PERFORMANCE NICHE: AN ECOLOGICAL SYSTEMS FRAMEWORK FOR TECHNOLOGY AND DESIGN

Michelle Laboy[1]

[1]Northeastern University, Boston, Massachusetts

ABSTRACT: Current paradigms of sustainability move the design and construction industry to pursue a comforting "independence" in function; the pursuit of *net zero* goals. If an "interconnected" paradigm of ecological design superseded the "independence" paradigm of sustainable design, alternative measures could look to define what particular performance niche a building must occupy or construct in an ecosystem. In evolutionary ecology, early definitions of niche refer to a location, independent of the organism occupying it, while more functional definitions refer to the role an organism assumes in sustaining ecosystem functions or constructing an environment. In architecture this may translate to site and performance, respectively. Recent translations in the architecture discourse explored principles of evolutionary ecology, including the notion of niche as site. This paper explores the notion of niche as ecological function, a view of performance with the potential to push design considerations beyond the system boundary of a site, and to understand how to best leverage technology and site construction, beyond site response, to perform in a larger ecosystem boundary. Thinking of buildings not only as consumers but also providers of ecological services, involves defining a niche, understood as the performance void or "recess" in a specific ecosystem to be occupied or replaced by the introduction of a building into an environment. The use of ecology as a metaphor in the design disciplines may be a productive catalyst for new collaborative ways of conceptualizing the relationship of architecture to the environment. However, the meaning of ecological has been stretched into countless definitions, modifiers and applications. This paper returns to the original science of ecology to examine how the concept of niche can trigger renewed thinking about the ecological performance of buildings. Real and speculative examples from practice and academia are presented to illustrate the concept.

KEYWORDS: Niche, Performance, Interconnected, Independence, Ecological

INTRODUCTION

Recently, scientists declared the dawn of the Anthropocene, a new human-influenced geologic epoch, marked by global signals of the spread of radioactive elements, unburned carbon spheres, plastic pollution, aluminum and concrete particles, high levels of nitrogen and phosphate in soils; and even the abundance of fossils of domestic chicken (Carrington 2016). The continued use of fossil fuels and increased carbon emissions are changing the climate at a faster pace than predicted, despite decades of mitigation efforts. Buildings still consume almost 40% of the primary energy and approximately 70% of the electricity in the United States, which continues to increase at a fast pace (Crawley 2009). Water withdrawals for thermo-electric power generation and irrigation have been reduced, but continue to be the largest uses of water (Kenny et al. 2009). In addition to sea level rise, climate change is expected to dramatically shift global groundwater patterns; reducing surface water flows while increasing use and depletion of groundwater in areas prone to drought; increasing heavy rainfall and flooding in regions of moisture convergence; decreasing groundwater levels in heavily urbanized areas due to low recharge, affecting surface and groundwater quality, and causing seawater intrusion in coastal areas (Richard G. Taylor et al. 2012). The urgency to design more sustainable and resilient buildings, cities, and landscapes, is very real, but generalized approaches can result in unnecessary redundancy and complicatedness, encouraging the implementation of highly technological solutions to loosely defined problems, increasing managerial requirements and the potential for accelerated obsolescence. A better understanding of the ecological impact of human-induced changes to the biosphere necessitates a dramatic transformation of ecological design thinking. In this new age, we must critically examine any existing paradigms of sustainability that yield universal solutions, while more intentionally defining the active ecological role of buildings—their performance niche—in multiple scales of specific ecosystems.

1.0. THE NET ZERO OR "INDEPENDENCE" PARADIGM

The current paradigm of sustainable architecture, embodied in the Bullitt Center in Seattle, pursues the idea of a self-sufficient building (Nelson 2011). While a powerful example of a building that performs like a complete and self-sustaining ecosystem; this approach is not feasible in all sites, and it is nearly impossible in many existing urban buildings. Net Zero Energy, Water, and Carbon, quantified as the net of inputs and outputs within a limited system boundary over a period of time (e.g. annually), pursues a comforting "independence" in function, but implies that each project must maximize the implementation of technology in each individual site without considering the optimal scale of performance for each system. The most ambitious sustainability rating systems (e.g. Living Building Challenge) measure building performance against the highest goal of Net Zero, i.e. buildings that harvest, produce or reuse as many resources as they consume within a site; potentially having the unintended consequences of making the highest level of sustainability an isolated rarity, providing an alibi for limited agency, and limiting the ability to conceptualize alternative potentials for ecological performance.

Making the energy goal confusing and inconsistent, various modifiers emerged to differentiate baselines and units of reference for the Net Zero goal, including Site Energy, Source Energy, Energy Costs and Emissions; and various designations based on the type of on-site or off-site sources of renewables (Crawley 2009). Net Zero Energy promotes reductions in energy demand first, which is a good goal for all buildings. It requires on-site production as the second step. However, on-site production is not always feasible, the most cost effective or at the optimal scale (Marszal et al. 2012). Often Net Zero Energy means displacing other important capacities inherent in the surface of a building: roof-mounted solar energy production may not co-exist with a green roof that provides habitat, microclimate modifications through shade and evapotranspiration, stormwater management, and open space for recreation. While "independence" is the apparent goal, the connections a Net Zero building is dependent on are worthy of critical examination. Net Zero Energy buildings can be grid-connected, but this approach can be criticized if it is depending on an electrical grid that still relies on fossil fuels. Net Zero Carbon is criticized on the basis that the "net" approach still allows emissions through distant offsets, and may promote land-grabbing for afforestation that threatens equity in poor areas of the world (act!onaid 2015). For Net Zero Water, the challenges of "independence" are not any less significant. The import of nitrates from rural to urban areas, and the scale of urbanization means that urban sites often do not have the capacity to treat high nitrate concentrations in storm or wastewater (Englehardt, Wu, and Tchobanoglous 2013). Clearly, the independence paradigm has real contradictions and limits.

1.1. An alternative ecological paradigm: interconnected systems

The definition of a system boundary is a critical aspect of ecological systems thinking (Kay 2008). It is imperative to redefine the appropriate scale of agency for every building site and for every resource. Unlike what LEED calls *regional priorities*, which apply equally to any project in any site within an entire region, this proposed alternative requires a campus or district-scale boundary, and a form of ecological cooperation for landscape-scale planning. The "interconnected" paradigm sees potential in buildings that, rather than isolated "self-sufficient" entities, are part of interconnected systems in which each organism, species, actor or component, has a unique space and role to play in the construction and destruction of ecosystems. For example, an emerging alternative to Net Zero, the Net Positive building, could conceivably provide energy for nearby buildings that cannot produce enough energy locally, are too shaded, or have limited area for renewables. Landscape-based water treatment systems require large open areas, which may be better managed at an intermediate scale—for example, within shared open space or ecological corridors. Strategies for stormwater recharge and mitigation of heat-island effect require a decentralized and networked approach, implemented as close as possible to the boundary of each site, to be most effective.

These scale shifts could suggest that some buildings may assume different or specialized roles at an appropriately larger boundary of investigation, based on their unique potential or place in the ecosystem. In that case building typologies could be categorized, similar to living species, based on their role and interactions in an ecosystem. Redefining the boundary of investigation requires a managerial understanding of how landscape or regional ecologies overlaps human ecologies. Some examples may include coupling programmatic requirements for open space in schools with landscape-based water treatment infrastructure that can support a neighborhood; identifying the waste from a high-intensity process or building program as potential input for another; and leveraging high potential sites through zoning based on ecological planning, where certain institutions or building types can adopt an infrastructural or ecological agency for the benefit of multiple buildings or the larger landscape.

If an "interconnected" paradigm of ecological design superseded the "independence" paradigm of sustainable design, an ecological design approach could help define what particular niche a building must occupy, construct or assume in an ecosystem. Examining the ecological concept of niche as a metaphor for design can enable rethinking the appropriate application of technology in each architectural project, requiring collaboration with and knowledge of landscape and urban ecologies.

2.0. THE ECOLOGICAL NICHE: CRITICAL DEFINITIONS

The word niche comes from the Latin word nidus for "nest," and the French adaptation *nicher* for "making a nest," also meaning "recess" ("Niche" 2017). The concept of nest, or recess, suggests a place to be occupied; thus the appropriation of the term by zoologist Joseph Grinnell to describe the relationship of an organism with its habitat, characterized by a set of environmental conditions including spatial and dietary dimensions, that influence behavioral, morphological and physiological adaptations (Odling-Smee 2003; Schoener 2009). Niche is a central concept of ecology, especially in autoecology, which studies the interactions of a single species with its environment; its counterpart being synecology which studies how multiple species interact with one another (Losos 2009). As a result of an expanding definition of the niche concept to include functional aspects and multi-species interactions, the term was used in community ecology to combine insights at the individual, population and community levels (Leibold 1995).

Numerous definitions for the concept of niche have emerged in the field of ecology since the 1920s, some more theoretical than empirical. Differences emerge in ways in which each definition models, measures, validates or characterizes interactions with the environment; and recent reviews of the literature suggest categories to organize them. One makes the distinction between two primary categories: those that define the niche as characteristics of the environment, and those that define it based on the characteristics of the species occupying it; while a third category (from population ecology) considers not only the interaction of a species with the environment but also the effects of competition with other species that share or occupy the same niche (Schoener 2009). Grinnell's original definition of a recess in the environment, which can be empty, considers the niche independent of the species occupying it. On the other hand, the zoologist Hutchinson's definition of niche focuses on the features of the species independent of a location; a conceptual n-dimensional hyper-volume defined by multiple axes for each essential environmental factor, such as required resources or tolerance range for a species to persist.

Both Grinnell's and Hutchinson's definitions have in common a focus on what the environment affords a species. In contrast, functional definitions emerged with Elton's trophic studies on what he called the species "roles;" representing a fundamental shift from the evolutionary view; moving from how the environment influences the adaptation and evolution of the species, towards how a species affects the environment or "what is doing" to its community (Leibold 1995; Odling-Smee 2003). Two other types of ecological niche make this distinction: the "requirement niche," concerning the environmental requirements of species, and the "impact niche," concerning the short-term impacts of species on resource use (Leibold 1995). This distinction is, according to Leibold, different from discussions by others (Schoener 1989; Colwell 1992; Griesemer 1992), which distinguish the "habitat" and "functional" aspects of the niche.

There is one other category within niche theory that is of interest to the topic of this article. The notion of a species engaged in *niche construction* suggests that the niche is neither an independently formed place (or recess) in the environment waiting to be filled, nor is it only a result of the unique evolutionary adaptation of a species to external factors that allows it to persist in a particular place. "Niche construction occurs when an organism modifies the feature-factor relationship between itself and its environment by actively changing one or more of the factors in its environment, either by physically perturbing factors at its current location in space and time, or by relocating to a different space-time address, thereby exposing itself to different factors" (Odling-Smee 2003, 42). Odling and Smee's concept also applies to population and community dynamics, defines as the *ecological inheritance* left for other organisms, *ecosystem engineering*, when one population changes the relativistic niche of a second population, and *ecosystem service*, when a species replaces or compensates for the service provided by another outcompeted species or transformed ecosystem. The notion of *niche as constructed* provides an appropriate point of departure to apply the concept of niche to human-designed environments, and a metaphor for architecture as a species that is occupying, modifying, adapting to, and servicing its environment.

2.1. Parallels in architecture discourse

Two broad categories of ecological niche have parallels in architecture: one defines the location in the environment independent of the organism occupying it but affording its existence (geography, topography, climatic conditions, resource availability); the other defines the role that an organism assumes in a particular place it helps construct (ecological function, ecosystem service, ecosystem engineering, ecosystem construction).

In architecture discourse, the first category can clearly translate to site, a place architecture occupies, and the environmental condition to which architectural form can respond and adapt to. Recently, Caroline O'Donnell proposed the notion of *niche tactics* or *niche thinking* in architecture, "a scenario in which the architectural organism is considered as part of a complex and idiosyncratic network" (O'Donnell 2015, 6–7). This theory focuses on a design process that is analogous to an evolutionary process, emphasizing the importance of tactical design practices. Comparing Michel de Certeau's definition of tactical, which operates in isolated actions as opposed to plans, to Darwin's continuous scrutinizing of slightest variations in evolution, O'Donnell proposes a more nuanced response to site, "not only to the visible, the whole, and the objective, but also to the hidden, the systematic, and the idiosyncratic"(O'Donnell 2015, 24). This response rejects typologies, images or symbolism, and contextualism; instead making the site legible through form.

Other architects drew from niche theory, specifically Hutchinson's n-dimensional hyper volume, to propose a "process of designing with evolutionary algorithms" that could account for multiple axes, including the typical environmental concerns or climatic factors of sustainable design, and "a whole slew of additional niche axes" to be defined by architects, that would allow formal responses to all sorts of complex environmental forces acting on the architectural object (Koltick and Lutz 2013, 254). Their focus on a parametric process of form-finding resonates with O'Donnell, who references Greg Lynn, as "one of the original proponents of evolutionary thinking in contemporary architecture." The foreword to Lynn's book introduces the idea of complex dynamic systems generating form, suggesting that just like chaos theory had drawn attention to natural phenomena previously excluded from physics, architecture must "start paying attention to forces that are by definition suppressed from a classical proportional system"(Bouman 1998).

The formal approach to evolutionary thinking, whether through algorithms of parametric design, bio-mimicry, animalism, or other forms of organicism, have plenty of proponents and critics in the discourse; and is not the main focus of this article. However, a critical distinction must me made; these formal translations are often confined to operations in the design process and internal to the discipline, culminating with the construction of architecture as a static form. An alternative translation of ecological niche concepts focuses on the performance of the architectural object that starts during and after its construction; thus the metaphor need only engage the design process of form-finding, insofar as it later affects ecological performance, which include human ecology factors.

While O'Donnell drew from views of perceptual psychologist J.J. Gibson, using the term affordance to distinguish between habitat (where it exists) and niche (how it exists) (O'Donnell 2015)—function was still a question of what the environment affords architecture, and how architecture formally responds to it. On the other hand, niche differentiation, according to landscape architects Sven Stremke and Jusuck Koh, sees individual sites, including buildings, as agents of sustainable energy landscapes through vertical stratification, horizontal and temporal zonation, increasing diversity of function, improving energy utilization and reducing resource competition (2011). The notion of performance niche, in its inherent need to push design considerations beyond the system boundary of a site towards scales of landscape and urban ecology, expands the scale and application of this translation. This is analogous to how functional definitions of niche enabled a shift from autoecology to community ecology. Its potential is to elucidate how to best leverage technology and site construction into instruments of productivity in a larger ecosystem boundary.

3.0. PERFORMANCE NICHE: A DIFFERENT FUNCTIONALISM

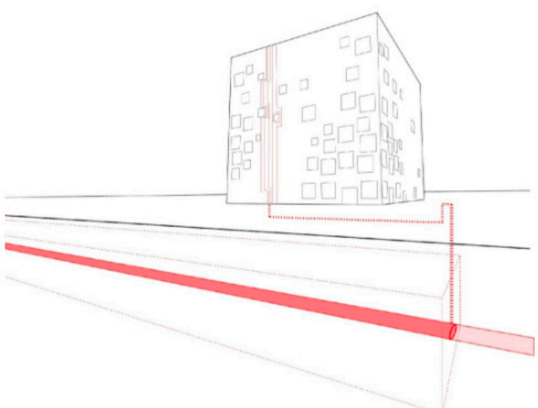
Realizing a performance-based concept of niche means a new form of design thinking that not only acknowledges that buildings, rather than independent entities, are networked with other external systems to receive some ecological services, but that can conversely be leveraged to perform some specific ecological service for other buildings, for a local ecosystem or a larger landscape. Thinking of buildings not only as consumers but also as providers of *ecosystem services*, as agents of *ecosystem engineering*, or builders of *ecological inheritance*, means understanding their potential interactions with an entire ecosystem; defining the performance void or "recess" to be constructed, occupied or replaced by the introduction of a building into an environment. This ecological metaphor can be a productive catalyst for new collaborations between architecture and landscape planning, towards conceptualizing the productive relationship of buildings and the environment, through renewed thinking about their ecological performance beyond current paradigms of sustainability.

The following case studies, viewed through the lens of performance-niche, illuminate the potential applications of this principle to three primary forms of architecture performance: energy, water and carbon. These examples operate at the scale of a community, district or campus–one that is larger than the building's immediate site but smaller than an entire region; to exchange resources, ecosystem services or building some capacity for the ecosystem in which they exist or will help construct

3.1. The energy niche: buildings that consume waste

District power and heat co-generation (co-gen) is an old and well-known example of a collaborative approach to building energy, commonly used on institutional campus settings, to locally recover excess heat from a power generation process, reduce energy losses from distribution, increase fuel flexibility, and reduce emissions. It is notable that district heating alone does not always result in reduced total energy when analyzed through Life Cycle Assessment or Emergy Analysis, because the savings are primarily dependent on fuel source and network size, with studies suggesting small to mid-size networks of renewables perform best (Andrić et al. 2017). Furthermore, while institutional co-gen plants find additional synergy between processes, these facilities are often single-use buildings, exclusively dedicated to primarily fossil-fuel energy infrastructure. The College of Environmental Science & Forestry at the State University of New York, in Syracuse, changes this typology by combining office, academic and research uses with a heat-and-power cogeneration plant that is interconnected with four adjacent campus buildings, providing 60% of the campus heating needs and 20% of its electrical peak demand (The American Institute of Architects 2014). This project provides an ecosystem service by metabolizing the by-product of a regional forestry management program into biomass for heat and energy that supplies not only its own site, but also sharing the surplus with campus buildings that cannot produce energy on their own, while connecting human capital in programs of research and education. Co-generation with biomass can have a Total Energy Cost 6.0 to 10.7 times lower than non-renewable fuels (Stanek, Czarnowska, and Kalina 2014), and when using waste wood, it can reduce the one-way flow of fossil fuel carbon emissions without significant impact to land use (Lippke et al. 2012). Finding waste from renewable sources, such as sustainable forest management, is most ecologically sound as a specific local or regional approach to cogeneration. The potential for district power and heating can be designed according to the fuel type available, optimal network size, growth conditions and volumes of biomass available.

Sources of residual heat or fuel resulting from the waste of an urban process or operation, such as landfills, abandoned mines, and contained deposit facilities, may not constitute a renewable source; but can last for decades or even centuries. For example, bacterial decomposition in landfills can produce methane for more than 50 years after a material is first deposited (Mann & ATSDR, 2001). Similarly, abandoned mines have great potential as energy storage. Mine water management keeps mines dry during operations, but shaft refilling continues to be necessary in order to seal off old mine shafts; an operation that can go on for several hundred years, and requires the discharge of water at relatively high temperatures to rivers (Thien 2015). Active mine operations are high consumers of energy and water, sometimes depleting aquifers and lowering groundwater levels; thus synergies and trade offs between lowering water use and increasing energy efficiency are being sought in many regions (Nguyen et al. 2014). Building energy use can become part of a regional approach to water and energy management in mining regions. Mapping those types of sources can identify sites to locate sinks of energy (Stremke and Koh 2011) Buildings in these sites can fill a resource-intensive performance niche. The Zollverein School of Management in Essen, Germany by SANAA and Transsolar (2007), built on the campus of a former mine, consumes the wasted heat of a local mine that would otherwise end up in the river, providing an ecosystem service to the riverine landscape. Energy is extracted from the high mineral mine water, through a heat exchanger and pumps, and cycles through tubing embedded in the walls and ceiling as a form of *active thermal insulation*, which loses close to 80% of the heat to the outside air (Moe 2010, 148), (Figure 1). This approach would not be sustainable in another place where energy was not being wasted anyway, and it may be improved on if it provided district heat. Yet in this case, the heat loss through the envelope has a trade-off in reducing resource use and embodied energy by eliminating the insulation and cladding layer, minimizing wall thickness to the minimum structural requirements, making the architectural expression possible, and improving access to daylight (Moe 2010).



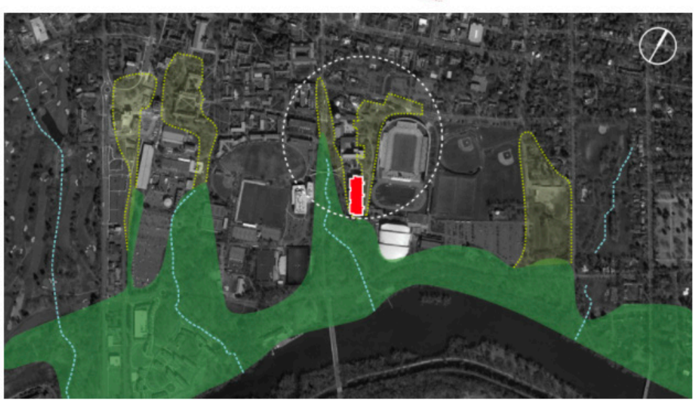


Figure 1 (top): Zollverein School of Management, Essen, Germany. SANAA, Transsolar. Image by author.
Figure 2 (bottom): Princeton University, Frick Chemistry building overlaid on the stream corridors, showing areas for future expansion of woodland. Project design: Hopkin Architects, ARUP, MVVA. Image adapted from mapping by MVVA and the Princeton University master plan, by author.

3.2. The water niche: buildings that create ecological flow

Most buildings reduce the ability of a landscape to recharge ecological groundwater flow. While underground, engineered recharge strategies and green roofs can replace some of those functions locally, some buildings can engage in niche construction by becoming instruments for a more ambitious ecological restoration project. Often, large landscape planning for decentralized groundwater recharge in urban sites is hard to implement due to the discontinuity and fragmentation of land uses. A form of landscape ecology planning can leverage critical sites for architecture projects as agents of *niche construction*.

Princeton University has proposed ambitious goals of integrated landscape and stormwater management towards ecological restoration of its campus natural systems. Working on an existing and dense campus means that the implementation must leverage strategic building sites that can serve the more ambitious and sensitive areas of the ecological restoration project. A campus master plan, for which landscape architect Michael Van Valkenburgh (MVVA) and Nitsch Engineering consulted (2005-2008), proposed strategies to restore a series of ecological streams and woodland buffer corridors that used to bring water from the campus on the north to Lake Carnegie on the south, using primarily landscape based strategies to reduce runoff, improve stormwater quality and increase groundwater recharge (Figure 2). MVVA initiated the implementation of the most significant stream restoration project on a site where new architecture was to be built adjacent to one of these corridors (MVVA 2017). The new Frick Chemistry building, completed in 2011, is located next to the Washington Road stream, which is slated for restoration. This building not only implements water use reduction strategies, including greywater recycling and rainwater collection (ARUP 2017) but most importantly, enabled ecological restoration through siting and landscape strategies.

While small on-site strategies for stormwater management, including green roofs in existing or new infill buildings across campus, are being considered to increase the capacity of the campus to retain stormwater, projects like the Frick Chemistry building filled a unique performative niche in the campus. The siting strategy prioritized the construction of an important *ecological inheritance* for the campus, building parallel to the stream to enable expansion and continuity of the woodland restoration project. Therefore the North-South orientation for the building favors water systems, rather than the energy-driven East-West orientation that governs most projects deemed sustainable. The extensive site work required for the construction of the building enabled the intensive landscape strategies, eliminating a 124-space parking lot that was a source of pollution adjacent to the stream, making space for three bioretention rain gardens that treat close to half of the stormwater from the roof, a 12,000 gallon cistern for the remaining rooftop runoff collection that is used for toilet flushing, and allowing the campus nature walks to extend through these formerly paved areas. That represents over 1.1 million gallons of stormwater that is retained on site (Princeton University 2011). The work to restore the Washington Road stream adjacent to the building was initiated with this project, which sponsored the extension and re-establishment of woodlands that once filled the stream valley and engineering rain gardens that provide biofiltration of campus stormwater (Stevens 2010). Through coordination of siting and construction strategies, the architecture engaged in a process of niche construction, building woodland buffers and rain gardens to reestablish ecological flows adjacent to the site. Other strategic architectural projects will be leveraged to expand the woodland corridors further into campus at each of the four corridors shown in Figure 2. This project demonstrates that by coordinating the design of major architecture with landscape planning efforts, the construction of buildings may have significant agency in implementing broader landscape ecological goals.

3.3. The carbon niche: buildings that capture emissions

Forests capture carbon from the atmosphere and store it in the tree wood material. Using wood for building products is more effective at carbon mitigation than using wood for fuels; especially if wood is substituting other products such as steel joists, the ratio of fossil carbon reduction per unit of carbon in the wood is 4.8 for building products versus 0.40 for gasoline (Lippke et al. 2012). Clearly, buildings as an aggregate can have significant impacts in the global climate mitigation efforts, and become agents of carbon sequestration, especially if coupled with sustainable foresting practices. The source of wood creates many challenges and opportunities: from raising issues of equity and social justice to enabling phytoremediation and recreational value, which can have broader impacts in landscape and ecological planning. For example, efforts to reduce emissions by developed countries by controlling deforestation and reducing forest degradation in developing countries, such as REDD+, has been criticized for promoting commercialization of forests based purely on carbon value, and touted as a new form of colonialism or land grabbing (Gotangco Castillo, Raymond, and Gurney 2012). Land-grabbing is defined as large-scale transactions by sovereign funds from resource-constrained nations to purchase large tracts of well-endowed land in poor rural areas of other countries to supplement, replace or offset their citizens' consumption (Rudel and Meyfroidt 2014). Beyond increased attention in utilizing wood products in the building industry to help carbon mitigation, there are no specific real examples of buildings that engage in constructing a specific niche for forest management in local ecosystems, towards sustainable landscape planning. A collaborative design studio at Northeastern University gave students the opportunity to engage with this question in a speculative project.

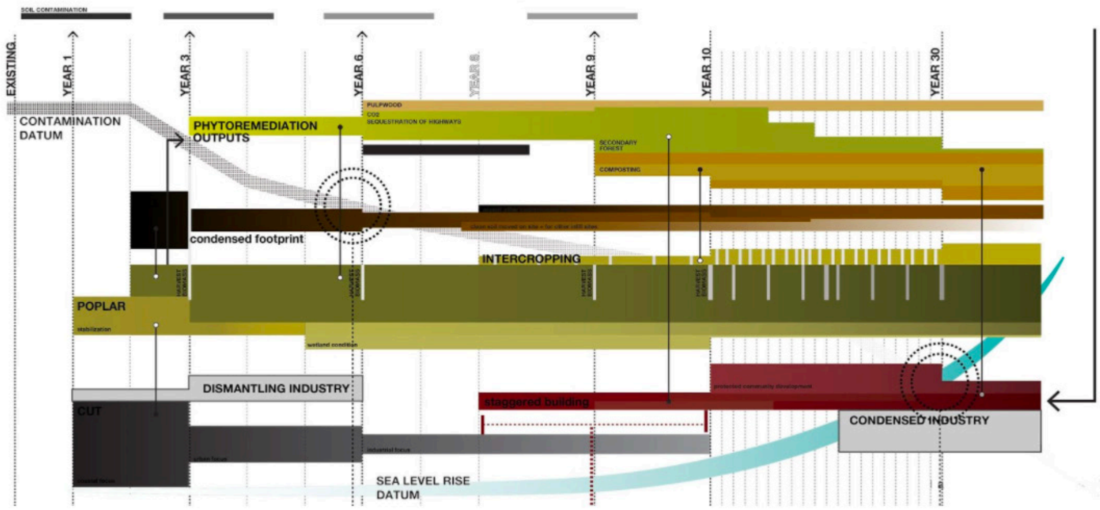


Figure 3: Cycles of material and energy flows between building and urban forest in an industrial district of Boston. Source: Northeastern University Comprehensive Design Studio (Students: Katie Laughinghouse, Molly McNally, 2016).

This interdisciplinary studio project between architecture and landscape architecture students explored the construction of a hyper-productive landscape by proposing a vast program of forestation in brownfields, planting fields of a very fast-growing hybrid species of poplar, a workhorse for phytoremediation, in the industrial center of Boston. A proposal included the design of industrial buildings for processing and manufacturing timber building products; and suggested a policy allowing new development in this previously unbuildable district if it utilized the rapidly developing timber product in its construction as part of the program of carbon and contaminant capture. The buildings would also use the compost of the urban forest for heating. The design mapped the flow of planting, phytoremediation, harvesting, material processing and building construction in this district, through the full life cycle of components (Figure 3). The potential of this project is integrating reforestation, phytoremediation and carbon capture locally, especially when considering that developed countries seek land in rural areas, sometimes in developing countries, to offset carbon emissions, while acres of urban brownfields sit empty with potential. These sites are often located in already dense areas, near existing infrastructure, but remain unbuildable due to high levels of contamination. A method of niche construction can leverage available land that cannot be built on using conventional approaches, by engineering new hyper-productive ecosystems that can provide soil cleaning, carbon capture and building materials. Another studio proposal calculated that if all Massachusetts brownfield sites were planted with poplar and harvested, enough power could be generated to nearly replace the local natural gas power plant in Boston. The design of the power plant became an architecture project that would occupy a unique niche: to enable the financing of the phytoremediation project, service an entire district with power and heat, and provide industrial development and recreational opportunities. These hybrid architecture and landscape models engage in a more equitable form of land-grabbing, or niche construction, enabling the construction of urban architecture with timber sourced locally, building a productive urban forestry program for energy and recreational open space, and unleashing a new urban industrial economy.

CONCLUSION

The metaphor of performance niche acknowledges that buildings already act upon ecosystems, and can be agents of ecological productivity; rejecting a dichotomy between being fully independent or ecologically destructive. The performance niche defines ecological roles or functions for buildings, whether as providers of ecosystem services (metabolizing waste), producers of ecological inheritance (building ecosystem capacity), or engineers of ecosystems (niche construction). The paradigm of interconnectedness rejects the assumption that every building must be a closed system containing everything necessary to sustain life within—but finds efficiencies in the things that buildings can do in groups, or as part of ecological communities; creates symbiotic relationships between buildings and other urban processes' by consuming many forms of excess or waste; leverages the energy of a destructive process (site excavation and construction) into an ambitious process of ecosystem construction; and creates keystone building species that are essential for ecosystem functions that allow other building species to co-exist. An interconnected paradigm replaces conventional sustainable design approaches with ecological design thinking, jumping scales from the architectural site to ecosystems.

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REFERENCES

act!onaid. 2015. “Caught in the Net: How ‘net-Zero Emissions’ will Delay Real Climate Action and Drive Land Grabs.” http://www.actionaid.org/sites/files/actionaid/caught_in_the_net_actionaid.pdf.

Andrić, I., A. Pina, P. Ferrão, B. Lacarrière, and O. Le Corre. 2017. “On the Performance of District Heating Systems in Urban Environment: An Emergy Approach.” *Journal of Cleaner Production* 142: 109–20.

ARUP. 2017. “Princeton University Frick Chemistry Laboratory.” *ARUP*. Accessed February 6. http://www.arup.com/projects/princeton_university_frick_chemistry_laboratory.

Bouman, Ole. 1998. “Amor(f)al Architecture or Architectural Multiples in the Post-Humanist Age.” In *Folds, Bodies & Blobs : Collected Essays*, by Greg. Lynn. Books-by-Architects. [Bruxelles] : La Lettre volée.

Carrington, Damian. 2016. “The Anthropocene Epoch: Scientists Declare Dawn of Human-Influenced Age.” *The Guardian*, August 29. https://www.theguardian.com/environment/2016/aug/29/declare-anthropocene-epoch-experts-urge-geological-congress-human-impact-earth.

Colwell, R.K. 1992. “Niche: A Bifurcation in the Conceptual Lineage of the Term.” In *Keywords in Evolutionary Biology*, edited by Evelyn Fox Keller and Elisabeth Anne. Lloyd. Cambridge, Mass. : Harvard University Press,.

Crawley, Drury. 2009. “Getting to Net Zero.” Edited by Shanti D Pless, Paul A. (Paul Allen) Torcellini, and National Renewable Energy Laboratory (U.S.).

Englehardt, James D., Tingting Wu, and George Tchobanoglous. 2013. “Urban Net-Zero Water Treatment and Mineralization: Experiments, Modeling and Design.” *Water Research* 47 (13): 4680–91.

Gotangco Castillo, C Kendra, Leigh Raymond, and Kevin Robert Gurney. 2012. “REDD+ and Climate: Thinking beyond Carbon.” *Carbon Management* 3 (5): 457–66.

Griesemer. 1992. “Niche: Historical Perspectives.” In *Keywords in Evolutionary Biology*, edited by Evelyn Fox Keller and Elisabeth Anne. Lloyd. Cambridge, Mass. : Harvard University Press,.

Kenny, Joan, Nancy Barber, Susan Hutson, Kristin Linsey, John Lovelace, and Molly Maupin. 2009. “Estimated Use of Water in the United States in 2005: U.S. Geological Survery Circular 1344.” U.S. Department of the Interior. https://pubs.usgs.gov/circ/1344/pdf/c1344.pdf.

Koltick, Nicole, and Matthew Lutz. 2013. “ACSA 101 : New Constellations, New Ecologies : Proceedings of the 101st Annual Meeting of the Association of Collegiate Schools of Architecture (ACSA).” In , edited by Ila Berman and Edward architect. Mitchell, 251–57. Washington, D.C. : ACSA Press.

Leibold, Matthew A. 1995. “The Niche Concept Revisited: Mechanistic Models and Community Context.” *Ecology* 76 (5): 1371–82.

Lippke, Bruce, Richard Gustafson, Richard Venditti, Philip Steele, Timothy A. Volk, Elaine Oneil, Leonard Johnson, Maureen E. Puettmann, and Kenneth Skog. 2012. “Comparing Life-Cycle Carbon and Energy Impacts for Biofuel, Wood Product, and Forest Management Alternatives.” *Forest Products Journal* 62 (4): 247.

Losos, Jonathan B. 2009. “Autoecology.” In *The Princeton Guide to Ecology*. Guide to Ecology. Princeton: Princeton : Princeton University Press.

Marszal, Anna Joanna, Per Heiselberg, Rasmus Lund Jensen, and Jesper Nørgaard. 2012. “On-Site or off-Site Renewable Energy Supply Options? Life Cycle Cost Analysis of a Net Zero Energy Building in Denmark.” *Renewable Energy* 44: 154–65.

Moe, Kiel. 2010. *Thermally Active Surfaces in Architecture*. New York: New York : Princeton Architectural Press.

MVVA. 2017. “Princeton University.” *Michael Van Valkenburgh Associates Inc*. Accessed February 9. http://www.mvvainc.com/project.php?id=95.

Nelson, Bryn. 2011. “The Self-Sufficient Office Building.” *New York Times*, October 4. http://www.nytimes.com/2011/10/05/realestate/commercial/seattles-bullitt-center-aims-to-be-energy-self-sufficient.html.

Nguyen, M.T., S. Vink, M. Ziemski, and D.J. Barrett. 2014. “Water and Energy Synergy and Trade-off Potentials in Mine Water Management.” *Journal of Cleaner Production* 84: 629–38.

“Niche.” 2017. *Merriam-Webster.com*. Accessed January 28.

Odling-Smee, F. John. 2003. *Niche Construction the Neglected Process in Evolution.* Princeton: Princeton : Princeton University Press.

O’Donnell, Caroline. 2015. Niche Tactics : *Generative Relationships between Architecture and Site*. New York, NY : Routledge, Taylor & Francis Group,.

Princeton University. 2011. “Stormwater Management.” Report on Sustainability. Princeton University Reports. Princeton University. http://www.princeton.edu/reports/2011/sustainability/conservation/stormwater-management/.

Richard G. Taylor, Bridget Scanlon, Petra Döll, Matt Rodell, Rens Van Beek, Yoshihide Wada, Laurent Longuevergne, et al. 2012. “Ground Water and Climate Change.” *Nature Climate Change* 3 (4): 322.

Rudel, Thomas K., and Patrick Meyfroidt. 2014. “Organizing Anarchy: The Food Security–biodiversity–climate Crisis and the Genesis of Rural Land Use Planning in the Developing World.” *Land Use Policy* 36: 239–47.

Schoener, Thomas W. 1989. “The Ecological Niche.” In *Ecological Concepts : The Contribution of Ecology to an Understanding of the Natural World*, edited by J. M. Cherrett and A. D. Bradshaw. Oxford [England] ; Blackwell Scientific Publications ;

Schoener, Thomas W. 2009. “Ecological Niche.” In *The Princeton Guide to Ecology.* Ed. Carpenter, S., Levin, S. Guide to Ecology. Princeton: Princeton : Princeton University Press.

Stanek, Wojciech, Lucyna Czarnowska, and Jacek Kalina. 2014. “Application of Life Cycle Thermo-Ecological Cost Methodology for Evaluation of Biomass Integrated Gasification Gas Turbine Based Cogeneration.” *Applied Thermal Engineering.*

Stevens, Ruth. 2010. “New Chemistry Building Reflects Its Environment.” *News at Princeton*. February 25.

Stremke, Sven, and Jusuck Koh. 2011. “Integration of Ecological and Thermodynamic Concepts in the Design of Sustainable Energy Landscapes.” *Landscape Journal: Design, Planning, and Management of the Land* 30 (2): 194–213.

The American Institute of Architects. 2014. “Gateway Center - SUNY_ESF College of Environmental Science & Forestry.” *Top Ten Projects.* http://www.aiatopten.org/node/336.

Thien, Leonhard. 2015. “Geothermal Re-Use of Coal Mining Infrastructure and Mine Water in Hard Coal Mining in the Ruhr Area/Germany.” In *Proceedings World Geothermal Congress* 2015. Melbourne, Australia: International Geothermal Association.