1-inch urbanism: an architectural agenda for decentralized storm water buffering

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ABSTRACT: Cities facing the dual environmental crisis of deteriorating water quality and threats of flood from increased rain are realizing the limits of centralized infrastructural capacity, projecting the need for temporary storage of large water volumes for both retention and detention. The notion that many sites should store a certain volume of water for periods from 24-72 hours for landscape-based treatment or delayed delivery to centralized systems—a buffering strategy—drives climate adaptation policies that connect building sites into the performance of urban ecosystems. Emerging urbanisms for decentralized storm water management usually follow standard parameters: e.g. retaining the first 1-inch (2.54cm) of rain during a storm, based on historic data and studies of water quality. As these standard parameters become concretized in the design of individual sites, rain events larger than 1-inch overflows into the centralized system, limiting capacity of the system to historical data and limiting the resilience of the system to future projections. As future rainfall projections intensify, sites will need to expand their buffering capacity. But while buildings still constitute the largest percentage of urban surfaces, their aesthetic, social and performative capacities for storage remains limited. When analyzed against urban scale storage needs, the standard measures of vegetated walls and roofs fall short. Explorations of the potential for buildings to temporary store larger volumes of water on site is fertile territory for new forms of urban architecture integrated to decentralized urban ecologies. This paper seeks to elucidate the idea of stormwater buffering at an architectural scale. A literature review provides various definitions and uses of the term buffering at a landscape scale, reveals the most relevant policy challenges that promote or limit strategies for buffering at various scales, and identifies the most common technical strategies and performance criteria to evaluate their capacity, environmental, experiential and aesthetic effects.

KEYWORDS: Decentralized, buffering, stormwater, storage, architecture

INTRODUCTION: THE WATER STORAGE PROBLEM

The recent discourse on the resilience of the built environment is heavily focused on the external threats of large water bodies: seas rising, rivers swelling, cities sinking, and delta cities disappearing to the loss of land caused by erosion from repeated storm surges—problems that require mega projects of reclamation, ecological restoration, infrastructure, and potentially the massive relocation of vulnerable populations. Those are real problems, and many researchers and designers are doing important work on modeling, predicting, mapping, speculating, prototyping, testing and designing for those situations. Many of the solutions operate at large regional landscape scales, occupying the time of landscape architects, civil engineers, and urban planners. But there is another set of climate change related problems and solutions operating at much smaller and localized scales: the increase in frequency and severity of rain events in urban environments and the excessive runoff generated on impervious surfaces that overwhelm urban systems from within. While these challenges are connected, e.g. storm drains backing up as a consequence of sea level rise, and will be made worse by them, rivers carrying urban runoff overflowing into cities downstream; many cities are facing the dual environmental crisis of deteriorating water quality and threats of flood from increased rain falling in their own space and running off their own surfaces.

Centralized infrastructure for stormwater—the pipes that carry water away from the source—has a maximum capacity for flow rate (volume of water per unit of time), and when that capacity is exceeded, i.e. too large a volume in too short of time, it will back up closer to its source. The solutions are to either increase capacity of volume conveyance, or increase the time to get into the system. This can usually be solved with detention, or the temporary storage of water to give the system time to move the initial load and open up capacity again. Due to limited capacity of centralized infrastructure in many cities, there is an emerging need for temporary storage of unprecedented volumes of water to manage larger and more frequent storm events. Rotterdam, for example, has described a shortage of 600,000 cubic meters of storage, or the equivalent of 200-acres of additional lakes and canals to store the projected excess rain water that their centralized system will not be able to handle (Municipality of Rotterdam et al. n.d.). In Chicago, one of the largest infrastructural projects transformed large old quarries into temporary stormwater storage, delivered in massive tunnels underground (Metropolitan Water Reclamation District of Greater Chicago n.d.) to delay conveyance to the treatment facility while the main system is over capacity. Intercepting and storing runoff requires understanding site-specific dynamics at scales from a building lot to a block to an entire watershed. In its gravity-led journey water can evaporate from impervious surfaces, drain into tanks, saturate soil, evapotranspire from plants or infiltrate through pervious ground surfaces into lower aquifers; and in that path it removes, carries and deposits materials, nutrients and contaminants wherever it goes. There lies the other side of the problem: contamination of underground or surface water bodies, especially where stormwater combined with sewer overflows without treatment.

The solutions to storage usually need to address the issue of quantity (how much and where and for how long) and quality (if and how to clean it during that time). In both cases it is preferable to do so near the source. Increasing capacity of centralized infrastructure to convey and treat all stormwater uses large amounts of embodied and operational energy and may need to rely on chemical treatment, while building large-enough retention and filtration landscapes that handle all the water excess and treat it biologically requires land areas that are often not available. The most feasible and resilient method is to find a way to slow down water closer to the source so that it does not all come to the system at once, and to use that time for treating, biofiltering and even polishing water with decentralized but intensively engineered landscape-based systems. This approach of green over gray infrastructure can have the co-benefits of socio-ecological resilience: more legible and multi-functional environments that provide protection from heat island effect while increasing the aesthetic and ecological performance of public space. Many cities have implemented regulations requiring sites to keep some amount of runoff on site, the often cited first one-inch of rain. As cities continue to grow and densify, buildings will need to become part of the solution to storage and infiltration. Some designers and planners facing daunting projections for rain volume and/or water quality are acknowledging these limits and innovating, but the scholarship of this work is limited.

This paper critically examines the limits of landscape-based strategies for buffering stormwater at an urban scale, and explores the potentials and opportunities for a more ambitious program of research into the tectonic, spatial and urbanistic implications of architectural stormwater storage to extend the capacities of urban landscapes. This problem is increasingly relevant to the architecture profession and provides an opportunity for place-making, policy-making and advances in building technology.

1.0. LITERATURE REVIEW

This paper seeks to elucidate the idea of stormwater buffering at an architectural scale by examining technical paremeters, policies, and current design practices of stormwater buffering; and speculating a future agenda for the discipline. The literature review provides various definitions and uses of the term buffering at a landscape scale, reveals the most relevant policy challenges that promote or limit strategies for buffering at various scales, and identifies the most common technical strategies and performance criteria to evaluate their capacity, environmental, experiential and aesthetic effects. Examining multiple peer-reviewed articles and books of case studies had two objectives: identify how many of these projects are purely landscape-based versus how many are affiliated or integrated into buildings; and evaluate the potential contribution of buildings to stormwater buffering. The search for case studies started with peer reviewed articles from leading journals and reputable presses specifically focused on design with water in the last ten years. Various searches of multiple combinations of keyword including *design, decentralized, stormwater, water*, in the previous ten years yielded a number of publications that were narrowed down to those including designed projects. The search concluded when a few projects started to appear more than once. In several publications that look at this issue broadly, the case studies were only mentioned as examples without offering other specific critieria or analysis. To the extent possible this research tried to identify additional sources on these case studies to obtain, analyze and compare similar criteria for all projects. The search resulted in 79 case studies, of which 38 were exclusively landscape projects (48%), 17 were exclusively architectural projects (22%) and 24 were a hybrid of architecture and landscape on a surrounding site or urban proposal (30%). By cataloguing a broad range of building practices – this type of research identifies and organizes knowledge from practice; and generalizes challenges, opportunities and future directions needed in education, policy and design thinking. Finally, the paper discusses the implications for current and future architectural practice, including limitations and potential contributions to the socio-ecological resilience in the face of climate change, typical challenges for retrofit, and strategies not yet explored in the repetitive architectural fabric; and points towards ways that architectural education can engage more rigorously with this problem.

1.1 Buffering

The etymology of the word buffering stems from the word *buff*, which means “to react like a soft body when struck;” thus the verb buffering refers to lessening the shock, or serving as a protective barrier or a cushion against the shock of fluctuations (“Buffer” n.d.). Some researchers define buffer-based solutions to the urban stormwater runoff problem as increasing hydraulic capacity of underground drainage, while measures that reduce volume and intensity of runoff using blue-green infrastructure (buildings and landscapes acting as storage) are considered “surface-based” (Haghighatafshar et al. 2018). But this distinction is redundant with, for example, the distinction between green and gray or soft and hard infrastructure, which refers to both storage and treatment using biotopes (plants, bacteria, and living systems in general) as green or soft, and those using concrete pipes, tanks and chemical treatment as gray or hard. What both green and gray methods of storage have in common is *buffering* – that is, to protect the system from momentary shocks while allowing the system to work far below capacity otherwise. The term buffering was found more often in European literature to refer to the decentralized storage of stormwater, and was used in both cases of gray or green infrastructure, and in many hybrid examples. But the concept is well known and applied in the United States and other parts of the world, albeit with more of a focus on the traditional landscape-based strategies. These strategies are called Low Impact Development (LID), Best Management Practices (BMP), Sustainable Urban Drainage (SUD), Water Sensitive Urban Design (WSUD), Integrated Catchment Planning, and Ecological Stormwater Management (Stahre 2002; Backhaus and Fryd 2013), and variations of these names have been customized to some location-specific programs, such as the Natural Drainage Systems in Seattle (Tackett 2009). These are all designed to manage time, essentially increasing what is called the *time of concentration* to delay storm peaks of flow. These versions of stormwater management strategies are embedded in policies that promote forms of spatial planning and urban design that connect place-making that combine open space planning, climate resilience planning and infrastructure.

1.2. Policy and regulations: design parameters for emerging urbanisms

The notion of storing a certain volume of water for periods from 24-72 hours for landscape-based treatment or delayed delivery to centralized systems—a buffering strategy—drives climate adaptation policies enforced through construction permitting processes (LaRoss 2016; United States Environmental Protection Agency 2016a), integrating building sites into regional landscape performance. Emerging urbanisms for decentralized storm water management usually follow standard parameters: e.g. retaining the first 1-inch (2.54cm) of rain during a storm. In regulations, the 1-inch (or equivalent) is usually referred to the “water quality volume” (WQV)– a specification in volume-based retention requirements (United States Environmental Protection Agency 2016b) which describes the depth of rainwater runoff over a certain area (D·A=V) that needs to be retained on site to effectively reduce runoff to pre-development levels. EPA regulations of Municipal Separate Storm Sewer Systems (MS4s) usually refer to a groundwater recharge volume (GRV) – or the volume that makes it into the ground through infiltration after all other losses. A report by the EPA on the regulations of different states identify what states use a specific depth of runoff in the requirement (50%) whether they require a volume of recharge or a volume of treatment, and what those quantities are (Fig.1). The 1-inch runoff depth requirement has a number of explanations. Reports by the EPA cite, for example, that the stay-on volume 60-years of data show that 90% of rain events in a specific place like West Virginia are under 1-inch.(United States Environmental Protection Agency 2015a) 1-inch has been found in some areas to be the depth of infiltration through plants at which most contaminants are removed, so that any remaining runoff going untreated into the stormwater sewer system is relatively clean. But that is not true everywhere and is likely dependent on soils, contaminant type and concentration, and the human use of groundwater. In some states, there are options for payments in lieu of on site retention, and this has paved the way for studies on the valuation of stormwater retention on site. One of these studies indicates that the GRV typically ranges between 0.5 and 2 inches, and are valued based on the cost of extraction of raw high quality drinking water from the aquifer (Tetra Tech and Tetra Tech 2016). Not all cities use groundwater for extraction, but some depend on keeping groundwater levels at certain levels to protect historic structures (Laboy 2017) or to prevent subsidence.

In the past decades, these policies inspired forms of urbanism that used sites around buildings to store, biofilter, and infiltrate stormwater in legible and experiential ways. The city of Malmö in Sweden is a well-known example of early forms of this urbanism developed in the late 1990’s (Fig.2a), and modeled on the U.S. EPA’s BMP’s for Low Impact Development. Residential buildings with green roofs are surrounded by open spaces with channels, bioswales, dry ponds and infiltration areas. Since, regulations in the UK and Sweden required community amenities as part of decentralized stormwater systems (Echols and Pennypacker 2015) combining ecological and social infrastructure. These urbanisms, even in dense European cities, rely on sufficient open space. In the United States, most jurisdictions have a threshold of 1 acre of disturbed or developed land to trigger these requirements, with the exception of nine states that use smaller thresholds between 0.1-0.2 acres (United States Environmental Protection Agency 2016a). In most municipalities in Germany, where decentralized stormwater systems are more widespread, regulations require building owners to pay for stormwater they discharge (Miller 2008), incentivizing implementation of innovative strategies through a “stick” approach, even in dense city centers.

There are two regulatory thresholds that limit the use of buildings as part of buffering strategies: the type/size of disturbance and the perceived practicability of implementation. The EPA requires controls and removal of pollutants to the Maximum Extent Practicable (MEP). MEP is ambiguously used, referencing Best Management Practices (BMPs) that should be applied in a “site-specific, flexible manner, taking into account cost considerations as well as water quality effects” (United States Environmental Protection Agency 1999). This regulation advocates for performance requirements rather than prescriptive design standards for small jurisdictions; but the agency’s lists of practices prioritize green infrastructure, which are mostly landscape-based, and only involve the building itself in green roofs, downspout disconnection and rainwater harvesting – tools described as not requiring infiltration (United States Environmental Protection Agency 2015b). Regulations in cities like Berlin, Seattle and Malmö try to build flexibility into the process of achieving decentralized stormwater goals (Lennon, Scott, and O’Neill 2014). For example Seattle uses a score-based systems that apply numerical factors (fractions of 1) to various strategies, which must add up to a specified number based on zoning designation (“Seattle Green Factor - SDCI | Seattle.Gov” n.d.). Some of these regulations incentivize the use of building surfaces (roof and walls) to reduce volume, while others place unintentional disincentives to their use by keeping outdated performance criteria that these are less likely to meet. For example, while the Green Factor regulation relies mostly on landscape strategies (e.g. landscape-based bioretention facility is the only area that can achieve a 1.0 factor) these regulations apply substantial factors to two building-related strategies: green roofs and vegetated walls. In European countries, like France and the UK, source control policies, based on infiltration and regulated as a required volume are considered better than flow-rate policies because of pollution control; but policies that provide different paths can unintentionally incentivize the flow-rate path because the lack of specificity on volumes (or policies that imply zero-runoff) can be considered disproportionate by developers (Petrucci et al. 2013). The definition of specific volumes for storage/retention, while allowing flexibility of methods, may provide the necessary clarity combined with perceived practicability, to incentivize strategies that use buildings to temporarily store water while leveraging small areas of landscape for infiltration over longer periods of time. In Chicago, a city ordinance recognized green roofs as rainfall runoff control measure as a method to significantly reduce volume, where they are most effective; but previous requirements for runoff rate control remained, reducing the overall contribution of green roofs to compliance (Miller 2008). That is because green roofs reduce the frequency and severity of peak flows, especially in the smaller and more frequent storms, but it has less effect in meeting regulations based on historical detention approaches, which prioritized rate control for larger storms usually through larger ponds or detention tanks (United States Environmental Protection Agency 2009).

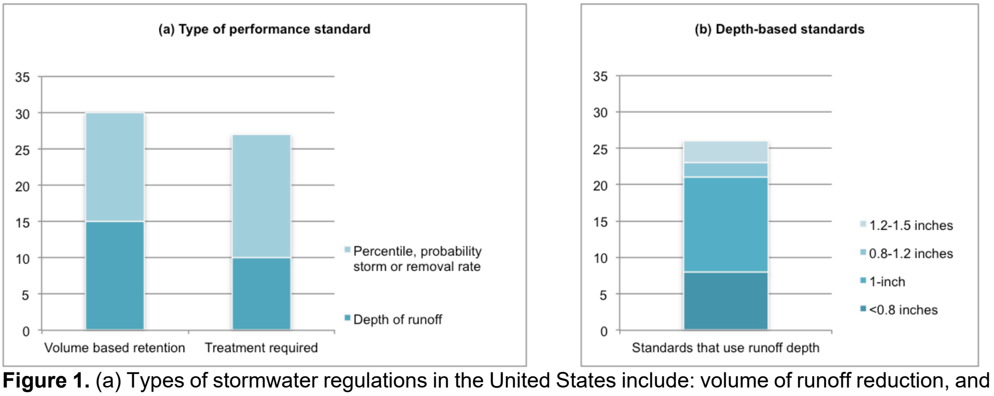

Figure 1. (a) Types of stormwater regulations in the United States include: volume of runoff reduction, and treatment of the runoff requirements. These stipulate the amount of volume based either on a depth of runoff (e.g. 1-inch of rain) or on parameters of storm size or flow (e.g. 10-year storm—a storm with a recurrence interval (probability) of 10 years, and/or the volume of rain that is in the 90th percentile). (b) Most standards that use depth of runoff are 1-inch, or close to 1-inch. Graph by author based on data published by the US EPA (United States Environmental Protection Agency 2016a).

The implementation of these regulations for stormwater storage or retention on site creates a network of site-specific infrastructures that provide a buffer to the centralized gray system during most common storms (around 1-inch). As these standard parameters become concretized in the design of individual sites, rain events larger than 1-inch overflow into the centralized system, limiting the capacity of the system to historical data and the resilience of the system to future projections. As future rainfall projections intensify, sites will need to expand their buffering capacity. A study modeled pre- and post-retrofit storm water in Augustenborg—an SUD project implemented in an area of Malmö between 1998-2002—and found the amount of infiltration to be about the same, speculating that the similarity was due to the infiltration that occurred pre-retrofit in broader unintentionally flooded areas (Haghighatafshar et al. 2018). The main benefit of the retrofits appeared to be a reduction in water in the pipe-bound system to less than half, with other volumes detained in blue-green systems (Haghighatafshar et al. 2018). This study found that green roofs in these projects contribute by reducing peak flows between 13% and 64% for the 10-year and 1/2-year storm respectively. In Malmö, centralized storm water systems were designed for the 10-year recurrence interval storm, which is about 26mm (1inch) in 1 hour; but now it is recommended that a climate factor is applied to increase this number (Haghighatafshar et al. 2018). More intense rains, called cloudbursts, can deliver approximately this much rain in 20 minutes (Haghighatafshar et al. 2018) The type of urban planning in the area of Augustenborg has proven effective at controlling floods. When a 50-year flood affected Malmö in 2007, being cut off from the rest of Sweden, Augustenborg was not affected, not only protecting themselves retaining water that did not cause bottlenecks further down the centralized stormwater system ("Urban Storm Water Management in Augustenborg, Malmö — Climate-ADAPT" n.d.). While this project delayed and reduced peak and total volumes, one shortcoming of the Augustenborg project was that the open channels between existing residential buildings in the development had to be lined with geotextile fabric, reducing the potential for retention on site, in order to protect adjacent buildings. This limitation of managing storm water in close proximity to buildings represents a consistent barrier to on-site retention, which can only be addressed by better design of buildings.

Figure 2 a-c. Three scales of buffering urbanism: (a) Left: Stormwater strategies in Malmö, Sweden extend to the building edge. Photo: La Citta Vita. (b) Center: Temporary flooding of basketball court at the Waterplein Benthemplein in Rotterdam by De Urbanisten (2013). Photograph: Stadlanschaft. (c) Right: Qunli Stormwater Park, Heilongjiang Province, China. Photograph: Turenscape.

3.0. DISCUSSION: LIMITS AND LATENT POTENTIALS OF ARCHITECTURAL PRACTICES

Landscape architects have proposed centralized landscape-based systems for stormwater management in cities, for example in Qunli New Town in China (Fig. 2c), where a recently built stormwater wetland park will presumably manage the projected volume of stormwater for a future urban area ten times the size of the park, leading designers to speculate that if a city can "allocate 10% of the total area as green sponge area for stormwater management, it can virtually solve the problem that is commonly seen in contemporary cities" (Turenscape 2017). While these projects do allow an understanding of the potential territorial scale of these solutions, there are limits to these comparisons because these projects do not scale up or down the same way in all places, based on climate and geology among many other variables. What may be feasible in completely new cities designed from scratch like Qunli, is very challenging in existing cities where stormwater infrastructure is already in place and intertwined with buildings, landscapes and other infrastructure. Speculative landscape-scale proposals for post-disaster recovery in delta cities, like Sponge Urbanism in post-Katrina New Orleans, examine the capacity of adaptive networks of high density plantations with underground storage to absorb ecological and social fluctuations (Sowell and Wiedemann 2009). Others identify low points, where rebuilding is less likely, to suggest a new landscape-based program of economic and ecological productivity (Mossop 2014). Both leverage empty land as an alternative to current forms of retrofitted high-density urbanism, which still rely on rebuilding buried canals and pump stations along road medians (Sewerage & Water Board of New Orleans n.d.). The speculative projects explore what can be achieved with living-systems at a landscape scale, but neglect the existing social and human capital that still aspires to rebuild their neighborhoods one house at a time.

Hybrid proposals operate at intermediate scales. In delta cities like Rotterdam, the city's climate initiative is based on the model of a water square, following new logics for urban design that transform below and above ground water storage into innovative design of public space in new developments (Bokern 2014). These squares are intended to combine green and gray infrastructure to maximize infiltration of stormwater, known as groundwater recharge (Laboy 2017), but also to transform conventional storage basins, which temporarily store water until the centralized system has capacity to deliver the excess runoff, into inundable public spaces with recreational programs (Fig.2b). A limitation of this model is the perception of cleanliness in the public space post inundation (Rotterdan Climate Initiative 2014); and that adjacent buildings only connect to this system by sending their roof runoff, but do not contribute to the storage capacity. The tunnel project in Chicago is an example of buffering at an urban scale, but the city is still pursuing pilot projects for street green infrastructure, which demonstrated significant capacity for reducing reliance on centralized systems and expanding decentralized networks(City of Chicago 2012). The project of the Benito Juarez School is an example of architecture that begins to engage with the green street at Cermac Road by amplifying its space and performance into the front landscape of the school, a very legible space where rainwater from roofs and plazas are biofiltered and infiltrated. However, beyond supplying roof runoff, the role of the building remains limited.

While many of these projects leverage the site of new buildings, buildings themselves rarely connect to or expand these ideas, driven by the long-standing defensive position that buildings take against water (to keep it out), and most matters of stormwater management and site relegated to separate client-owner contracts with the civil engineer and landscape architect. A critic of this is Herbert Dreiseitl, an artist and landscape architect who considers it rare or exceptional for architects to address other water themes, except liking sites on the water's edge for experiential reasons, and suggests they are more likely to see water as “a hostile force that damages their buildings.” (Dreiseitl and Grau 2009, 44). David Leatherbarrow confirms that view: “Water is also the building's greatest enemy, a foe that eventually victorious in every single case,” (Leatherbarrow 2014) while advocating for the acceptance of continual change and alteration of buildings over time, but limiting his references to LeCorbusier projects as formal and visual metaphors of maritime or nautical structures. Another writing referenced two examples: the city halls of Austin and Seattle, to illustrate how architecture reflects the politics of urban runoff: Austin's City Hall uses materials that reflect the layers of its aquifer, while Seattle's has an artificial waterway running through the building, a “deliberate and visible recognition of the importance of nature to the political culture of these cities” (Karvonen and Gottlieb 2011). Most examples where architecture acknowledges this aspect of the site are mostly limited to legibly and physically celebrating the path of stormwater to the landscape, whether through sculptural scuppers that project or vertical channels on the façade. A more promising view is provided by Marion Weiss who describes water as “volatile, fragile, violent, serene, elusive, ubiquitous, nourishing, devastating and fundamental to life;” and that architecture had to do more, to “somehow reveal the more powerful forces that were once at work on the site” (Weiss 2014), evident in examples Weiss cites, like the Museum of Earth, the McCann residence and the Brooklyn Botanical Gardens, where architecture adopts forms from the landscape to slow down water. These examples show that even in the best case architects limit the potential of buildings to being a metaphor, just a mere part of the path in the hydrological cycle, or a reflection of landscape forms, rather than becoming a performative instrument of the landscape.

Landscape-based approaches may “undermine compact city policies through a greater emphasis on multifunctional green space provision and less intensive urban development patterns” and require urban design that reconciles these competing goals (Lennon, Scott, and O'Neill 2014). Unfortunately, while buildings still constitute the largest percentage of urban surfaces, their aesthetic, social and performative capacities for storage remain limited. In existing cities where there is no additional open areas there is a potential to leverage architecture to become a vessel for stormwater storage in ways that also create socio-ecological resilience. This design and planning challenge has been dominated by the disciplines of civil engineering and landscape architecture, as evident in the review of many projects that have masterfully combined aesthetic and environmental performance (Backhaus and Fryd 2013), but which are mostly limited to constructed basins, meadows, swales, wetlands, street gutters and channels, open water elements, dry infiltration areas, water playgrounds, water fountains, around or adjacent to building developments that either infiltrate or connect to natural water bodies. The literature review revealed that most case studies still follow a fairly traditional landscape approach to green infrastructure. The majority of architecture projects examined had limited agency in the landscape-based systems, sometimes relying on landscape courtyards, green roofs, green walls inside and outside of buildings (mostly limited to university buildings, retail and commercial office space) and sculptural conveyance of stormwater to adjacent landscapes. Temporal limitations need to be considered, as green roofs tend to be less effective in Winter, Spring and Fall, when evapotranspiration rates are much lower and there is less capacity for storage; and in back-to-back events; but they would better resemble the natural hydrological cycle if they were combined with other practices for groundwater recharge (Van Seters et al. 2009) in multi-tier strategies of storage. Furthermore, these are likely less effective in areas with extreme rains (monsoons or tropical storms) (Miller 2008), raising questions about how much these alone can contribute in a future where climate change causes more extreme rain events in more areas of the country. However, climate change is likely to cause both extremes of extreme rain and drought, and a good buffering strategy could consider not only the temporary storage of water for flood control and water quality, but also a more strategically timed release in times of drought to better manage the groundwater levels and risks of heat island effect. A handful of hybrids are emerging that begin to leverage architecture in a more integrated way: the Institute of Physics at Humboldt University in Berlin and the Prisma Numberg, both in Germany, stood out for managing all water on site, combining building and landscape strategies for storage and treatment within relatively limited footprints, and actively including rainwater as part of the thermal comfort and experience of the building.

Beyond these notable examples, most of architecture is generally in the “gray infrastructure” equivalent of stormwater management: relying on pipes and cisterns, rarely including biotreatment or integrating the process into the user experience. A literature review by urban ecosystem researchers in Australia proposed a green-to-gray horizontal continuum, represented in section, from the surface water body with low vegetation (green) to the building (gray) where the building (gray). The building is only represented as the surface of façade and roof, and both the building and the adjacent street were drawn as gray, with “man-made” vegetation applied to the surface. The open space is situated between the “natural” water body and the gray environment of street and building, with trees that are labeled as “naturally created” (Bartesaghi Koc, Osmond, and Peters 2017). But in most places in the world neither the water bodies nor landscapes are naturally created, having been modified, and in many cases requiring just as much construction and maintenance as the gray environments to achieve high performance. Man made or engineered vegetation on the building surface can be just as wild and unpredictable as the vegetation in other spaces deemed more natural, being part of a complex urban ecosystem. Starting from the premise that these are all constructed environments that combine living and non-living systems, a common goal is for the urban environment to perform like the pre-development landscape, or in some cases outperform it. But when analyzed against urban scale storage needs, the standard measures of common vegetated roofs fall short, meeting less than half of this minimum 1-inch (2.54cm) requirement (Happe 2005). The potential for buildings to temporary store larger volumes of water on sites continues to be fertile territory for new forms of urban architecture integrated to decentralized urban ecologies. As Charlie Miller said:

> Ultra-urban environments can begin to emulate the performance of natural, undeveloped landscapes…buildings can become as efficient as forests in how they use the precious water resource. (Miller 2008).

Patrick Blanc, the botanist researcher that practices the design of green walls, observes that the height of many urban buildings, especially in cities like Paris, is comparable to the height of many trees in forests and their surface similarly shaded—suggesting that these surfaces can be manipulated and designed to grow certain species of plants— a design strategy that has been subject to critique as simulacra that lends “some degree of eco-lustre irrespective of their actual functions” (Gandy 2010). This critique may be well deserved, especially when these systems use potable water and fill it with fertilizers that can worsen the quality of runoff; but the skepticism in the architecture field may be due to the fact that most research on the performance of these systems resides in other disciplines, and that the architecture discourse pays more attention to the formal and visual effects and much less to post-construction performance measurements.

4.0. CONCLUSION

This research points to the potential for storm water buffering at an architectural scale, suggesting that innovative architectural projects can be instruments of the landscape. Cataloguing strategies and projecting their environmental performance reveals potential future directions in design research that can examine their social and aesthetic performance, as well as other potential benefits for buildings thermal, seismic, and energy performance. As the legacy of 1-inch urbanism needs to expand to become a 2+inch urbanism, architecture will become the only next available space to innovate in stormwater buffering. A change to performance-based regulations rather than prescriptive volumes may be one solution to leverage high capacity sites and compensate for lower-capacity ones. Improved modeling based on downscaled sampling of climate projections could inform more sophisticated and site-specific design. All of this requires a field of research that can inform practice, and a professional field that understands the science and technique of stormwater buffering. Design education will need to engage interdisciplinary projects where the qualitative and quantitative aspects of this challenge are explored. This is a task that this author has undertaken, working with architecture, landscape architecture and environmental engineering students in real sites with real clients to demonstrate what may be possible; although pedagogical implications are subject of another article. Nonetheless, this research suggests that there is space for researchers and educators to advance the architecture discourse and practice towards more effectively and controllably buffering stormwater.

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