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Mapping the Design Process for Urban Ecology Researchers

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The integration of research into the design process is an opportunity to build ecologically informed urban design solutions. To date, designers have traditionally relied on environmental consultants to provide the best available science; however, serious gaps in our understanding of urban ecosystems remain. To evaluate ecosystem processes and services for sustainable urban design and to further advance our understanding of social–ecological processes within the urban context, we need to integrate primary research into the urban design process. In this article, we develop a road map for such a synthesis. Supporting our proposals by case studies, we identify strategic entry points at which urban ecology researchers can integrate their work into the design process.

Keywords: applied urban ecology, collaboration, interdisciplinary, design process, ecological design

The widespread impact of humans on ecosystems (Kareiva et al. 2007) and the recognition that ecosystem services are essential to the future of human survival have catalyzed a shift in the field of ecology (Collins et al. 2010). Although they are historically disengaged from cities (Martin et al. 2012), ecologists are seeking to become instrumental in managing the built environment and studying its interaction with the natural world (Chapin et al. 2011, Palmer 2012). Building on foundational studies on topics such as urban metabolism (Newcombe et al. 1978), vegetation (Sukopp et al. 1990), remediation and restoration (Bradshaw and Chadwick 1980), and gradients (McDonnell and Hahs 2008), researchers are advancing theory, methods, and practice in a relatively new field—urban ecology (Grimm and Redman 2004, Pickett et al. 2011).

The city as a living laboratory for urban ecology presents challenges for the conduct of research and the development of theories of the urban environment (Forman 2002, Young and Wolf 2006, Pataki et al. 2011). These challenges stem from the complex interplay of the biophysical, socioeconomic, and political processes that affect how the built environment itself is shaped (Ernstson et al. 2010). Working in this context, urban ecology researchers require frameworks for their input into these processes so as to facilitate research and its role in shaping sustainable urban environments (Cadenasso and Pickett 2008, Miller et al. 2008, Musacchio 2009, Palmer 2009). Researchers also require entry points into the process of shaping cities such that they can establish sufficient replication and control to ensure the quality of the experimental design (Pavao-Zuckerman and Byrne 2009).

Designers, engineers, and planners already rely on scientific information that they, along with environmental consultants and scientists, have adapted to the design process (e.g., McHarg 1967, Spirn 1984, Johnson and Hill 2002, Forman 2008; also see *www.sustainablesites.org*). Although environmental consultants have played an important role in this process (Azerrad and Nilon 2006, Pouyat et al. 2010), they typically do not conduct primary experimental research, nor do they frequently have the flexibility to do so. Moreover, they often draw their "best available science" from past research on nonurban sites (Pataki et al. 2011), even though the assumptions underlying nonurban systems may not necessarily directly apply to urban areas (Collins et al. 2010). Furthermore, although rapid assessments are commonly used to evaluate sites and inform design decisions, the timing and budget constraints all too often compromise the accuracy of these assessments. Rapid assessments can fill crucial gaps in the face of land-use change, but their methods are yet to be fully validated (Kareiva et al. 1999). Given the growing demand for environmental consultants to both address regulatory concerns and provide ecological input on urban sustainable design projects (Meyer et al. 2010, Nassauer 2012), the time is ripe for urban ecology researchers to forge partnerships directly with designers (Felson et al. 2013a; *http://lafoundation.org/research/case-study-investigation*). Therefore, urban ecology researchers could use the design

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process as a framework for engaging with cities (Felson 2013).

In the present article, we distinguish the urban ecology researchers from others involved in the design process on the basis of their ability to establish hypothesis-driven research and monitoring protocols, to formulate theories relating to urban ecosystem interactions and rigorously test them, and to participate in cross-disciplinary design collaborations. The term *urban ecology researcher* here refers to research ecologists, research engineers, and social science researchers. We demonstrate how urban ecology researchers can integrate their work into urban development projects through the *designed experiments* approach (i.e., controlled experiments shaped as designed landscapes), whereby researchers work with designers to generate real-world, site-specific data while also influencing the process and the outcomes of urban design and landscape architecture (Felson and Pickett 2005, Felson et al. 2013b). First, we outline the design process for both public and private urban projects (figure 1). Next, we suggest key entry points in the design process at which researchers can integrate urban ecological research into urban designs (box 1). We follow with two case studies that highlight strategies for integrating and strengthening research goals (figure 2). Using examples from the case studies, we conclude with a summary of lessons learned for moving forward.

Design process phases

The design process is multifaceted, creative, nonlinear, and iterative (e.g., McHarg 1967, Halprin 1970, Rittel 1984, Wall 1999). In United States–based projects, a landscape, urban design, architectural, or engineering team typically leads the process, with consultants contributing at different stages. These stages can be generalized into five phases, each varying in cost and duration: contract, evaluation, design, construction, and postoccupancy (figure 1).

The client issues a request for proposals, a request for qualifications, or a competition brief and invites consultants to bid. Once a bid is accepted or awarded, the contract is drawn up. Contract negotiations include the determination of the project team, program, time frame, services and deliverables to be provided by each consultant, schedule, cost, and method of payment. Contracts are legally binding instruments. Amendments have cost implications.

Site evaluation can be perfunctory or extensive. It involves research, analysis, and synthesis of site history and context (e.g., utilities, zoning, circulation), physical and biological features (e.g., topography, water conditions, vegetation, soil quality, habitats), cultural elements, and other factors. Together, these inform and determine the general location, constraints, and opportunities to be further explored through the design process (Lynch and Hack 1984, LaGro 2001). In this phase, environmental consultants conduct their assessments and submit their reviews or environmental impact statements to the relevant agencies for approval (Alter 2012). Environmental consultants usually rely on available biological information and limited monitoring and rarely apply hypothesis-driven research (Pouyat et al. 2010). Outreach and stakeholder communication may also be initiated and may continue over the course of the project.

Three drawing submittals drive the design phase: the schematic design, the design development, and the construction documents with specifications. Each submittal package marks the resolution of an increasing level of specificity of detail and allows the project estimator to periodically refine the budget. Environmental consultants are typically invited to review the design and to provide advice on reducing environmental impacts and addressing related concerns. The team then modifies the project components in response to budgetary constraints, a procedure known as *value engineering* (Harris and Dines 1998).

On completion of the construction documents, the project is sent out to bid. The client uses various criteria to select a contractor, including the project scope, contractor experience, proposed fees, and the type of client. During construction, the design team typically oversees the contractor's execution of drawings and specifications. When construction is near completion, the designer conducts a walk-through inspection and prepares a punch list to identify the remaining tasks (Harris and Dines 1998). Once these tasks are completed, the client signs off on the punch list and accepts the project.

Designers are occasionally involved postconstruction through commissioning stages of the built project. This is usually specific to the performance of equipment or other functional aspects of the built work. Otherwise, designers are not involved in postoccupancy phases. Qualitative success metrics have been used in the past to assess ways in which people use designed spaces and buildings (Halprin 1970, Whyte 1980, Lynch and Hack 1984). Contractors usually include a limited-time guarantee on a project. However, with the increased interest in postconstruction monitoring and commissioning, researchers are likely to become more involved in this phase (*www.gbci.org/main-nav/building-certification/leed-certification.aspx*).

Entry points for urban ecology researchers in the design process phases

Each phase of the design process presents opportunities for researchers to participate in urban design projects (box 1). The most crucial entry point is the contract phase, in which the researcher can negotiate inclusion on the design team and can seek to define the time frame, budget, and deliverables as components of the scope of work. In addition, the researcher can press for multiyear funding of postconstruction monitoring to cover postconstruction research costs.

Urban ecology researchers can also advocate for the integration of research into the design process at the evaluation phase (Alter 2012). The typical compressed time frame of this phase does not currently facilitate primary research, but it does not necessarily preclude it. The challenge for

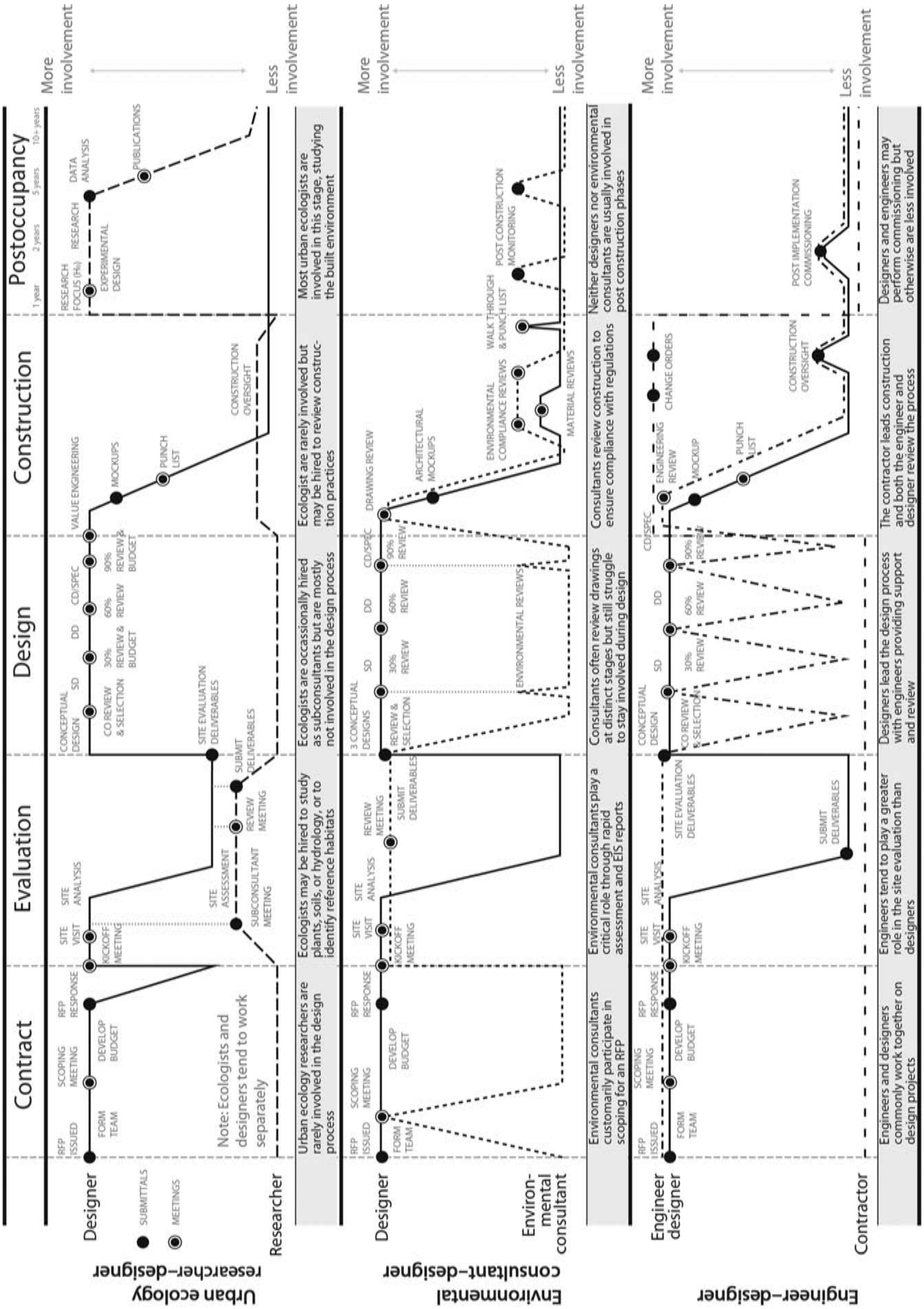

Figure 1. A road map illustrating the current duties of research ecologists, environmental consultants, and engineers in the design process and how those duties overlap with those of designers. Abbreviations: CD/SPEC, construction documents and specification; CO, contract; DD, design development; H_0, creation of a null hypothesis; RFP, request for proposals; SD, schematic design.

Box 1. The proposed involvement of urban ecology researchers at different stages of the design process.

Initial contact
Identify possible clients (e.g., developers, landowners, managers) and meet with them to understand their goals and cultivate ways in which research could benefit their interests. Develop research that feeds the value of ecological science for informing urban projects. Partner with organizations (e.g., nongovernmental organizations, nonprofits, government agencies) working with communities on urban environments to encourage research. Enter design competitions as consultants on teams (e.g., *www.worldlandscapearchitect.com*). Identify relevant requests for proposals and reach out to design firms to propose partnerships.

Contract
Define the ecologist's time frame, budget, and deliverables as a component of the scope of the work to clarify the role that the urban ecology researcher will play during contract negotiations. Structure the timing of the research to ensure that some of the findings can inform the design process. Avoid underselling the research contributions. Identify contingency funds as a backup for potential costs attendant to construction so as to avoid compromising on the rigor and quality of the research. Attend initial meetings to assert the value of research for site evaluation and design.

Evaluation
Emphasize the limitations of urban data and the need for experimentation. Negotiate a time frame adequate for gathering baseline data. Negotiate for hypothesis-driven research as an alternative to rapid assessments. Explore partnerships with academic institutions so as to extend the scope and rigor of baseline data assessment and to tap into potential sources of funding through grants and fellowships. Examine hybrid research and rapid assessments to balance the costs, time, and information relevant to decisionmaking. Prioritize research methods such as before-and-after or comparative studies that respond to the challenges of working on urban sites, such as navigating politics and establishing control studies. Select sites strategically to generate greater control over the data and to reduce permit requirements (e.g., prioritize sites remote from typical urban conditions).

Design
Engage with designers on decisions that will affect the research and on design decisions that the research results may inform. Orient the objectives of the research to study and to shape sustainable design solutions and to better position and translate basic and applied ecological research to function as drivers of the form, layout, and program (intended use) of the site. Apply as is appropriate the designed experiment approach, which incorporates applied research goals into the design and layout of projects and facilitates additional experiments for adaptive management.

Construction
Go through the client to emphasize to the contractor the need for consistency in craftsmanship and for a reduction of variables during the experiment's setup. Clearly identify the purpose and needs for constructing a designed experiment to the contractor. Engage the contractor early to communicate your research goals, to identify areas of concern or clarification, and to seek advice on cost-saving measures.

Postoccupancy
Expand urban researchers' focus from postconstruction research (the typical purview of ecologists who target existing built environments) to include hypothesis-driven research that informs the design, construction, and postoccupancy of projects. This avoids the inherent issues of nonreplicable one-off designs that lack controls. Establish a postconstruction maintenance and operations plan to be put into practice for the long-term, in order to ensure commitments to the research over time, especially as the project transitions to public or private ownership. Identify and engage the ultimate owner early to help instill an understanding and a sense of ownership in the project and to encourage long-term stewardship. Address long-term maintenance funding issues, which plague parklands and will, likewise, negatively affect research experiments.

researchers is convincing clients, who tend to fund project-specific information gathering more often than basic research, to support hypothesis-driven research as a complement to rapid assessments and as a means to surmount regulations or other obstacles (Kareiva et al. 1999). To do so, researchers can explore partnerships with academic institutions to access grants and fellowships and also as a way to extend the scope and rigor of site evaluation, including baseline data collection (Shirk et al. 2012). Researchers must demonstrate how their research can balance cost, time, and the information relevant to decisionmaking; can respond to the myriad agents affecting the conduct of urban research, including political social and regulatory needs (Shirk et al. 2012); and can reduce variables, establish replication, and provide control studies.

The next crucial entry point is the design phase. This is a definitive stage for the project, in which designers will make most of the decisions that will affect the potential for research integration. Researchers can pursue designed experiments (Felson and Pickett 2005, Felson et al. 2013b) and can orient the objectives of research toward studying and shaping sustainable design solutions and toward better positioning and translating basic and applied research to function as drivers of the form, layout, and program of

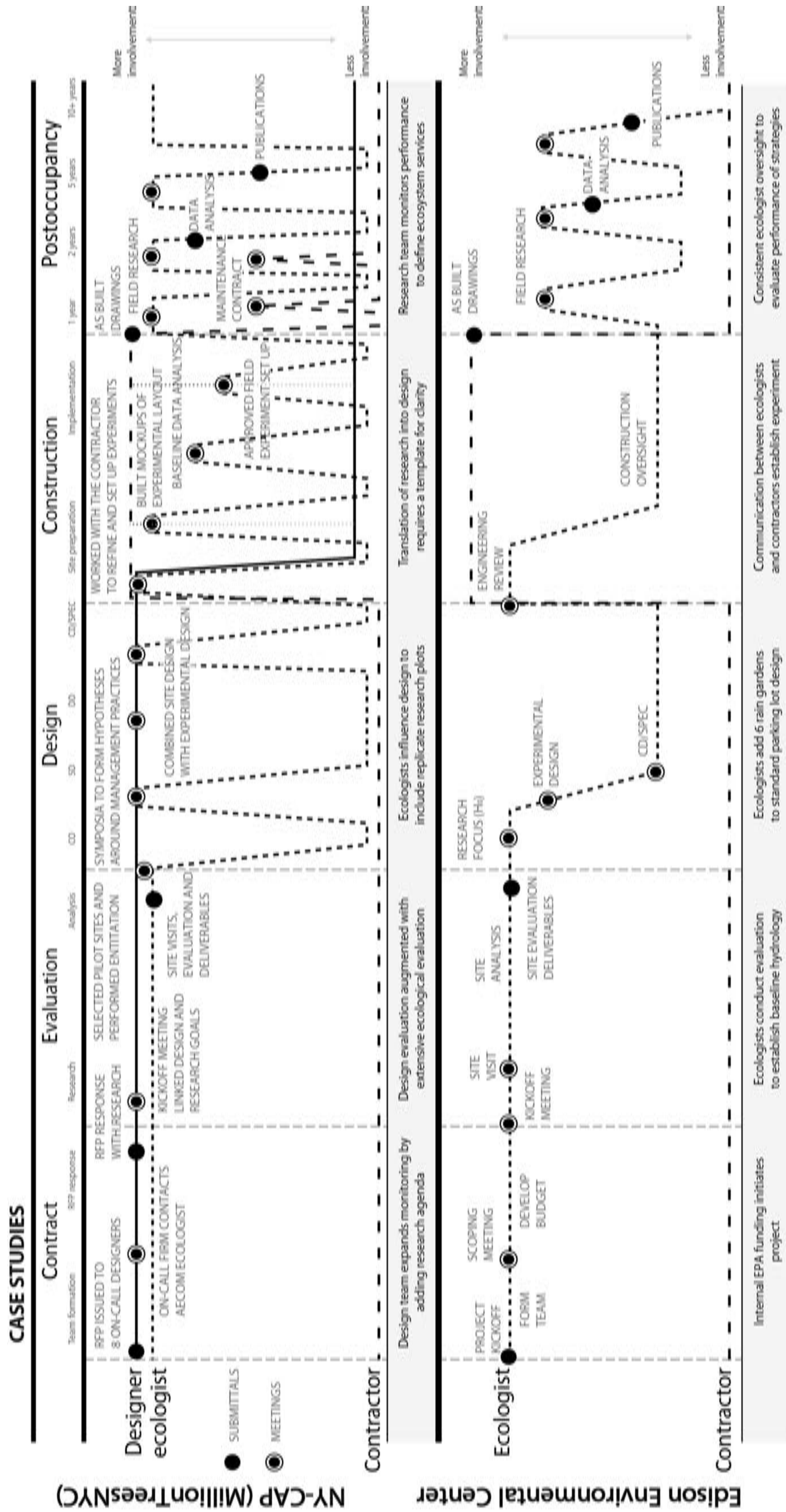

Figure 2. Case studies illustrating the role of the participants in the design process. Abbreviations: CD/SPEC, construction documents and specification; CO, contract; DD, design development; H_0, creation of a null hypothesis; NY-CAP, New York City Afforestation Project; RFP, request for proposals; SD, schematic design.

the site. Prior to construction, articulating the experimental design parameters to the contractor is essential. To do so, researchers should gain client support and ensure that this is communicated to the team in order to gain credibility and standing, and they should engage with contractors early to communicate research goals, to identify areas of concern or clarification, and even to seek advice on cost-saving measures.

Postconstruction is the current domain of urban ecology researchers (Felson et al. 2013b). However, as was outlined above, there are other opportunities to expand researchers' focus beyond postconstruction research to include hypothesis-driven research from the outset of the design process or preconstruction. At the postconstruction phase, the final steps for researchers should include establishing a postconstruction maintenance and operations plan to ensure long-term commitments to the research, especially as the project transitions to public or private ownership. In addition, leveraging grants to cover postconstruction maintenance and monitoring will help to avoid a portion of the compromises on the rigor and quality of the research. The researchers could identify and engage the ultimate owner early to help instill an understanding of and a sense of ownership in the project and to encourage long-term stewardship.

Case studies

The case studies below illustrate ways in which ecologists have established experiments as components of urban systems. The first is an example of a researcher-driven project to establish an experiment configured as a functional parking lot. The second is a designer-driven project that leverages a large-scale urban forestry initiative for the construction of a long-term urban forestry research experiment as a designed public park.

Permeable pavement parking lot research and demonstration site. The Edison Environmental Center's green parking lot project, in Edison, New Jersey, illustrates one strategy for integrating full-scale, long-term experiments into urban sites in order to guide real-world applications (figure 3). US Environmental Protection Agency (USEPA) environmental researchers analyzed the performance of multiple porous pavement surfaces in a full-scale parking lot and an associated series of rain gardens, designed to serve as a research and demonstration site (figure 2). They established hypothesis-driven research objectives and sought to reduce variables, in order to empirically test the viability of green infrastructure for storm water runoff reduction and pollutant removal.

The researchers were engaged in the design process (box 1) from contract to postconstruction. Their consistent involvement throughout demonstrated the role for researchers and the benefits of integrating research in each phase of the design process. At the outset, they convinced the USEPA to prioritize the transformation of a traditional parking lot to a "green" parking lot years ahead of the agency's schedule. Because it was a green project, the researchers' technical expertise in storm water management practices

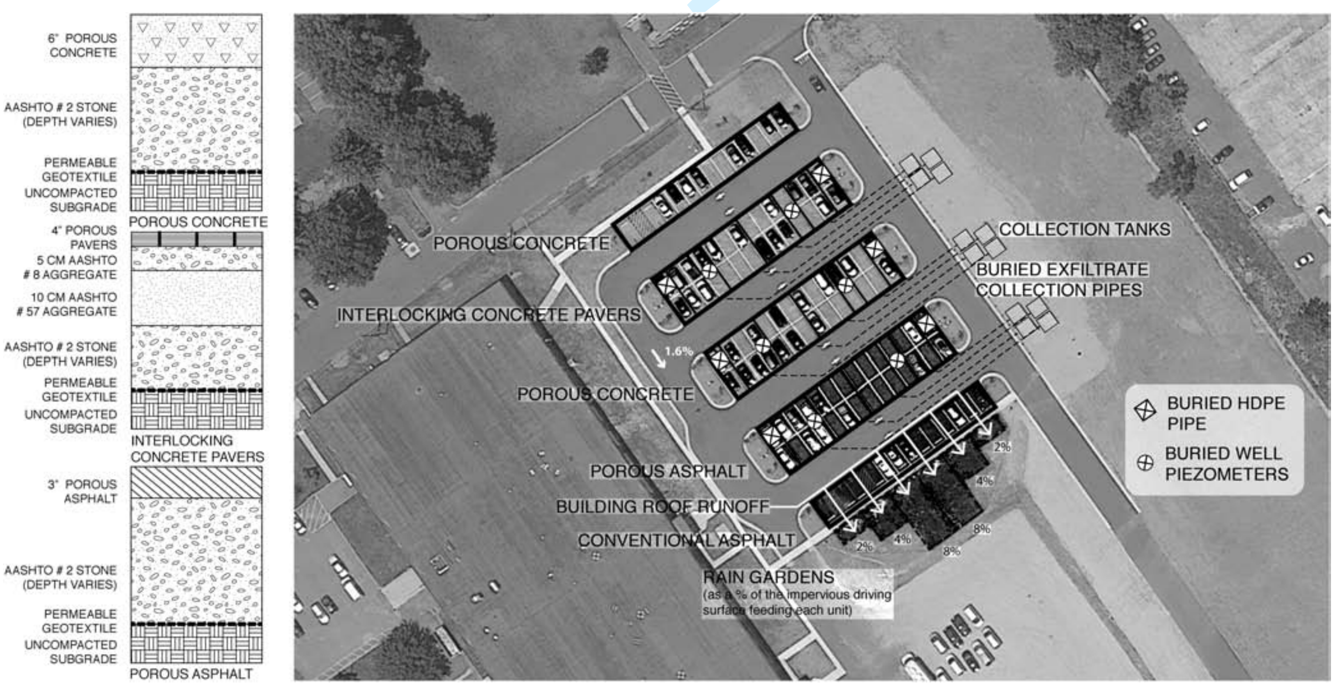

Figure 3. Plan of the permeable pavement parking lot demonstration at the Edison Environmental Center, with vertical cross sections of permeable zones. Portions of the parking rows infiltrate to subgrade soil, whereas others are lined and drain to the collection tanks. Abbreviations: AASHTO, American Association of State Highway and Transportation Officials; CM, centimeters; HDPE, high-density polyethylene.

was essential, which gave them leverage to accommodate research and monitoring objectives and physical components of the experimental research project in the design. This inclusion resulted in an expanded evaluation phase, a requirement that the researchers approve all design drawings, on-site supervision of multiple contractor teams by the researchers during construction, and continued researcher input into the postoccupancy maintenance regime of the parking lot, including ice and snow removal, vacuuming of the permeable parking surfaces, and rain garden plant maintenance. During construction, the researchers' control of the design and coordination was crucial for implementing the research component of the project. The involvement of researchers from the outset ensured a robust experimental design for generating data on the performance of rain gardens and porous surfaces (Rowe et al. 2010). This data can inform storm water regulations, facilitate innovative efforts, and position the USEPA to act as an honest broker in evaluating permeable and traditional parking surfaces and rain garden design parameters.

Although the project prioritized research goals, and thus differs from a traditional parking lot design, the Edison case illustrates the necessity of involving researchers early and throughout the design process, particularly during the initial phases from contract to design. Without such involvement, aligning research goals with design goals would require renegotiating at a later stage, with extra cost implications as well as the likelihood of considerable compromise of research rigor.

USEPA researchers worked with the USEPA facilities staff to conceptualize a parking lot experimental design that accommodated the research objectives of the research team, was fully functional, and was environmentally friendly. The agency then engaged contractors on the basis of a request for proposals, as in the initiation of a traditional project. No negotiation of research objectives was necessary, because the purpose of the request for proposals was the build out of a functioning parking lot designed as a research and demonstration site (Rowe et al. 2010). Moreover, because the site itself is government owned and the project is part of a long-term, government-sponsored research program, few issues arose related to the prioritization or siting of the research. Several functional design elements were actually adjusted to accommodate the green design and research agenda. For example, the facilities and research teams agreed to "overdesign" the parking lot; they incorporated a greater depth of subbase layers than is normally specified in a permeable pavement parking lot to allow for more subsurface storm water storage and thus to minimize the risk of surface ponding, even during a severe storm. In addition, the parking lot was undersized in terms of the number of parking spaces in order to ensure that the three permeable parking surfaces would be fully used on a daily basis.

Over the period of 1 year prior to groundbreaking, the researchers conducted baseline data analyses, bench-scale tests of design elements such as geotextile type and rain garden media composition, and an assessment of soil permeability and hydrology. Although most design projects have limited time frames and budgets that constrain site evaluation, in this case, the extensive site evaluation was integral to the experiment. These analyses overlapped with the contract and design phases, because the site assessments and bench-scale tests informed the conceptualization of the parking lot and research project. Technical questions and challenges that arose during the design phase triggered additional assessments and tests.

The goals of the design included building a functioning, permeable parking area as a research experiment to test the hydrologic and pollutant-removal performance of three different types of permeable pavement. In order to provide guidance to state and federal regulators regarding the minimum rain garden size, the research team designed experimental rain garden cells associated with the parking lot at 2%, 4%, and 8% (with replication) of the size of the impervious driving surface upslope of the rain gardens. During the design of the parking lot, the researchers had to ensure that the constructability and uniformity of the experimental setup, postoccupancy access to buried research instrumentation, and the necessary experimental controls (e.g., equal-size impervious driving surfaces to provide equivalent volumes of runoff to the permeable parking surfaces). The research team met face to face with the design firm in order to align the construction drawings with the research objectives and to ensure the necessary detail in the construction notes. In this way, they avoided damage to buried research instrumentation and limited the production of sediment that could clog geotextiles and aggregate layers and could prevent the infiltration of storm water to the underlying soil.

During the construction phase, the research team supervised the contractors and coordinated with the design firm that was legally responsible for supervising this phase. The prime construction contractor had been solicited through a bidding process and had no experience constructing a green parking lot—much less one with subsurface monitoring equipment. Consequently, coordination was ongoing between the researchers and the prime and subcontractor teams. Not surprisingly, problems arose during construction that were related to accommodating the research objectives and instrumentation. The research team and the design firm collaborated periodically to modify the design elements, brainstorming and testing engineering solutions to solve the problems and achieve the research objectives; for this reason, the design process extended into the construction phase. This adjustment required additional time to ensure proper installation of the monitoring equipment, to redesign control and drainage structures, and to coordinate all of the participants involved in the research, design, and construction.

The 6-month construction phase and the cost were both greater than those of a typical parking lot. Facilitating the coordination and complementarity of the research design and construction required an iterative process of construction monitoring and troubleshooting, with a high degree of teamwork, timely communication, patience, and mutual respect and trust.

Initially considered in 2007 and completed in 2009, the project provides a research site for the long-term monitoring of hydrologic and pollutant-removal performance in different permeable pavement surface types and in rain gardens of varying sizes. The researchers are also investigating the impacts of seasonality, life cycle, and maintenance protocols on hydrologic and pollutant-removal performance. Instruments regularly monitor the soil moisture, wetting-front dynamics, and temperature. Water quantity and quality sampling has been conducted on a monthly basis since the opening of the parking lot in the fall of 2009.

The MillionTreesNYC afforestation study. The New York City Afforestation Project (NY-CAP) illustrates one strategy for achieving a long-term urban forestry research experiment embedded in a public green infrastructure project. The design team worked with the client, the New York City Department of Parks and Recreation (NYCDPR), and a voluntary science advisory board to establish hypothesis-driven research and an experimental design to evaluate the impacts of varied site preparations and plant diversity on ecosystem functioning—carbon dynamics, invasion dynamics, species recruitment and turnover, and the time to canopy closure—to test the performance and persistence of a constructed native urban forest (Felson et al. 2013a).

Bringing the client on board with the research required aligning the research goals with crucial management issues, with the NYCDPR time frame for implementation, and with community expectations for a public city park. Indeed, the time frame and budget for the design project did not allow for an optimized baseline assessment. Therefore, during the evaluation phase, during which extensive baseline data might have been collected, the researchers were restricted to seeking limited improvements to the rapid assessment approaches typically used by the NYCDPR. This limitation and others arose from political pressures for rapid implementation and high success rates. Nurseries were hard-pressed to produce the large volumes of saplings sought for planting, given the short notice and the risks associated with investing upfront in land and years of labor to produce the trees. Nonetheless, during the contract phase, the design team successfully proposed a project scope and priorities that expanded the client's original intent for constructing a native urban forest from simply monitoring tree survival into a broader experimental research initiative to study the health and resilience of a planted forest.

Involving designers with ecological knowledge and experience setting up experiments in the contract phase helped situation experimentation as a component of the project, creating multiple entry points for subsequent phases. The design and construction phases provided the greatest integration, with flexibility in both the design process and the design of the experiment, which allowed the designers and researchers to work iteratively with the client and contractors toward establishing viable research within the built ecosystem (Felson et al. 2013b). The partnership during the design and construction phases led to the establishment of an urban forestry experiment that enhanced the original goals of the request for proposals. With the execution of the designed experiment across two pilot sites and in locations citywide as part of the MillionTreesNYC initiative (*www.milliontreesnyc.org/html/about/parks_planyc.shtml*), a number of academic institutions became heavily involved in research on the sites (e.g., McPhearson et al. 2010), affording the researchers access to an experimental layout and locations not available through traditional academic sources and bringing funding and resources to the initiative. This successful transition from a design process into a research program illustrates the kinds of opportunities that researchers have in working with designers to implement urban ecological research.

NY-CAP used capital investments from PlaNYC 2030, New York City's sustainability plan, to fund the design and construction of a large-scale urban forestry experiment. The request for proposals included a general request for monitoring. The design team persuaded the city to pursue hypothesis-driven ecological experiments that assess patterns of forest performance and to evaluate NYCDPR management practices, with the intent of collecting data that would better inform future park management practices and capital decisions. These research goals were raised in response to the request for proposals; however, the contract and budget did not include an experimental design component. Therefore, the research had to be embedded within the design process at no extra fee. On completion of the design contract in 2009 (and after the establishment of the experimental layout), academic institutions were invited to establish direct relationships with NYCDPR so as to further refine the experimental design and research protocols (Felson et al. 2013a).

Large-scale land assessment and site categorization drove the original site evaluation in 2008. Like those of most design projects, the evaluation practices fell short of the level that a research ecologist would require for baseline data. The brief contract time line (approximately 1 year) and low budget constrained the options for establishing effective baseline analyses. For consistency, the team followed the NYCDPR "entitation" practice, relying on a rapid characterization of the dominant vegetation, soil type, and adjacent conditions (Natural Resources Group 1988). Extensive geographic information system and ground-truthing analysis, along with city agency outreach, informed the site selection for 2000 acres of potential afforestation sites.

An academic partnership with Yale University in 2009 allowed for a second phase of ecological analysis that included baseline assessments preconstruction for research purposes. This ongoing research program includes one season of preconstruction soil analysis and vegetation cover studies executed in 2009. The project includes two additional years of soil analysis, 3 years of tree performance studies, and 2 years of species recruitment studies, with plans for ongoing research (Felson et al. 2013a). In the case of NY-CAP, scientific input informed the project design at crucial intervals. The researchers shared their perspective and worked toward common goals with the designers and park managers. The researchers played a crucial role not only in defining the research needs but also in translating those needs into an experimental design layout. At the same time, the research goals demanded compromises. Rather than planting the widest selection of possible species in the research plots, the team planted plots with either two or six species, with the goal of reducing variability and establishing low-diversity and high-diversity configurations for testing biodiversity. Building on management questions, the species richness set up was then crossed with stand complexity (with shrubs and herbs versus without), and soil amendment (with compost versus without).

The NYCDPR expressed concerns that experimental plots situated in public parks would be unattractive. Embedding the research plots within clusters of trees and surrounding these areas using a picturesque planting helped to diffuse the research grid (figure 4). Redesigning the typical plot grid as a naturalistic plot, with patches of trees and shrubs, proved to be a win–win scenario; rather than a focus on the plot scale as the experimental unit, each plot now included six interior quadrats of 24 trees, for a total sample of 336 quadrats across the 56 plots (figure 4). This layout supported park usability and fit the restoration goals of the NYCDPR.

The relationship between the contractor and the research team proved crucial for the implementation of the experiment. Although the contractor selection followed the normal protocol for public contracts, the contractor was brought in early and proposed additional cost-saving measures. The contractor educated himself on the larger research goals and actively sought to simplify the layout and implementation strategies in order to reduce variability in the plot establishment, which helped to avoid change orders and other costly pitfalls. The research team added greater detail to the construction documents and specifications that were developed by the design team and constructed mock-ups (built templates) prior to construction.

The NY-CAP functions as a long-term research project linked to public parkland. Yale's involvement in the pre- and postoccupancy research has ensured continuous monitoring and data collection that are used to study basic questions in urban land-use change about native ecosystems, with a focus on vegetation dynamics, soil biology, biogeochemistry, and above- and belowground linkages. Relevant data results will be conveyed for applied management practices and made public over time through a data clearinghouse. Some of the preliminary results may influence the MillionTreesNYC initiative; however, most of the research will likely be used to influence future management practices and other metropolitan tree initiatives. The experimental design of the site provides a platform for additional research, including nematode and wood-decomposition studies currently under way.

Summary of urban ecology researchers and the design process

At present, the environmental consultant fills a crucial role in providing scientific input on design projects. However, that input is limited to certain phases of the design process and geared toward addressing regulatory concerns and facilitating the meeting of design goals. Researcher- and designer-driven projects create a markedly different and complementary role for the urban ecology researcher (Dorney 1973, Johnson and Hill 2002, Felson and Pickett 2005).

These case studies begin to answer the question of how researchers can initiate contact with project managers when the structures or links for that contact are not already in place (box 1). Convincing project designers of the value of research and coordinating the research with project timing are essential. Engaging with multiple stakeholders through partnerships (e.g., Redman et al. 2004) and addressing issues such as private property rights, zoning, and human subject research are valuable steps toward positioning ecologists to work in an urban context. Additional steps include developing institutional knowledge around professional practice and even modeling applied ecology after the professional role that designers or engineers currently play.

We argue that researchers can tailor their approaches to a variety of projects, sizes, locations, and management structures (box 1). First, we emphasize the value of involving researchers from the start of the design process and during contract negotiation to ensure that research goals are a part of the request for proposals. Pursuing designed experiments and situating the research experiment as a feature of the design project is one strategy (Felson and Pickett 2005). Second, the researcher and the design team must strike a balance between design and research goals during the design process. Third, involvement during the construction phase is crucial for ensuring that the experimental design is implemented properly. Fourth, and linked to the balancing of goals, the research results must feed back into the design. Fifth, to further contribute to the build up and dissemination of scientific knowledge of urban systems, the results must be published in both the science literature and publicly accessible publications.

The nature of the design process—creative, flexible, and iterative—provides a suitable platform to accommodate the role of urban researchers to conduct basic research (Felson et al. 2013a). It also supports a more transformative role for researchers to participate in the management and shaping of urban systems (Felson et al. 2013b). Within the design process, the transition from evaluation to schematic design marks a fundamental shift in intention, from seeking to understand how a system works to systematic modification and improvement of that system over time. This

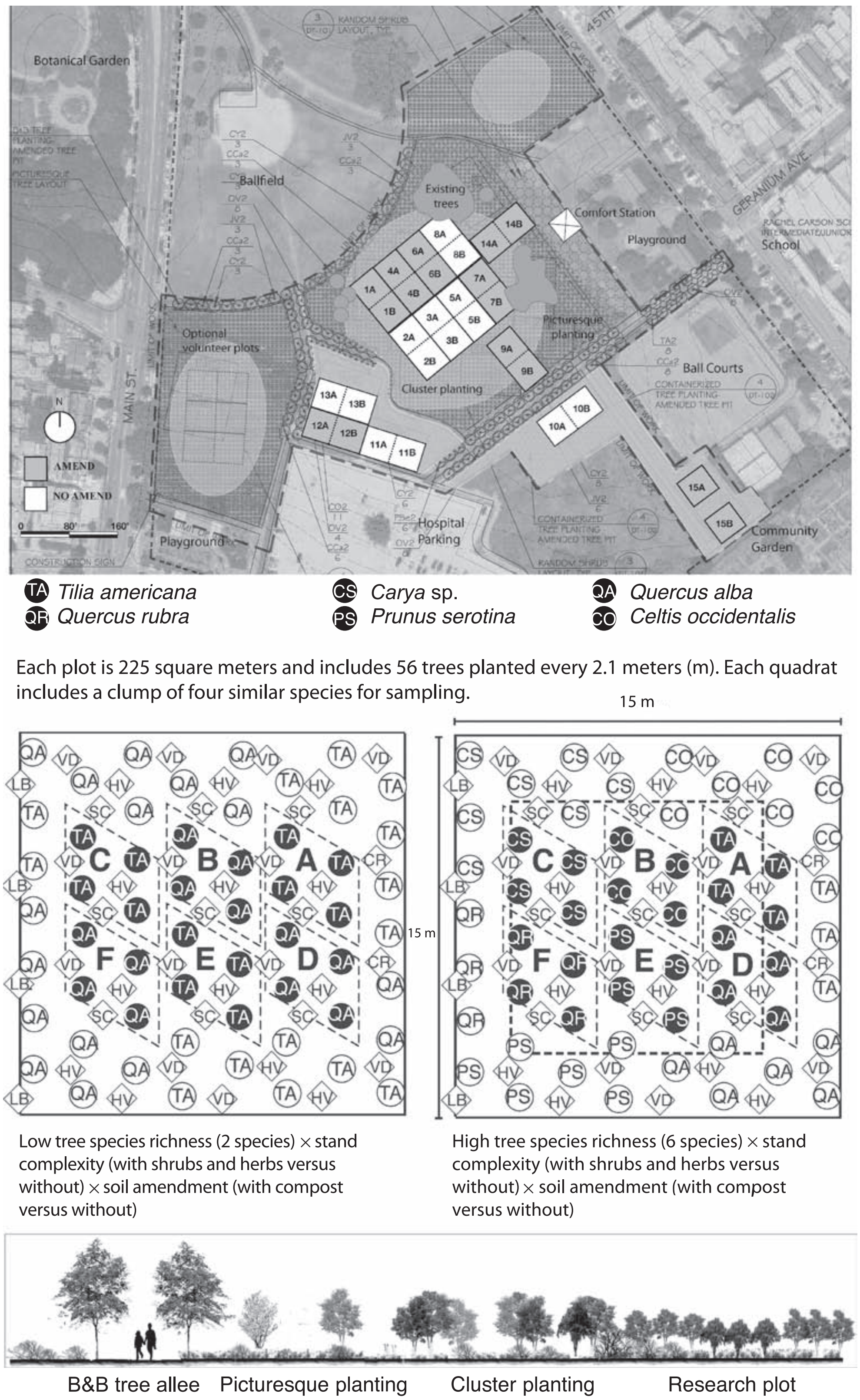

Figure 4. The research site and plots for the New York City Afforestation Project. The plots were originally designed as a randomized grid. The revised plots were designed as an offset grid, with patches of similar species embedded within each plot. These naturalistic plots were designed to address an aesthetic demand from the New York City Department of Parks and Recreation. The revised plots also improved the sampling options at the subplot level. Abbreviation: B&B, balled and burlap, a method of tree planting.

transition from assessment to conceptual design occurs early at the end of the evaluation phase and early in the schematic design phase. Developing the role of the researcher in the design process provides a valuable learning opportunity for ecologists to shift from studying to shaping ecosystems (Pickett and Cadenasso 2008) and thus to shaping society (Chapin et al. 2011).

Conclusions

The process of integrating research into design and of reorienting the researcher's role from studying to shaping the environment requires compromises; it also allows for the expansion of research opportunities in urban systems, which are currently understudied and in which controlled research is limited. This reorientation can enable the researcher to advance the agenda for more-robust research in the urban context. Our road map (box 1) shows what institutional buy-in is necessary at certain stages to produce the best hybrid (i.e., design–research) results. The case studies presented above also illustrate how to overcome some of the incompatibilities between ecological research and urban design practices.

Expanding the researcher's role in the design process has the potential to integrate current research into the design and management of the urban built environment and to establish a new paradigm for both studying and actively shaping urban ecosystems. Currently, the concerns outweigh the perceived benefits of integrated research among private funding agencies involved in land development—specifically, they fear that research is time consuming and is not easily contained within the design process or budget. There are also concerns about the limited application of research results to management issues. In confronting these concerns, urban ecological researchers will need to actively assert the value of ecological science, research, and experimentation in urban design projects. To this end, urban ecologists will need to address the broader objective that their research will accomplish; principally, although basic ecological research is used to study a system, and design is used to shape the system, the urban ecology researcher will benefit both from studying a system in order to better shape that system and from shaping a system in order to better study it. Coordinated research and knowledge exchange, advanced data and information sharing, and new research technologies, as well as education and public outreach strategies, will all support the growth of urban ecology and the integration of ecological principles into the design process, ultimately providing the baseline data and proof of concept to implement tested urban sustainability strategies worldwide.

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