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Intersecting disciplinary frameworks: the architecture and ecology of the city

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ABSTRACT

Introduction: While many studies have explored the link between ecology and urban design, this paper examines two major conceptions that can promote deeper connections between architecture and ecological science.

Outcomes: Rather than providing a comprehensive review, the paper explores in detail two frameworks that have not yet been exploited as foundations for a bridge between these fields. One is the seminal work of Aldo Rossi on the architecture of the city, as opposed to a more traditional architectural focus on specific buildings, lots, or specific clients. The complementary framework for ecological science is the ecology of the city, developed to support and explain a new era of more integrated social-ecological study of urban systems than had existed previously.

Discussion: This paper draws heretofore unexamined parallels between architecture as represented by the work of Rossi and the ecology of the city as represented by the Baltimore School of Urban Ecology. The ecology of the city has become a widely used framing in the science of urban ecology, while the architecture of the city continues to influence a deeper understanding of the built environment as a whole. The parallels provided by the architecture of the city and the ecology of the city help to understand the historical interrelations between nature and culture.

Conclusion: Intersecting the two conceptual frameworks of the architecture and ecology of the city can help satisfy the call for an actionable ecology for the city. This call demands both disciplines integrate their conceptual frameworks with communities in the collective enterprise of creating urban ecosystem health, justice, and sustainability.

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Introduction

Architecture and ecology have developed conceptual disciplinary frameworks that reflect separate evolutions and therefore present multiple opportunities for substantive integration. This paper is motivated by the remarkable similarities in the conceptual shift to an ecology of the city over the past 20 years (Pickett et al. 1997a, 1997b; Grimm et al. 2000), to a similar shift to the architecture of the city introduced to an English-reading audience in the 1980s (Rossi 1982). The conceptual reframing of architecture not just as the design of individual buildings *in* the city, but the architecture of the city as a complex and systemic whole was followed by the shift in urban ecological science from examining analog green spaces within cities to entire urban mosaics that incorporate biological, social, and built components (Cadenasso et. al. 2006a ; Zhou et. al. 2014). While both ecology and architecture provide distinct conceptual frameworks for the city, one for nature and one for culture, these frameworks need to be intersected to further an actionable ecology *for* and architecture *with* cities.

The word “architecture” comes from the Greek “arkitekton,” αρχιτέκτων, translated as “master builder,” and in modern society the architect is defined by professional

licensure as a public servant responsible for human health and well-being, and more recently sustainability, in the built environment. In Latin, “architectura” means the “art of building,” and therefore implies a broader collective cultural enterprise. Architecture, as the art of building, entails the creation of places which provide environmental comfort and enhance human experience and activity in relation to esthetic, spiritual, and cultural traditions. Buildings and cities are the hard and enduring factual evidence of historical civilization’s values, cultural identity, and environmental practices. However, professional architects in the United States are involved in only a small percentage of building: 75% of building construction in the US is within the urban sprawl shunned by most architects, and astonishingly only 2% of houses in the US involve the hand of the architect (Durham-Jones 2000).

The word “ecology” (“Ökologie”), coined in 1866 by the German scientist Ernst Haeckel (1834–1919), is the branch of biology that studies the relations of organisms to each other and to their physical environment. “Ökos” means house, so ecology as a discipline begins with an architectural metaphor for the study of the Earth as our collective house. More recently, the word is associated with the politics of environmentalism, due to concerns

first about pollution and more recently public discussions on climate change. It has been notably misused in urban studies, such as in the Chicago School's use of terms like "succession" and "blight" as a metaphor for social transformations in cities (Light 2009). In post-modern cultural discourse, the term, often used in the plural "ecologies," metaphorically points to relatedness and fluidity of elements in cultural systems. This complex cultural understanding of ecology reflects its recent definition as "the scientific study of the processes influencing the distribution and abundance of organisms, the interactions among organisms, and the interactions between organisms and the transformation and flux of energy and matter" (Likens 1992). The ecosystem approach: its use and abuse. Ecology Institute, Oldendorf/Luhe, <http://www.caryinstitute.org/discover-ecology/definition-ecology>).

The work of Aldo Rossi best illustrates a radical shift in the framework in architecture that provides crucial conceptual and practical intersections with evolving thinking in urban ecological science. The publication of *L'Architettura Della Citta* in 1966 and its translation into English as *The Architecture of the City* in 1982 initiated the establishment of a rational urban science based on a careful study of the physical reality and historical evolution of the architecture of the city as a complex cultural system rather than as the design of individual buildings within limited property boundaries. Rossi wrote his book two decades after the end of World War II and his project grows out of both the close observation of the ruins of many historical European cities and the new modern construction that was erasing traditional urban form. Rossi's structural analysis of cities still resonates as a critique of modern city planning. Rossi's text is both a critique of the naïve, quasi-scientific functionalism of modern city planning, and an argument for a more rigorous empirical approach to urbanism drawing from geography, history, economics, political science, and urban ecology as understood at the time. Examples of Rossi's influence around the world include Mario Gandelsonas structural analysis of North American cities (1999), Kaijma, Kuroda, and Tsukamoto's study of Tokyo (2001), and Pritzker Prize winning architect Wang Shu based his Ph.D. dissertation based on a careful reading of Rossi's theories in the face of the destruction of historical cities in China (Wang 2000).

The distinction between ecology *in* and *of* the city is a foundational concern of the Baltimore Ecosystem Study (BES), which first appears in a special issue of *Urban Ecosystem*, marking the establishment of the first urban sites in the US National Science Foundation's Long Term Ecological Research program. Fundamental to the definition of this new expansive urban ecosystem research is the challenge to create integrated urban ecological research of the

city (Pickett et al. 1997a). The conception of the ecology of the city has become a predominant perspective in urban ecological science and is used as a framing device in several textbooks on the topic (e.g., Niemala 2011; Adler and Tanner 2013; Forman 2014). The BES was established in order to understand urban areas as integrated systems linking social, cultural, economic, biological, and physical processes of cities (Pickett et al. 1997b; Grove et al. 2015). The integrated approach to human ecosystem observation and analysis goes beyond the metaphorical similarities taken by the Chicago School of Urban Ecology of the 1920s and 1930s (Grove and Burch 1997; Light 2009; Cadenasso 2013). Cultural metaphors are important integrative tools in ecology distinct from technical scientific meaning and modeling (Pickett, Cadenasso, and Grove 2004; Larson 2011). Succession, community, disturbance, competition, and ecology itself have acquired rigorous ecological connotation, but are also creative and provocative metaphorical figures of speech. The term architecture itself is often used metaphorically in ecology to describe the general structure of an ecosystem, so a dialog between the architecture and the ecology of the city needs to carefully understand the metaphorical use of language that has technical meaning in each respective discipline.

The intersection between the architecture and ecology of the city implies a move from specialists designing individual buildings or scientific experiments within the city to a broader structural conceptions of cities as complex systems (Batty 2013) comprised of biotic and abiotic elements in continual co-evolution (Alberti 2015). While architects and ecologists both serve specific societal roles within distinct disciplines that emerged during the Enlightenment and scientific revolution, the broader discursive fields of architecture and ecology have important cultural meaning as arenas for the production of every-day knowledge in a global urban society. Recent calls to create an actionable ecology for the city parallel current debates in design that distinguish top-down practices of designing for people to ones that work bottom-up *with* communities (Dodd et al. 2012; Maier 2014; Rahman and Lim 2016). The shift to an ecology for the city also announces the arrival of ecology's cultural moment, implying a move from specialists working within established environmental planning, policy and management regimes to a new cultural role joining architects in framing our collective image of the city.

The paper is structured around four conceptual intersections through which architecture and ecology can join forces to develop new rules and models for the design of cities. The first intersection compares Rossi's notion of collective urban artifacts to an integrated science of patches structured across mosaics (Forman 2014) of ecological gradients. Second, the

cultural history and collective memory of the architecture of the city is discussed in relation to the temporal framework of long-term ecological research (Redman, Grove, and Kuby 2004; Collins et al. 2011). Third, urban morphological and typological classification systems in architecture are examined in relation to methods of classifying high-resolution spatial heterogeneity in ecology (Cadenasso, Pickett, and Schwarz 2007; Zhou et al. 2016). Finally, the architectural dynamics of urban elements are compared with methods of measuring structure, flow, and feedback in urban ecosystem science (Grimm and Redman 2004; Chapin, Matson, and Vitousek 2011). The structure of the essay is an effort to go beyond the generalities of ecologically informed landscapes *in* the city and to point to specific research *of* cities as integrated architectural and ecological systems. The paper illustrates these four points based on the 1982 translation of Rossi's book and the insights of the BES (e.g., Pickett et al. 2011; Grove et al. 2015) rather than comprehensive reviews of urbanism (cf. Shane 2011; Ellin 2006) or urban ecology (e.g., Alberti 2008; Forman 2014) as entire disciplines.

Collective urban artifacts as ecological patch structure

The city is preeminently a collective artifact that is a complex work of art made by human hands over time (Rossi 1982, 126). Rossi repositions architecture, not as just the specific profession of designing individual buildings as practiced by licensed specialists, but as a more universal and scientific way of understanding the structure and evolution of urban form. Rossi proposes his scientific approach based on a method of "reading" the "singular physical form" of urban artifacts as the result of their unique geography and history (32). The city itself and its surrounding regional land form are seen as large and complex human-made objects that grow (or shrink) over time. "[a]rchitecture clearly represents only one aspect of a more complex reality, of a larger structure; but at the same time, as the ultimate verifiable fact of this reality, it constitutes the most concrete possible position from which to address the problem" (16). Comprehensive knowledge comes from carefully reading the evolution of urban artifacts, from the city in its totality, to a fine grain understanding of its street system and topography, to its landmarks and monuments, and most importantly, what we perceive and experience while walking down a city street (35).

Rossi repeatedly writes that city making is complex and collective, where social and cultural rules change over time. His book introduces both the integrated idea of the *collective* handmade material fact of the city and the *autonomy* of urban artifacts as the objects of specialist reading. While the word autonomy gives the sense of independence, self-

governance, and freedom, for Rossi the autonomy of architecture provides a unique type of observation that no other artistic or scientific point of view possesses (133). He sees reading the architecture of the city as "an autonomous urban science" (57) with value that simplistic functionalist planning lacks (46, 81, 82). Architecture is described as "a circumscribed domain which develops autonomously" (107) with its own principles and forms (127). Architecture has both disciplinary value but also a larger intrinsic cultural value as a way to analyze urban form, especially in relation to residential districts (65, 150), specialized zones (66), or agricultural domains (93) as relatively "autonomous parts" of the city region (65), which Rossi calls urban artifacts and urban ecologists describe as patches.

The concept of ecological gradients, an important foundation for the ecology of cities, incorporates mixtures of built, vegetated, and surface areas, not just the green components of the city with which ecologists are familiar. Gradients provide ways of measuring the abstract orderings of this huge variation in changes in land cover, human activity, and the fluxes of capital, energy, material, and information in and around city regions (McDonnell and Pickett 1990; Pickett and Cadenasso 2007; Cadenasso et. al. 2006; Grimm et al. 2016). Gradients are constructs used for understanding systems across a wide range of defining variables, stress factors, disturbances, and other controlling factors (Pickett et al. 1997a; Dow 2000). City and nature are not seen as separated between an urban core and rural periphery, but the urban is seen as a continuous ecological phenomenon comprised of all types of land cover that are controlled by social processes (Cadenasso, Pickett, and Grove 2006b). Urban gradients are composed of differentiated patches, which parallels the concept of urban artifacts as described by Rossi. For Rossi, there is also no distinction between city and country. All inhabited places are comprised of artifacts that demonstrate the transformation of nature through the handiwork of humans. Urban and rural artifacts include built, vegetated, and surface areas across vast city regions including city centers, landmarks, neighborhoods, parks, lawns, and gardens, as well as agricultural and forest land. These works are collective cultural artifacts in that they are an immense material repository of human thought and labor. Cities and other human landscapes testify to social values that constitute ecological memory and notions of continuity and permanence.

Architecture is the result of specific cultural processes and is understood in its built reality, which in turn shapes real human experiences, such as when moving between built and open spaces. For Rossi, the type of experience of walking through a particular

building, street, or district (33), or for that matter, forest, farm, garden, or park, results from the active perception of the intentional transformation of an environment for human occupation. The city, and its cultivated landscape, is seen as the human achievement par excellence, both as a subject of culture and an object of nature. Imagination and collective memory become imprinted on people and landscapes and custom our sense of space, enabling us to orient ourselves within both the city and countryside. The architecture of the city is not a policy or plan but is “a great, comprehensive representation of the human condition” (101). Rossi’s book is not just a call to develop the ability to read the complexity of cities but addresses many contributions from psychology, sociology, and urban ecology (cf. Burch, Machlis, and Force 2017 for social science parallels). He is convinced that all disciplines will develop a deeper understanding once they pay more attention to the structural and material form of cities and landscapes.

An intersection of the architecture and ecology of the city recognizes the reciprocal, functional relationships between human and non-human patch patterns, the autonomous yet collective nature of urban artifacts (e.g., Lachmund 2013), and their dynamics across ecological gradients. For both architecture and ecology, urban form is the cultural and spatial pattern and processes of the built, infrastructural, and biotic components of cities. Both the architecture and ecology of cities should seek to describe relationships between urban form, structure, processes, and change to develop not only models, tools, and data sets, but also cultural concepts that better incorporate interactions among the social, ecological, and infrastructure components of urban systems (McGrath and Pickett 2011). In long-term research, linking ecological flows, functions, and processes as structured by collective urban artifacts across ecological gradients provides a novel starting point for an integrated examination of urban structure and form. This generates a unique platform on which to build cross-city comparative research (Pickett et al. 1997b; McDonnell and Hahs 2009), but also provides the basis through which to intersect the parallel concepts of the architecture and ecology of the city.

The city as the object of long-term research and the subject of history and collective memory

In addition to being by nature collective, the architecture of the city is something that *persists* through many transformations as buildings and city forms often outlive their initial uses. Rossi’s empirical science of cities involves the careful study of the transformations of functions or uses that buildings, landscapes, and cities gradually undergo over time

(57). The phenomena of the persistence of architecture, related to the concept of legacies in ecology, constitutes the history and collective memory of the city, and can be examined in fixed monuments, landmarks, and the general layout and experience of the city. Rossi demonstrates with numerous examples how buildings, landscapes, and cities often persist beyond their intended use, and are adapted and reused over time. Reading both the historical transformation of urban artifacts and the ecological patch change serves not only as a way to understand the complexity of the architecture of the city over time, but also incorporates understanding ecological processes and dynamics. By combining studies of ecological and cultural processes, the city is both an object of long-term research and the subject of history and collective memory.

An interest in the history and evolution of cities is the shared foundation for intersecting research on the architecture and ecology of cities. Urban Long-Term Ecological Research was established because integrated social ecological systems, as Rossi observed in the architecture of the city, continually change over time. A long-term perspective on the city reaches back into the past and projects into the future. Of interest to scientists are socioeconomic and ecological changes, cumulative and indirect effects, feedbacks, and time lags resulting from urbanization (Pickett et al. 1997b). Remnant ecological processes also persist in cities and, like important buildings, have cultural memory, which also are maintained or restored (Cadenasso and Pickett 2008). The role of past states of an urban system in determining current conditions is also a major concern of ecological science (Cadenasso et al. 2006).

For Rossi, the city is a material artifact, a human-made object built over time and retaining the traces of its history. Change can be slow and continuous or abrupt and discontinuous. Historical research is the most practical method for understanding the complexity of urban artifacts (e.g., Melosi 2000, 2010). Episodic growth and shrinkage mark the historical transformation of cities, just as do natural processes such as successions, climatic periodicities, and species population densities (Pickett et al. 1997b). Urban artifacts and landmarks are adjusted to these episodic changes, both natural and cultural. The design of parks as urban artifacts and important subjects of collective memory, for example, has evolved over time. American parks designed at the turn of the twentieth century for designed, leisurely encounters with nature, were redesigned later for intensive recreation, and yet later for specific community needs (Cranz 1982). In the 1970s, at a time of diminishing finances in the city, William Burch developed a strategic action plan for the Baltimore Department of Recreation and Parks to redefine the city’s historical

park legacy (Burch 1991) incorporating a social-ecological approach which became part of the basis for the BES.

Urban history demonstrates struggles over natural and human resources and disparities of wealth, education, status, property, and power. Based on the early work of Burch, BES social scientists examine the interrelation of critical biological and social resource flows and cycles together with how those flows are allocated unevenly in space and among social groups. The basic resources on which humans and their societies depend are the fruits of historical processes (Burch and Grove 1997; Burch, Machlis, and Force 2017). For Rossi, cities can be read as historical texts of these past social and ecological processes manifest in the empirical evidence of the built reality of urban artifacts themselves. Archaeological and archival approaches both lend insight to architectural changes and ecological processes that have been erased or obscured. The written history of cities yields very important information, but documents such as building plans, property deeds, and maps provide ways to trace historical and ecological change (McGrath 1994; Sanderson 2013). Historical strata reveal fundamental characteristics of the entire urban dynamic deeply buried within the layered structure of urban artifacts (Rossi 1982, 128). It is equally important in understanding the structural depth of both the ecology and the architecture of the city.

There are many phases in the formation of the city and a city may change its face, but people's collective memory is associated with urban objects and places, even when they no longer exist (McGrath 1994). Special urban artifacts, such as Baltimore's Washington Monument at Mount Vernon Place, are physical signs of the past, and are "phenomena of persistences" both symbolically and physically. "A monument's persistence or permanence is a result of its capacity to constitute the city, its history and art, its being and memory... The value of these artifacts often resides solely in their form, which is integral to the general form of the city" (Rossi 1982, 60). At Mount Vernon Place, the monumental column contains a staircase to examine the topographic Fall Line and Chesapeake, as well as providing four small parks comprising small watersheds cascading downhill in each cardinal direction. For Rossi, the dynamic processes of the city tend more toward evolution than preservation. Individual buildings may change in the surrounding blocks, but a city's basic layout and plans persist. Within this evolution, monuments are not only preserved but may propel or limit surrounding development.

In addition to noting the persistence of landmarks, Rossi also reads the architecture of the city through the historical changes of residential neighborhoods. Similarly, BES established neighborhood patch dynamics as a key theoretical framework to model long-term research on change to urban ecosystems

(Cadenasso et. al. 2006b). The role of history is crucial to understanding patch dynamics and individual patches have distinct histories (Pickett, McGrath, and Cadenasso 2013a). Neighborhoods are of particular interest in reading change in both the architecture and the ecological patch structure of the city, as they reveal the continuity and change of the city's form. The uniqueness of a densely packed European neighborhood or sparse, single-family housing in North America, in Rossi's words is "intimately bound up with the problem of the city, its way of life, its physical form and image – that is, with its structure" (Rossi 1982, 72). While much of the Baltimore region is comprised of single-family homes, Baltimore city's nineteenth-century street grid structure consists of stately row houses on the streets and more humble dwellings on the alleys. BES grew out of an historical moment in some ways similar to Rossi's post-war Europe. Structural racism, urban renewal, and the discriminatory development of suburbs left an urban region with vacancy and abandonment in the older row house neighborhoods alongside the functionalist modern planning of the sprawling American suburb.

Intersecting the architecture and the ecology of the city relates social and biophysical patterns and processes at different scales to broader cultural understandings of historical legacies. Historical contingency, referring to ecological relationships that extend beyond direct, contemporary ones, is a major aspect of the spatial heterogeneity of cities (Cadenasso et. al. 2006b). This history of heterogeneity has cultural and symbolic value as well as use in providing scientific information on ecological function and process. By articulating the relationships between and among architectural and ecological patterns and processes over time, different types of system change such as resilience, resistance, persistence, and variability can lead to effective collaborative efforts to achieve sustainable and just urban transitions. Human ecological systems are self-aware, and non-genetic information plays an important role in system dynamics (Burch and Grove 1997); in other words, they embody collective cultural memory. Individual life cycles, the rise and fall of institutions, the shifting seats of power and influence, the development and deterioration of neighborhoods, and economic cycles, among others, are the points of contact between the dynamics of the architecture and ecology of cities and keys to integrated work for effective ecosystem change (Pickett et al. 1997b).

Morphological and typological classification systems of spatial heterogeneity

The architecture of the city has been defined as a complex structure composed of urban artifacts while the ecology of the city is described as a mosaic of

model that is copied from other locations like in modern urban planning (Choay 1997).

Understanding fine grain spatial heterogeneity has been a key component in understanding both the architecture and ecology of the city. For example, the BES encompasses a vast number of different residential neighborhoods that exhibit diverse architectural forms and types, as well as economic and social histories, from large houses on 5-acre lots, to older dense neighborhoods of densely packed one-story ranch, to the row-house grid of the older neighborhoods (McGrath and Pickett 2011). Patch creation and the changes within patches together constitute the spatial mosaic of patch dynamics. Patch dynamics in ecology focuses on spatial heterogeneity and organizational hierarchies in both the social and natural components of urban ecosystems and concerns the reciprocal effects of these spatial relations, patterns, and dynamics on ecological processes (Pickett and Cadenasso 1995; Wu and Loucks 1995). Typomorphological classification of neighborhoods as urban artifacts can contribute to understanding various combinations of stresses, disturbances, structures, and functions in ecological systems that characterize a patch mosaic (Pickett et al. 1997b). This fine-grained study of the dynamics of urban neighborhoods is essential in understanding historical patterns of social injustice.

The architecture of the city is a system bound up with the development of its typological elements. It begins with the street and block, two fundamental elements of the city, which can be classified into different typomorphological structures that constitute distinct ecological patches in the city: a block of apartment houses surrounded by open space; single family homes with front yards; a block of row houses connected to each other constituting a continuous wall facing the street itself; or houses with closed courts, gardens, and small interior structures (Pope 1996; Marshall 2005). Each street and block type relates not only the objective fact of their material form but reveal real-estate and economics on the one hand and historical, social, and cultural influences, including class structure, on the other (Rossi 1982, 49). Rossi's identification of different typomorphological street and block structures complements the ecological characterization of specific land cover elements within patches, including vegetation type, amount, and layering, the presence and condition of paved and bare surfaces, or built structure configuration, height, and density (Cadenasso, Pickett, and Schwarz 2007).

Architects and ecologists of the city are also both attentive to the historical and cultural forces acting with and on natural sources of heterogeneity such as topography, geology, geomorphology, and soils, as

different parts or components referred to as patches. Urban artifacts and ecological patches can be seen as overlapping concepts. Rossi's interest in an "immediate urban context," what he calls "study areas" (Rossi 1982, 65), parallels the patch definition and concern with boundaries in ecology (Cadenasso and Pickett 2008). Both share a fine grain focus on limited parts or elements of the city rather than the coarse grain land use classification and zoning system used in modern urban planning around the world in sharp contrast to coarse grain attempts to develop a unified science of cities (Bettencourt and West 2010). Rossi's interest is in typological and morphological classifications rather than functional distinctions in the city. His use of a typomorphological rather than land use classification system parallels the shift in the ecology of the city toward operationalizing patch dynamics in a high-resolution land cover classification system called HERCULES (Cadenasso, Pickett and Schwartz 2007). In HERCULES, urban covers are analyzed as hybrid complexes of three elements: vegetation, surfaces, and buildings that jointly define the spatial heterogeneity of human settlements. A typomorphological study of urban artifacts complements the fine-scale, ecologically relevant spatial heterogeneity that is expressed in this integrated land cover model. The HERCULES model of integrated urban land cover classification sets the stage for a direct link between the architecture and ecology of the city.

Rossi's critique of coarse grain functional segregation in modern city planning leads him to instead call for the description and account of all of the facts that can be quantified through rigorous observation and study of the types and forms of urban artifacts (Rossi 1982, 17). An urban artifact is a study area distinguished within the urban whole by its location, its imprint on the ground, its topographical limits, and its physical presence (64). This fine-grain typomorphological reading of the architecture of the city is extremely useful for understanding the structure of urban artifacts (Moudon 1994). Reading an urban artifact presupposes a kind of language, and typomorphology is a description and classification of the linguistic structure of the city. Before mechanical environmental control systems and the automobile, the city, above all else, was built for human comfort through the transformation of nature in the creation and extension of a microclimate with all needs met within walking distance. The design of historical building typologies, especially residential neighborhoods, reflects this need to provide comfort, security, and walkability within particular climates and biomes. Rossi defines the concept of type as "something that is permanent and complex, a logical principle that is prior to form and that constitutes it" (40). It is an environmental rule that guides rules and variations in a certain place rather than an ideal

well as processes of disturbance and stress such as hurricanes, fires, droughts, and floods. However, the ecology of the city brings new questions around biological agents, such as the growth, interactions, and legacies produced by organisms. The patchiness, striking heterogeneity, and sharp contrasts between neighborhoods of urban areas have ecological dimensions and ecological implications that are fundamental to both the architecture and ecology of the city. The first dimension of complexity is illustrated by the three-dimensional architectural richness evident in the different kinds of neighborhoods, which reflect various densities and styles of residence, mixed with commercial activity, industrial production, transportation, and institutional occupancy in time, both current dynamics and fluxes and legacies of past states (Grimm et al. 2000).

The maturity of the ecology of the city framework as well as a major development of reading the architecture of the city is evident in modeling and mapping urban spatial heterogeneity in new ways (Zhou et al. 2016). High-resolution spatial imagery supports urban ecosystem design beyond a focus on biological patch types that are isolated analogs of habitats familiar outside of cities (McGrath and Shane 2005; Zhou et al. 2016). High ecological resolution land cover classification is designed to account more effectively for the heterogeneity, connectivity, and history of urban systems by incorporating built and human components into integrated classes (Cadenasso et al. 2006a), and is therefore also an advancement in reading the hybrid nature of the architecture of the city.

In the architecture of the city, typomorphology is not only used for the classification of the known; it is the essence of urban design and can serve as a catalyst for invention (Rossi 1982, 8) and the representation of heterogeneity is a critical concern in the ecological design of cities (McGrath et al. 2007). A patch atlas has been created for Baltimore as a visualization tool for high-resolution land cover classification and can serve in linking the architecture and ecology of the city as it exists, but hybrid heterogeneity also supports urban design (Marshall et al. forthcoming; Cadenasso et al. 2013; Cadenasso and Pickett 2012; Cadenasso 2013). The atlas pairs a fine-grained study of the composition of patches with a comprehensive and extensive analysis of spatial mosaics. Mosaic thinking is a spatially explicit form of systems thinking that recognizes the spatial arrangement of the components of urban ecosystems (Pickett et al. 2016). How specific urban artifacts connect and interact with the larger, functional urban mosaic has implications for the larger patch mosaic of urban ecosystems. The patch mosaic model of an urban system examines the reciprocal relationships of the patch of interest with adjacent and distant patches in the system (Shane 2011). The larger scales can be

encompassed by megaregional visions and operationalized by an inclusive dynamic mosaic or “metacity” framework (McGrath and Pickett 2011).

The dynamics of urban artifacts: structure, flux, and feedback

The typomorphological architecture of the city, neighborhoods, and blocks reflects both naturally occurring patchiness and human-generated heterogeneity, which in turn affects the generation, flow, and concentration of resources in cities (Pickett et al. 1997b). The influences of heterogeneous spatial patterns in cities on cycles and fluxes of energy, materials, nutrients, genetic and non-genetic information, population, labor, and capital is central to the intersection of architecture and ecology (Grove and Burch 1997). The patch and typomorphological structure of urban artifacts is a major determinant of ecological processes and both structure and process change through time. People respond to and affect ecological change by altering the architecture of the city. Incorporating design thinking into ecological models improves the dialog with citizens, communities, and institutions and informs their choices (Pickett, Cadenasso, and Grove 2004; Felson, Bradford, and Terway 2013). Three broad questions foster this social dialog between ecology and architecture: the **structure** of the system from biophysical, social, and architectural perspectives, the **fluxes** of energy, matter, population, and capital, and the **feedback** between ecological information, environmental quality, and architectural design (Cadenasso, Pickett, and Grove 2006b). An ecological design cycle framed around the architecture and ecology of the city moves from the structure of streets, buildings, vegetation, and hydrology, to the informed knowledge and collective desires of local residences, combined to generate a new intentional mosaic of these elements.

For Rossi, city growth manifests primarily through the application of economic forces and speculation. The most common process in the evolution of a contemporary city is its market in plots of land, speculative building, alteration, subdivision, rental, and reuse. Land fragmentation and power differentiation through private markets in ownership and uneven access to resources lead not only to urban development but also to segregation, vacancy, and decline (Rossi, 154, Grove and Burch 1997). Baltimore has transformed dramatically, shrinking within the city boundaries due to these social and economic processes, while its larger urban region has exploded radically in scale. For Rossi, this expansive phase of a city's scalar transformation begins with the development of means of automotive individual transportation (Rossi 1982, 160), which has become

the defining agent in the transformation of the northeast coast of the United States between Boston and Washington from compact port cities to a sprawling megalopolis. This is, of course, currently a worldwide phenomenon (Lang and Dhavale 2005; Vecino et al. 2007; Brenner 2014).

The megalopolitan conurbation stretching southwest to northeast between the forested Appalachian chain and the North Atlantic coast is structured by watersheds as it is crossed by scores of river systems flowing north/northwest to south/southeast. The Chesapeake Bay is the largest estuary in the United States, drawing on a watershed that overlaps seven states, including several streams or “falls” defining the landscape of greater Baltimore. While policy and management decisions are promulgated for the entire watershed to reduce nitrogen pollution and sedimentation to the bay, much can be done within the millions of houses and properties that constitute the majority of the architecture of the megalopolitan region (McGrath and Shane 2005). For Rossi, while this new scale does modify his concept of urban artifacts in some ways, it does not change the substance or quality of an urban artifact as the fundamental unit of urban typomorphology, now at a vast megaregional scale comprising a mosaic of ecological gradients.

The integrated ecosystem approach of studying sociocultural and biophysical patterns and processes responds to the increasing concentrations of carbon dioxide in the atmosphere, alterations in the biochemistry of the global nitrogen cycle, and ongoing land use/land cover change that has resulted from private property regimes resulting from this new scale of car-based urbanization (Grove and Burch 1997). Large watersheds, outside of municipal and other political boundaries, are used as the spatial integrators for urbanization at the megaregional scale in relation to global environmental change. The Hubbard Brook Experimental Forest in New Hampshire serves as the conceptual framework for an integrated watershed approach, extended to a human dominated ecosystem. The various architectural patterns of urban, suburban, exurban, and rural land uses, management practices, and social behaviors affect watershed structure and function (Likens 1992; Pickett et al. 1997b). The watershed is also a scaling device that can integrate the nested dynamics of urban patches or artifacts as either sources or sinks as well as regulators of flows and cycles of critical resources (Grove and Burch 1997; Kaushal and Belt 2012). By monitoring stream flow and water chemistry at the lowest point in a subcatchment, influences from adjacent land mosaics as well as instream processes can be measured (Likens and Bormann 1995). Like Rossi’s scalar hierarchy of urban artifacts, patch dynamics has spatial

complexity at various scales within nested mosaics across these large watersheds (Pickett, McGrath and Cadenasso 2013; Jenerette, G. D., and J. Wu. 2001; Wu, J. G., and O. L. Loucks).

We have seen how the architecture of the city connects to a conceptual understanding of urban ecological systems at the parcel and neighborhood scale, but there is also an architecture of a watershed, defined as a shifting mosaic of urban artifacts or patches controlling nutrient cycling; the hydrologic cycle; species distribution, abundance, and interactions; ecosystem and landscape structure; and disturbance (Grimm et al. 2000). An ecosystem approach opens the way toward understanding feedbacks between the architecture of the city and the biophysical components of the watershed system. The architecture of the city can be examined in dynamic spatial and temporal contexts, measuring the effects on inputs and outputs at various social scales (Grove and Burch 1997). The specific social attributes of humans and their institutions add learning and feedback between the architectural and ecological components of urban systems. The architecture of the city is what structures that learning and feedback in the spatial experience of topography, soil properties, water table elevation, soil moisture fluctuations in precipitation and temperature, as well as variable amounts of water and nutrients to streamflow (Grove and Burch 1997). Linking the architecture and the ecology of the city includes the human experience of feedbacks between the biophysical and built components of the system in their spatial and temporal context, and the examination of their role on ecosystem inputs and outputs at various scales (Cadenasso et al. 2006a).

Urban dynamics include not only how cities evolve but also how human perceptions and attitudes change as a result from the interaction between social movements, architectural transformations, and new ecological patterns and processes. These interactions and feedbacks reflect temporal dynamics. The architecture of the city is a field within which the application of various forces directs the evolution of urban artifacts. A city changes completely every generation, and the experience of this process of transformation is part of the embodied knowledge, memory, and agency of city dwellers. Combined with typomorphological research, the ecology of the city approach allows predictions that are testable in architectural interventions, and it also provides tools that can activate citizens and decision-makers (Grimm et al. 2000). These feedbacks form a learning loop where designs affect ecological processes and have social impacts, which can be measured and quantified. Communicating and monitoring is necessary as projects mature, environmental effects accumulate, or social understanding of the project changes (Pickett, Cadenasso, Grove 2004). Temporal analysis

includes direct and indirect interactions that happen contemporaneously, as well as historical legacies and lagged interactions or slowly emerging indirect effects (Pickett, Cadenasso, Grove 2005).

Urban artifacts can be seen as comprising nested mosaics of process, choice, and outcomes (Pickett, McGrath and Cadenasso 2013). A mosaic of artifacts can depict the spatially complex state of a system at a given point in time, or it can expose the dynamics of the system over time. Some of the changes can be adaptive, while other changes may impair the degree to which the system matches the demands and opportunities presented by the environment. *Process mosaics* include biogeochemical (water, nutrient contaminants, energy); human and non-human population dynamics; as well as genetic and non-genetic information flows. *Choice mosaics* reflect the decisions that organisms, individual people, and social institutions make, including individuals, households, and larger social organizations. *Outcome mosaics* are the spatial patterns and feedbacks that result from choices people and other organisms in urban systems make. It is the interactions and combinations of the different “layers” as a “meta mosaic” that are the essence of the interaction of the architecture and ecology of the city (Pickett, McGrath and Cadenasso 2013; Shane 2005).

Mosaics of process, choice, and outcome constitute an integrative ecology *for* the city through broad methods of participatory action research and methods of an open cycle of design (Grove and Burch 1997; Pickett and Cadenasso 2008; Pickett, McGrath and Cadenasso 2013). Open cycles of design within mosaics of process, choice, and outcome connect to Rossi’s recognition of the collective nature of the architecture of the city, which has meaning only when the city is seen in the entirety of its parts as a complex dynamic structure. Rossi is ultimately interested in human experience, and his interest in the structure of typomorphology extends to how the architecture of the city creates human perceptions, actions, and memories that inform collective decision-making. While an architecture *for* the city is often seen as professional patronization of communities where experts are criticized for telling people what kind of city they should have (Dodd et al. 2012, Maier 2014; Rahman and Lim 2016), an architecture *with* the city is compatible to the participatory action goals of an ecology *for* the city. Intersecting the ecology and architecture of the city is essential in achieving social and environmental justice.

Conclusion

As we have seen, architecture and ecology have conceptual frameworks that reflect a separate

evolution, and therefore present an opportunity for multiple avenues of intersection that form the basis of an integrative cultural contract. Four intersections have been presented where architecture and ecology can join forces to develop new cultural rules and scientific models for the design of social and environmentally just cities. The two disciplines must first work to develop an integrative science of cities as patches of artifacts within ecological gradients, not just green spaces and buildings as separate realms in functionally planned urban systems. Second, the city should be studied as the cultural subject of human history and collective memory as well as a scientific object of long-term ecological research. Third, morphological and typological classification systems of spatial heterogeneity form the basis a common fine grain empirical science of the city. Finally, the role of collective human experience within the dynamics of urban elements can decisively redirect the biophysical structure, flux, and feedback of the city as a whole toward socially and environmentally just outcomes.

Society should not look to architecture or science to remake the city as in modern functionalist planning, but instead use empirical methods to understand the reality of the city better (Rossi 1982). The intersection of the architecture and the ecology of the city goes beyond the metaphorical misuse of concepts from science. The architecture of the city already comprises a vast cultural enterprise. It is discussed and criticized as a matter of concern well beyond the narrow circle of its specialists. There is also broad cultural interest in how the environment influences us individually and collectively and how human actions have influenced nature. Since the 1970s, concerns about air, water pollution, and acid rain, and more recently with the irrefutable evidence of human induced climate change, ecology has been thrust into a public, cultural role. Furthermore, the shift to the ecology *for* the city places the discipline in a broader socially activist position. Instead of collecting data and publishing papers to effect top-down policy change, an ecology *for* the city joins architecture as a cultural framework developed with city dwellers in the collective enterprise of city making.

Rossi’s argument at the conclusion of *The Architecture of the City* dovetails with Pickett’s mosaics of choice (Pickett 2013a). In the final section of his book, titled “Politics as Choice,” Rossi asks who ultimately chooses the architecture, and ultimately for us, the ecology of a city, if not the city itself, and always and only through its politics and forms of governance. The city, or polis, is shaped by its politics; it is the symbol of our collective will. The architecture of the city begins as

formal and structural arguments and ecology of the city develops an integrated understanding of structure, flow, and processes. But the intersection of the architecture and ecology of the city ends with these political questions. Embracing choice in altering ecological processes complements architectural questions involving society, power, and economy. Environmental impacts are manifest at the point of design, and an ecology *for* the city calls for transformative models that merge architecture and ecology into an inclusive, creative, knowledge-to-action process (Childers et al. 2015). An ecology *for* and an architecture *with* cities are calls for participatory action-based urban research and knowledge that is part of new political praxis working at all scales of urban decision-making, from individual households, to blocks and neighborhoods, and across regions. These inclusive, creative processes will produce new and innovative solutions that will allow tomorrow's cities that solve long-standing structural injustice to be better prepared for a climate-uncertain future. An integrated architecture–ecology nexus has the potential to stimulate a new era of urban health and sustainability based on deliberative, collective decision-making and just governance.

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