HEALTH IMPACT ASSESSMENTS
A Tool for Designing Climate Change Resilience into Green Building and Planning Projects

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INTRODUCTION

Historical records have documented considerable changes to the global climate, with significant health, economic, and environmental consequences. Climate projections predict more intense hurricanes; increased sea level rise; and more frequent and more intense natural disasters such as heat waves, heavy rainfall, and drought in the future (1; 2). The coast along the Gulf of Mexico is particularly vulnerable to many of these environmental hazards and at particular risk when several strike simultaneously—such as a hurricane disrupting electricity transmission during a heat wave.

Due to its significant contribution to global greenhouse gas (GHG) emissions, the building sector already plays an important role in climate change mitigation efforts (e.g., reducing emissions). For example, voluntary programs such as the LEED (Leadership in Energy and Environmental Design) Rating System (3), the Architecture 2030 Challenge (4), the American College and University Presidents' Climate Commitment (5), and the Clinton Climate Initiative (6) focus almost exclusively on reducing energy consumption and increasing renewable energy generation. Mandatory regulations such as the International Energy Conservation Code (7), the International Green Building Code (8), and CalGreen (9) also emphasize GHG emission reduction targets.

This leadership role is necessary. After all, the United States EPA estimates that the building sector accounts for 62.7% of total annual GHG emissions in the U.S., when the construction sector, facility operations, and transportation are factored in. In fact, the construction sector alone is the third largest industrial emitter of GHGs after the oil and gas and chemical industries, contributing 1.7% of total annual emissions (10; 11).

As significant as these contributions appear, the built environment's true contribution to climate change is much larger than the GHG emissions attributed to building construction and operations. It is also a major determinant of which populations are vulnerable to climate change-related hazards, such as heat waves and flooding (12; 13). Architecture and land use planning can therefore be used as tools for building community resilience to the climate-related environmental changes underway (13).

Climate change regulations and voluntary programs have begun to incorporate requirements targeting the built environment's ability to work in tandem with the

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natural environment to both reduce greenhouse gas emissions and protect its occupants from the health consequences of a changing climate. For example, 11 states have incorporated climate change adaptation goals into their climate action plans (14). In 2010, the not-for-profit organization ICLEI: Local Governments for Sustainability launched a climate change adaptation program (15) to complement their existing mitigation program, which supports municipalities who have signed the U.S. Conference of Mayors' Climate Protection Agreement (16).

New tools have been introduced to measure community vulnerability to the impacts of climate change. One of these tools, Health Impact Assessments (or HIAs), has emerged over the past decade as a powerful methodology to provide evidence-based recommendations to decision makers and community planning officials about the likely health co-benefits and co-harms associated with proposed policies and land use development proposals (17). While HIAs are becoming a more common feature of community planning efforts, this paper introduces them as an approach to designing climate change resilience into specific building projects.

HIAs have been used in Europe and other parts of the world for decades to provide a science-based, balanced assessment of the risks and benefits to health associated with a proposed policy or program (18). In the U.S., they have been used over the past decade to evaluate transit-oriented developments, urban infill projects, and California's cap-and-trade legislation, among other topics (17; 19). To date, HIAs have been used mainly to inform large-scale community planning, land use, industrial, and policy decisions. However, the recommendations generated through the HIA process often bring to light previously unforeseen vulnerabilities, whether due to existing infrastructure, building technology, or socio-economic conditions.

Designers can make use of the HIA process and its resulting recommendations to prioritize design/retrofit interventions that will result in the largest co-benefits to building owners, the surrounding community, and the environment. An HIA focused on the health impacts of climate change will likely generate recommendations that could enhance the longevity of a building project's useful life; protect its property value by contributing to the resilience of the surrounding community; and result in design decisions that prioritize strategies that maximize both short-term efficiencies and long-term environmental, economic, and social value.

KEYWORDS

climate change, public health, vulnerability, adaptation, resilience, health impact assessment, evidence-based, adaptive reuse, policy, natural disasters, heat, flooding, sustainability, LEED, greenhouse gas emissions

HEALTH IMPACTS OF CLIMATE CHANGE

While climate change could be characterized as an environmental issue, the effects of climate change have already caused widespread economic, social, and political disruption both in the U.S. and internationally (1; 2).

Climate change is defined by the Intergovernmental Panel on Climate Change (IPCC) as "... change in climate over time, whether due to natural variability or as a result of human activity." (1) It is caused by the greenhouse gas effect, the tendency of the global ambient temperature to increase over time as the Earth's atmosphere traps solar radiation due to a buildup of certain types of gases—such as carbon dioxide (CO_2), Nitrous Oxide (N_2O), and Methane (CH_4). These gases, dubbed "greenhouse gases" or GHGs, absorb a portion of the infrared radiation reflected off of the Earth's surface and re-emit it back into the atmosphere rather than allowing it to pass out into outer space (1).

Scientific samplings show a marked increase in the levels of GHGs in the Earth's atmosphere over the past three hundred years, roughly correlating with the increased burning of fossil fuels that accompanied the Industrial Revolution (1). In spite of efforts at various levels of government and within private industry to reduce the human contribution to GHG emissions, scientific measurements have outpaced the most aggressive models developed by the IPCC since 2004 (20).

The health impacts of climate change can be divided into three categories: injuries and death resulting from direct exposure to climatic events, indirect exposures (such as waterborne disease resulting from increased exposure to harmful algal blooms as water bodies warm), and the health impacts associated with social and economic disruption (21). Due to the complexity of measuring the relative influence of a specific climatic event on the indirect health effects of climate change, the majority of research to date has focused on the health impacts of direct exposure to extreme weather events such as heat waves and flooding.

For example, the frequency and severity of heat waves have increased over the past fifty years and are projected to continue increasing as global ambient temperatures continue to rise (1; 2). The health effects of extreme heat are hyperthermia and increased severity of respiratory and cardiovascular illness (22). Precipitation patterns have also changed over the same time period, exacerbating the drought/flood cycle. Total precipitation has fallen during winter, spring, and summer, leading to widespread drought in many areas of the country. On the other end of the spectrum, heavy precipitation events have increased during the fall, leading to flooding, which can cause particular public health concerns in areas with combined storm water and sanitary sewers (13). Along the coast, land is lost each year due to hurricanes. For example, 85% of the above-water landmass on the Chandeleur Islands off the coast of New Orleans was lost during Hurricanes Rita and Katrina in 2005. Air quality has also deteriorated in many areas of the U.S. over the past fifty years. The increased number of ozone action days is linked in many cities to increased CO_2 emissions from cars and trucks. Studies have shown a positive correlation between increases in ground-level CO_2 levels and dramatic increases in pollen counts (2). The resulting combination of hotter summers, compromised air quality, and increased pollen counts has been shown to increase health risks for people suffering from chronic respiratory illnesses such as asthma (23).

Some populations, such as children, the elderly, and people with preexisting medical conditions are especially vulnerable to all of the health impacts of climate change disruption (12). However, in many cases, vulnerability is heavily influenced by the population's location (13; 24). Do they live and work in an area of town with particularly high surface temperature due to the urban heat island effect? Do they travel across low water crossings located in or near flood plains? Do they have access to transportation options in the event of disruption to the gasoline supply?

Socioeconomic factors also play a role in determining a population's vulnerability to the health impacts of climate change. For example, low-income residents may not have the ability to pay both the electricity bill and cover all of their other expenses. A study in California identified voluntary air conditioning rationing on the part of residents as the most significant avoidable cause of heat-related health impacts during heat waves (25). A study of the 1996 heat wave in Chicago found that neighborhoods with strong social cohesion experienced dramatically fewer deaths than neighborhoods with socially isolated populations (26).

THE HEALTH IMPACT ASSESSMENT (HIA) PROCESS

The current built environment in the U.S., including buildings and infrastructure, has been shown to be fragile in the face of the types of extreme weather events predicted to increase in frequency and/or severity due to climate change (13). Historically, the client has driven the extent to which the design for a typical development responds to its context. In many cases that response is strictly form-based—"fitting in" with the aesthetics of surrounding properties. Local planning and building code officials may also offer incentives to include additional amenities, such as public space or retail. However, assessments of the property's vulnerability to future climatic events are rarely performed for anything other than structural resistance to earthquakes, fire, flooding, and wind. The frequent result of extreme weather events, therefore, is widespread destruction and forced abandonment of urban areas, as was seen following Hurricane Katrina and the 2011 tsunami in Japan.

Tools such as HIAs offer an opportunity to proactively enhance the resilience of a building project to avoid the recurring damage to property, human health, and the economy attributed to the changing climate.

The U.S. Centers for Disease Control and Prevention identify the following steps in conducting an HIA (27):

1. Screening
2. Scoping
3. Assessing risks and benefits
4. Developing recommendations
5. Reporting
6. Evaluating

While most HIAs follow this six-step methodology, the level of rigor can range from a quick, desktop (or preliminary checklist) assessment to a more comprehensive assessment that relies on active stakeholder involvement and results in detailed data collection (28). HIAs have been used at the global, community, and local scales to weigh the relative co-benefits to health of leading mitigation and adaptation strategies. These assessments have focused mainly on sustainable urban design practices and the relative risks and benefits associated with switching to renewable energy sources. However, an HIA evaluating climate change resilience should be incorporated into every development project's due diligence process, whether resulting in a new building, an addition, a renovation, or a revision to the operations and maintenance program of an existing building.

By evaluating the possible environmental and associated health, social, and economic vulnerabilities of a project site and the surrounding community, the HIA's recommendations can contribute to increasing the longevity and property value of the building project. Furthermore, the HIA process will identify the major public health concerns in the neighborhood and region surrounding the site. While at first glance this may appear to lie outside of the scope of a traditional building project, enhancing resilience in the surrounding community will reduce the likelihood of social and economic disruption occurring around the building site in the aftermath of an event. HIAs also provide an evidence-base to guide community stewardship decisions.

The design and operations decisions resulting from the HIA may also lead to financial benefits to the building owner. For example, the evidence base supporting decisions to increase the building's and surrounding community's resilience to specific climatic events offers the opportunity to negotiate improved insurance rates and possible incentives from the authority having jurisdiction, such as: expedited plan review, increased rentable square footage, exemption from paying for connection to the storm sewer system, etc.

SCENARIOS: APPLYING HIA TO SPECIFIC BUILDING PROJECTS

HIAs show promise as a powerful design tool at the project scale, as demonstrated by the following hypothetical scenarios: a downtown office building renovation, an urban infill development, and a university campus sustainability plan. The following assessments were conducted using the desktop (or preliminary checklist) assessment approach to demonstrate that they can rely exclusively on existing data sets. They follow the methodology outlined in the online course "Planning for Healthy Places with Health Impact Assessments," which is available on the Internet at http://professional.captus.com/Planning/hia/. The course was developed by the American Planning Association and the National Association of County & City Health Officials with funding from the CDC.

While the scenarios outlined below are hypothetical, they have been based on actual locations to allow for real-life recommendation outputs and to simplify comparison between the project types. These scenarios were developed to support a presentation at the Gulf Coast Green 2011 conference in Houston, Texas. However, the data sources used to conduct the assessment are easily translatable to other locations.

Step 1: Screening

The purpose of the screening step is to clearly define the project or policy that will be assessed and verify that an HIA is feasible based on the project schedule and budget. Ideally, the HIA should be conducted during the visioning phase or early in the schematic design phase of the project so that its recommendations can be integrated into the project's underlying design approach.

The results of the screening process for each of the three scenarios is listed below:

Downtown Office Building: Renovation of a 500,000 sq. ft. office building in downtown Houston, which plans to pursue certification under the LEED 2009 for New Construction and Major Renovations rating system.

Urban Infill Development: Redevelopment of three acres spread over two blocks in a central Houston neighborhood. It will combine renovation of historic residences with construction of new, higher density residences. The project plans to pursue certification under the LEED 2009 for Neighborhood Development rating system.

Urban University: Campus sustainability policy at a small university in central Houston. The policies under assessment address capital projects, facilities management, transportation, student clubs such as the on-campus farmers' market, and class curriculum that incorporates sustainability principles.

Step 2: Scoping

The scoping step sets the parameters of the HIA. It also identifies the research methods it will follow, which health impacts will be addressed by the assessment, and what type of data will be collected.

Parameters Under Assessment:

The assessment analyzed both qualitative and quantitative impacts attributable to climate change over the short-term (i.e., 1–3 year payback period) and the long-term (i.e., 50–100 year horizon).

Downtown Office Building Parameters: The central business district and the neighborhoods (defined as census tracts) immediately surrounding it.

Urban Infill Development Parameters: The census tract where the development is located. Surrounding census tracts were used for comparison purposes.

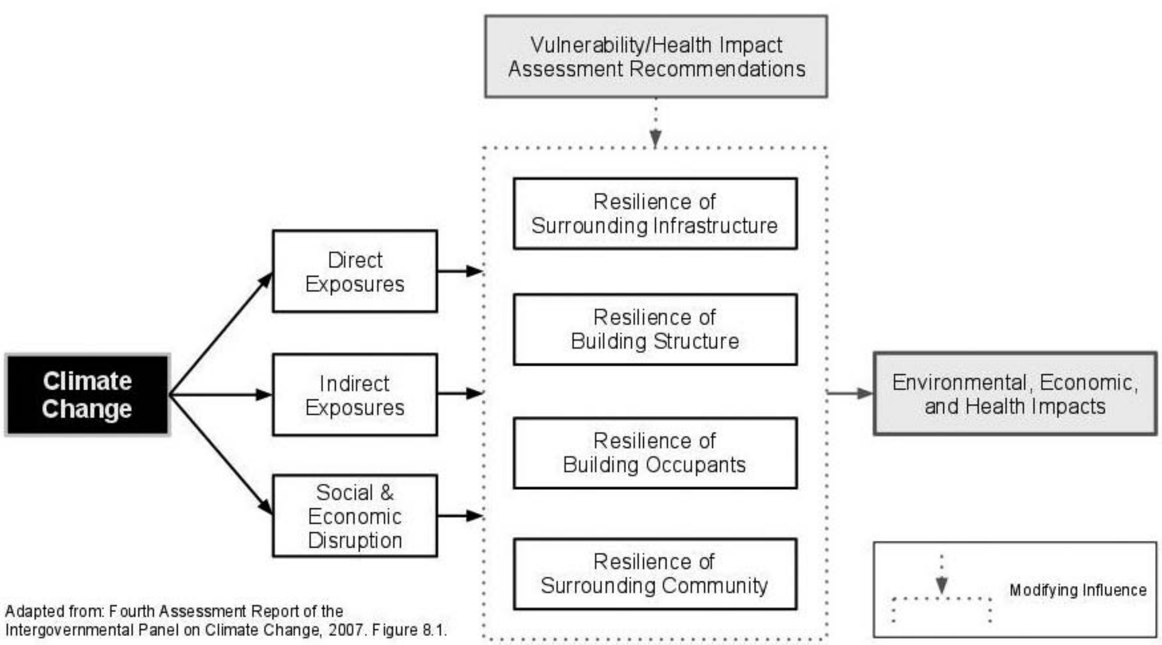
Urban University Parameters: The census tract where the university is located. Surrounding census tracts were used for comparison purposes.

Research Methods:

As a quick desktop HIA, research was confined to using visual evidence in online geospatial datasets and images as the basis for design recommendations. The conceptual diagram in Figure 1 provided a framework for answering the following questions:

1. How resilient is the surrounding infrastructure?
2. How resilient is the building structure?
3. How resilient are the building occupants?
4. How resilient is the surrounding community?

FIGURE 1. Conceptual Model for the Modifying Influence of Health Impact Assessment Recommendations on the Climate Change Resilience of Individual Development Projects (4).



Health Impacts:

Following the methodology outlined in Borden and Cutter (2008) (5), the HIA identified tornadoes, hurricanes, heat/drought, and lightning as the natural hazards with the highest direct health risks in the county where Houston is located: Harris County, Texas (Table 1).

Table 2 reviews the health effects, populations most vulnerable, and suggested adaptation measures suggested by the scientific literature to address these four natural hazards.

TABLE 1. Natural Hazards with the Highest Direct Health Risks in Harris County, TX, 1960–2009(6)

	Injuries	Mortality	TOTAL
Tornadoes	211	7	218
Hurricanes	102	9	111
Heat/Drought	10	89	99
Lightning	72	27	99

TABLE 2. Health Effects, Vulnerability, and Adaptation Measures Associated with Tornadoes, Extreme Weather, and Heat/Drought (7; 8)

	Health Effects	Vulnerable Populations	Adaptation Measures
Tornadoes	Head injuries from flying debris Soft tissue injuries Death	Middle latitudes of U.S. Heavily populated areas Elderly Mobile homes Motorists Language barriers	Early warning systems Architecture Engineering Planning Distributed, Resilient "smart power grid"
Extreme Weather (e.g., Flooding, Hurricanes, Lightning, Sea-Level Rise)	Injuries Drowning Water and soil salination Ecosystem and economic disruption Waterborne disease Mass population movement	Coastal, low-lying land Low Socio-economic status	Architecture Engineering Planning Early warning systems Hard and soft barriers (i.e., levees, restored wetlands, etc.) Abandonment
Extreme Heat	Heat stress Death	Elderly Athletes Socially Isolated Poor Respiratory Disease Cardiovascular Disease	Architecture Air conditioning Warning Systems Distributed, resilient "smart power grid" Community response
Drought	Food & water shortages Malnutrition Food-, water-, & vector-borne diseases	Low socio-economic status Elderly Children Swimmers Outdoor workers Outdoor recreation No a/c, window screens	Enhanced food/ water delivery Trade negotiations Public education Watershed management Water treatment Vector control Vaccination/medical care

Adapted from: Frumkin et al. Climate Change: The Public Health Response. *American Journal of Public Health,* 2008. 98(3):435–445. Greenough et. al. The Potential Impacts of Climate Variability and Change on Health Impacts of Extreme Weather Events in the United States. *Environmental Health Perspectives,* 2001. 109(suppl 2): 191–198.

Data Sources:

Data was gathered from publicly available, open-source locations.

Step 3: Assessment

This step, outlined in Tables 3–6, is the core of the HIA. Figures 2–5 illustrate the spatial nature of several elements of the assessment.

TABLE 3. How Resilient Is the Surrounding Infrastructure?

	Downtown Office Building	Urban Infill Development	Urban University
OVERALL	**Neutral**	**Good**	**Neutral**
Roads/Transit	Good. • Strong sidewalk infrastructure. • Pedestrian-friendly sized blocks. • Bayou poses the only real threat for trapping occupants in the development during and after an event. • Access to numerous forms of transportation: bus lines, Metrorail, bike lanes, hike and bike trail along bayou, and sidewalks. • Freeway can be both an asset and a liability depending on the type and scope of disaster.	Good. • Strong sidewalk infrastructure. • Pedestrian-friendly sized blocks. • Access to numerous forms of transportation: bus lines, Metrorail, bike lanes, and sidewalks. • Freeway can be both an asset and a liability depending on the type and scope of disaster.	Good. • Strong sidewalk infrastructure. • Pedestrian-friendly sized blocks. • Access to numerous forms of transportation: bus lines, Metrorail, bike lanes, hike and bike trail around the campus, and sidewalks.
Floodplain	Poor. • Part of the Central Business District is located in the 100- and/ or 500-year floodplain.	Good. • Not near a floodplain.	Poor. • The entire campus is located in the 500-year floodplain. • Roughly 50% of the campus is located in the 100-year floodplain.
Urban Heat Island	**Poor.** • High percentage of impervious surface.	**Good.** • Substantial tree canopy, except for along the freeways surrounding the neighborhood on two sides.	**Good.** • Substantial tree canopy, although Hurricane Ike reduced it by 30%.

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TABLE 3. *(continued)*

	Downtown Office Building	Urban Infill Development	Urban University
OVERALL	**Neutral**	**Good**	**Neutral**
Stormwater Mitigation	Poor. • Central business district relies almost exclusively on a structural stormwater mitigation system. However, on the positive side, the stormwater sewer is not connected to the sanitary sewer. • High percentage of impervious surface. Vegetation along the bayou will help speed infiltration until the soil is saturated. • Part of the Central Business District is located in the 100- and/or 500-year floodplain.	Neutral. • Increased pervious surface benefits stormwater mitigation efforts. • The condition of the storm sewer is unknown.	Poor. • Even with the large quantity of pervious surface, the location of the campus in a floodplain puts its structures at risk of flood damage. • Furthermore, it is located next to a highly built up area with very low pervious surface. The pervious open space on the university campus is therefore likely to receive stormwater from adjacent properties in addition to the stormwater generated on site.
Water, Electricity, Telephone, Cable	Poor. • Central distribution of utilities. This condition may affect people working or living on higher floors more than lower floors, because they may find it difficult to exit the building if the electricity is disconnected. • The downtown Houston district cooling system is currently supplied via the central energy grid. If it were converted to on-site electrical generation via natural gas or hydrogen fuel cells, it could become less vulnerable to a power outage from the main electrical grid.	Poor. • Central distribution of utilities.	Good. • Central distribution of utilities. However, on-site water well and electrical generators available to supplement city utilities if needed.

TABLE 4. How Resilient Is the Building Structure?

	Downtown Office Building	**Urban Infill Development**	**Urban University**
OVERALL	**Neutral.**	**Good.**	**Good.**
Structural Integrity	Good. • Withstood Hurricane Ike (2008) without major structural damage.	Good. • Wood stud construction on pier and beam foundations that is typical for the neighborhood provides redundancy and the ability to flex in hurricane-force winds. • The scale and low-tech nature of the construction also makes it easier to repair any damage.	Good. • Most buildings on campus withstood Hurricane Ike (2008) without major structural damage.
Passive Survivability*	Poor. • No operable windows. • The air conditioning is in working order, but on-site energy production is not available to keep it running in the event of an extended power outage. • No on-site water storage.	Good. • Operable windows with screens. • Pier and beam construction allows air to flow under the buildings, contributing to cooling during the summer. • Trees shade the buildings in summer. • One- and two-story construction facilitates evacuation prior to or during events. • No on-site water storage.	Good. • Operable windows in some buildings, but mostly not including screens. • Trees shade the buildings in summer. • One- and two-story construction facilitates evacuation prior to or during events. • On-site water well and electrical generators available to supplement city utilities if needed. • Locations for on-campus shelters have been identified to accommodate students living off-campus during an extreme event.
Resistance to Flooding Damage (i.e., mold)	Poor. • Water has entered the building in the past when hurricane-force winds blew out the windows. • Downtown Houston Tunnel system and underground parking act as on-site retention cisterns for stormwater and should help prevent flooding of upper floors.	Good. • Not in a flood plain. • Pier and beam construction raises the building off the ground, reducing the likelihood of flooding. • As long as the renovations do not trap moisture inside of the walls, renovated historic structures (particularly structures constructed prior to 1945) are less likely to harbor mold due to their construction, unless they are flooded for a considerable period of time.	Good. • Even though the entire campus is located in a floodplain, the current amount of pervious open space appears to be sufficient to minimize long-term flooding damage. • Most buildings are not raised to a safe level above the ground, so flooding problems may increase as the campus continues to be built up.

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TABLE 4. *(continued)*

	Downtown Office Building	Urban Infill Development	Urban University
OVERALL	**Neutral.**	**Good.**	**Good.**
Access to stairs	Neutral. • The building contains fire stairs. However, they are not easily accessible, and therefore are not necessarily occupants' first choice for vertical transportation.	N/A	Good. • Most multi-story buildings have ready access to stairs.

*Passive Survivability refers to ability of occupants to survive in the building for a period of time after the building systems have been shut off or disrupted due to a utility outage.

TABLE 5. How Resilient Are the Building Occupants?

	Downtown Office Building	Urban Infill Development	Urban University
OVERALL	**Good.**	**See data below on the surrounding community.**	**Good.**
Population (9; 10)	Good. • Most concentrated worker population in the city. representing 21% of total regional office space.		Good. • 8,000 students, faculty, and staff. • Generally young, healthy demographic.
Race/ Ethnicity (12)	No information		Good. • Roughly 50% of all students are Caucasian. • Roughly 20% of undergraduates are Asian; 10% are Hispanic; and, 7% are African-American.
Income Level (10)	Good. • Above average, according to the industries located in the area: energy, legal, accounting, finance, banking, transportation, design & engineering, medical, business services.		Good. • Over 70% of undergraduates receive financial aid, half of which is need-based.
Access to Transportation (11)	Good. • Easy access to multiple bus routes, the light rail line, sidewalks, and bike paths, in addition to multiple surface and structured parking options.		Good. • Easy access to multiple bus routes, the light rail line, sidewalks, and bike paths, in addition to multiple surface and structured parking options.

TABLE 6. How Resilient Is the Surrounding Community?

	Downtown Office Building	Urban Infill Development	Urban University
OVERALL	**Poor.**	**Poor.**	**Good.**
Population (10; 12; 13)	Poor—marked difference between the population inside the office building under review and the surrounding residents. • 3,086 residents in census tract. • Only 2% of downtown workers walk to work. • The central business district is also an arts and entertainment destination.	Neutral. • 2,373 residents in census tract. • More affluent, predominantly Caucasian neighborhoods west of the neighborhood reach 6,000 in population density. However, they also do not have the range of commercial and residential establishments that are located in the Third Ward.	Good. • Strong sense of community builds the resilience of the overall community during a natural disaster, as evidenced during Hurricane Ike. • The small size of the university population also facilitates implementation of the emergency response plan.
Race/Ethnicity (12; 14)	Poor-marked difference between the population inside the office building under review and the surrounding residents. • Residents are relatively equally representative of racial and ethnic groups: Non-Hispanic Caucasian, Non-Hispanic African-American, Hispanic, and Asian. However, there is a strong concentration of Non-Hispanic African-Americans and Hispanics in the far northeast quadrant of the downtown core, a strong concentration of Non-Hispanic Caucasian populations immediately west of the area, and two pockets almost exclusively comprised of Hispanic populations east and north of the area.	Poor-Minorities have been identified by the scientific literature as generally more vulnerable to climate change. • 71% African-American • 27% Non-Black Hispanic	Good. • 75% or more of residents in the surrounding census tracts are Non-Hispanic Caucasian.

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TABLE 6. *(continued)*

	Downtown Office Building	Urban Infill Development	Urban University
OVERALL	**Poor.**	**Poor.**	**Good.**
Income Level (12; 14).	Poor-poverty buffer between households east and west of the area. • 36% of Downtown Houston residents earn less than $30,000 annually, whereas the neighborhood immediately east of the central downtown district reports 50% of households in that income range. The area west of downtown reports less than 20% of households earning under $30,000 annually.	Poor. • 64% of households earn less than $30,000 annually.	Good. • Less than 25% of the households in census tracts surrounding the campus earn less than $30,000 per year. This percentage is likely higher than reality, because many of the households reporting less than $30,000 income may be students living off-campus.
Mixture of Business and Residential (13)	Poor. • Much higher density of businesses in comparison with residential.	Neutral. • Largely residential. However, a number of businesses are within a five to ten block radius. • A park, several schools, and a hospital are also located within five blocks of the development.	Neutral. • Largely residential. However, a number of businesses are within a five to ten block radius. • A park, several schools, and a medical campus are also located within five blocks of the development.
Access to Grocery Stores (15)	Good. • A Google map search of grocery stores shows an adequate density access to food sources from the downtown core, should the building occupants find themselves trapped in the neighborhood for an extended period. There are also numerous restaurants throughout the area at an average density of several per block.	Good. • A Google map search of grocery stores shows an adequate density access to food sources within a five to ten block radius. • Two community gardens are also within walking distance of the site.	Neutral. • No grocery store within walking distance. • However, a number of small delis and restaurants are within easy access of the campus.

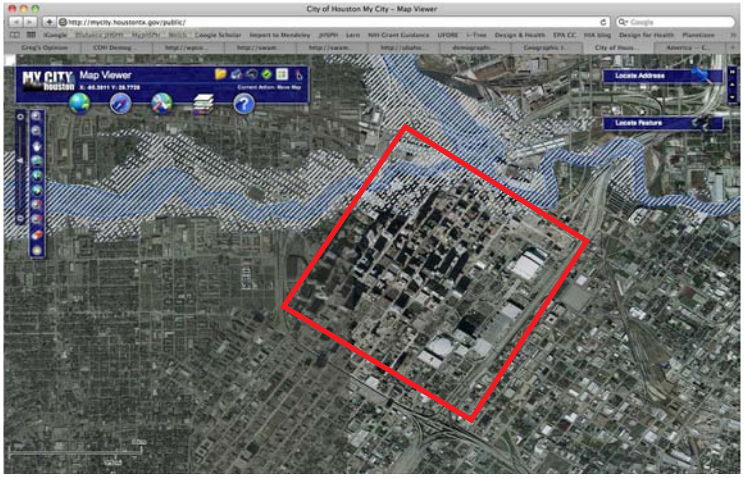


FIGURE 2. Satellite Image of Downtown Houston: 100- and 500-Year Floodplain.

Source: My City Houston Map Viewer, available at: http://mycity.houstontx.gov/public/.

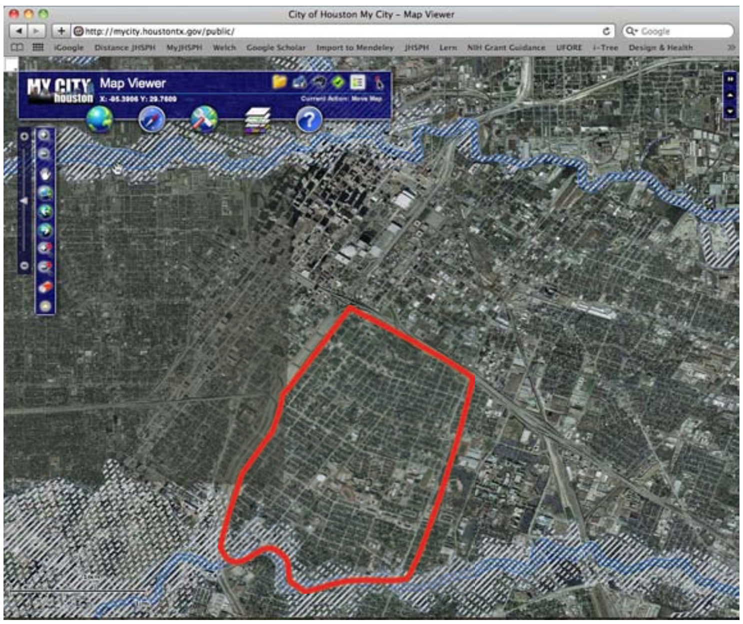


FIGURE 3. Satellite Image of Urban Infill Neighborhood: 100- and 500-Year Floodplain.

Source: My City Houston Map Viewer, available at: http://mycity.houstontx.gov/public/.

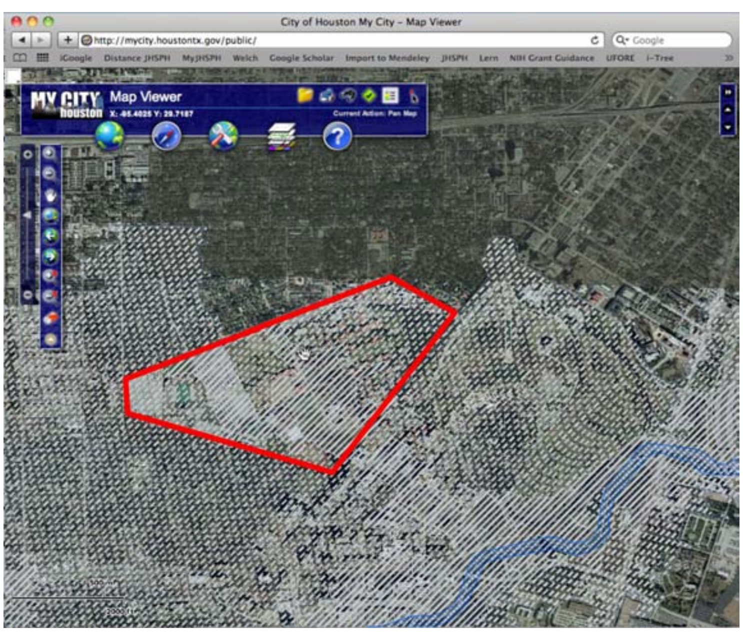


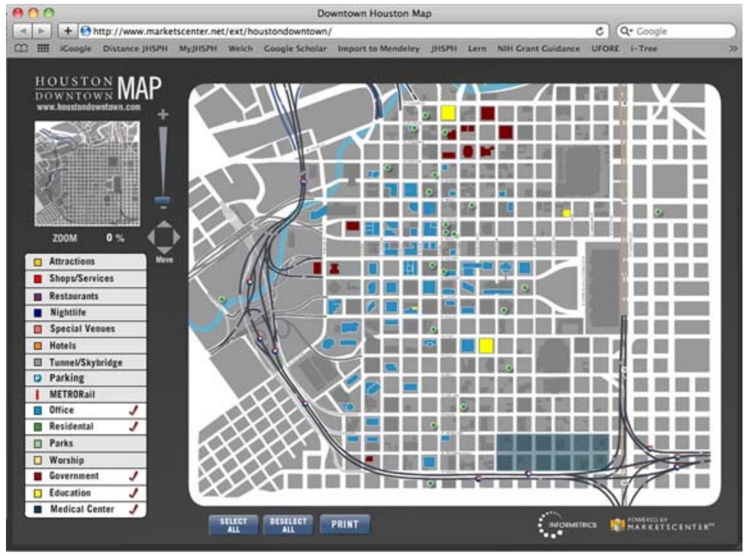
FIGURE 4. Satellite Image of Urban University Campus: 100- and 500-Year Floodplain.

Source: My City Houston Map Viewer, available at: http://mycity.houstontx.gov/public/.

FIGURE 5. Downtown Houston: Mixture of Business v. Residential Buildings.

Note: Residential buildings are identified with circles. Businesses (e.g., office, government, education, medical) are identified with shaded building footprints.

Source: www.houstondowntown.com



Step 4: Recommendations

While many of the measures in the assessment address emergency preparedness, the HIA's recommendations should stress that the circumstances under review—namely, hurricane- or tornado-force winds, flooding, extreme heat, drought, and disruptions in utilities and transportation—are likely to become the region's "new normal" within 50 to 100 years as a result of the changing climate. All recommendations should therefore evaluate the relative risks and benefits to both climate change adaptation and mitigation. A complete HIA would also identify the co-benefits and co-harms associated with each recommendation, drawing from the scientific literature. However, due to space constraints, this article has not performed that additional activity.

Table 7 identifies which recommendations cut across one, two, or all three hypothetical scenarios under consideration by this article. It also calls out synergies between the HIA recommendations and GHG emissions reduction programs, on the one hand, and green building programs, on the other hand, to compare the relative risks and benefits of each recommendation in relation to common approaches to climate change mitigation. Because most green building programs in the U.S. address GHG emissions reduction, the "Green Building Program" column assumes that all of the strategies listed in the "GHG Emissions Program" column apply to green building programs as well. The "Green Building Program" column, therefore, focuses exclusively on additional synergies not already covered by the "GHG Emissions Program" column.

Key findings for each scenario include:

Downtown Office Building: The height of the building and the density of its surroundings reduce opportunities for a renovation project to use "soft" changes to the infrastructure (such as increasing pervious surface and shading) to increase resilience to heat waves, flooding, and hurricane-force winds. Instead, the project should focus on increasing the passive survivability of the building occupants and the surrounding community. For example, the lower floors of the building should be retrofitted with operable windows to support habitation in the event of a long-term power outage. The renovation should also install on-site renewable energy production and water capture and storage facilities that are

TABLE 7. HIA Recommendations and Synergies with GHG and Green Building Programs

Abbreviations: DOB: Downtown Office Building Scenario; UID: Urban Infill Development Scenario; UU: Urban University Scenario

Recommendations	DOB	UID	UU	GHG Emissions Program	Green Building Program
INFRASTRUCTURE					
1. Analyze how much water can be funneled to underground areas such as parking garages or the downtown Tunnel to avoid flooding inhabited floors.	X		X	Use water as a heat exchanger.	Install underground water cisterns with filtration devices that will allow water reuse, either as irrigation or to flush toilets.
2. Consider converting the district cooling system into a source of distributed energy production.	X		X	Consider using renewable technologies such as fuel cells rather than diesel or another fossil fuel. Convert the system into a cogeneration unit to maximize energy efficiency.	
3. Consider collecting water on-site to provide minimal water utilities in the event of a disruption.	X	X	X	Reuse water on-site as part of normal operations.	Contributes to stormwater mitigation.
4. Consider working with the city health department to test the filtration level of on-site water collection so that the development is authorized to use the water as drinking water in the event of an emergency.	X		X	Reuse water on-site as part of normal operations.	Contributes to stormwater mitigation.
5. Consider working with the city health department to pilot an on-site wastewater treatment system that would clean water enough to reuse it for irrigation.			X	Reuse water on-site as part of normal operations.	Contributes to stormwater mitigation.
6. Assess access to alternative forms of transportation. Understand and remove the barriers to using them.	X	X	X	Reduce occupant commuting using single-occupancy vehicles.	Provide access to hike and bike trails and other infrastructure supporting active living.
BUILDING					
1. Analyze structure for resilience to multiple tornadoes and hurricanes and upgrade if necessary.	X	X	X	Recycle all construction waste.	
2. Consider upgrading windows to withstand torque in the structure and other effects of high winds. For housing, build storm shutters and train residents on how to install them.	X	X	X	Install energy-saving window systems.	

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TABLE 7. *(continued)*

Recommendations	DOB	UID	UU	GHG Emissions Program	Green Building Program
BUILDING					
3. Store basic construction supplies on-site and train residents on how to make emergency structural repairs.		X			Collaborate with the local salvaged materials warehouse to provide storage and/or to deconstruct buildings and reuse the recovered materials after an event.
4. Analyze the overall building design and upgrade it to take advantage of natural cooling and heating.		X	X		Improved access to ventilation. Increased occupant control of thermal comfort.
5. Build structures raised high enough above the ground to comply with the flood risk elevation set by FEMA.		X			Avoid constructing in a flood plain. Mitigate the urban heat island effect by incorporating parking under the building.
6. Install materials that resist mold growth on lower floors that might be flooded.	X		X	Install local materials. Install materials that do not require energy-intensive cleaning.	Enhance indoor environmental quality. Green cleaning.
7. Move all mechanical systems to the upper floors (but not roof).	X	X	X	Insulate the area where the mechanical system is housed. Install closed-loop mechanical systems. Run them off of on-site non-potable water sources, such as AHU cooling coils.	Address the acoustical concerns associated with mechanical system noise and vibration.
8. Install a reflective or vegetated roof to mitigate the urban heat island effect.	X	X	X	Increases the insulating value of the roof.	Contributes to stormwater mitigation. Depending on the height of the building and the size of the roof, consider using the roof to grow food crops.
9. Design plantings and exterior hardscape to act as rain gardens, capturing and filtering water before it leaves the site.	X	X	X		Restore native habitat. Provide access to hike and bike trails and other infrastructure supporting active living.
10. Maximize pervious surfaces (including vegetated roofs) and on-site rainwater collection.		X	X	Reuse water on-site.	Contributes to stormwater mitigation.
11. Operable windows with screens—at least in some areas of every floor. Ceiling fans, where applicable.	X	X	X	Integrate natural ventilation mode (or economy cycle) into mechanical system design.	Improves access to ventilation. Increases occupant control of thermal comfort.

TABLE 7. *(continued)*

Recommendations	DOB	UID	UU	GHG Emissions Program	Green Building Program
BUILDING					
12. Design vegetation to provide shading, but minimizing the likelihood of causing roof damage.		X	X	Coordinate with envelope and roof design to maximize insulating properties.	Restore native habitat. Provide visual and actual access to outdoor natural areas.
13. Consider installing PV, wind power, or another on-site renewable power source to provide minimal utilities in certain areas of the building (lobby at a minimum) during extended power outages.	X		X	Reduces reliance on electricity derived from fossil fuels.	
14. Verify that stairs are accessible and passively ventilated.	X		X	Establish an active living campaign to encourage occupants to use the stairs as a way to reduce energy use.	Restore native habitat. Provide visual and actual access to outdoor natural areas.
BUILDING OCCUPANTS					
1. Develop an emergency management plan, both for building evacuation and for passive survivability.	X	X	X	Integrate into occupant alternative transportation program and community garden/ farmers' market.	
2. Broadcast early warning information to all building occupants.	X	X	X		
3. Educate occupants about the neighborhood emergency management plan and how to help the surrounding community during a longer-term event.	X	X	X		
4. If designing the building to accommodate natural ventilation, establish a seasonal dress code and seasonal work hours to accommodate temperature fluctuations.	X		X	Integrate natural ventilation mode (or economy cycle) into mechanical system design.	Improves access to ventilation. Increases occupant control of thermal comfort.
5. Establish a weekly farmers' market and/or community garden on-site.	X	X	X	Reduce the food miles associated with the food consumed on-site. Compost organic waste generated on-site.	Restore native habitat. Provide visual and actual access to outdoor natural areas. Encourage active living.

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TABLE 7. *(continued)*

Recommendations	DOB	UID	UU	GHG Emissions Program	Green Building Program
SURROUNDING COMMUNITY					
1. Collaborate with occupants and the surrounding community to identify ways to improve the resilience of the entire neighborhood—through tree planting, gully clearing, installing distributed energy and water systems, building a community garden, improving access to alternative forms of transportation, etc.	X	X	X	Identify ways to reduce energy and water use and single-occupancy vehicle miles travelled.	Restore native habitat. Provide visual and actual access to outdoor natural areas. Encourage active living.
2. Develop and educate occupants and the surrounding community about the neighborhood emergency management plan, relating to both evacuation and passive survivability.	X	X	X		Community education about green building.
3. Establish a buddy system to help the socially isolated and individuals with limited mobility during events.	X	X	X		
4. Turn a building lobby/ community center/ etc. into a cooling center in the event of a heat wave.	X	X	X	On campuses, consider rotating building closures and staff telecommuting schedules to reduce overall campus energy usage.	
5. Coordinate with nearby restaurants, grocery stores, and the local Office of Emergency Management and Red Cross to develop a shelter plan.	X	X	X		

connected to the lower floors of the building. The project could increase the resilience of the surrounding community by working with the local office of emergency management, Red Cross, and public health department to establish the building lobby as a cooling center and shelter in the event of an adverse weather event.

Urban Infill Development: As a moderate-density residential development surrounded by a vulnerable population (e.g., minority and low income), this project should focus on making use of available vegetated open space to build the resilience of both the building structures and the neighborhood's economy and access to healthy food. The project team should work with the surrounding community and forensic architects and engineers to identify what aspects of the historic structures in the neighborhood have withstood hurricane-force winds and have been most successful at providing passive thermal comfort when the utilities are disrupted. The project team should consider using the upgrades to historic buildings on-site to train local residents on how to upgrade their own houses, as well. In particular, they should attempt to achieve a "net zero energy" level of energy efficiency on both renovated and new construction. They should also consider pursuing a bulk purchasing contract or a third-party renewable power purchasing agreement with a renewable energy manufacturer to benefit the entire neighborhood. Landscaping should be designed to increase access to shade, reduce the risk of flooding, capture and store rainwater, and maximize the production of edible plants on-site.

Urban University: The location of the campus in a floodplain should be addressed in its construction master plan. As the percentage of impervious surfaces both on-site and in the business corridor adjacent to the site increases, the campus's vulnerability to flooding will increase. The campus should therefore consider ways to maintain its current percentage of pervious surface (or increase it) as capital projects move forward through the installation of vegetated roofs and similar strategies. While the campus has instituted a strong emergency management plan that has successfully protected human life during the past few natural disasters, it has not been integrated with the campus sustainability plan. The HIA provides an opportunity to assess how the two plans could be better coordinated to minimize property damage and continue to improve the campus's resilience. It could also highlight opportunities for the campus to provide assistance to the surrounding community during disasters, rather than focusing exclusively on its student population.

Step 5: Report

After completing the assessment and developing recommendations, the results of the HIA should be compiled into a clear and concise report and presented to relevant decision-making bodies. Ideally the report would be completed prior to the project's first sustainability charrette, so that its recommendations could be integrated into the project team's fundamental design approach.

In order to validate the HIA's credibility as a tool for making evidence-based decisions, all assessment data and recommendations should be fully referenced to supporting scientific literature. However, the bulk of the report should focus on linking the risks and benefits associated with the HIA's recommendations with the project's primary system for evaluation. For the purposes of this article, the Downtown Office Building and the Urban Infill Development scenarios would likely reference a combination of the owner's project requirements and the applicable LEED rating system. The Urban University, on the other hand, would likely reference the campus sustainability plan.

Step 6: Evaluate

The goal of the report is to present the results of the assessment using language and graphics that are accessible to decision makers and support the decision making process. As such, each recommendation should be accompanied by an explanation of how it could be integrated into the project's primary system for evaluation. For example, LEED credits demonstrating strong synergies with HIA recommendations could be prioritized on the LEED checklist. Likewise, projects pursuing the Architecture 2030 Challenge or the American College and University Presidents Climate Commitment could use the HIA to prioritize design and policy decisions that both reduce GHG emissions and build the resiliency of the development and the surrounding community to the environmental, economic, and health impacts of climate change.

CONCLUSION

The design, construction, planning, and facility operations professions can and should be leaders in both approaches to addressing the changing climate: mitigation efforts (e.g., reducing GHG emissions) and adaptation efforts (e.g., building the resilience of our communities). Climate change adaptation has already been implicitly included in a number of green building and planning tools and regulations. And, it is increasingly called out directly in local and state climate action plans. Tools such as HIAs respond to these new expectations by providing an evidence-base for making specific design and policy decisions that will maximize synergies and result in a well-rounded solution. Green building leaders should therefore proactively coordinate their environmental efforts with public health professionals and climate scientists to ensure that their designs address the long-term environmental and public health impacts of climate change specific to the site's region.

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