Urban Heat & Vegetation: A Literature Review with Austin, Texas as a Case Study

Pascal Stevens

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Introduction

As our world population continues to increase – crossing 8 billion for the first time in 2022 – we are becoming increasingly urbanized. Over half of the world lives in urban areas, with that number expected to rise to over 68% by 2050 [1]. As this pattern accelerates, particularly across Asia and Africa, the United Nation stresses the importance of "Sustainable Urbanization" as our urban spaces change and adapt to rapidly accept the changing demands placed on them by mass immigration and harsher climate realities. While the pull factors for these cities often include better economic, educational, and cultural opportunities, mass urbanization is often associated with health hazards, environmental degradation and population demands that overwhelm existing systems [2]. The additional demand for utilities such as water, electricity, transportation, and waste collection cause these services to degrade, often contributing to polluted water and air, rolling blackouts, and buildups of garbage throughout rapidly urbanizing centers, which lead to adverse health effects [3]. These societal issues of rapid urbanization coupled with raising concerns about climate change and its potential impacts on urban spaces raise valid alarms for many urban spaces around the world.

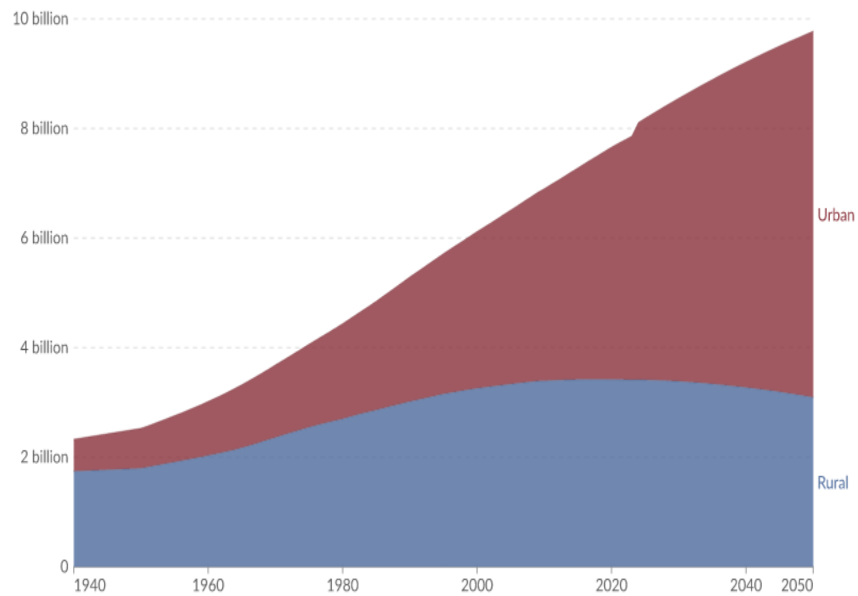

Figure 1: The total urban and rural population as projected by the United Nations through 2050. [4]

Much of this rapid urbanization is occurring in equatorial regions—such as Nigeria, India, and southeastern China—and across the Sunbelt in the United States, notably in Texas and Arizona, where soaring temperatures are an increasing concern. The rise of living spaces without vegetation and open areas significantly increases the dangers of the urban heat island, where cities climb to higher temperatures than the surrounding countryside and stay at these temperatures, sometimes upwards of 10°C warmer, for longer periods of time [5]. Heat island effects are exacerbated by factors such as low albedo heat-storing materials like asphalt, lack of trees and vegetation, urban canyons, and increased waste heat, all of which are on the rise with increased urbanization [6].

Figure 2 (below) is a simplified example of the heat island effect, as typically seen in textbooks and websites. The red line demonstrates real temperatures, with the y-axis representing temperature. As the density of the city increases and vegetation decreases, the corresponding temperature also increases. Parks are the notable exception – although they are in urban areas, the temperature still decreases.

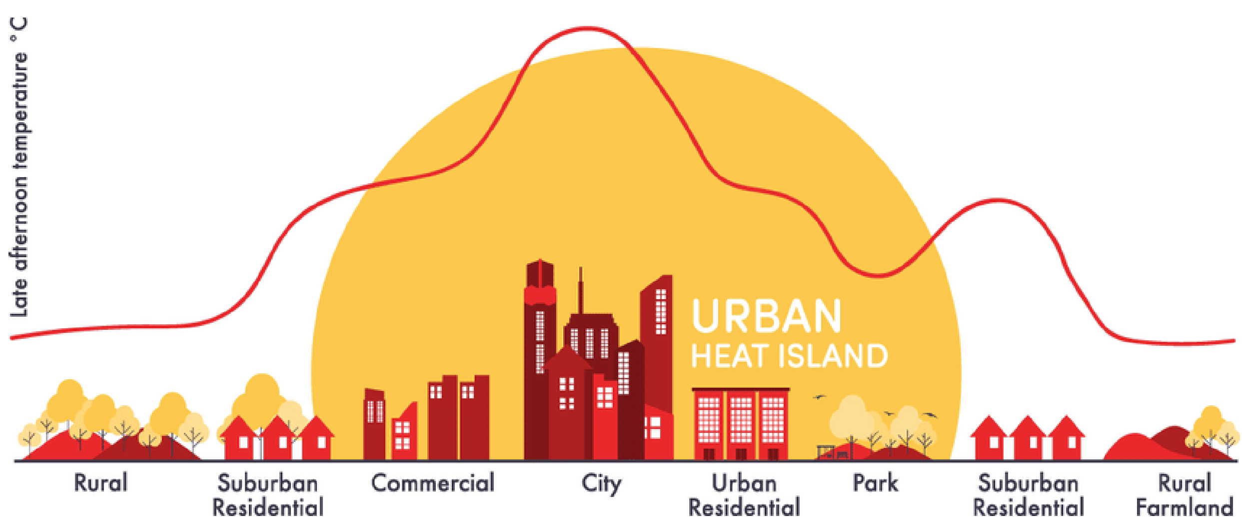

Figure 2: A basic description of how the heat island effect looks, and how temperature differs in different type of city development. [7]

Research Goal

The aim of this research project is to examine the inclusion of green space within increasingly urban areas, and its impact on the heat island effect. Specifically, this project covers the broad global trend of raising temperatures in urban areas and then examines the impacts of local planning and urban policies, as well as building-specific microclimates that can arise from specific building design choices. Lastly, this project focuses locally on Austin, Texas, and examines the rapid rise of urbanization and the steps the city is taking to reduce heat island concerns.

Urban Heat: Global Trends, Local Solutions

As the world continues to urbanize and cut down virgin vegetation cover, our cities and urban spaces are getting hotter. There has been significant research across many countries showing this heating pattern, and the effects that small, local zoning and urban planning choices can have on mitigating such heating rises around the world. Research has also shown that even decisions made on an individual building-by-building level can dramatically reduce the heat island effect.

Urbanization, Vegetation, & Rising Heat

The effects of rapid urbanization are no more apparent than mainland China, which has experienced a 30% (around 420 million peoples) increase in urban population over the last 35 years [8]. This meteoric shift from rural to urban centers has fueled an economic, social, and cultural revolution, while also changing the infrastructure and natural environment across every major city in China. A 2017 study from Wuhan find that across the 10 largest cities in the Yangtze River Basin, annual vegetation cover had decreased in 9 of them, while the surface urban heat island effect had increased substantially across all ten cities [9]. Additionally, the correlation between vegetation loss and increased heat island effect was observed to be substantial. A second 2019 study noted that “the current urbanization has usually resulted in increasing levels of vegetation degradation in the urbanized areas of China’s main cities”, with a deterioration of urbanization in all of China’s 48 major urban spaces over the span of 30 years [10].

In Beijing City specifically, a 2010 study found that there was a negative correlation between brightness temperature and difference of vegetation index, calling the distribution of hot temperatures the “opposite” of vegetation covert. The study stated that the more dense the land use structure is, the more important this relationship is, tying together the importance of incorporating vegetation and green spaces in reducing the heat island effect and impact of temperatures in urban areas [11]. The rise of China as an influential urbanized powerhouse throughout the past half-century has provided a case study to examine the lasting effects of rapid urbanization, and a clear trend has emerged; as urban spaces expand and reduce vegetation cover, the temperature in these cities rise to unprecedented levels.

The Role of Green Spaces in Mitigating Heat

Luckily, however, this trend also works in reverse. A 2013 study in Florence tracked many different urban indicators such as tree cover ratio (TCR), street cover ratio (SCR), lawn cover ratio (LCR), and many more. The study found that each indicator can be used to assess air temperatures [12]. More specifically, it observed direct numerical correlations, such as a 10% increase in LCR resulting in a 0.14-0.53C temperature decrease, whereas a 10% increase in SCR resulting in a 0.22-0.66C temperature increase. A 2019 study from Madrid found that the real temperature 380 m and 665 meters from El Retrio, the city’s largest park, was 0.63 and 1.28 degrees C lower respectively than the surrounding Madrid city blocks. The study also found that the perceived temperature difference, the temperature that residents thought it was when asked, was 2.0 and 2.30 degrees C lower than the real temperature at the same respective distances. This suggests that “large-scale urban parks generally play a significant part in creating a cognitive state of high-perceived thermal comfort;” that residents experience a temperature cooler than the real temperature, which contributes to better resident psychological well-being [13].

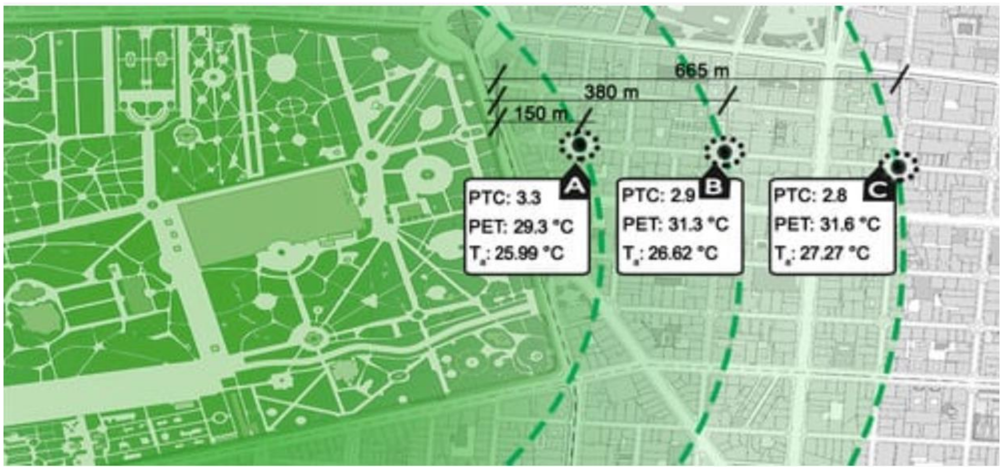

Figure 3: This graphical abstract from [13] shows correlation between resident thermal comfort (measured with PTC) and distance from El Reotio, Madrid’s main park.

El Retrio, however, was placed in the center of Madrid long before its cooling effects were known, which is not the case for parks and green spaces today. Determining both the placement of parks and vegetation in urban spaces as well as the most effective plants and greenery is a challenging issue. A 2019 study from Xuzhou China found that of eight factors individually tested, vegetation density, evapotranspiration, and green space shading degree were the three most impactful at reducing the heat island effect in urban spaces [14]. Furthermore, the inclusion of dense, high evapotranspiration and shade-rich plants can simultaneously reduce ambient temperature while decreasing noise and air pollution. The positive effects of parks are the greatest when they are developed in high density, urban areas, as there is a direct correlation between population density and building density, and thus between population density and urban heat index effects [15]. The inclusion of parks and green spaces in these areas improves city life, provides strong support for achieving sustainability and resiliency goals, and helps to mitigate the heat island effect.

Green Infrastructure and Microclimates

While large-scale green spaces play a critical role in reducing urban heat, integrating green infrastructure at the individual building level offers a more targeted (and often more achievable) approach to shaping local microclimates and mitigating the heat island effect. For example, roofs constitute 25% of the urban surface, and many black roofs could be converted into green or white roofs, both of which create up to a 2 degree C lower ambient temperature in urban areas. Green roofs were also found to lower heating and cooling costs from between 40-110% and have a lifecycle CO_2 contribution less than their black and white counterparts [16]. Moreover, green roofs have been found to improve stormwater attenuation, improve water quality, reduce noise and air pollution, and improve the aesthetic appeal of buildings, drawing up land values. A particular advantage of green roofs is they can be retrofitted on top of existing roofs and provide the same benefits at a fraction of the price, making them an appealing option for quick, effective urban environmental revitalization [17].

Figure 4: An example of a green roof on top of Chicago City Hall. [18]

Two other green infrastructure ideas on the forefront of the microclimate revolution are green facades and vertical forests. Green facades are walls which have vegetation, typically a type of climbing greenery, which covers the surface. Vertical forests are a more aggressive approach, in which vegetation such as bushes and trees are planted on balconies and other cavities in tall urban buildings. While results vary significantly depending on plant type, weather, and climate, some green facades show temperature differences of up to 12 degrees C between the outer and inner envelope of the building and potential energy savings ranging from 25-50%, while helping to mitigate noise and air pollution [19]. Vertical forests also show substantial thermal cooling properties (mainly from the shade provided), but their creation of a street canyon has been shown to block surface level windspeeds by 14-20%, leading to a build-up of fine particles and other pollutants [20]. Nevertheless, the incorporation of different green infrastructure mechanisms to reduce city and building climate impacts is imperative to build livable, urban spaces that counterbalance the heat island effect. Adding this infrastructure helps urban areas both adapt and mitigate with respect to our warming climate, preparing us for a better, healthier future.


Figure 4 (left): Stefano Boeri Architetti's Vertical Forest Milan, a well-known urban forest construction [21]. Figure 5 (right): Oasia Hotel in Singapore, a well-known example of a green façade [22].

Case Study: Austin, TX

These global trends also appear in Austin, Texas. For twelve years the Austin metro area was the fastest growing city in the country and has more than doubled its population [23]. With more people comes a massive growth in urbanized area, particularly with traditional suburban sprawl and cheap, open land being major pull factors for immigrants. Between 1993 and 2011, an increase in dark land cover (particularly asphalt), a reduction in natural vegetation, greater use of air conditioners, more motor vehicle traffic, and other effects of urbanization collectively contributed to an average increase of 4.7°C in surface temperature. Simultaneously, the population rise lead to a vast reduction in forest, cultivated, herbaceous, and shrubland during the same timeframe, most of which was replaced by developed open space and low intensity development such as single-family homes. The loss of cultivated land led to the largest temperature increase, rising by 8.2 °C when replaced by other land types, significantly contributing to the overall average temperature rise [24].

In Figure 1, there is a clear increase in average surface temperature in Austin during July–August from 1993 to 2011 – by 2011 nearly all of Austin was experiencing temperatures between 31-37 degrees C every day, compared to only 60% in 1993. Much of this rise corresponds to the development of large undeveloped areas south of the river—originally green in 1993—into urban zones. These changes resulted in localized temperature increases exceeding 10°C over the 18-year period.

Figure 2 supports this by showing a strong correlation between land cover change and rising temperatures. Significant areas of forest and farmland on the outskirts of Austin's denser areas in 1993 were replaced with low-density housing, while pre-existing medium- and high-density areas decreased in density. Together, these shifts point to widespread urban sprawl as a major contributor to the observed heat increase.

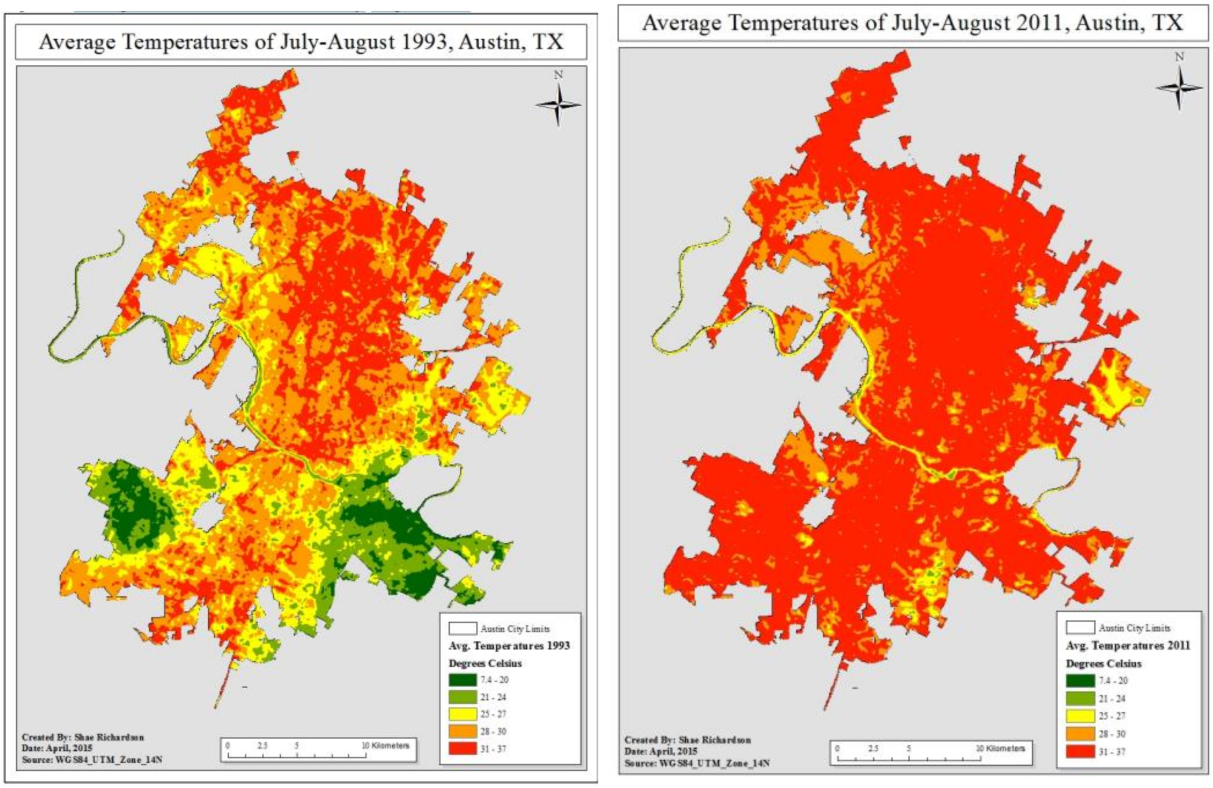

Figure 1: Austin average temperatures in 1993 (left) and 2011 (right).

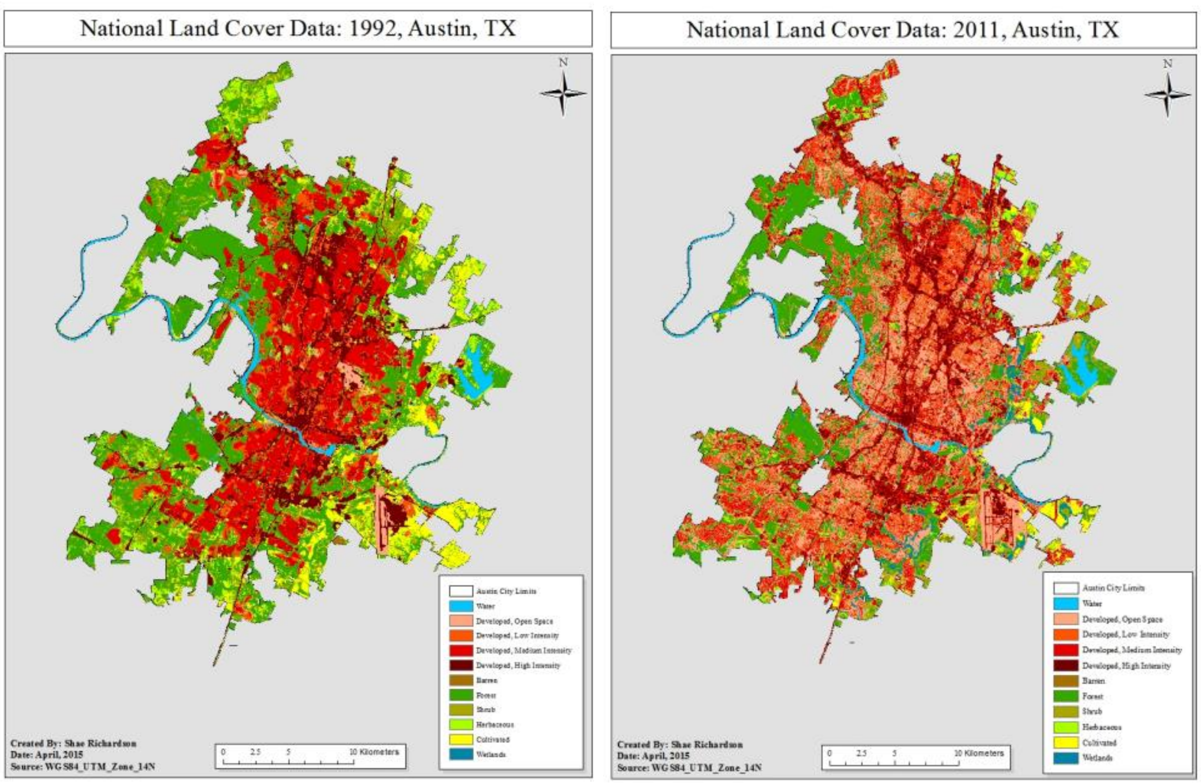

Figure 2: Austin National Land cover data from 1993 (left) and 2011 (right).

Austin has plans to fight these heat increases. Models of the Downtown Austin Plan (DAP), which dictates most development and environmental changes between MLK and Lady Bird Lake from 2011-2039, however, show that while claiming to create "one of the most sustainable cities in the nation", the plan would still result in an additional 2 Degrees C of Urban Heat impacts [25, 26]. While DAP envisioned the incorporation of green spaces, vegetation, and walkability, these considerations do not significantly decrease the rise in urban heat generated from the plan. The plan, which focuses on density growth throughout downtown, does not offset the additional thermal mass, creation of urban canyons, and waste heat that rapid downtown urbanization promises to bring, farther contributing to the heat island effect.

Although not mentioned in DAP, Austin does show promise for incorporating strategies that could stabilize or even decrease its heat island effect [27]. Shortly after the creation of DAP, the Imagine Austin Comprehensive Plan was created in 2012 to establish a "green infrastructure" network that would simultaneously boost the quality of life while providing relief from and reducing the impact of the heat island effect, primarily through added vegetation. The Austin Urban Forest Council, a branch of the city of Austin local government, is a huge part of this operation, as they use GIS programs and urban sensors to identify neighborhoods with higher ambient temperatures or low canopy cover and allocate resources to support tree growth. As of 2014, the Austin area had 33.8 million trees, resulting in 30.8% urban forestry coverage, ranking 22nd national in all large and medium urban centers [28].

Changes in building code, such as ordinance NO. 20160623-099 [29] which requires a specific amount of radiant barrier or reflective roofs on buildings, are also beginning to produce changes in the city. The city also published its first heat resilience playbook in 2020, which discusses how the city will adapt for more extreme temperatures [30]. Through a multi-pronged approach, Austin will help adapt both public and emergency response services to be more prepared for extreme heat, while helping (particularly low income and minority) communities become more resilient through green infrastructure and increased vegetation.

Conclusion

The dramatic rise in both global population and global urbanization has caused a worldwide environmental crisis unlike any in human history – one that is particularly dangerous to urban centers near the equatorial region. The rise of impervious black surfaces, reduction of virgin vegetation and farmland, and lack of airflow through urban spaces compounds with rising global temperatures to create dangerous heat island effects. Adapting urban spaces at both macro and micro environmental scales has shown great promise in reducing—and in some cases reversing—the impacts of the urban heat island effect.

As cities around the world grapple with these challenges, Austin, Texas emerges as a compelling case study in trying to balance rapid urban growth with a mixture of heat mitigation strategies. Whilst undergoing rapid urbanization and growth, Austin has simultaneously drafted multiple development plans and councils that work to reduce and mitigate the effects of extreme heat for all residents in the ATX community. Moving forward, the integration of green infrastructure at both citywide and individual building scales will be critical. By coordinating efforts across planning, public health, and environmental policy, cities like Austin can lead the way in creating cooler, healthier, and more resilient urban environments for generations to come.

Future Works

Future work on this project should focus on the specific effects of microclimate design decisions at the building scale, as well as the role of local zoning and urban planning policies. Further research is also needed on the direct cognitive and physical impacts of the urban heat island effect on city residents. In addition, a deeper investigation into the detailed strategies being implemented by Austin and other cities to mitigate the heat island effects, as well as the major political, economic, and technological barriers preventing rapid change would provide valuable insights. There is significant potential for this project to expand as more time and resources become available. A better understanding of how urban environments respond to development will support the creation of safer, more resilient communities.

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