A Holistic Approach to Stormwater Green Infrastructure

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Abstract: One of the factors that threaten fresh water quality is the input of anthropogenic nutrients, a problem heightened in urban areas with lots of impervious surfaces. The implementation of stormwater green infrastructure allows stormwater runoff to be filtered before entering waterways, reducing nutrient input. Stormwater green infrastructure includes installations such as green roofs, green alleyways, and parks which can provide environmental, mental and physical health benefits to local residents who may have lacked access to green space. However, such installations can also have the counter intuitive effect of gentrification, termed the 'green space paradox'. Through the review of published literature and case studies, a holistic design of stormwater green infrastructure implementation is presented in this study, which includes public participation, sustainability, and equity of distribution.

Keywords: Green infrastructure, Stormwater, Pollution, Nutrients, Human activity, Urbanization.

INTRODUCTION

According to the National Research Council, one of the major pollution problems facing coastal rivers, estuaries and bays in the United States (U.S.) is nutrient pollution [1]. Nutrient pollution is mainly due to eutrophication, caused by harmful algal blooms, fish kills, and dead zones. As a consequence, fish populations are reduced, and hypoxic and anoxic zones are formed [2-4]. Nutrient pollution is likely to increase with the intensive anthropogenic use of fertilizers and fossil fuels, which are the leading sources of nutrients. Human activity greatly influences the cycling and transport of nutrients to estuaries and other coastal waters [5].

Forms of nitrogen (N) and phosphorus (P) are the two elements of concern in terms of nutrient pollution. Global P fluxes are largely composed of the one-way flow of eroded materials and wastewater from land to ocean, where it eventually settles in ocean sediments [6]. Estimated amount of P entering the ocean from freshwater is between 12-21 MMT P yr^{-1} [7]. Howarth *et al*. (1995) estimated that, in the past, the size of P flux was 22 Tg P yr^{-1}. The flux was estimated to have been 8 Tg P yr^{-1}prior to the increase in human agricultural and industrial activities [8], suggesting a major anthropogenic contribution of P flux to the coastal ocean water every year.

There is evidence to suggest that two decades ago the anthropogenic influence on the cycling of N is equally intense [9]. Bioavailable (reactive) nitrogen (N_r) has increasingly been produced to meet the demands of food and energy. Anthropogenic production of N_r has exceeded natural production and continues to increase every year [10]. The balance of the N cycle pre-Industrial era has been broken and heavily altered by anthropogenic practices [11]. More than half of the human alteration of the N cycle comes from synthetic inorganic fertilizers [9]. In 1996, the global consumption of N as a fertilizer was 83 Tg P yr^{-1} [5]. Other human activities that mobilize N include the combustion of fossil fuels and the production of N-fixing crops, which converts atmospheric N into biologically available forms of N [5, 12]. Anthropogenic N fixation has increased globally by 2 to 3 time between the years 1960 and 1990 and continues to increase [13]. In 2012 an EPA assessment of streams and rivers in America yielded 41% of the nation's river and stream length had a high level of nitrogen and were in poor condition for aquatic life. It was also determined that about 4% had a higher total nitrogen (TN) concentration (>5 mg L^{-1}) [14]. According to the Global NEWS model TN and dissolved inorganic nitrogen (DIN) are predicted to continue to increase [15].

The anthropogenic influence on the nutrient cycle is not uniform globally and is dependent on areas of high population density and high agricultural production. Management of nutrient pollution will be site-specific. Most water quality management focuses on point source pollution such as discharges from wastewater treatment plants despite non-point source pollution being of a higher concern for coastal eutrophication [5]. This is because point source pollution is measurable and easier to regulate than non-point source pollution. Typically, non-point source pollution is attributable to agricultural or impervious surface runoff. The source of non-point source pollution tends to be difficult to trace.

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An earlier, regional-scale study of N fluxes into the North Atlantic Ocean by Howarth *et al*. (1996) found that non-point sources of N exceeded sewage inputs in both Europe and North America. Sewage contributed only 12% of the flux in North America [16]. Synthetic N fertilizers are another source of non-point source pollution and when applied to soil are not absorbed completely by crops. Globally, about 10% of the applied N is used by the crops [17] while a large portion of the remaining N is lost from soil by leaching and surface runoff [18]. About 23% of the N applied to watersheds in the Northeastern United States is lost to rivers [19]. In 2003 it was estimated that globally, 55 Tg N per year was leached from agricultural soils and entered into rivers [20]. Non-point source pollution is also a dominant contributor of P inputs into coastal waters [6], and because of a focus on regulating P point-source pollution there has been an increasing importance in the input of P non-point source pollution since 1980 [21]. Management of nutrient pollution should therefore focus on both point and non-point source pollution. Stormwater green infrastructure is a method that focuses on urban non-point sources. Based on literature review of previous work, this paper addresses the efficiency of green infrastructure in reducing nutrient pollution and the holistic application of this method in city planning.

STORMWATER GREEN INFRASTRUCTURE

Development of urban areas with population growth increases cover of impervious surfaces, increasing the chance of stormwater runoff and flash floods [22]. This problem has been exacerbated by the advent of climate change which increases the likelihood of extreme rainfall events [23]. Urban water resource management requires utilizing methods to retain, retard, and use stormwater within the urban landscape. Urban trees in pervious spaces contribute to the management of urban catchment hydrology by slowing down rainfall before it reaches pavement by their leaves, stems, and roots, and capturing and storing rainfall that will be released later [24], which is the basis for stormwater green infrastructure.

Conventional stormwater management, or gray infrastructure, has been designed to move urban stormwater away from the built environment. Typical gray infrastructure includes curbs, gutters, drains, piping, and collection systems. These systems are engineered to collect and move stormwater from streets, parking lots, and rooftops into piping such as combined sewer overflows (CSOs), which discharge untreated stormwater into a local water body. Stormwater green infrastructure mimics the natural system as it captures rainfall where it falls [25]. This reduces the volume of water to combined sewer and stormwater systems, which reduces the treatment costs at wastewater treatment plants [26]. Stormwater green infrastructure includes increasing pervious surfaces and tree cover in urban areas, which can play a significant role in reducing nutrient pollution in urban water bodies [24]. It can manifest itself as urban forests, green roofs, green alleyways, and green parks. Urban forests and green roofs will be discussed to determine their efficiency in reducing nutrient pollution.

Urban Forests

In their study, Livesly *et al*. (2016) presented the role of urban trees in soils in terms of water pollution. Their review makes use of 14 different studies conducted in North America, Europe, Asia, and Australia. They explained that tree crowns intercept rain, which reduces the amount of precipitation that becomes street runoff. Stormwater runoff reaches impervious surfaces can be directed into an urban forest system to reduce, retard, and retain stormwater from entering the drainage system or urban water body. Trees have the ability to reduce oxidized N and reactive P from entering waterways. Turfed green spaces such as grass yards, receive large inputs of inorganic and organic fertilizers, which is exemplified by the fact that urban turfgrass is the largest irrigated and fertilized crop in North America [27]. As such, there is a potential for excess nutrients to pass through and enter urban water ways. Therefore, urban green spaces should include trees and understory because of their high soil carbon/nitrogen ratios which can improve nutrient capacity. These areas can be utilized as nutrient buffer zones that border water ways or other high risk areas that receive inorganic nutrient fertilizers [24].

Green Roofs

Urban roof surfaces contribute a significant amount of nutrients in receiving waters as non-point source pollution which can cover 12% in residential areas and 21% in commercial areas [28]. Green roofs are used as a tool to reduce this source of runoff and have added benefits such as an added aesthetic value, insulation and noise reduction, and wildlife habitat [29]. Research on the effectiveness of green roofs has shown that they intercept, retain, and evapotranspire between 34% and 69% of precipitation with an average of 56% retention [30]. The range in retention was caused by the climate, the time the study was conducted, and sampling and retention calculation methods. Studies have also shown that green roofs contribute P in runoff due to the percentage of compost and fertilizer used in the soil media of the green roof [30].

Bruce Gregoire and John Clausen (2011) evaluated the effect of a green roof system in the northeastern U.S. on the amount of stormwater runoff and nutrient concentration [30]. A 248 m^2 green roof was installed on a public plaza atop a University of Connecticut building on September 2, 2009. Sampling was done in two periods: calibration and treatment. The control was a building that had no green roof. From January 25, 2009 until February 1, 2010, flow was monitored from drain pipes from both buildings. Evapotranspiration and nutrient concentration were also measured and analyzed. The green roof was able to retain 41.6% of the precipitation during the treatment period. The control roof retained 26.8% of the precipitation. Total nitrogen (TN), nitrite-nitrogen (NO_2-N), and nitrate-nitrogen (NO_3-N) concentrations were not significantly different between precipitation and green roof runoff. However, the control had significantly higher concentrations of TN ($p=0.002$). Total phosphorus (TP) and phosphate phosphorus (PO_4-P) concentrations from the green roof runoff was significantly higher than in precipitation ($p<0.001$). Total runoff was greater in the control runoff than in the green roof runoff. The large amounts of P in the green roof runoff was attributed as coming from either the green roof modules or storage from other compartments on the roof. Overall Gregoire and Clausen (2011) concluded that the green roof was successful as a sink for N pollution.

OTHER GREEN INFRASTRUCTURE BENEFITS

One of the primary drivers to implement green infrastructure in urban areas is to manage urban stormwater. Cities are required to meet regulatory objectives for water resource management under the Clean Water Act. However many cities are prone to implement gray infrastructure since its regulatory effectiveness has been proven over time and green infrastructure is perceived to be more uncertain [26]. However, green infrastructure provides many other services than reducing nutrient pollution and maintaining healthy water quality standards to cities that implement them. Assessing multiple benefits when identifying best management practices for stormwater runoff is vital when proposing green infrastructure, otherwise green infrastructure will likely appear to be less efficient than gray infrastructure [31]. The economic feasibility of green infrastructure is also greatly improved when multiple benefits are considered during implementation [32, 33].

Trees and vegetative spaces can offer wildlife habitat and landscape connectivity [34], support biodiversity and assist in climate change adaptation [35]. Green roofs, community gardens, water retention ponds, and green space preservation and creation increase vegetative cover which reduces airborne pollutants, offsets urban heat island effects, participates in the up-taking of carbon, and reduces the heating and cooling demands of buildings. Energy savings due to green roof installation can reach up to 12% [31, 36]. The energy efficiency of green buildings can thus reduce costs for the urban poor, by leading to more affordable energy bills [26]. Research has also determined that ready access to green spaces has positive correlations with longevity and quality of life [37] providing a space for culture, sport, and recreational activities that increases a stronger sense of community [38]. In some cases, green infrastructure can even lower food costs for the urban poor by creating spaces such as community gardens as a source for produce [26]. It may also increase land and property values [39], which can attract tourists, new industry [40], and reduce crime [26]. A case study in Sydney, Australia determined that rain gardens increased the median property value by six percent within 50 m [41]. Green infrastructure can also create jobs in low income urban areas within the construction sector, and operation and maintenance of green installations. Beyond the jobs that green infrastructure can create in the areas where it is installed, the planning of green infrastructureprojects includes the work of architects, designers, and engineers, and its implementation utilizes work in construction, maintenance, and installation [26] creating more jobs.

IMPLICATIONS OF GREEN INFRASTRUCTURE

Though green infrastructure provides many services that can revitalize urban areas that are suffering from flash flooding, urban heat island effect, lack of green space, and lack of industry or jobs; the implementation of green infrastructure does not always result in an equitable distribution of green space. This revitalization can contribute to the gentrification of urban areas due to rising property values and industry, and not be designed in a way to address all the services it has the potential to provide. Three different studies [42-44] are examples that analyze the counter intuitive effects green infrastructure distribution may or may not have on urban communities and ways in which each issue can be resolved.

Distribution Equity

Just distributions can be defined as the equal distribution of benefits and burdens among individuals or groups. Parks are treated as environmental amenities and they provide the same multiple social, economic, healths, and environmental benefits as green infrastructure. Most urban parks are public which should stand up to the scrutiny of just distribution. In regard to parks, just distribution can manifest as equal number of acres per person or recreation funds per capita by neighborhood. However, this method of measurement does not take into consideration needs, merits, and choices of the population which can differ among the spectrum of socio-economic status. Just distribution should also incorporate the just procedure for allocating amenities as well, to make sure that the institutions that guide social relations and decision structures include equity [42].

Historically, the decision to establish a public park reflected the motives of an elite group. The public park movement in the late nineteenth century brought about larger social engineering goals in mind including reducing juvenile delinquency which forced city planners to confront the issue of distribution. However, principles did not always lead to practice and elite influences continued to find their way into city budgets [42].

Boone *et al*. (2009) assess the equity and distribution of parks in Baltimore, Maryland. To measure access to open space, a quarter mile was used as the standard threshold that people are willing to walk to a park. A quarter mile buffer from the perimeter of all parks was used as a measure of accessibility presumably on a geographic information system program. Spatial data were taken from the Maryland Department of Planning for the parks layer and supplemented by data from the Parks and People Foundation for Baltimore to map out the parks layer. Aerial imagery from Google Earth and flat maps from Thomas Guide confirmed the accuracy of the parks layer. Demographic data was obtained from census block groups (CBGs), census tracts (CTs), and census attributes data from 2000. CBGs were used for populations within a quarter of a mile buffer from the center of parks, and also assessed value of properties within a quarter of a mile of the buffer. In addition, the potential park congestion (PPC) which is the number of people per park acre (PPA) was used to assess the equity of park distribution. Lastly, official documents were studied to assess the procedural history of the city's parks. It was concluded that African Americans and high-need populations have better walking access to parks however they have less acreage per person than whites and low need populations. Their accessibility to parks came in spite of the city's historical segregation and neglect of the African American population's recreational need [42].

Their study provided a method in analyzing distributional equity of parks with the link to historical procedures in the city of Baltimore. Similar results were determined by case studies conducted in Tampa, Florida and Phoenix, Arizona where green spaces in these cities exhibited disparity when quality, diversity, and size of green spaces were considered [45, 46]. These case studies provide an assessment tool for city planners who are tasked with revitalizing neighborhoods in urban areas. Empirically assessing the current equitable distribution of environmental amenities is a powerful tool in city policy development.

The Green Space Paradox

One central issue with the distribution of greening initiatives like green infrastructure is that they can be associated with gentrification in historically marginalized communities, called the green space paradox [43]. Parks and gardens can become an initiative for neighborhood revitalization that changes demographic, real estate, and consumption patterns which become accessible only for more privileged social and ethnic backgrounds. Although the casual relationship between green initiatives and gentrification is uncertain, it is well established that higher income residents do move into revitalized neighborhoods due to higher property values and economic resources. A case study in Philadelphia, Pennsylvania exhibited how neighborhoods near other gentrified neighborhoods held a higher susceptibility to being gentrified than those that were further away [47]. This illustrated the point that parks in neighborhoods alone do not cause gentrification, however may serve as a support in the process. Emerging research is beginning to link gentrification with the health impacts on displaced residents. Gentrification may lead to increases in stress, crime, poor mental health, and changes in social and environmental justice. Green spaces in cities are also more concentrated among residents that are least vulnerable [48].

J. Wolch and her co-worker [43] address the green space paradox by reviewing literature regarding green spaces and public health. In their study, Wolch *et al*. (2014) determine whether access to quality green space improves physical and mental wellbeing. Wolch *et al*. (2014) provide evidence that access to green spaces is differentiated by income level and ethnic group. They also review a case study of the Chinese city, Hangzhou, to assess whether the effort to expand inner city green space has been successful there. They city has been combating rapid urbanization by restoring lost green space in abandoned factories, dilapidated canals, underneath and along main roads and railway lines, and along city streets. In 2014 Hangzhou had 166.5 km2 of green space (40% of the city area). However, this does not represent the quality and characteristics of these green spaces. Many of the parks are small with few facilities, not suited for active recreation, contain extensive pavement for high use, and are near main roads which increases the users' exposure to air pollution. Although not ideal for the mental and physical wellbeing of the users, the goals of these green spaces are to reduce heat island impacts, lessen stormwater runoff and flooding, catch pollutants, and reduce wind speed. The green spaces in Hangzhou might also be contributing to inflating property values, leading to the displacement of lower income residents, thus contributing to the green space paradox.

Wolch *et al*. (2014) conclude that the most effective way to combat the green space paradox is to design "just green enough" green space projects. This is illustrated in the case of Greenpoint, a community in Brooklyn. Working class residents and gentrifiers worked together to demand environmental cleanup strategies for a toxic creek that allowed for the continued use of the present industries and preservation of blue collar work while explicitly prohibiting "parks, cafes, and a "riverwalk" model of a green city [49]. This illustrates that residents have the propensity to become resilient, resist displacement, and remain in communities that have improved environmentally as a result of private and public investments [43].

Green Infrastructure and Sustainability

Green infrastructure initiatives usually are designed to target stormwater issues instead of incorporating the full breadth of benefits and amenities that green infrastructure projects can provide. This may be due to the availability of federal, state, and city funding for stormwater management. Green infrastructure is also a broad term that has been defined in different ways. The applicator of this concept can focus on any aspect of green infrastructure without being held accountable for not implementing a holistic or sustainable approach. According to Benedict and McMahon (2002) green infrastructure must be linked to sustainable development, arguing that green infrastructure is "the ecological framework needed for environmental, social, and economic sustainability" [50]. This simplistic structure can provide a framework for green infrastructure initiatives to conceptualize priorities.

Joshua P. Newell *et al*. (2013) profile eight different alley greening programs in seven different U.S. cities to assess the extent to which these programs fulfill sustainability objectives [44]. Alley greening programs convert back alleys into green spaces that may facilitate urban runoff management through infiltration, groundwater recharge, heat island reduction, and expanded wildlife habitats. Eight different green alley programs that met set criteria were selected and analyzed through print and online policy and program documents, media coverage, and in-person and telephone interviews and email correspondence. It was found that alley greening programs are substantially oriented towards stormwater management goals because of the availability stormwater management funding and operated solely by a city department or environmental nongovernmental organizations (NGOS). The Los Angeles Green Alley Program serves as an example of an integrated approach that incorporates diverse sustainability goals such as business development and addressing social inequities. This program also uniquely has a larger multi-departmental Green Streets Committee that collaborates across city departments, non-profit organizations, and university researchers [44].

Interdepartmental collaborations in the public and private sectors can broaden the narrow focus that green infrastructure initiatives have conventionally been designed. Government agencies, NGOs, and community members have the potential to work together to become the backbone of green infrastructure [44]. These relationships can foster catalysts to start green infrastructure initiatives beyond stormwater management and incorporate sustainability principles.

PUBLIC PARTICIPATION AND PROCEDURAL JUSTICE

Beginning in the 1980s, the United States Environmental Protection Agency (EPA) started using "negotiated rule-making" where citizen and stakeholder support works in collaboration with federal, state, and local government agencies. Public agencies tasked with formulating environmental regulations are increasingly involving citizens and stakeholders at various stages of the rule making process. There are several environmentally oriented statues that mention citizen and/or stakeholder involvement. One primary example of this on a federal level is contained in the Clean Water Act. Under the National Pollutant Discharge Elimination System (NPDES), within the Clean Water Act, the statute mandates that public participation be, "provided for, encouraged, and assisted by the Administrator and the States." [51] This means EPA mandates local governments to include public participation as part of their stormwater management programs [52].

The amount and degree of public participation that is associated with environmental laws and policies is dependent on the statute that they fall under. There is no universal standard to define how much, and in what way, public participation can be instituted. In many instances, public participation comes in the form of comment periods and public hearings [53]. What this means is that when a new law or regulation is proposed by an agency, a set amount of time is given for the pubic, which includes private citizens, industry, and lobbyists, to write letters to the agency proposing the regulation with their concerns over how the proposed legislation will affect them. Then there is a public hearing in which the public my address their concerns in front of a panel of legislators.

Citizen and stakeholder support of, and concerns with, regulations not only depend on the regulation's impact on them personally, but also their perceptions of the procedural process. Procedural justice studies have determined factors that contribute to the acceptance of regulations made by authorities: "voice, being treated with respect by authorities and other participants, perceived lack of bias on the part of the authorities, fair treatment of all parties by authorities, and decisions that are responsive to information" and correctable in face of new information [52]. Studies have shown that public participants are apprehensive over just and equitable processes which would suggest that government authorities should practice transparency to appease citizen and stakeholders' perceptions of justness and fairness [52]. The concerns over the just and fair ability to participate in law making under these statutes is reflected in several state and federal cases. One such case, Western Watershed Project v. Kraayenbrink (2011), heard in the 9th Circuit of the U.S. Court of Appeals, dealt with issues of public participation in the permitting program for the use of public range lands in Idaho. The 9th Circuit in this case decided that under the National Environmental Policy Act, the public participation requirements mean that an agency that is crafting and enforcing a regulation must engage in a, "full and fair discussion" [54] of environmental impacts with the public, and take a "hard look" at how the pubic responds. The decision of the 9th Circuit in the case is a good example of the public's concerns over their perceived ability participate in the law-making process, and the court's acuity in determining and rectifying instances when the public's ability to participate is hindered.

Lynn Maguire and E. Lind (2003) evaluate the case of environmental rule-making and stakeholder involvement from the proposals of regulations controlling nutrient pollution in the Tar-Pamlio watershed undertaken by the North Carolina Division of Water Quality (NCDWQ) in winter of 1998-1999. The objectives of their study were to identify factors that influence perceptions of procedural injustice, to understand factors that lead to the acceptance of a policy, and to recommend a design for this process so that the quality of proposed regulations are not compromised and there is a higher probability of the proposal's public acceptance. A qualitative study was performed by analyzing archived official documents between NCDWQ and working groups by hand coding and tallying themes. A quantitative analysis was performed using a short questionnaire to working group participants about their perceptions of the process. Though the quantitative analysis was using a small sample there were interesting patterns between procedural justice elements. Those in the working groups who had previous experience with stakeholder processes believed there was not enough time given to sufficiently understand technical issues, which was also agreed to by the NCDWQ organizers. The authors attest that for stakeholder involvement to be productive in decision making the elements of fair process should be observed and enough time should be given to cover all aspects of the process [52].

With the case of NCDWQ as an illustration, negotiations over the implementation of a green infrastructure or environmental program should be genuine and plan substantial time for public participation to deliver a just and fair process. A "half-way" or manipulative implementation of mandated public participation will not garner public acceptance and instead foster a "frustration effect" which will garner a more negative attitude towards the outcome of the procedure than if they had not participated at all [52]. Furthermore, community education and capacity building should be part of the participation process as exhibited by a case study in Atlanta Georgia where green infrastructure was implemented in the Proctor Creek Watershed. Residents were able to gain knowledge which allowed for community buy-in and advocacy for green infrastructure. Residents were also able to contribute their local knowledge to discussions and were consulted for their input [55].

CONCLUSION

Nutrient pollution is a major problem in urban areas with high population densities and high percentage of impervious surfaces. It contributes to detrimental environmental and health effects. Increasing green infrastructure such as pervious surfaces, tree cover, and green spaces, rather than exclusively increasing traditional gray infrastructure, can facilitate nutrient buffer zones that reduces pollution. Green infrastructure can also offer other environmental benefits such as reducing the urban heat island effect and airborne pollutants. Green spaces in neighborhoods are also attributed to better physical and mental health of residents. Green spaces may also revitalize neighborhoods and boost property values and economic activity.

Though green infrastructure has the propensity of many amenities, traditionally cities are funded to implement forms of green infrastructure for stormwater management. Through the collaboration of different departments in public and private agencies, citizen, and stakeholder participation, green infrastructure initiatives can be much more than a resource for stormwater management. In implementing such programs, substantial time must be given for every stakeholder to voice their concerns and opinions in order to facilitate just procedure and be educated on the process and implementation of green infrastructure.

Through just procedure, the implementation of green infrastructure can also avoid the counter intuitive effect of distribution inequity and the green space paradox. The development of green infrastructure in neighborhoods should have targeted goals and not go beyond agreed parameters. If residents have the potential to be pushed out of green revitalized neighborhoods, the focus on bettering the neighborhood's economy through walkways and businesses should not be included. Though green infrastructure development should also include just enough added benefits for local residents. For example, parks and green spaces in low income neighborhoods should be large enough for residents to exercise and spend time in, and close enough to residential areas where it can reduce crime and facilitate better community connections.

Through careful planning and strategizing, green infrastructure can become more than a means of reaching regulatory environmental goals. It can foster a holistic and sustainable approach to city planning. This can be done by reaching every stakeholder in the process and ensuring just distribution of benefits across the board.

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CONFLICTS OF INTEREST

The authors declare no conflict of interest.

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