Genetic Water-Energy-Food Nexus Design Research for Miami's Greater Islands

Climate Resilient Urban Nexus Choices (CRUNCH), and Scripting

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Abstract

The International COP 21 Paris Agreement was created to generally support professional and municipal architecture and urban design practice emphasizing greenhouse gas reductions and carbon-neutral city planning and operations (1). Miami benefits through multiple large-scale grants focused on strategic solutions to combat and adapt to the effects of global warming, sea-level rise, flooding, hurricane impacts, and salt-water intrusion. However, Miami's sustainability master plans do not sufficiently target the International COP 21 carbon-neutrality targets. This paper critically describes a recently funded three-year research project by EU agencies and the US-National Science Foundation in partnership with nineteen partners from six countries (the UK, the Netherlands, Sweden, Poland, USA, and Taipei). The paper describes how transdisciplinary, parametric-algorithmic, generative design research workflows, combined with cloud-based artificial intelligence and machine learning simulation engines can produce architectural and urban-infrastructural outcome scenarios for the period from 2019 to 2100. These genetic scenarios are generated by the FIU Miami research team at the Urban Living Lab (ULL), The ULL's research sectors include green-blue infrastructures to combat sea-level rise, synthetic biology scripting, robotic urban farming, local food production mixed renewable energy design, and carbon-neutral power generation with adaptive infrastructure projects that support the local and regional Food-Energy-Water Nexus.

1..Interactive Baseline-Scenario-App

AI data-driven Geospatial-BIM workflows

The Integrated Decision Support System (IDSS) is an nd-digital geo-map and BIM-based platform that allows decision-makers and citizens with different knowledge levels to provide consistent and coordinated support for multiple users on varied decisions. It includes carbon-neutral building, city and infrastructural analysis, design scenario planning, and AI data-driven optimizations (Figure 1).

The beta version was developed to calculate the CRUNCH Energy-Water-Food-CO2 Nexus at a municipal level using Rapid Energy Modelling (R.E.M.) techniques to create zip-code referred baseline calculation from which to consider building optimizations, retrofitting, and renewable energy production. The baseline data sets were then utilized for nature-inspired design studio experiments to create carbon-neutral energy outcomes of city scenarios from 2018 to 2100.

The dynamically changing AI-data driven and automated cloud-based workflows, adaptive design research, and synthetic biological investigations are critical to question our imagination on how we can mitigate the effects of sea-level rise, salt-water intrusion, tropical cyclone genesis, extreme precipitation, and increasing latent heat events. The fundamental research questions, hypothesis and conclusion are as follows: What will a carbon-neutral AI-powered smart infrastructure of Miami's coastal island city look like in 20, 40, 60 and 80 years?

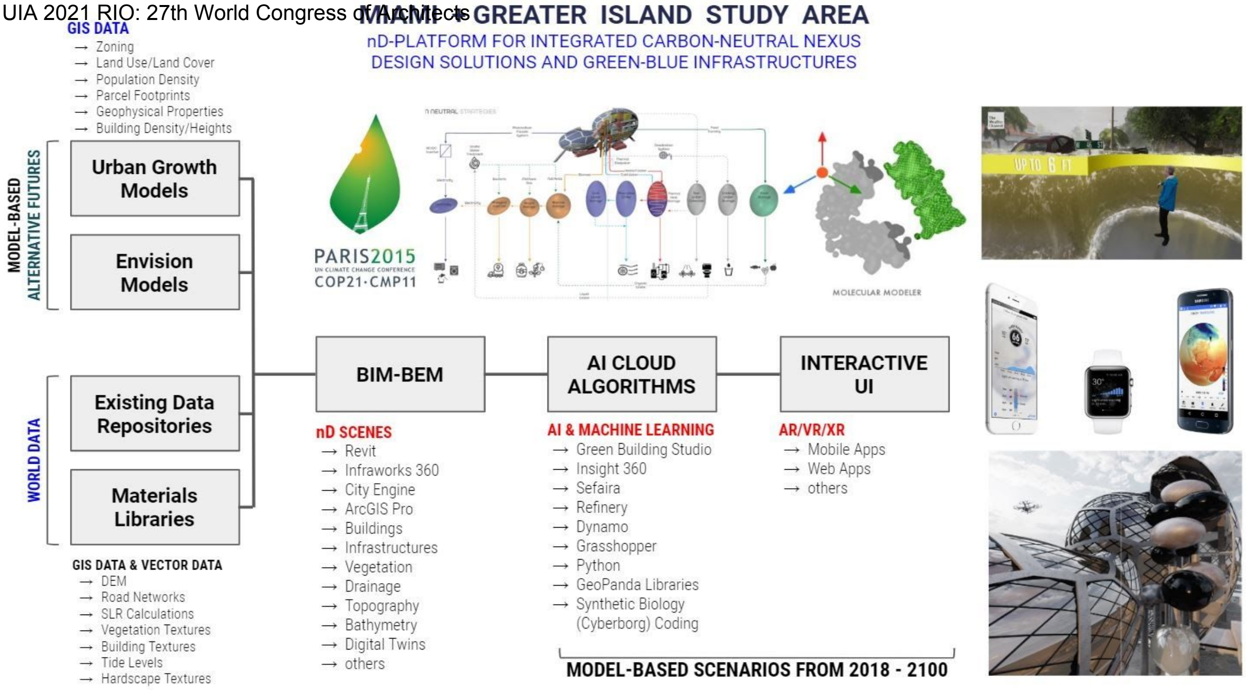

Figure 1. CRUNCH workflow diagram with open source GIS into Autodesk Infraworks, Civil, ESRI ArcGIS Pro, Revit-BIM, GreenBuilding Studio, Insight360, Dynamo, Grasshopper, Python, GeoPanda, etc. for analyzing, coding, designing, scripting, and optimizations of cities and buildings. This includes design studio scenarios from 2018 to 2020. (PI Thomas Spiegelhalter, Fall-Spring 2018-2020).

How will nature inspire the design and operate urban green-blue buildings, cities, and infrastructures interact with their ecosystems? The Autodesk R.E.M. baseline and optimization method do not require lengthy in-depth onsite analysis of individual buildings within a municipality, rather it uses verified industry standards. It uses real-time retrieved cloud-based performance data for building typologies, zonings, schedules, and generic systems mix of municipalities (1). Further test workflows include processing Food, Energy, and Water (FEW) Nexus parameters such as resource consumption, CO2, population changes, sea-level rise, and storm surge increase, among others.

The paramount goal of this research entails scenarios to transitioning to self-sufficient and carbon-neutral city operations in the next 80 years, cross-examined with the first baseline data repositories and workflows from 2019. The selected focus with geospatial data was on the two cities, namely South Miami and Miami Beach. The estimates and data processing for the online beta IDSS were made at the census block level.

2. Existing Data Repositories and Libraries

For Model-based Alternative Futures

Existing data repositories of the beta IDSS version are based on clarity. Only open data and free tools were used for analysis and estimation. The computation was done using Python. QGIS is supported by Python and is an open-source tool for working with geographical data visualizing the energy consumption of South Miami and Miami Beach on QGIS. Also, Pandas and GeoPandas libraries in python were used extensively. Pandas is a library for working with tabular data and GeoPandas is for working with geographical data. Census block shapefiles and population are publicly accessible. The BIM data shared by the county was imported into a platform called OpenStreetMap, which is a volunteer project, similar to Wikipedia but with spatial data and maps. The retrieved census block data and building shapes consist of polygonal shapes represented by the latitude and longitude of each vertex. From the polygonal shapes of each building, the base area can be calculated using existing functions in GeoPandas. Machine Learning was applied to estimate the height using the rest of the available parameters as predictors. The python library Sklearn was used for this purpose. The Solar PV potential was processed through the Google Project Sunroof that offers estimates of solar PV potential. Google Earth provides high-resolution imagery of rooftops. After the initial estimation phase, Artificial Intelligence was used to predict the solar system's potential based on weather stations data.

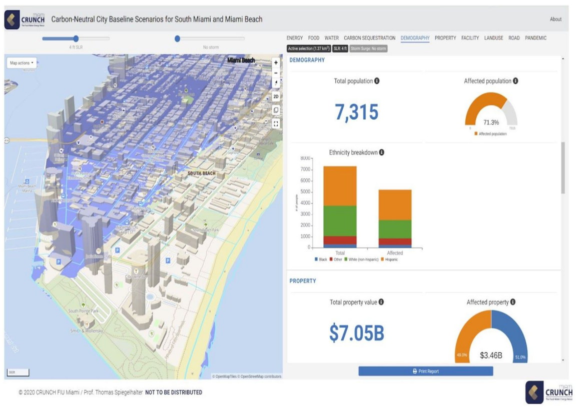

Figure 2: IDDS 3D interface capability to visualize between Sea Level Rise, Storm Surge, Energy, Food, Water, Carbon Sequestration, Infrastructure, Demography, Property, Facilities, Land Use, and Pandemic, (CRUNCH PI Thomas Spiegelhalter, Levente Juhaz, 2019-2020).

3. IDDS Data and Methods

Climate Change induced Sea-Level-Rise

The rate of sea-level rise (SLR) is not constant across the globe and it shows great local variations. As a result, adapting to changing water levels and planning has a strong local component and each coastal area must consider their unique characteristics. For example, Wdowinski et al. (2016) show that the rate of SLR in Southeast Florida is more accelerated than the global average (9 +- 4mm/year vs. 3.2 +- 0.4mm/year) which will likely be manifested in larger social and economic impacts compared to some other parts of the world. In addition to the challenges posed by the rising sea levels, anthropogenic climate change also poses risk to coastal communities by higher storm surges (2) and the co-occurrence of sea-level rise, storm surge and flooding caused by heavy precipitation (3).

4. Modelling Inundation Levels

Mean Higher High Water Surface (MHHW)

A necessary step in modelling inundation levels is to choose a reference surface to which water height or depth is compared to. Tidal datums are locally standardized elevations set to certain phases of the tide for a certain area with the same oceanographic characteristics. Water levels were measured to the Mean Higher High Water (MHHW) surface, which is the average of the higher high water level. A series of SLR inundation scenarios between 1 ft and 10 ft with 1 ft increments was created using a so-called bathtub model. The digital elevation model (DEM) used in the computations was derived from a 2015 LIDAR dataset of Miami-Dade County given in the NAVD88 vertical datum. This surface is 0.1m below the MHHW in South Florida which was adjusted in the calculations.

The methodology is described by Zhang et al. (2011). In addition, relevant structures, such as levees and weirs were also considered to create a hydrologically accurate model. The Sea, Lake and Overland Surges from Hurricanes (SLOSH) model developed by the National Weather Service (NWS) was used to derive storm surge inundations caused by hurricanes category 1 through 5. In SLOSH, the Maximum Envelope of High Water (MEOW) shows the maximum likely extent of flooding in a basin for a given storm category with a certain trajectory and forward speed (4). Our calculations use the MOM (Maximum of MEOWs) output of SLOSH for the Miami basin. It also considers a worst-case snapshot for a particular storm category like the historical 23 ft storm surge of hurricane Dorian in the Bahamas in 2019.

5. IDSS Web Application, API, Database for Scenarios

Interactive and dynamic visualizations

Communicating complex environmental challenges and future scenarios with potential impacts on a diverse audience of professionals and citizens is a challenge. In particular in political times of denial and pandemics that are often linked to the human destruction of ecosystems that cities are relying on. Consequently, our goal was to develop a user-friendly web application that interactively visualizes the potential social and economic parameters related to the food, water and energy nexus for any given area within the City of South Miami and Miami Beach. Free and open-source software has already been used to build interactive web-based GIS applications to model excess waters (5).

Two types of data are being visualized in the application: spatial and non-spatial. Non-spatial data consists of the pre-calculated socio-demographic variables and food, water and energy nexus parameters for each block within the study cities. To present these statistics in a web environment, a custom application programming interface (API) was developed for the sole purpose of serving these data over the web. This API connects to a MySQL database that was optimized with multi-column indexes for performance. The API accepts HTTP GET requests through six endpoints that correspond to the food-energy-water nexus parameters. The main functionality of the IDSS application is to present and visualize details for a user-selected area within the study cities. Upon selecting an area, the statistics on the right pane are dynamically updated visualization of SLR and storm surge inundations and results are instantly reflected in both the map and statistics panes for the energy-food-water nexus.

6. Carbon-Neutral and Biology Inspired Design Studio Experiments

Envisioned Scenarios from 2018 to 2100

As part of the IDSS scenario tool for professionals and citizens, the CRUNCH research studios have been working on a series of resilient design projects for the City of Miami Beach and South Miami since Fall 2018. One specific scenario presents a stage of the flooded City of Miami Beach for the year 2100. All new buildings are 25-30 feet above the current sea level on stilts, totally off-the-grid and self-sufficient, and floating structures. Building hybrids sitting in, out, or under the water with the ability to be self-sustaining against any sea-level rise and climate change impacts in Miami Beach (Figure 3). All designs have been modelled with Revit-BIM, GBS-Insight360, Robotic-Structure, Infraworks 360, CFD, Fusion360, Dynamo, Grasshopper, Python, Pix2PixHD with Generative Adversarial Neural Network workflows due to its geometric complexity for carbon-neutral operation. hurricane and tornado induced resilience impact forces. This includes multi-functional systems and modules, renewable energies from solar/ wind/water/kinetic building skins, autonomous transportation, artificial intelligence, robotics, and urban outdoor and indoor farming with self-healing facade tectonics for climate emergencies in 2100. (Figure 3, 4, and 5).

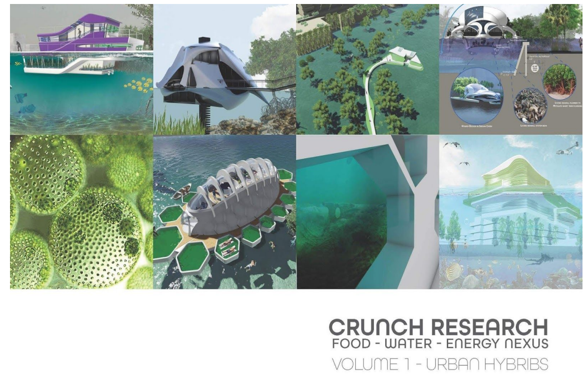

Figure 3. CRUNCH DESIGN RESEARCH Fall 2018, "Volume 1 - Urban Hybrids, Food-Water-Energy Nexus", (https://www.francoangeli.it/Ricerca/Scheda_Libro.aspx?CodiceLibro=1098.2.57 Edited by Thomas Spiegelhalter, Darren Ockert, 2020)

7. Biology inspired carbon-neutral Island City Scenarios

Scripted, coded, adaptively self-growing

All the design research projects included in the new beta IDDS app are organized by indicators based on the Energy-Water-Food Nexus. Biomimetics inspired research workflows open innovative opportunities for programming physical materials, organic and inorganic building systems. For example, Autodesk's Project Cyborg software for programmable matter offers cloud-driven information storage, computation and transformations in material property and/or physical shape like DNA origami. The studio experiments focused on these types of biology-inspired AI data-driven designs that include speculations on self-assembly and programmable materials (Figure 4, 5).

8. Subtropical, Carbon-Neutral and Resilient Bio-City Building Designs

Peninsula and Island Scenarios 2018-2020

Another worth citing design studio is the collaborative spring 2020 design studio by Prof. Spiegelhalter and Prof. Andia. This one developed a more large-scale and speculative master plan for the Biscayne Bay estuary that envisions a self-sufficient high rise community in Biscayne Bay that adapt and grow by themselves using biology-inspired behavioural patterns and programmable matter. This includes living shoreline with self-sufficient high rise structures that also assist the relocation of the impacted population in low lying areas threatened by SRL. These growing islands will have increased soil

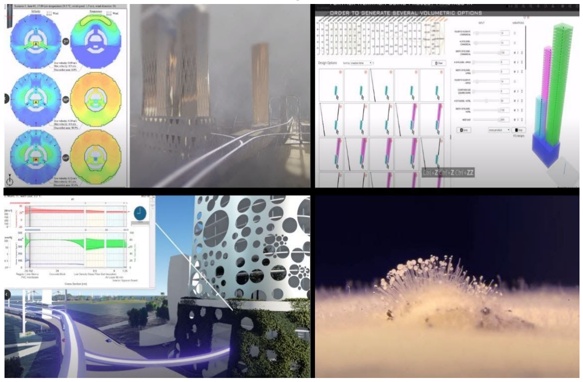

Figure 4. Crunch Master thesis excerpt in 2018 with research scenario simulations with CFD, WUFI and Dynamo-Python to fitness test 10 feet SLR, climate change impacts with new buildings and infrastructures on stilts of 30 feet above MHHW in 2100.
(CRUNCH PI Thomas Spiegelhalter, 2018).

pressure that will self-transform according to changing SLR rising above MHHW. The proposed system of islands works like atolls that will create defences from currents and surges.

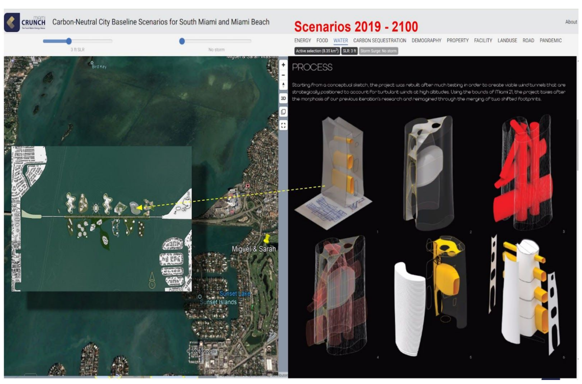

Figure 5. IDDS beta app with an excerpt of the biology-inspired CRUNCH research studio of Miami Biscayne Bay. (CRUNCH PI Thomas Spiegelhalter with Alfredo Andia, Spring 2020).

9. Conclusion and Future Work

Climate Change, Greenhouse Gases, and AI's

Designers are often unable to adequately explore alternatives of their impact on the environment, on energy, water, and resource consumption with Greenhouse Gas Inventory benchmarks upfront. Any integrated project delivery process must require early on participatory cloud-based AI data-driven master planning with machine learning and deep neural learning processes for shared modelling, analysis, and fitness test processes. Our critically discussed research is not finalized and more funded work needs to be done in the future.

Acknowledgement

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