 2004 to 2010 (Figure 4). An additional $680,000 in revenue was generated in Uptown Normal by conferences held in

Normal that featured the Uptown redevelopment. Although the circle plaza and fountain are not the only drivers of the economic benefits, they are the centerpiece of the redevelopment effort and deserve credit for the success.

3 Conclusions

The case studies illustrate the unique nature of landscape performance for any given site. Differences in existing site functions, social contexts and client needs call for performance measures that are tailored specifically to the individual site. For example, the Kresge Foundation headquarters called for temperature measurements on a variety of surfaces to determine heat island effects. It also called for survey questionnaires to elicit responses from workers about their opinions of the alternative landscape.The Uptown Normal Circle and Streetscape called for hydrologic modeling to determine water recycling volumes and contaminant reductions. It also called for interviews with local businesses and agencies to determine the impacts of the design on property values and the local economy. To adequately determine the landscape performance for a given site the measurements chosen must be based on the unique site and program characteristics rather than from a general formula of measurements that can be applied to all sites.

The case studies also illustrate the multifunctional nature of landscape performance. In the case of Kresge Foundation headquarters, the design functions environmentally by lowering urban heat island effects, reducing stormwater runoff, and saving potable water use. It functions ecologically by use of native planting and varied habitat conditions that has attracted a diversity of wildlife despite its location within a highly urbanized context. It also functions socially by replacing the traditional lawn and garden style landscape with a native habitat style that was shown to be desirable and appreciated by the people working in the office.

Similarly, the Uptown Normal Circle and Streetscape design functions environmentally by recycling stormwater runoff, reducing potable water use, improving tree health and increasing carbon sequestration. It functions economically by improving property values and generating economic activity. And it functions socially by improving traffic safety and by providing a social activity center for a growing area of the City of Normal, Illinois.

Both case studies illustrate landscapes that function in multiple dimensions to achieve a balance of economic, environmental and social benefits. There is clearly an effort to achieve an appropriate mix of sustainable functionality. But because no two landscapes are alike in every way, the measurement of their functional benefits also must be different. This is the challenge of landscape performance and the goal of sustainable landscape design: to identify the unique functional characteristics of a landscape that address a balance of social, environmental and economic benefits and can be measured with a broad set of available tools and methods. The Landscape Performance Series shows that this is possible (Landscape Architecture Foundation, 2010-2014). The next step is to advance the measurement of landscape performance as a standard practice in the design of sustainable landscapes.

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