Design Narrative

CO2 Crew blends the Astrodome's scale with efficiency, proposing a new community above the surrounding parking lots for sustenance, walkability, and resilience. A carbon-neutral platform reduces the heat-island effect, boosting density, diversity, and activity. Innovative zero-carbon buildings maximize solar gain and offset energy with solar arrays. The Astrodome is repurposed into a terraced urban farm, education center, and community farmers market addressing food security within Houston. Removing the existing roof unveils the elegant lamella structure transforming the stadium into an open-air pavilion for farming. While the terraced seating becomes 4.5 acres of urban farmland with vertical hydroponics, the lamella structure harnesses solar energy through a sun-tracking array. The Education Center Pyramid emerges from the interplay of ley lines, connecting prominent Houston landmarks to its center and informing the pyramid's geometry. The Center includes classrooms, research and exhibition spaces, a library, bike storage, two theaters, a café, and a restaurant. The public plaza at the heart of the Education Centre is a communal hub with a thriving farmers' market, music, and a lively space for interaction and dialogue. Astrodome's transformation honors its history, reimagines the present, and shapes a vibrant future while redefining urban landscape and community experience.

Climate Risk Assessments

Site & Program Description: To effectively handle stormwater and mitigate the possibility of floods, rain gardens, porous pavements, and green roofs were proposed while committing to utilizing rainwater for non-potable purposes such as irrigation and flushing.

Resilience: Bringing agriculture into urban settings increases the climate resilience of the affected communities. Produce in the US travels a long way from farm to sale (50% of purchased produce comes from off-continent), with many external factors impacting future access. On average, produce grown in the US travels 1,500 miles from farm to sale, and often much further when a community exists in a food desert, as is Houston. This emphasizes the need to develop unused and available urban infrastructure into stable and reliable sources of food.

Adaptability & Durability: The building was designed to accommodate the extreme climate conditions of Houston, including humidity, high rainfall and flooding potential, and extreme heat. Rainfall recovery systems throughout the building and site enable large water volumes to be re-directed and stored for later use. Proposed site development buildings are to be on a pedestal, with parking areas throughout ground-level areas, minimizing potential flood-related damages. The proposed HVAC system harnesses natural heating and cooling strategies and tools to improve energy efficiency and resiliency. This is accomplished through night sky radiation cooling to supercool the borehole thermal storage field, separating HVAC performance and capacity from outdoor temperatures, especially important for warming temperatures in future years.

Visual Comfort: To ensure sufficient natural light into spaces while minimizing glare risk, simulations were undertaken on an annual and hourly basis resolution. Annual observations confirmed spatial daylight autonomy (sDA) and annual sun exposure (ASE) could meet 51.9% and 8.2%, respectively, surpassing LEED v4 criteria. Annual Glare Autonomy (GA) was tested, resulting in a glare-free environment more than 97% of the time due to the added horizontal louvers. Hourly simulations were conducted to assess discomfort glare risk for specific hours of the year for south-faced spaces including the restaurant, lobby, market, and gallery, which determined the requirement of motorized roller blinds.

Additionally, view analysis was assessed in the main spaces through Horizontal Radial View and Sky Exposure, thus adding internal curtain walls within spaces is recommended to keep the outdoor view for the occupants.

Healthy Material: Mass Timber was used as the primary structure of the new design. Materials are envisioned to be selected through a rigorous process of integrating a sustainability layer into product selection and specifications. This includes our commitment to AIA 2030 Materials pledge focusing on human health, social health & equity, ecosystem health, climate health, and circular economy. LEEDv4.1 credit material ingredient and low-emitting material incorporation also include CDPH v1.2-2017, ANSI/BIFMA standard for furniture, Cradle to Cradle certificate, Declare Labels, Health product declarations (HPDs), Living product challenge, LBC Redlist free.

Biophilic Design: A mass timber inner pyramid construction was selected due to the low embodied carbon aspects, while also providing a warm ambiance to the interior areas and impersonating natural landscapes. The mass timber lattice structure was created to mimic and tie in the existing dome lamella structure of the roof, while providing a place for low-maintenance natural shades (such as ivy) to grow, improving temperature control, humidity regulation, and pollution filtration. The vegetation throughout the dome is apparent in farming areas, with botanical vegetation woven throughout the common lobby space, corridors open gathering space, and exterior greenspaces and development site areas. Water features were also considered throughout the design, including the central opening in the inner pyramid, providing a waterfall effect during precipitation. Additionally, the open lamella structure provides substantial fresh air and natural lighting throughout the facility.

Thermal Comfort & Indoor Air Quality (IAQ): Indoor air is filtered with 3 stages: Merv-8, Merv 13, and UV-C decontaminant section. IAQ parameters of temperature, humidity, volatile organic compounds, and pathogens are directly measured and the mechanical systems are controlled to achieve the desired air quality with the minimum ventilation required. Applying ASHRAE 241 standards, outdoor air requirements are minimized through this monitoring and control strategy. Critical zones were analyzed using CFD to determine the operative temperature to prove comfort levels. An unmet hour analysis was completed to analyze indoor comfort and verify equipment is properly sized and able to provide the required heating and cooling loads. Demand control ventilation strategies were considered to optimize ventilation requirements to occupied spaces, with displacement ventilation to provide the necessary cooling and IAQ requirements to the occupied zone levels only. A Computational Fluid Dynamics (CFD) analysis was completed in ANSYS Fluent using a k-omega turbulence model to highlight the potential application of CFD for the Houston Astrodome. Through leveraging existing simulation capabilities, we were able to optimize many aspects of the development; ultimately leading to a more efficient design. External zones are tempered using displacement ventilation along the occupied harvesting zones. When the dry cool air contacts the humidity released by the hydroponics a localized evaporative cooling effect is generated. The dry air also improves plant growth by improving nutrient transport through increased transpiration.

Energy

Design Optimization: Robust optimization and parametric analyses were completed to determine optimal design parameters to minimize energy usage while maximizing occupancy comfort. A brute-force approach was conducted through algorithms and parametric analysis using Grasshopper and Ladybug tools. Design inputs included external wall insulation, glass thermal and optical performance, horizontal shade depth and distance, and ventilation mode (hybrid vs. Fully-air conditioned) which resulted in over 140 design options. This approach studied the impact of each design input on the selected performance target including energy use intensity (EUI), daylight autonomy (DA), discomfort glare risk, indoor thermal comfort, and reference case scenario performance. Results are hosted in a web-based application and available here: https://bit.ly/3QaE7im. An optimal design solution was selected and then refined to meet each of the objectives' criteria.

Building Envelope: The building envelope has a window-to-wall ratio of 45% where the design optimization suggested a high-performance double-glazed system with U-value and SHGC of 2.0 and 0.30, respectively, to control the solar gains in this cooling-dominant climate and to outperform the pre-defined reference case performance and permit sufficient daylight into the spaces.

On the other hand, the opaque part of the envelope is proposed with a Cross Laminated Timber (CLT) structural system to mitigate the upfront embodied carbon. Peak summer and winter conditions were modeled in THERM LBNL to understand two-dimensional heat-transfer impact in the designed external wall where thermal bridges are of concern.

Mechanical Strategy: A decoupled sensible and latent system was proposed, applying a liquid desiccant dehumidification system. Regeneration from the liquid desiccant comes partially from rejected compressor heat while providing sensible cooling at the system's evaporator. Additional input heat comes from PV/Thermal (PVT) collectors located along the upper dome perimeter. The liquid desiccant system super-dries air, allowing for direct evaporative cooling to deliver 33% of the sensible cooling demand. High occupancy zones with larger sensible loads are cooled directly from a cold borehole thermal energy store (BTES) at the beginning of the cooling season or actively using the chilled water loop delivered to fan convectors or chilled beams. The cool dry air is delivered through displacement ventilation, based on demand control signals from CO_2, humidity, and temperature, and only to the occupied height of the zone. The BTES is used to supply cooling to the system, acting as a heat sink for vapor compression cooling at the end of summer. The PVT array rejects heat radiatively to the night sky in the fall and winter charging the BTES with cold energy. At the end of winter, vapor compression cooling is used to further reduce the temperature at the center of the BTES by rejecting the PVT array. This allows the BTES to be charged with cool energy for the beginning of the next cooling season. The coefficient of performance (COP) for passive cooling is around 20 while the active charging of the BTES is around 8, achieving very high seasonal cooling efficiency.

Energy Performance: The design for the Astrodome has undergone a complete optimization process. Substantial optimization into the geometry, building orientation, and fenestration location was done to maximize daylighting opportunities to reduce reliance on lighting systems while also reducing glare and overheating through external shading devices and Low-E glazing products. Opaque assemblies and fenestration thermal resistance are optimized with the balance of economically feasible and reductions in annual heating and cooling consumptions. Indoor setpoints for temperatures and humidity levels were chosen specifically for Houston's climate to maximize thermal comfort but minimize impact and strain on the mechanical systems. Lighting systems implemented use efficient LED fixtures controlled via daylight harvesting sensors and occupancy sensors for all space types and modeled with the expected absence of occupancy rates for all spaces. The optimization of the envelope and glazing combined with the high-performance displacement ventilation system creates very low energy consumption. Natural ventilation was explored to further reduce the cooling load, which was applicable for 721 hours per typical meteorological year. However, due to the very high COP of the mechanical system and overall system complexity, natural ventilation was found to be unsuitable for this design. High density hydroponics would require supplemental lighting, even outdoors due to shading. Due to the large area of the farming system as well as the highly efficient system design for the conditioned area, the supplemental grow lighting is the highest end use consumer of energy. In the end, due to the optimization and efficient repurposing of space, a total site EUI of 8.71 kBtu/ft² and an annual consumption of 7,345,098 kBtu of energy for the whole facility is achieved, all of which is offset via renewable energy generation to meet a net-zero energy state. Integrated Environmental Solutions Virtual Environment (IES VE) was used for energy modeling and performance, with modeling inputs derived from optimization studies/analyses, as detailed above.

Renewable Energy: Wind turbine types (vertical axis, horizontal axis, and kite power), solar PV, and solar PV-thermal were all considered, with solar PV selected due to its cost-effectiveness, existing site conditions, generation potential, aesthetic appeal, and occupancy comfort effects. PV-Thermal was utilized to drive the liquid desiccant dehumidification system. Various solar glazing transparencies were considered for the dome, with the ultimate decision to utilize fully opaque modules, covering 25% of the dome lamella structure. The solar glazing was simulated to be installed on a rotating track system to optimize azimuth angles throughout each day and provide shading to interior dome spaces. Dual axis tracking shade trees were selected to supplement the dome glazing solar, to provide large, shaded areas for occupant activities/gathering surrounding the dome greenspace areas. Solar PV along the curvature of the dome was modeled in RETScreen Expert, using appropriate tracking functions. Overall, renewable energy systems provide 100% of the proposed electricity usage for the Astrodome, totaling 1,300 kW of Solar PV, producing 7,345,098 kBtu of annual electricity generation.

Water Conservation: Various water conservation measures were considered throughout to design to maximize grey and rainwater recovery. Rain gardens were considered while porous pavements were utilized to reduce stormwater runoff and to provide cooler surface temperatures. While green roofs in site development areas are employed. A hydroponic farming system was proposed for growing areas inside the dome, significantly reducing the watering requirements compared to traditional soil-based farming. This significantly reduces water usage, while increasing overall food growing density and productivity, improving food production by 10 times, and reducing water use by 92% per kg of food produced. Low-flow domestic water fixtures were included to reduce overall domestic hot and cold-water use by 36%, calculated through the LEED V4 water use calculator and ASHRAE occupant densities for the various space types. Greywater recovery systems were considered for all greywater fixtures. Efficient irrigation strategies are proposed using soil-moisture monitoring to prevent over-irrigation and subsurface drip irrigation to eliminate surface water evaporation. Rainwater harvesting was proposed to capture and store runoff from dome glazing, internal dome hardscapes, hydroponic growing, and site development areas. Daily rainfall data for a typical year was overlayed with daily water consumption, optimizing storage tank sizing and reducing overall water use by 96% throughout the facility.

Carbon

Operational Carbon: The facility utilizes a fully electric heating and cooling system, resulting in no on-site fossil fuel combustion. As a result, all operational carbon is offset using the proposed renewable energy systems, resulting in 0 tCO_2e of net annual operational carbon.

Embodied Carbon: Embodied carbon utilized Adaptive reuse, repurposing many of the existing Astrodome features; Design optimization, comparing recycled foamed glass aggregate to traditional landscaping filling material; and lower carbon material choices, such as mass timber design for the primary structure, lower carbon concrete with at least 40% cement replacement, and high recycled content steel for rebars (~97%). Overall, incorporating the above strategies achieves a CO_2e reduction of 33,281 tCO_2e, or 98% compared to baseline scenarios.

Zero-Carbon Approach: Operational carbon is fully offset using on-site renewable energy generation, located on the Astrodome glazing and surrounding perimeter greenspace. This results in a reduction in operational carbon emissions by approximately 803 tCO_2e per year, achieving net zero carbon. The proposed design has approximately 3,929 tCO_2e (lifecycle of 60 years) of embodied carbon. It was important for the project team to create a sustainable facility in all aspects of design, including offsetting embodied carbon. As such, local food production within the Astrodome is expected to reduce transportation-associated emissions compared to traditional produce supply chains. The Astrodome is estimated to produce 1.4 million kg of food per year, offsetting the long-haul transportation of 40 fully loaded tractor-trailers to local grocery stores, restaurants, and residential homes throughout Houston. This is expected to save 227 tCO_2e per year, requiring 17 years of facility operation to offset the initial embodied carbon emissions.