Using an Urban Growth Model Framework to Project the Impacts of Climate Change on Coastal Populations

Becca Naurath, E.I.T.,[1] Jennifer L. Irish, Ph.D., F.ASCE, P.E., D.CE,[2] and Yang Shao, Ph.D.[3]

[1]Department of Civil and Environmental Engineering & Center for Coastal Studies, Virginia Tech, 200 Patton Hall Blacksburg, VA, USA 24061; E-mail: bnaurath@vt.edu
[2] Department of Civil and Environmental Engineering, Virginia Tech, 200 Patton Hall Blacksburg, VA, USA 24061; E-mail: jirish@vt.edu
[3] Department of Geography & Center for Coastal Studies, Virginia Tech, 238 Wallace Hall Blacksburg, VA 24061; E- mail: yshao@vt.edu

ABSTRACT

Coastal populations are facing increasing environmental stress from coastal hazards including sea level rise, increasing tidal ranges, and storm surges from hurricanes. The East and Gulf Coasts of the United States (U.S.) are projected to face high rates of sea level rise and include many of the U.S.'s largest urban populations. This study proposes modelling land-use change and coastal change between 1996-2019 to project the impacts of intensifying coastal hazards on the U.S. Gulf and East Coast populations and to estimate how coastal populations are growing or retreating from high-risk areas. The primary objective is to develop a multifaceted spatial-temporal (MuST) framework to model coastal change through land-use projections and thorough analysis of the indicators of coastal urban growth or retreat. While urban growth models exist, one that presents an interdisciplinary evaluation of potential growth and retreat due to geographic factors and coastal hazards has not been released.

This study proposes modelling urban growth using geospatial metrics including topographic slope, topographic elevation, distance to existing urban areas, distance to existing roads, and distance to the coast. The model will also use historic hurricane data, including storm track and footprint for named storms between 1996-2019 and the associated flood claims data from Federal Emergency Management Agency (FEMA), to account for existing impacts from coastal storms. Additionally, climate change data including sea level rise projections and future tidal ranges will be incorporated to project the impacts of future coastal hazards on urban expansion over the next 30 years (2020-2050). The basis of the urban growth model compares land-use change between 1996-2019 to complete a geospatial analysis of both the areas shifting from rural (agricultural, forest, wetlands) to urban, indicating growth and population data from 2000-2020, to evaluate coastal retreat or abandonment over the next 30 years.

INTRODUCTION

Coastal populations are facing increasing environmental threats from sea level rise and hurricane impacts. It is important to understand how populations are reacting to storm impacts to project how coastal communities will change. This work uses an urban growth model to help predict how coastal areas are developing, in order to project population change. The population projections are further refined to include the impacts of climate change on coastal communities by overlaying hurricane paths and factoring in sea level change to model how increasing storm impacts may affect coastal development.

METHODS

In order to evaluate how coastal populations are changing, the population data used for this work is prepared by the Integrated Public Use Microdata Series (IPUMS) National Historical Geographic Information System (NHGIS), which provides United States (U.S.) census data on population statistics suitable for use in GIS (Manson et al. 2022). The population data considered as part of this work spans the decades of 2000, 2010, and 2020 focusing on the U.S. East and Gulf coast states including Texas, Louisiana, Mississippi, Alabama, Florida, Georgia, South Carolina, North Carolina, Virginia, Maryland, Delaware, Pennsylvania, New Jersey, New York, Connecticut, Rhode Island, Massachusetts, New Hampshire, and Maine. The NHGIS data provided by IPUMS is geographically standardized to the 2010 Census units, providing consistent geographic blocks to evaluate population change over time. The data includes statistical bounds capturing the potential population related to the 2010 boundaries in instances where the 2000 and 2020 census blocks changed shape. The time series data table provided by IPUMS has been linked to the NHGIS shapefile of U.S. Counties using the GISJOIN attribute, and the census blocks were aggregated up to the County level. This population data will be used to calibrate the urban growth model to the existing population change experienced in coastal areas over the 20-year period.

The population change shown between 2000 – 2020 will be evaluated against land-change and climate change indicators in order to predict how coastal populations will change between 2020 – 2050. The urban growth indicators include land-use, topographic slope, topographic elevation, distance to existing urban areas, distance to existing roads, and distance to the coast. The land-use change included in urban growth model compares the change between 1996-2019 using 1996 Coastal Change Analysis Program (C-CAP) Regional Land Cover and Change Data from National Oceanic and Atmospheric Administration (NOAA) as the initial land use dataset and the National Land Cover Database (NLCD) 2019 land cover data from the Multi-Resolution Land Characteristics Consortium at the United States Geological Survey (USGS) as the present-day dataset. Both datasets are processed in RStudio to reclassify the land-use codes to five general categories for comparison to determine areas that have urbanized over the period between 1996-2019. These categories are urban, agricultural, forest, wetlands, and other.

In the 1996 dataset, NOAA tracks land-use using Landsat Thematic Mapper imagery to categorize land-use into 26 categories ranging from 0 - 25 (Office of Coastal Management, 2022). For the purpose of this work, categories 0 (Background) and 1 (Unclassified (Cloud, Shadow, etc.)) have been excluded from consideration. Categories 2 – 5 have been reclassified to urban(1), categories 6 – 8 have been reclassified to agricultural(2), categories 9 – 12 have been reclassified to forest(3), categories 13 – 18 have been reclassified to wetlands(4), and categories 19 – 25 have been reclassified to other(5).

The 2019 dataset from the USGS also uses Landsat imagery to categorize land-use, into classes ranging from 11 – 95 (Dewitz and U.S. Geological Survey, 2021). Categories 22 – 24 have been reclassified to urban (1), categories 71 – 82 have been reclassified to agricultural (2), categories 41 – 52 have been reclassified to forest (3), categories 90 – 95 have been reclassified to wetlands (4), and categories 11, 21, and 31 have been reclassified to other (5). The comparison of these two land-use data sets will show urban development in the coastal region between 1996 – 2019.

In RStudio, the 1996 and 2019 datasets were compared using the classification codes described above to determine areas that experienced no change (codes were the same from 1996 to 2019) and areas that shifted to urban. The areas that shifted to urban were identified as areas coded as agricultural (2), forest (3), or wetlands (4) to urban (1) between the two datasets. The areas that shifted between other classifications were not evaluated as part of this work, because the focus of the model is on urban growth only. Areas that shifted from other (5) to urban (1) were not included as part of this work as they were unlikely to be developed and were assumed to be errors or irregularities in the data as they would indicate a shift from open water to urban or similar changes that are unlikely. Figures 1 and 2 on the following page show the urban change along the U.S. East and Gulf coast in the 100 kilometers (km) adjacent to the coastline, and the growth at a sample location of Houston, Texas to show the extent of growth captured at a larger scale.

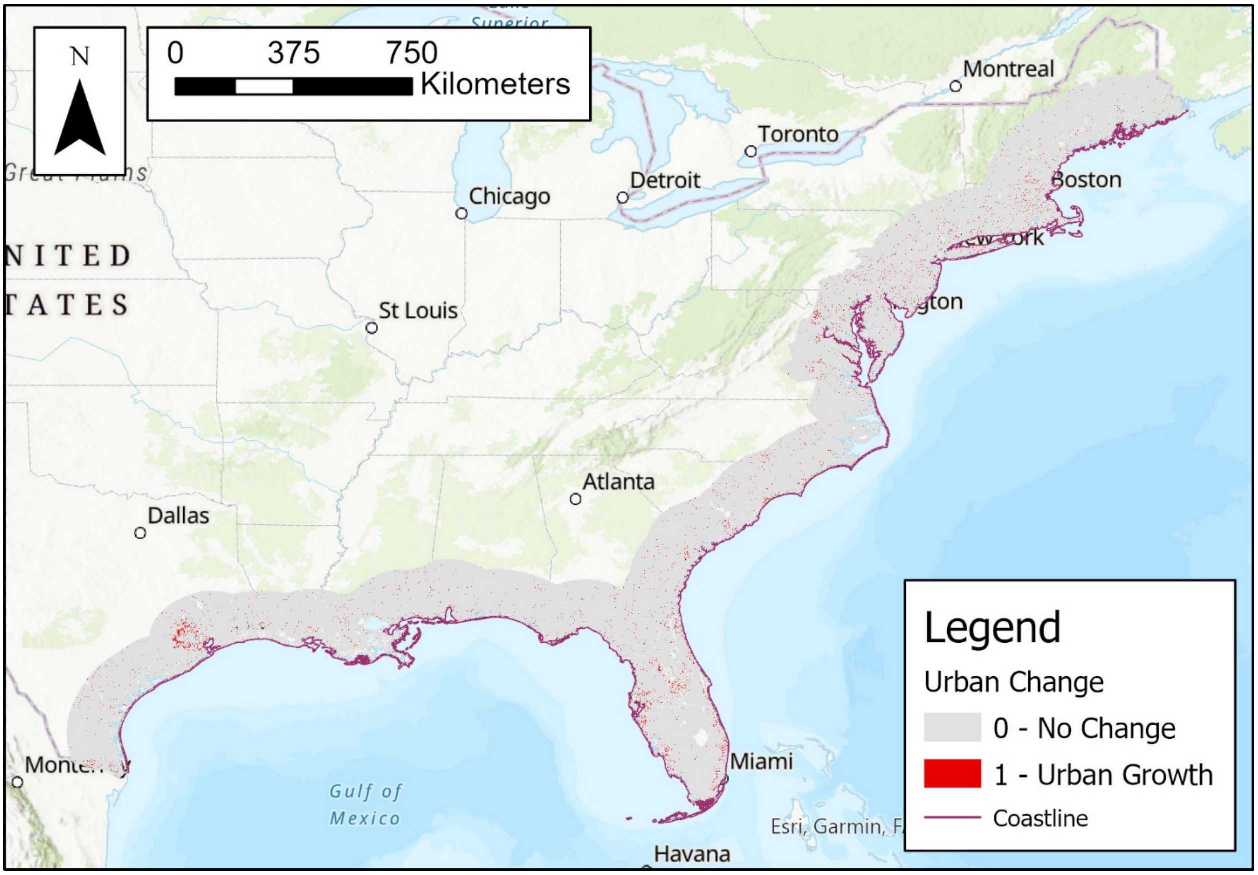

Figure 1. U.S. East and Gulf Coast Urban Growth (100 km buffer).

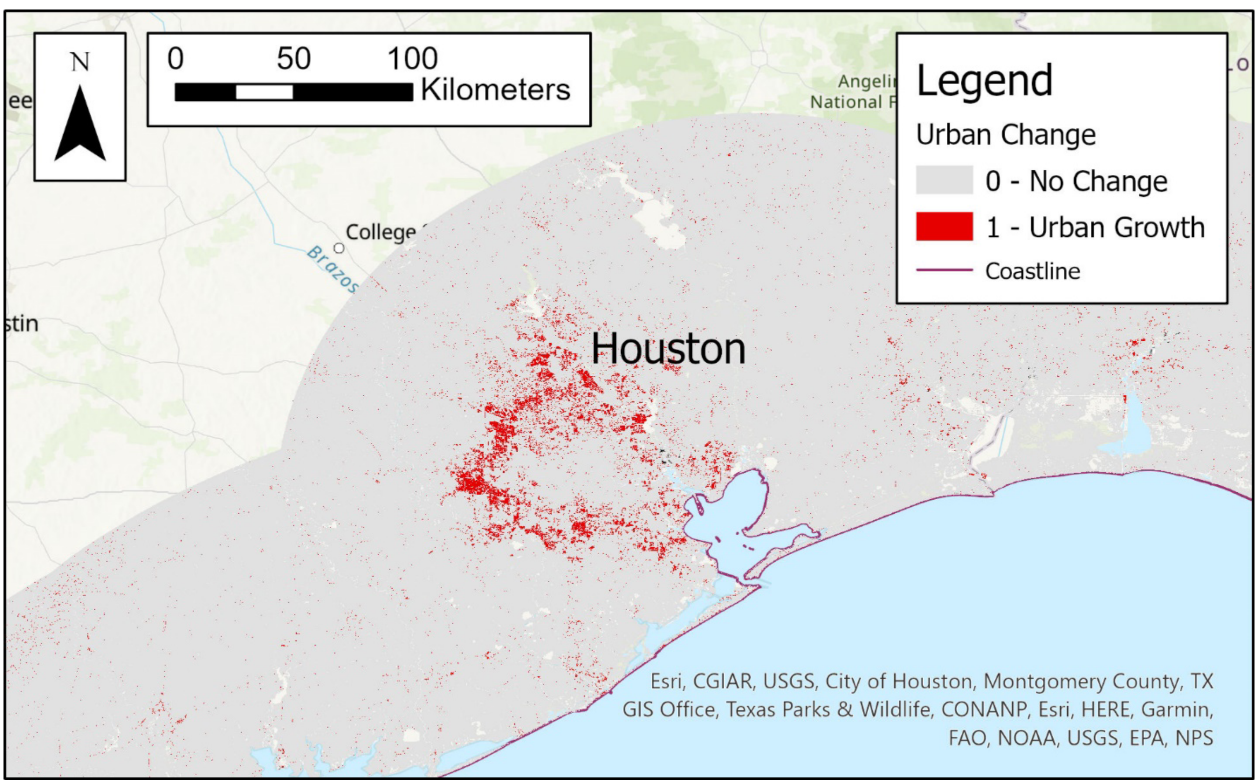

Figure 2. Houston, Texas Urban Growth (100 km buffer).

The next urban growth factor evaluated as part of this work will be a digital elevation model (DEM) which accounts for the elevation along the coastal buffer. The DEM used for this work is the 1-meter DEM collected as part of the 3D Elevation Program (3DEP) from the USGS; this data holds the elevation layer of the Nation Map for the United States (U.S. Geological Survey, 2020). The elevation collected throughout the coastal region will be analyzed in relationship to urban growth and elevation, and it will also be used when analyzing the impacts and projections for sea level rise and vulnerability to hurricane flooding. The DEM data will additionally be processed to calculate the slopes throughout the coastal buffer. The slopes calculated from the DEM data will further assist in modeling urban growth potential based on the land with would be developable based on the existing slopes.

The final urban growth factor evaluated as part of this work is the distance to existing roads from non-urban areas. It is expected that areas closest to other urban areas or existing roads will be the most likely areas to develop due to the ease of development and existing access to infrastructure. The existing roads data used for this work is the USGS Transportation data that is part of the Nation Map (U.S. Geological Survey, 2020). The roads data is analyzed in ArcGIS using geoprocessing to determine the Euclidean distance to existing roads.

All of the urban growth indicators will be used to train a generalized linear model built in R to perform a statistical analysis of the impact of indicators on urbanization and help predict urban growth between 2020 – 2050. The results of this model will be used to correlate population growth with development. This will serve as the basis for the population projections.

In order to accurately account for climate change in the modeled population predictions, sea level rise and hurricane impacts will be used to force the population model. Sea level rise is quantified in this work by applying the sea level rise scenarios from the 2017 NOAA et al. Global and Regional Sea Level Rise Scenarios for the United States technical report to the existing mean sea level data collected at NOAA gauges along the Gulf and East coasts using the United States Army Corps of Engineers (USACE) sea-level change curve calculator (Sweet et al. 2017). The relative sea level change calculated as part of the 2017 NOAA et al. analyzes multiple projection scenarios, and for this work the Intermediate scenario will be included in the model to project sea level. The projected sea level change for 2030, 2040, and 2050 is added to each NOAA water level station along the coast to best model the local change along the entire coastline.

The final environmental factor included in this work is the hurricane track data to help determine if hurricane paths and the resulting impact from the storms is impacting coastal population change. The Hurricane Database (HURDAT2) storm data from the National Hurricane Center (NHC) provides post-storm data measuring the hurricane location and magnitude throughout the progression of each storm. This data will be used create a buffered area along each hurricane’s track to analyze population change in the buffered area. Additionally, the areas where there has not been a direct hurricane impact over the period of 2000 – 2020 will be analyzed to determine how the populations in those areas have been growing without the impact of a storm.

PRELIMINARY RESULTS

The initial result of the population analysis shows that when comparing the 2000 census data for population to the 2020 census data for population, the coastal counties see growth in many areas of the coast. The urban growth model shows coastal communities, specifically urban areas and cities, as continuing to develop and grow as well. However, there is a significant decline in population in the New Orleans, Louisiana area that is estimated to be a result of the 2005 storm, Hurricane Katrina. Figure 3 shows the population change in coastal counties along the U.S. East and Gulf coast in the 100 kilometers (km) adjacent to the coastline. Figure 4 shows this same date in more detail in the New Orleans, Louisiana area, showing the lasting impact on population resulting from Hurricane Katrina. This storm showed the extent of how devastating a storm can be to a coastal community and the lasting impacts on population and development that can result from a powerful storm.

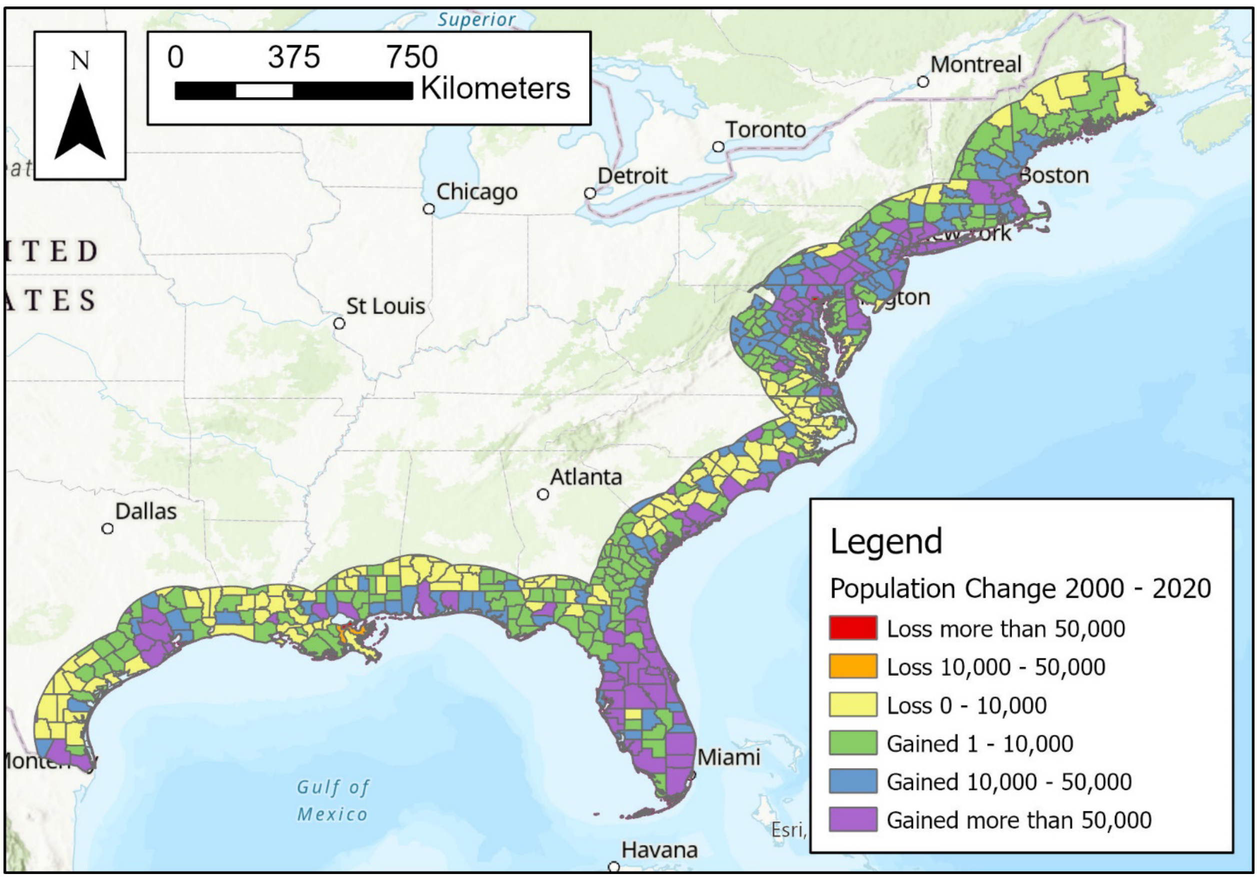

Figure 3. U.S. Population Change between 2000 – 2020 (100 km buffer).

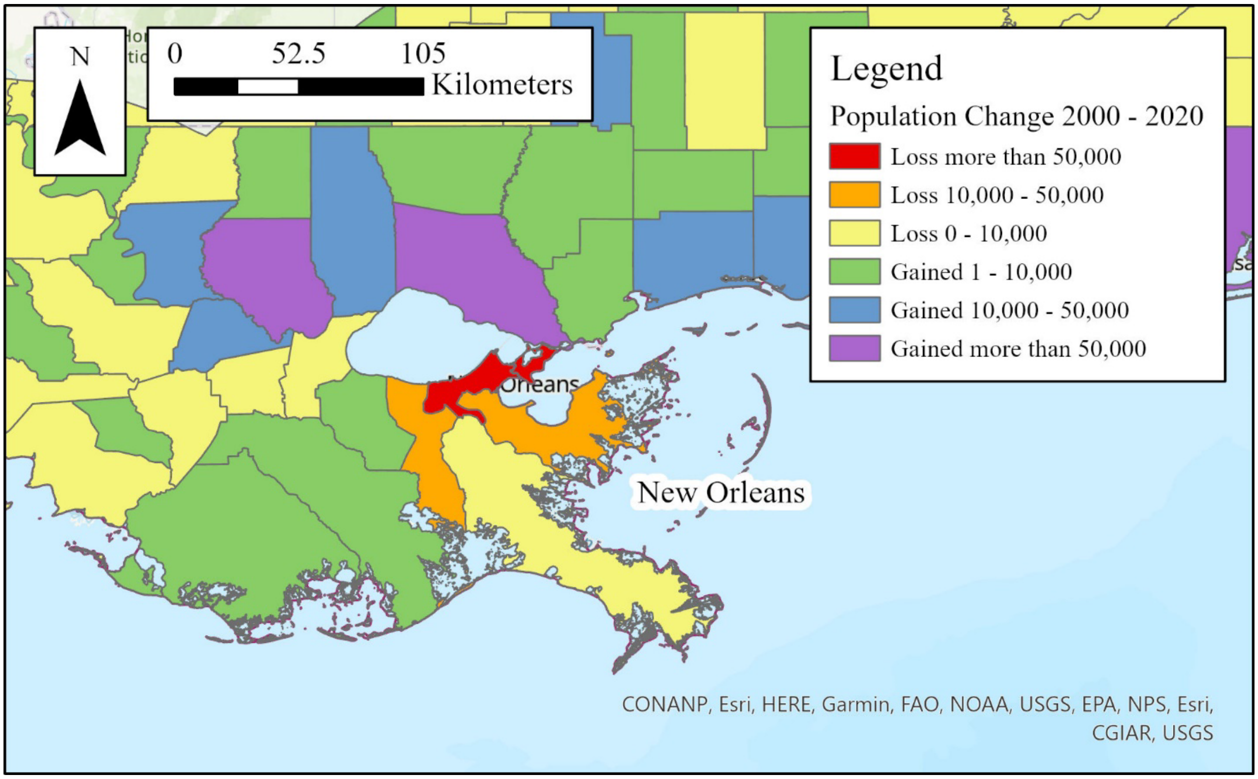

Figure 4. New Orleans, Louisiana Population Change between 2000 – 2020 (100 km buffer).

The New Orleans area demonstrates the permanent impact a large storm can have on a coastal population. This storm alerted many coastal communities to the risk of high intensity hurricanes and the need for coastal resilience and emergency preparedness plans.

EXPECTED RESULTS AND FUTURE WORK

It is expected the majority of the Gulf and East Coast areas will show significant growth over the period from 2000 – 2020, particularly in existing urban areas. This growth will be further analyzed along the paths of hurricanes, where in some cases population in the area declined. The primary example of this population shift away from the coast is presented in New Orleans following the 2005 storm Hurricane Katrina.

In order to further isolate the direct impact of hurricanes on coastal populations, the population data will be further refined to include the 2010 census population data as another point to help project population shift over a shorter period of time. If possible, the population data collected at more frequent intervals will be included to investigate storm impacts on population for each storm or hurricane season.

This work currently uses the 2017 NOAA Intermediate scenario projections for sea level change, but additional work will include the Low and High scenarios for sea level change to evaluate uncertainty in population change as it relates to uncertainty in sea level projections. Additional ocean impacts could include modeling the impacts of tidal ranges on storm intensity and flood risk to a coastal area and determining whether these factors increase the potential for hurricane to displace, temporarily or permanently, part of the population.

Future work will include the additional analysis of the Federal Emergency Management Agency (FEMA) National Flood Insurance Program (NFIP) claims to identify damages resulting from storms and flooding and to identify areas that have not redeveloped as a result of storm damage.

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