6 Directions for Future Research

6.1 TRANSFORMING THE SINGLE-FAMILY RESIDENTIAL UNIT

Single-family residential units make up the largest percentage of residential housing units in the United States. Thus, redesigning private homes to make them adaptable for life in 2050 and beyond requires a concerted and collaborative effort in which housing policy specialists and affordable housing advocates must consciously work with urban planners, architects, landscape architects, interior designers, engineers, and the building trades.

Architects, interior designers, and home builders often use the claim that they deliver *what the market wants*. One of these adaptations relates to the size of a single-family unit. According to data analyzed by the National Association of Home Builders, the average single-family unit was about 2,200 square feet in 1999 and that number has gradually increased to about 2,500 square feet in 2022. The recent pandemic experiences of 2020–2022 have prompted homeowners to seek out more open spaces and natural light/ventilation within and around their residential units, expanding the footprint of the house. Privileged individuals and their families relocated from urban to rural or semi-rural areas and these series of individual location-choice decisions prompted additional housing challenges, both in areas that lost residents and in the areas that gained them. The pandemic also prompted a re-thinking about the nature of paid work; as people worked at/from home, they discovered challenges ranging from the aesthetic to the practical need for auditory and visual privacy. They also sought safe recreational opportunities at or close to their place of residence. Yet, creating a backyard swimming pool or other kinds of play spaces for every single-family residential unit is neither feasible nor desirable from the perspective of climate change impacts – one of the three challenges identified at the beginning of this volume. In sum, housing policy professionals and housing advocates should be prepared for changes in the workplace that now include remote work and hybrid work arrangements that will directly impact housing preferences such as housing size and housing location and support services (Adikesavan and Ramasubramanian, in review, 2023).

Presently, housing activists are appropriately focused on tackling challenges of increasing residential density, which requires (i) building new housing, focusing on the alternatives to single-family houses on large lots, (ii) retrofitting existing housing to accommodate additional residential living units, (iii) changing zoning laws and local regulations to allow for different types of housing typologies in residential areas, and (iv) creating live-work spaces by blurring/weakening the rigid adherence to single-use zoning. However, housing activists and housing policy experts appear to disregard the cultural ethos that is deeply opposed to densification of the residential landscape. While we agree that all but the most rural counties in the United States should consider facilitating an increase in residential densities, we do not believe that

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a singular focus on increasing residential density by outlawing single-family zoning will find favor with a majority of the American public.

Shaping public opinion in favor of higher densities requires housing policy professionals and urban planners to partner more closely with architects, landscape architects, and urban designers to create commodious interior spaces within a smaller footprint and create dense living environments that are visually appealing and are scaled to conform to the existing character of residential neighborhoods. We advocate for a deeper commitment to retrofitting and adapting the nation's older housing stock because the design of a typical single-family housing unit is not conducive for our nation's elderly to successfully age in place. Figure 6.1 (US Census, n.d.; NHGIS, n.d.) visualizes the spatial concentration of older homes, considering all residential living units, clustered in a large swatch of the Midwest and the Northeast. These areas are also highly correlated with the location of aging populations.

While the size of the total American population tripled since 1900, the population group aged over 65 years increased 11 times (Rivera-Hernandez et al., 2015). The retrofitting of single-family housing units to accommodate the day-to-day living needs of older adults is a national imperative, if we want to preserve the fabric of our neighborhoods. In other words, although the design/redesign/retrofit of the home may be perceived as the exclusive domain of architects and interior designers, the strong interconnectedness of housing with neighborhood level quality of life makes this issue relevant for housing reform advocates and urban planners. Research suggests that older people are happier living in their own home and that relocation to long term care facilities often reduces the quality of life (e.g., Cohen and Weisman, 1991; Wiles, et al., 2012). Yet older adults put off making much needed modifications and adaptations to making their homes safer for them (such as ramps, wider doorways, lower kitchen counters, etc.) because of social stigmatization around aging and being perceived as vulnerable (Bailey *et al*., 2019).

In this context, housing policy analysts and housing advocates could encourage the retrofitting and ways to improve the quality of the housing within Naturally Occurring Retirement Communities (NORCs). NORCs have been identified as such since the 1970s (Hunt, 1998), first in New York and then with varying definitions in many states and at the federal level. Regardless of the specific numerical constraints (percentage of population, minimum number of seniors, and age threshold), the term "natural" is crucial because it (i) indicates that it is not a planned development (as in nursing homes, or purpose-built senior residence communities), (ii) the seniors involved have been living in those areas since before growing old, and (iii) in consequence of (i) and (ii) a NORC is ephemeral and will cease to be a NORC as its inhabitants cease to exist. NORCs can be located in aging suburbs, where individuals have aged in place, remaining in their homes after children left, or in newer suburbs as a result of migration among immigrant communities (especially Asian), where established and well-settled older children bring their parents from their home countries to live with them (Albrecht, 2007). The fleeting nature of NORCs can be problematic from a policy perspective because investments that attempt to address the special needs of such communities tend to experience a temporal lag. Bluntly put, during the time that elapses between the identification of a NORC, the allocation of special purpose funds (improving building infrastructure, specialized transportation services, etc.) and their implementation, many NORC residents may die without benefitting from such services, while the services/interventions will remain beyond the

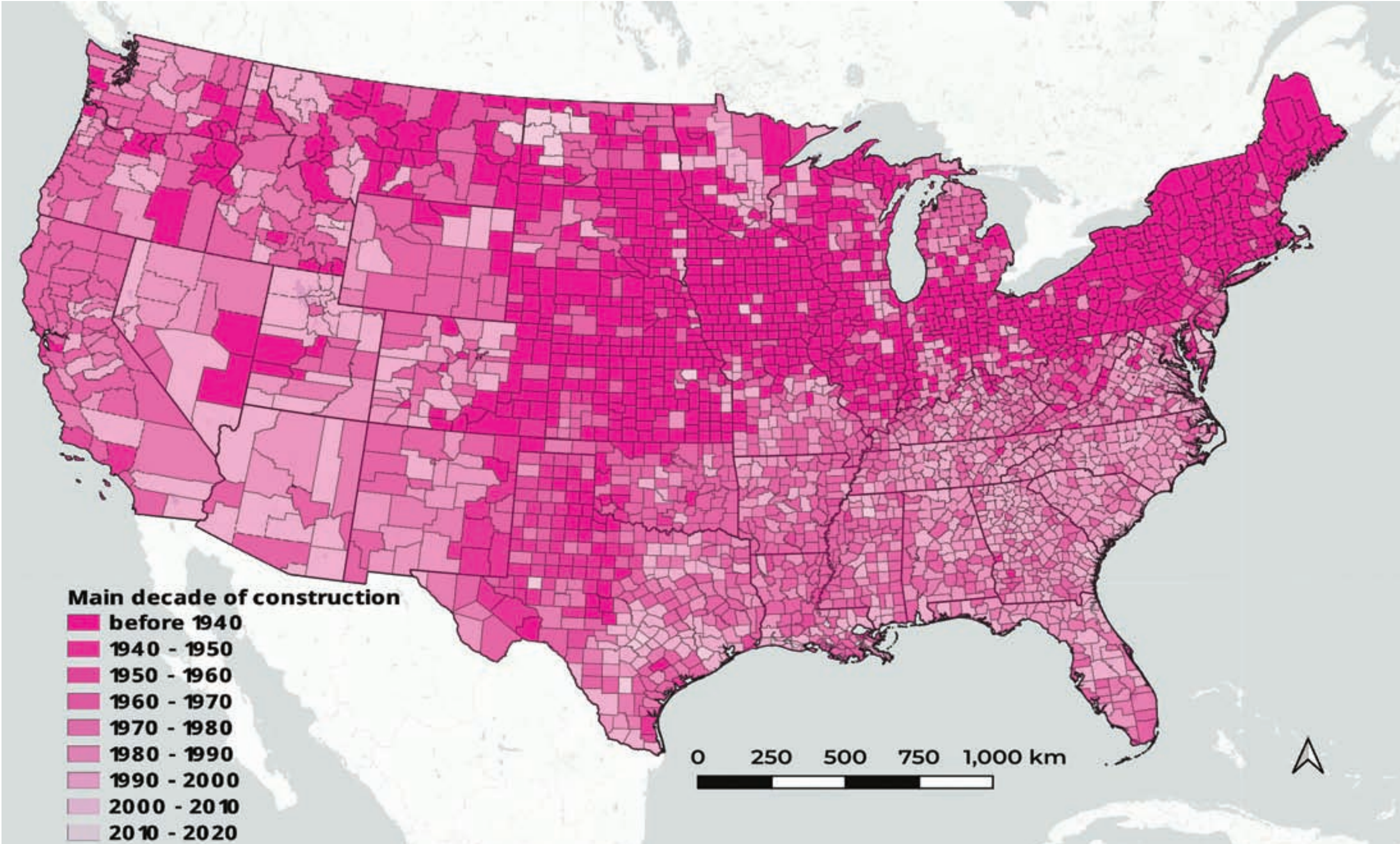

FIGURE 6.1 Building age – main decade when homes were constructed by county

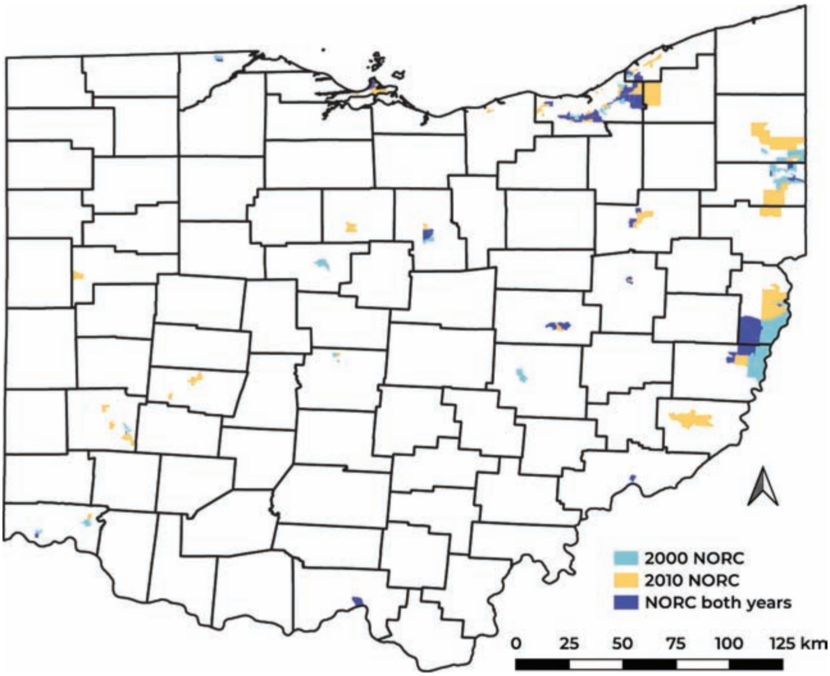

FIGURE 6.2 NORC map of Ohio

cresting of the wave of local aging. However, considering that the American population is graying rapidly, investing in NORCs can encourage the creation of a great proportion of housing stock that includes the design and modifications to accommodate a wider range of aging adults by focusing on active aging (Scharlach, 2012).

The GIS implementation to identify NORCs is fairly straightforward. The US Census Bureau provides us with all the necessary data at the Census tract level. Depending on the age threshold chosen, we can calculate the percentage of those beyond that threshold as a percentage of the whole population of the respective tract. If that percentage is higher than the local or state regulations specify, we then have to check whether this is caused by the presence of nursing homes or other artificial distractors and subtract those residents from the calculated percentage. Alternatively, we could select the Census question "have you lived at this location ten years ago?" to determine whether the concentration is natural, see Figure 6.2 (ACS, 2010).

In terms of addressing the costs of owning and retrofitting single-family homes, architects and planners would do well to consider energy efficiency. The average age of a single-family home in New York is 60 years, while even in the state with the newest housing stock, Nevada, the average age is 23 years (NAHB, 2021), de facto assuring that the far majority of these homes are not particularly energy efficient. Depending on the materials used in the original construction, older homes cost more than modern homes to heat/cool. According to 2015 data provided by the *US Energy Information Administration*, single-family detached homes used 54% of their total energy consumption on space heating and air-conditioning while apartments with five or more units used only 32% for the same purposes. One way to increase energy efficiencies is for households to invest in

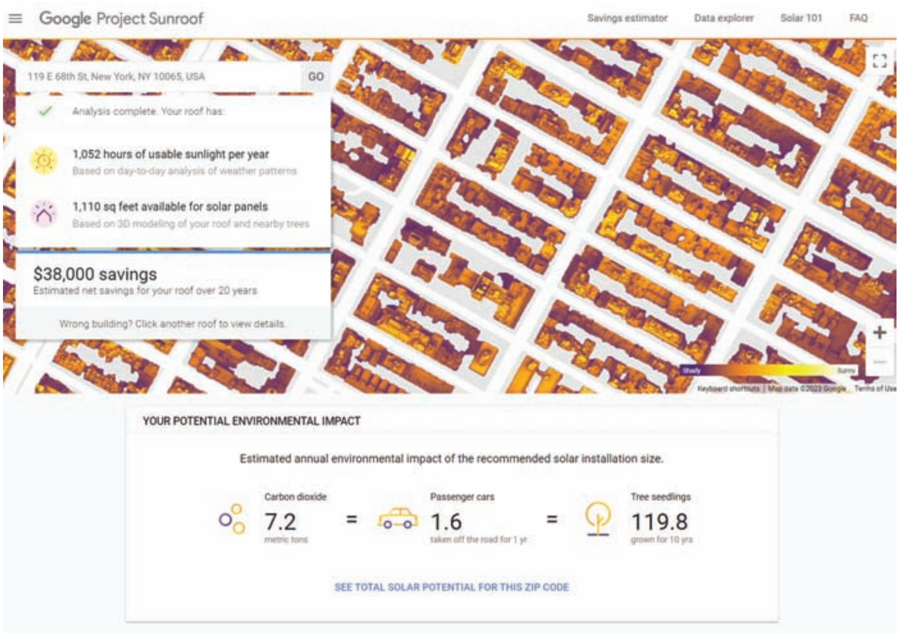

FIGURE 6.3 Solar map of New York City

rooftop solar panels to reduce their draw on the power grid. GIS is an ideal instrument to calculate the solar potential of rooftop photovoltaic (PV) cells. The input data consists of aerial imagery and geophysical solar insolation measurements. The imagery is the basis for the calculation of the sizes and angles of roofs as well as the identification of any shading objects (trees and neighboring higher buildings). The combination of roof angle and insolation provides the amount of energy per area unit available. Given some stock measures of PV efficiency, the size of each roof, and the price for both the solar cells as well as local electricity rates, it is then straightforward to calculate the amortization time for each potential installation. Numerous states have released web maps that provide building owners with property-specific calculations (see, for example, https://nysolarmap.com/ or https://sunroof.withgoogle.com/), see Figure 6.3.

We have provided two examples where GIS can be used to strategically identify and improve the quality of life for individuals who live in single-family residential dwelling units. The next section will discuss potential GIS-based interventions at the neighborhood and community scale.

6.2 HOUSING AND NEIGHBORHOOD DESIGN

The single-family residential unit seldom exists as an island. Even the expansive and expensive estates of the wealthy are often integrated as part of cloistered enclaves. Housing scholars have observed that zoning regulations and restrictive covenants impact and influence these urban/suburban morphologies (Jackson, 1985). Housing policy specialists would benefit from acquiring a deeper understanding of these morphologies. Urban morphologies and subsequently suburban morphologies have been shaped by several factors, chief among them mobility patterns. Historically, as Southworth and Ben-Joseph (2003) write, two morphological patterns have dominated – the grid and the cul-de-sac, see Figure 1.13. The New Urbanism movement has long advocated a return to the grid, citing its superiority in improving walkability and reducing auto-dependence.

Most suburban layouts are set up as cul-de-sacs. While they can create a sense of safety for some, most suburban layouts that are designed with cul-de-sacs, coupled with the absence of sidewalks reduce mobility options for children, elderly, parents with small children, and anyone who may be temporarily or permanently disabled – forcing them to rely on an automobile to access the outside world. These communities emphasized the sanctity of the private sphere, privatizing available open spaces with visible fences or invisible boundary markers that cordon off space into developer-assigned lots. For groups of individuals or Home Owners Associations (HOAs) that want to create more opportunities for communal living and creating space-sharing arrangements, through a cohousing model discussed in Section 3.2.5, GIS can come in handy to facilitate the (i) identification of available shared spaces and (ii) reallocation and reestablishing of newer shared spaces to support play areas, kitchen gardens, and greenhouses. Specifically, the user would identify a study area, create a new layer of non-built-up space, and calculate the available acreage and create a centroid that equitably accommodates common/shared spaces. If HOAs are interested in adding sidewalks and bike paths to reduce auto-dependency, GIS tools can easily be deployed to identify optimal networks that connect individual properties without having to destroy existing built and green infrastructure.

The New Urbanists have consistently and with modest success sought to bridge the gap between design and policy, by demonstrating how design principles and building codes that are applied at the scale of a residential unit can be linked with neighborhood level regulations that can contribute to creating a neighborhood character without compromising individual autonomy. At the same time, they have advocated for including neighborhood codes that take into consideration building form, in addition to building use (Talen, 2011). Historically, new urbanism has focused on soft targets, implementing principles among people and communities that are already receptive to their ideas, such as those who are planning lifestyle or resort communities, or where the residents are affluent so as to not be concerned about the costs associated with emphasizing walkability, public transportation options, and creating neighborhood character. For older suburbs that are already walkable and built on a grid, GIS can be used as part of a neighborhood quality assessment toolkit (CNT, 2022). Urbanists and landscape architects such as Clare Cooper Marcus (1986) and Dolores Hayden (1980) have long argued that retrofitting suburbs is a viable social project that can yield many dividends. This is a societal project that cannot be successful in a top-down way, given how land use controls are managed at the local level. However, we are confident that easy-to-use GIS analyses and visualization tools can assist planners in small suburban communities to increase densities and improve accessibility options. For example, GIS software extensions such as *CommunityViz*® allow small towns and rural communities to have conversations about increasing density and assessing impacts on other variables associated with the quality of life (like traffic or school enrollment). It is much easier to conduct these types of analyses in small towns that operate as a distinctive local housing market. The Orton Family Foundation based in Vermont has developed a planning framework called Community Heart and Soul that relies on the use of GIS tools to translate values statements into assessment metrics.

However, successful urban design requires an assessment of space and place by considering massing, bulk, solids, and voids, essentially requiring a three-dimensional place analysis. Architectural software like SketchUp™ can create that immersive experience and these models can be incorporated as part of Google Earth visualization to situate a particular project in its real-world context. Such an approach is suitable for building scale projects, see Figure 6.4 (NYC Planning and NYCHA, 2020).

Although a true 3-d GIS is hard to come by, advanced parametric modeling approaches using software such as ArcGIS Urban or Rhino can create a neighborhood-level analysis of a cityscape. Regardless of their implementation, whether it is a building information model (BIM) or CityGML data, these implementations require a 3-d base map that in turn is generated from LiDAR data. This data generation process is reliant on outside experts as is working with (satellite) imagery data. We assume that the objects have been created to conform to existing data. Computer Generated Architecture (CGA) rules can create new analytically rigorous visualizations as depicted in Figures 6.5 and 6.6 (Kelly, 2021).

Working with building typologies as objects, we can now drop them onto a parcel or zoning map. Each object comes with a set of characteristics describing its services offered (floor space for specific functionality, energy efficiency, tax generated, etc.) as well as requirements (consumption values, demand on other services such as schools, hospitals, traffic, etc.). All of these characteristics then can be summarized by planning project indicators that describe the potential impact of a planning proposal (see Figure 6.7).

This is an advanced integration of GIS, 3-D modeling, and urban land use planning – while it can be used to evaluate policy proposals, there are very few American examples of this approach. The more innovative deployments of these techniques come from Asian countries like China and South Korea where city planners and architects use these approaches as part of their day-to-day work, see Figure 6.7.

6.3 EXPANDING INTRA- AND INTER-NEIGHBORHOOD MOBILITY ALTERNATIVES

The United States is a suburban nation (Bruegmann, 2005; Kruse and Sugrue, 2006) and the challenges of creating more housing have to directly engage with ways to densify suburbia. The term "suburbia" is widely used but poorly defined. There is an obvious relationship to 'urban' but sometimes it is part of the urban (vs. rural) fabric, while others see it juxtaposed to urban. Suburbia may be defined by its donut-like structure around the core of cities (in Europe often referred to as the "bacon belt"), with population densities and the subsequent provision of amenities that place it in the middle between fully urbanized and rural. A useful way to delineate suburbia is then to identify urban cores (places with >50,000 people and a population density of 7,500 people per square mile (appr. 3,000 people per km^2). We can then identify the surrounding areas where a threshold percentage of people commute to the urban core (the OECD, for instance, sets this threshold at 15%). Alternatively, if the commuting data is not available, travel time isochrones from the urban core may be used to delineate catchment areas. Using these measures, we arrive at the following Table 6.1 of suburban areas in the United States.

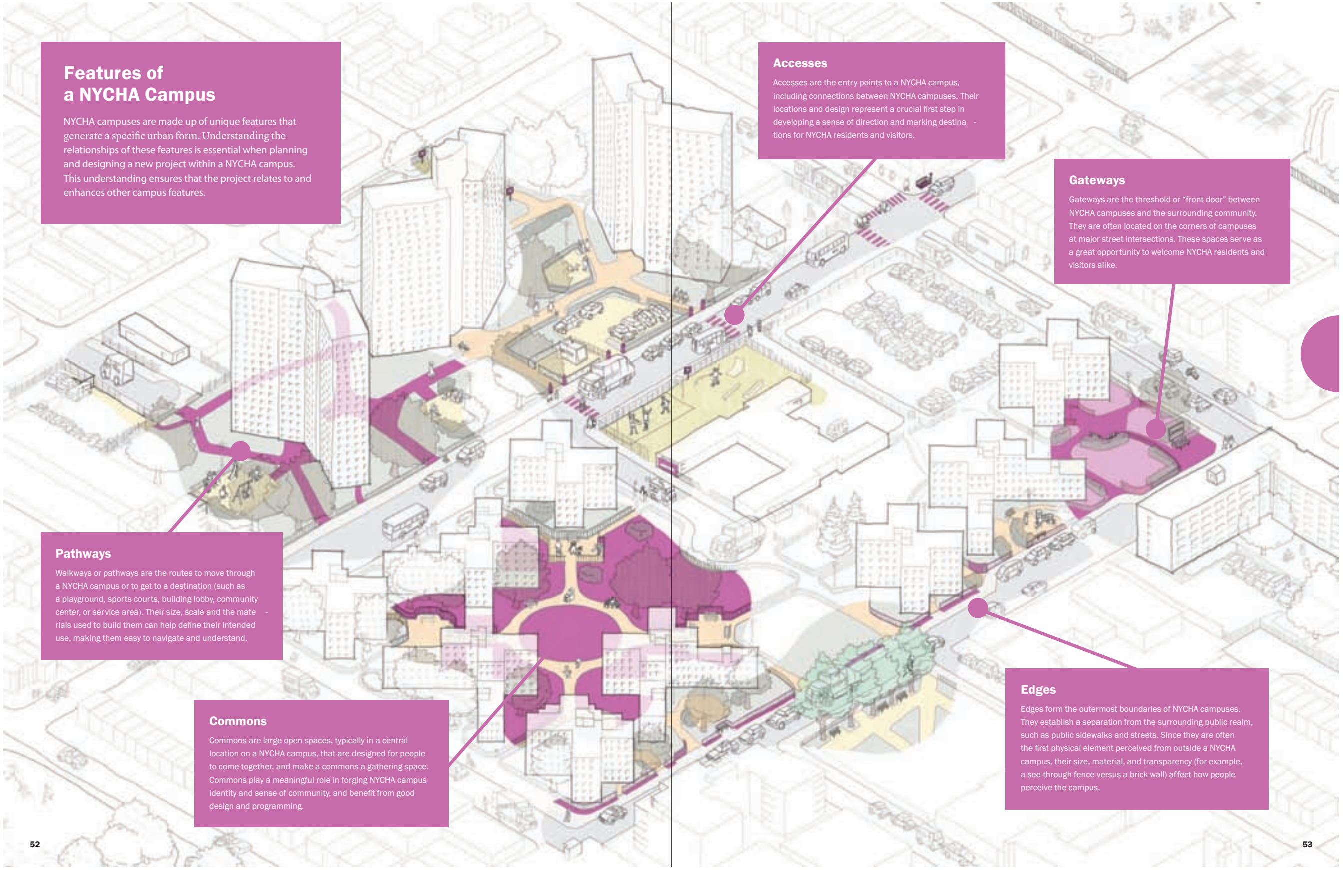

FIGURE 6.4 HUD defensible space

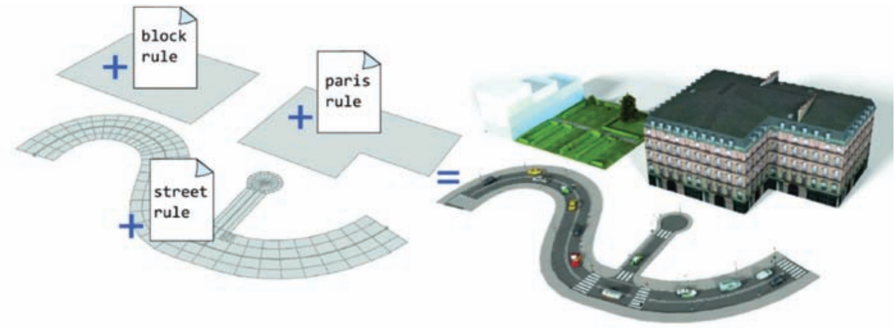

FIGURE 6.5 Combining CGA rules to develop a planning project

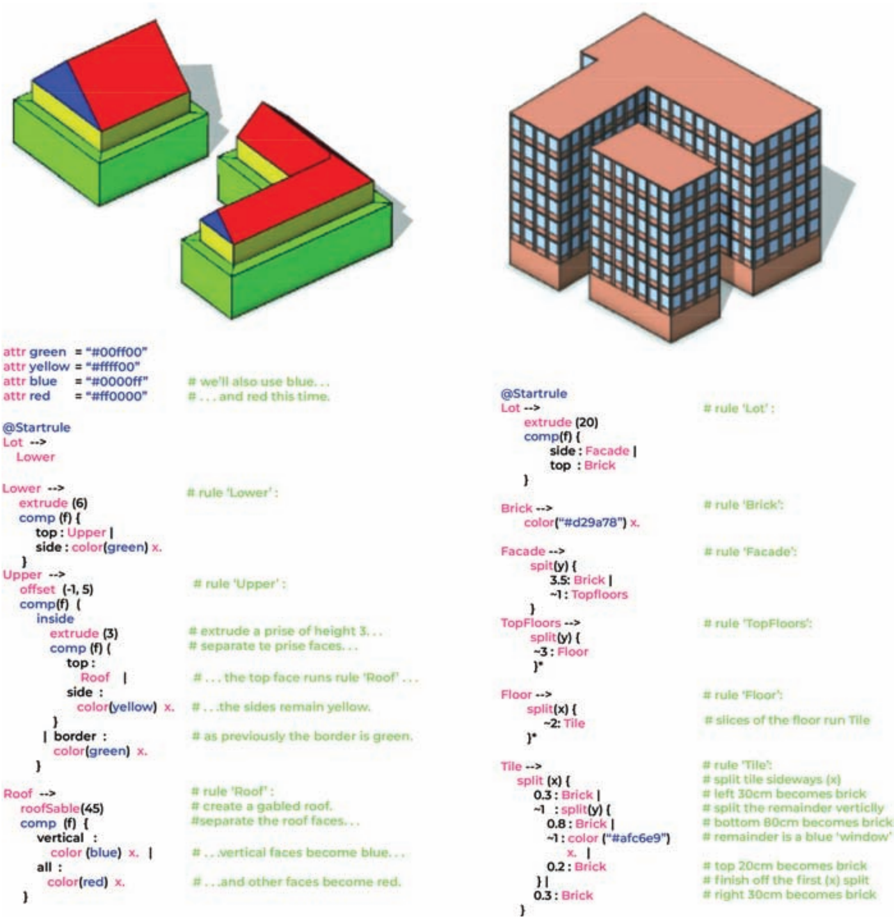

FIGURE 6.6 Examples for the parametric generation of housing objects based on CGA rules

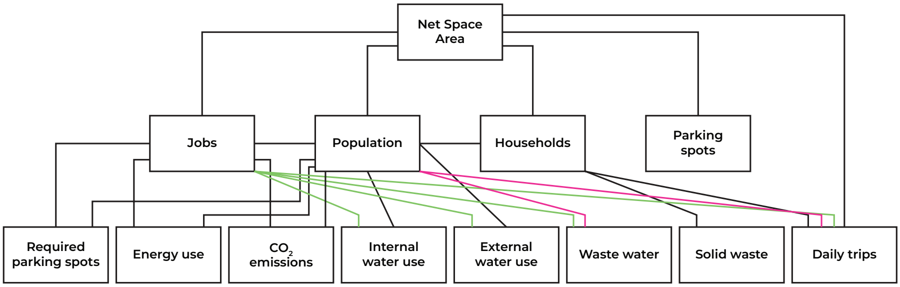

FIGURE 6.7 Flowchart depicting the indicators required to determine the effects of a particular plan

TABLE 6.1
The Size of Suburbia

2020 Census Data	Area (km²)	Population
Urban core	1,046	15,775,060
Suburbia	202,420	216,254,698
Exurban/rural	8,957,492	102,705,397

Yet, suburbia itself is not homogeneous and transportation choices shaped suburban development, see Figure 6.8 (SEDAC, 2019; MAP, 2015). The earliest suburbs, prominent in the densely populated north-east United States, were shaped by fixed transit lines that moved workers from outlying areas into Manhattan (New York) or Boston (Massachusetts). Walkability to and from the transit hub shaped these early suburbs. Automobile transportation allowed for further expansion and the cul-de-sac became a favored alternative.

Transforming car-dependent suburbs in the United States into walkable and bikeable neighborhoods requires a lot of planning and coordination between land use planning, housing, and transportation agencies, not to mention the commitment and involvement of the private sector (Dunham-Jones and Williamson, 2021). Such transformations will require physical changes like the introduction of sidewalks to improve walkability, and changes in local zoning laws to allow for mixed-use development, not to mention the provision for public transportation options. As we discussed in Section 5.5 of Chapter 5, cadastral data such as building age, planimetric data about the presence/absence of sidewalks resulting in the derivation of a walkability score, and zoning changes are starting points for a requirements analysis addressing future challenges in housing and neighborhood design. A full-fledged analysis would require a comprehensive agent-based modeling system (see Section 7.3 in Chapter 7).

While the re-design of suburban neighborhoods is a necessary step to alleviate the need for both new housing overall and different types of housing to serve diverse populations, movement within and between suburban neighborhoods deserves far more attention than it has in the past. Most suburban neighborhoods are entirely automobile dependent, and newer suburbs in most parts of the United States are sprawling

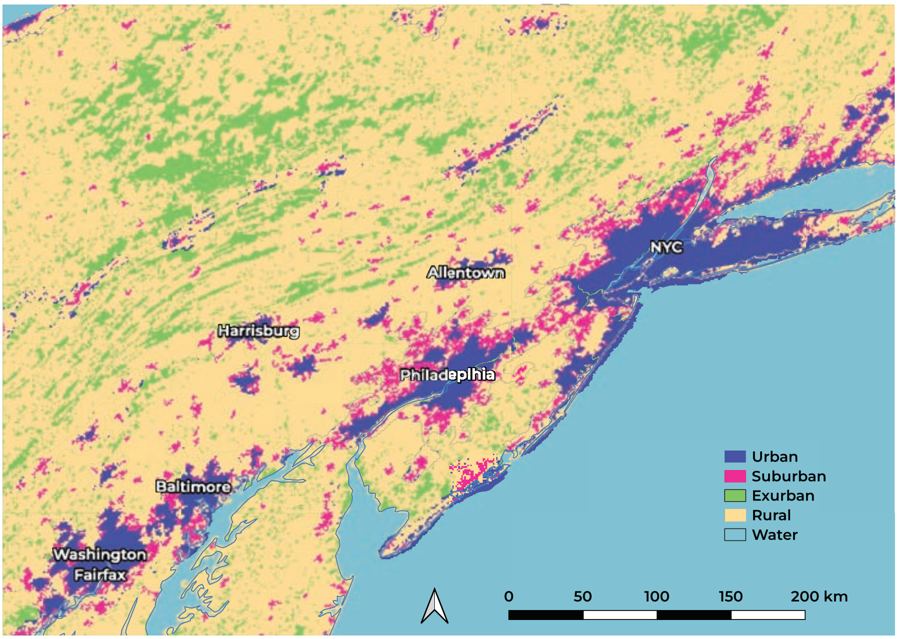

FIGURE 6.8 Figure of Suburbia

sub-divisions that are not easily accessible on foot, even with the presence of pedestrian walkways. Furthermore, public transportation infrastructure in the United States was designed for a previous century where commuters were expected to travel (i) from the suburb to the city and back, (ii) leave and return at fixed times every weekday, and (iii) were going to the city to work in an "office". Our transportation systems have not easily adapted to the changing characteristics of commuting, and the changing nature of work. Fortunately, the newer solutions to solve this "last-mile problem" can be addressed by the provision of micro-mobility alternatives like e-bikes and scooters (at least for non-physical mobility-impaired populations). Now being pilot-tested in many areas around the country, this option is an affordable alternative to create intra- and inter-neighborhood mobility, reducing dependence on automobiles. In many parts of the country, it is not financially feasible to provide robust public transportation options; investments in just-in-time commute options can solve transportation problems for students, office workers, and low-wage workers who travel to suburbs to provide service work.

Additional complexities have been introduced as a result of post-pandemic shifts in the geography of US tech work. Jobs associated with the knowledge sector, and heavily aligned with Silicon Valley began to disperse as large firms like Alphabet (aka Google) and Meta (formerly Facebook) allowed their workers to work from anywhere. Workers dispersed to less expensive metropolitan areas in the Sunbelt and Mountain-West. Although this migration has great economic benefits to communities in Dallas, Denver, Orlando, Salt Lake City, Kansas City, St. Louis, and San Diego, it has created new ripple effects that housing policy professionals and housing advocates must seriously consider. Specifically, these mobilities are from higher density/higher cost metropolitan areas such as Los Angeles, San José and other Bay Area cities, Portland (Oregon), Seattle, or New York City to relatively low-density suburbs with lower housing costs, creating undesirable ripple effects such as reducing housing affordability and spurring gentrification (Adikesavan and Ramasubramanian, in review, n.d.; Florida and Kotkin, 2021; Muro and You, 2022; Peiser and Hugel, 2022). GIS tools can and have been successfully deployed to study the economic geographies of tech work (e.g., Zandiatashbar and Hamidi, 2022).

6.4 COMBATING HOMELESSNESS AND HOUSING INSECURITY

Homelessness in America is rising rapidly. A 2019 White House report stated that "over half a million people go homeless" on any single night in the United States. Although about 65% are temporarily housed in homeless shelters, the remaining 35% are living rough, on the streets. The vast majority of the homeless population, approximately 45%, is found in California, Hawaii, New York, Texas, Florida, Oregon, Washington, and the District of Columbia.[1] There is no "typical" homeless person. Men, women, children, elderly, people with disabilities, and veterans are part of the homeless population. The face of homelessness is the person on the street – typically an adult male, perhaps panhandling for change, talking to himself, or quietly suffering. Yet single adults actually constitute a minority of the city's homeless. The invisible face of homelessness is that of a child (ICPH, 2015). In New York City alone, approximately 28,000 school-age residents are living in shelters, 49,000 are living doubled up with other households, and 7,000 are living outside shelters or residences. These numbers derive from a survey of the NYC Dep of Education survey, which illustrates the degree to which official homelessness counts are underestimating the true dimensions of the homelessness problem. In addition to those who are actually without shelter, over 3.7 million people are experiencing housing insecurity, according to the National Alliance to End Homelessness, citing a Census Bureau survey (week 36, August 2021) that is tracking the impacts of the coronavirus pandemic. The shortage of affordable housing is an obvious cause – but the chronic homeless require more than shelter provisions – they need a bundle of services and support systems.

This suggests that the traditional way of counting the numbers and describing the problem is not helpful. GIS can be used both as a diagnostic as well as predictive tool, which in the hand of a GIS-savvy housing specialist provides the early warning signs that alert us to where interventions can be used to prevent homelessness. We suggest that *economic hardship*, *housing quality*, *stability*, and *affordability* are good indicators, which together provide a fairly accurate measure of where people live on the brink of homelessness. We discussed many of the necessary variables in Chapter 4, including the calculation of compound variables such as rent/mortgage burden, which may be countered by the availability of subsidized housing such as LIHTC. The lack of housing stability may be captured by any number of variables such as evictions, foreclosures, units whose rent subsidies expired, or just the percentage of new neighbors which can be derived from the US Census question, which is "How long have you lived at this address?". As Desmond (2017) describes vividly, homelessness is often precipitated by tenants living in places that eventually become unlivable. Crowding, building code violations, maintenance complaints, and increasingly common lists of bad landlords are excellent indicators of problems waiting to happen – especially to tenants whose landlords know that they don't have any other

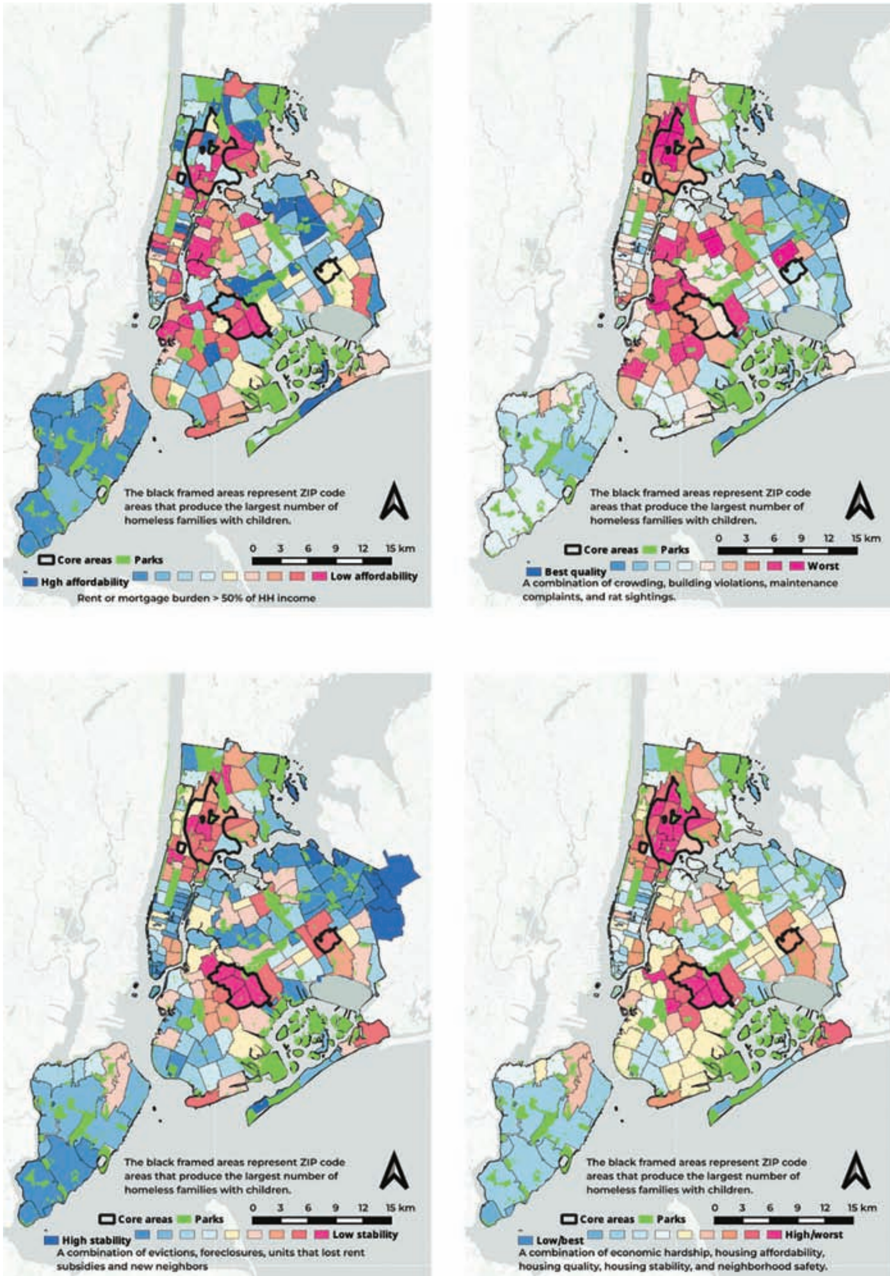

FIGURE 6.9 Probability of increasing the ranks of homelessness

options. Figure 6.9 (Abramovitz & Albrecht, 2016) illustrates the rankings of New York City neighborhoods according to each of the four aforementioned indicators and how their aggregated effects in The Bronx and East New York.

New York City recently passed a local law that requires the local government to provide its citizens with information about a similar set of factors contributing to homelessness (or displacement risk as they put it). They aggregate four variables each to three higher-level categories: population vulnerabilities, housing conditions, and market pressures. The result can be explored online at https://equitableexplorer.planning.nyc.gov/map/drm/nta.

6.5 CLIMATE CHANGE AND SUSTAINABILITY

Global climate change has a significant impact on housing insecurity. In recent years, there have been dramatic disruptions in people's lives as weather patterns and climatic conditions have changed. There are climate-related catastrophes such as the destruction of entire neighborhoods and communities as a result of wildfires, flooding, and extreme heat. Climate change impacts and is impacted by the production of housing.

This last sentence deserves to be parsed carefully. One of the authors walked in October 2012 the promenade in Brighton Beach, NY, with their visiting relative, who asked how come there is no flood protection for the apartment high rises just across the street; one of the authors responded with "*because we have never experienced more than a foot of water*". A week later superstorm Sandy hit and hundreds of thousands had either fled or were trapped in their buildings. Unprecedented "natural catastrophes" are now occurring on an annual basis in one part of the country or another. Housing planners in a number of states are now busy developing buy-back plans to convince homeowners to move to less hazardous areas. And the storm-proofing of existing apartment complexes has become a new budget item that neither public nor private builders had never anticipated – not just in the Mississippi or Tennessee valleys but throughout the country. The question of where to allocate such resources is obviously a pertinent one. Yet, as we are looking to minimize the effects of climate change, we also need to be aware of the fact that housing itself is a driver of human-induced climate change. Urban sprawl contributes to climate change through higher emissions from land use change, embedded emissions in infrastructure, and transport energy consumption (NRDC, 2017; NREL, 2018; IPCC, 2021). Atmospheric CO_2 concentrations have reached a level that is unprecedented over the last 3 million years and the impacts of climate change are widely observed to be worsening globally (WMO et al., 2019). These impacts are strongly evident in cities, where urban policymakers and residents face extreme weather events – including heat waves, wildfires, flooding, and landslides – that particularly have an impact on vulnerable populations living in informal, low-quality, and overcrowded housing without the basic infrastructure, services, or green space that can offset the worst impacts of climate hazards (CUT, 2019). Those two aspects are intertwined when we look at the (need to) use air conditioning.

As we discussed in Chapter 2, air conditioning made large parts of the United States habitable. The building booms in the whole swath from Miami to Los Angeles would never have occurred without air conditioning. Yet, there are large parts of the country where people live without air conditioning, and this is about to change as climate change will alter the number of 100° days from a handful to several months. Figure 6.10 (First Street, 2022) depicts the counties where housing will have to adjust – preferably in such a way that it does not put an additional burden on an electricity grid that already struggles to provide charging stations for electric vehicles.

Organizations such as *First Street Foundation* are using GIS to perform parcel-level risk analyses for flood, fire, and heat hazards. While they are working with the Big Data

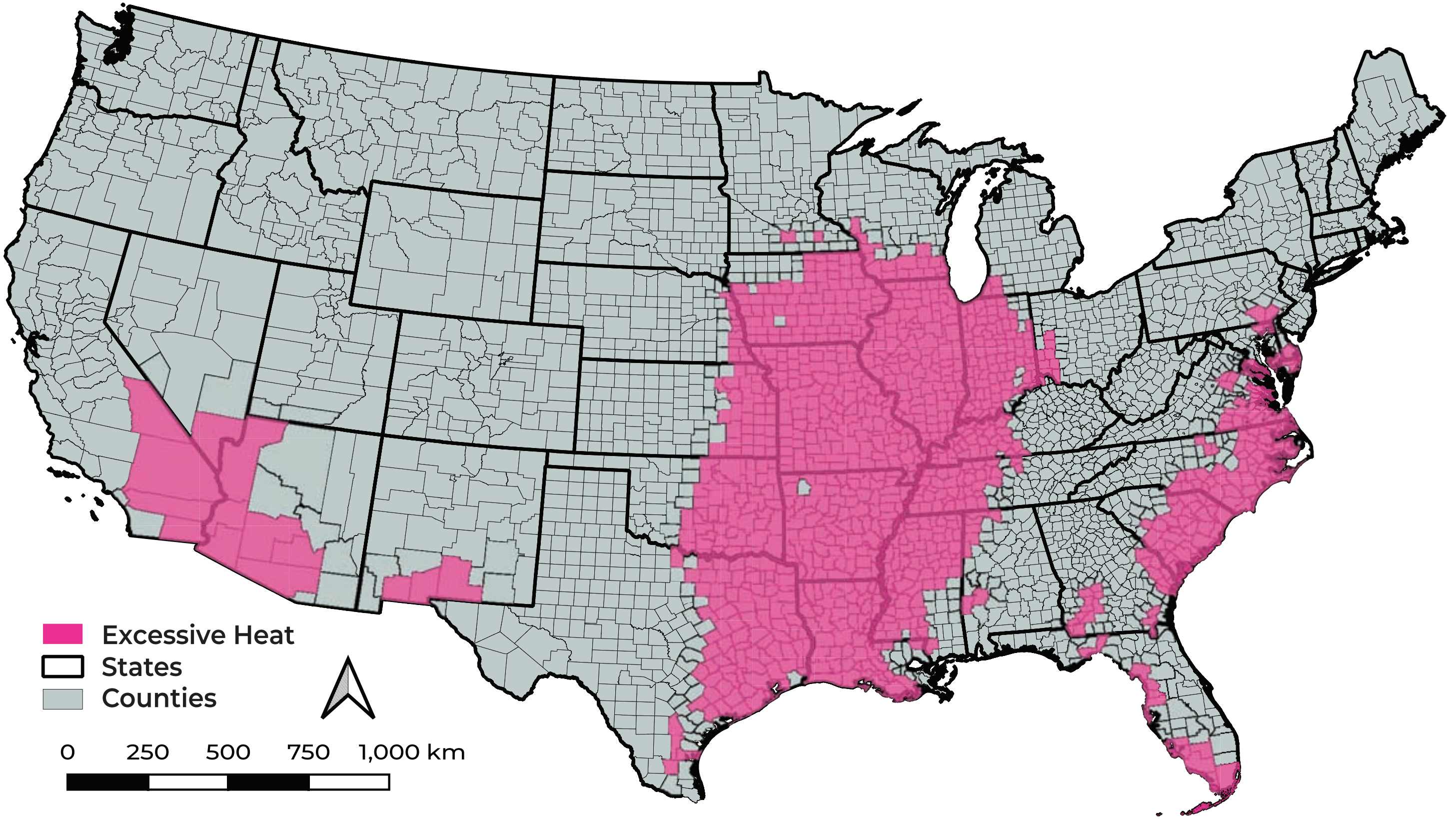

FIGURE 6.10 Areas of excessive heat requiring adjustment in insulation and air conditioning

techniques further described in Section 6.7, local and regional planners have access to all the same public domain data and due to the smaller extent can then perform the same analyses and even improve on them because of their knowledge of local contexts. Quite similar to that private endeavor is the federal *Climate Mapping for Resilience and Adaptation* program, which is tract-level based but covers a wider range of calamities. As the flooding of Katrina or the heat waves in Chicago and Seattle have shown, climate change adaptation is a social equity issue. Intersecting (literally in the sense of a GIS operation as well as metaphorically as in addressing a housing issue from two different perspectives) such climate risk maps with social vulnerability factors will assist policy researchers with their prioritization in the allocation of sparse resources.

We mentioned the federal Hazus MH program before in Chapter 4 in the context of unusual data sources. The compilation of the data is an auxiliary function in service of its main purpose, which is hazard mitigation and management. Effective emergency response during or in the aftermath of a disaster is contingent on having a plan, which in turn requires having run scenarios of what is needed where in case of a disaster striking. We mentioned the surprise of superstorm Sandy before; the irony is that the NYC Department of Emergency Management had actually run a scenario of what would happen if the remnant of a hurricane is stalled by a blocking low-pressure system and that scenario predicted everything that was then actually happening. The scenario was considered too unlikely to invest the resources necessary to prevent the effects. But having run the scenario gave local and state authorities the information necessary to prioritize responses, which resulted in far fewer human casualties than Hurricane Katrina. GIS helps us to determine temporary shelter needs, even when local means of communication are interrupted because the geoprocessing models of systems like Hazus MH allow us to immediately calculate the follow-up effects of one resource outage or the other (e.g., gas station pumps not working when the electricity fails, preventing generators to be used as a substitute, or prioritizing the evacuation of mobility-impaired residents whose medical equipment at home is out of commission).

6.6 PUBLIC HEALTH AND SAFETY

The Covid pandemic provided us with examples for this delicate balance between public and private interests. Crowd control and enforcement of masking or vaccination requirements have first been modeled and then enforced using early adoptions of edge computing techniques. As in so many other spheres of life, the pandemic accelerated the adoption of techniques that otherwise would probably have taken decades to find acceptance. Two examples might illustrate this. In 2012, during Hurricane Sandy, some 80,000 residents of high-rise buildings, including elderly New Yorkers and those with physical limitations, were for 2 weeks stranded on upper floors when their buildings lost elevator service. Threats from water and food shortages, food poisoning from refrigeration not working, disease outbreaks from malfunctioning sewage systems/drinking water supply, and deficits in health care had become serious issues (Kunz et al., 2013) (see Figure 6.11 (Haraguchi & Kim, 2014)). And a repeat of the over 700 deaths during the 1995 Chicago heat wave (Klinenberg, 2002) is now unlikely even when we consider the climate change scenarios discussed in Section 6.5. The reason for that is that we now (potentially) have a much more detailed picture of vulnerable populations. The above experiences have led many local emergency response centers

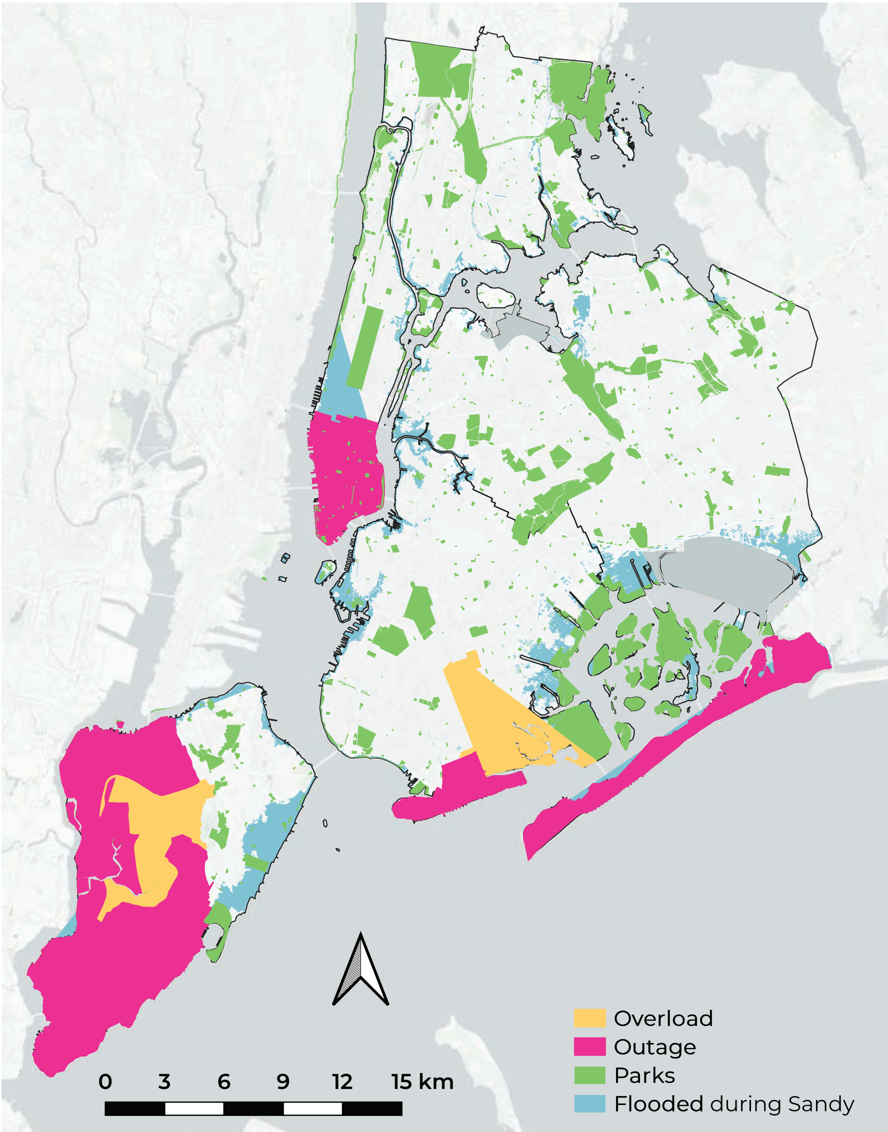

FIGURE 6.11 Map of elevator failures in public housing during superstorm Sandy

throughout the United States to continuously collect individual-level data of vulnerable populations – where vulnerability is a multidimensional measure based on age, race, health status, linguistic isolation, etc. The limitations these days are less a function of available technologies but of inter-departmental workflows that alert the appropriate administrative unit to potential dangers and trigger individualized responses.

This is a recurring theme: while GIS is an ideal medium to share data and trigger administrative actions, mental and procedural silos are limiting its use. Take the public health issue of walkability, for instance. Walkability maps are a type of map that shows the mobility of pedestrians in an environment. These maps can rate the walkability by different types of variables and generally include variables like proximity to amenities or public transit. Walkability maps can also be based on the characteristics of the physical environment, such as paved sidewalks or dangerous crossing locations, or on the convenience of walking to dining and drinking establishments, grocery stores, shopping, errands, parks, schools, and culture and entertainment.

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Albrecht et al. (2021) have shown that the Census Bureau's LODES data is representative not just for commuting but all kinds of trips. It can therefore be used to reflect the number, lengths, and modes of all forms of people's local and regional movements. In a separate study, Miller (2022) used the same LODES data to measure the effect of distance on movement mode. Looking at all commutes among the 51 neighborhoods of Brooklyn, NY, he found unsurprisingly a high correlation between the number of trips on foot and the density of residents and jobs in a neighborhood. More surprising is the amazing consistency of movement mode depicted in Figure 6.12: once locked into a mode, NYC commuters remain in that mode. At the same

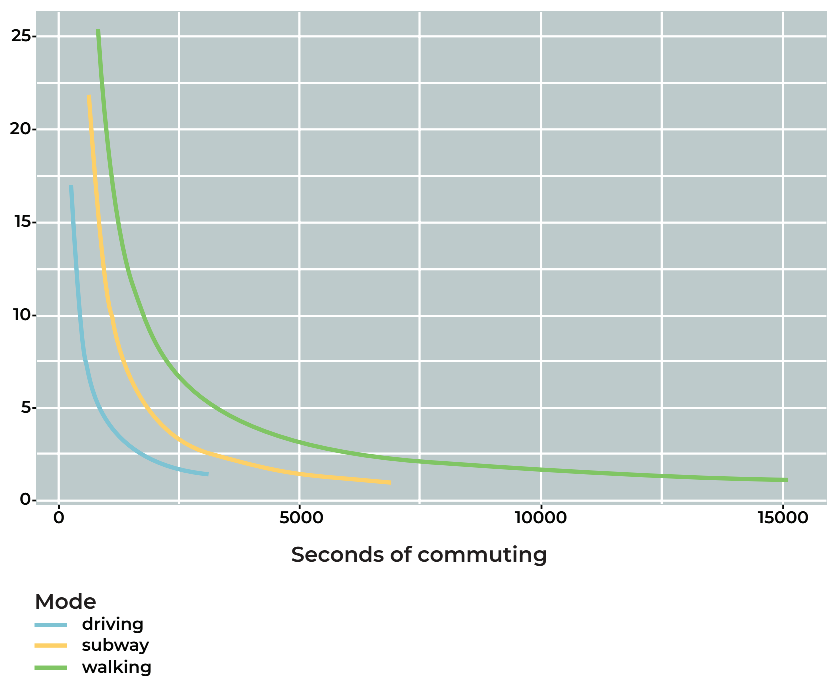

FIGURE 6.12 Movement mode as a function of commute density

time, Mr. Miller showed that compared to driving and walking, the use of public transportation showed the highest elasticity. Any decrease in commute time on the subway increases the number of commuters using that mode the most.

6.7 HOUSING AND SENSEABLE CITIES

Advances in AI and the ubiquity of sensor technologies help create a city that is a network of sensors that are passively "sensing" and gathering information about different aspects of the built environment. Just as a smart home can adjust its own temperature, turn lights off and on etc., both mobile and stationary devices can be deployed to improve the built environment. A variety of technologies come into play here: 5-G telecommunication, the so-called Internet-of-Things or IoT (expanded upon in the following), locational awareness, "Big Data" and associated methodologies such as neural networks and genetic algorithms combine to facilitate information flows without reliance on human intervention (see Figure 6.13 (EC, 2020)).

IoT architectures contain three layers:

- a perception layer consisting of sensors and actuators;
- a network layer that provides the communication between IoT devices and the Internet through Bluetooth or Wi-Fi; and
- an application layer either at the device level, within a local area network, or on some remote server.

From a housing policy perspective, the one aspect where GIS comes to bear is locational awareness. In the early 2000s, phone apps that allowed citizens to report outages were celebrated as a way to bridge the gap between citizens and the local authorities serving them. This is (or can) now be automated by way of sensors that report elevator outages or failing lights. Adopting the purpose behind a 311 call system, such

FIGURE 6.13 Schematic of information flows in a sensible city (based on European Commission, 2020)

FIGURE 6.14 Urban energy visualization of Brooklyn, NY

events can now be logged and service efficiency be measured. Especially with larger housing complexes or off-site landlords, such sensor-based maintenance and prevention promise a high return on investment. The combination of building information systems (BIM) and facility management results in what is now known as Smart Facilities Management (SFM), which has been successfully deployed in commercial office buildings (Gao and Pishdad-Bozorgi, 2019; Wang et al., 2022).

One aspect that Figure 6.14 above fails to reflect is the issue of scaling systems from the hyper-local (within a building) to the neighborhood or even city level. Each of the red keywords represents its own application development domain, which is typically unaware of the others. The link between SFM and city-wide models, say in the form of CityGML, has been implemented in a number of European pilot projects (as well as in China and Singapore) but is not a good fit in the US housing landscape. This leads to the ironic situation that European academicians such as Würstle et al., 2020) use open data repositories such as the one mandated in New York City as a rich source for their city-wide energy models.

Such models make use of the hierarchical organization of CityGML, which allows to scale information from individual windows and HVAC elements to nationwide building models such as Gilliland's 2019 Open City Model that covers every building in the United States. The energy model depicted in Figure 6.14 requires the same kind of information that we discussed in Section 6.2 Building and Neighborhood Design; the parameterization depicted in Figure 6.15 is akin to the CGA rules in Figure 6.5 but adjusted to the needs of an energy model.

Yet, the promise of Smart Cities remains so far largely unfulfilled. Most housing authorities were created many decades ago and are equipped with antiquated systems that are incapable of coping with the stream of data that sensors provide. The question now is who gets alerted, and do they have the means to react to the event triggered? An example of the need to adjust internal workflows to the changing I(o)T

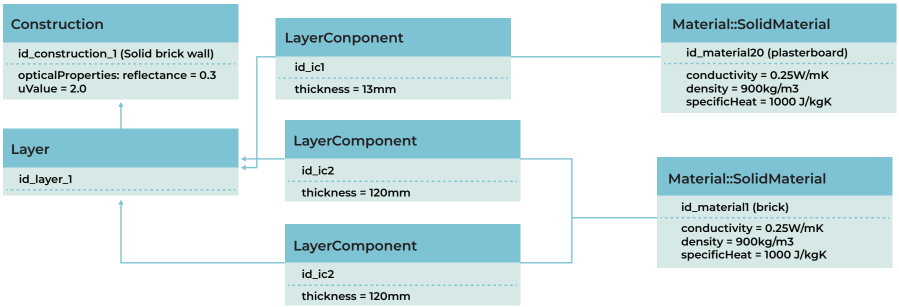

FIGURE 6.15 Parameterization of a masonry wall as part of a CityGML based energy model

infrastructure is the New York City's Housing Authority's slow reaction to the detection of arsenic in drinking water (NY State Senate, 2022). In addition to the financial constraints of public authorities, there is the issue of perceived (and real) intrusion of privacy. One of the first applications of local sensors has been security cameras. Typically, in a public US context, they are used to record and act as a deterrent but in private as well as in East Asian environments, cameras are combined with face recognition to provide live access control. Western European and US authorities are, as of 2022, in the process of developing a regulatory framework to deploy federated or edge computing (Almutairi and Aldossary, 2021; Mondragón-Ruiz, Tenorio-Trigoso, Castillo-Cara, Caminero, and Carrión, 2021) that allows for decentralized local analysis and hence provide options to balance privacy with security options in local networks that do not require sharing with centralized servers.

The Scottish Cities Alliance defines a smart city as "the integration of data and digital technologies into a strategic approach to sustainability, citizen well-being and economic development" (Urban Foresight, 2016). Issues of cybersecurity, privacy, and sustainability, and public policy that prioritizes them, are central to understanding and successfully deploying smart city technology.

The vision of smart city services is built on data and system integration. These are the very same elements that make smart city infrastructures high-value targets for malicious actors. Their interdependent nature by design also means that attacks on one service frequently will have negative ripple effects on others. Incidents such as the Mirai botnet, which disabled a large part of the internet in 2016 have shown the vulnerability of multiple sensor networks to malicious interference (Wright, 2019).

Smart cities rely on using machine learning techniques; however, these techniques are prone to amplifying human biases that inform the design and training of such systems (Barocas and Selbst, 2016). Smart cities must function equally well for different stakeholder groups such as residents, commuters, and visitors to mention a few. City planners must ensure that bias in the machine learning ecosystem does not lead to systematically underserving identifiable sub-groups. Similarly, policy makers should target broad and fair access and application of machine learning techniques. This can be achieved through transparent planning and decision-making processes for smart city infrastructure and application developments, such as open hearings, focus groups, and advisory panels. The goal must be to minimize potential harm while maximizing the benefits that algorithmic decision-making can bring. The European Commission's High-Level Expert Group on Artificial Intelligence has published guidelines for trustworthy AI (EC, 2022) that addresses similar issues, including awareness of possible biases and harms and accountability.

Investment in smart cities has the potential to contribute significantly to achieving regional and global greenhouse gas emission reduction targets. Devices placed throughout cities, for example, can collect large volumes of data to enable coordinated decision-making toward more efficient use of resources (Barcelona, 2023). Ongoing research into both lower-energy devices and low-power wide-area networks to reduce the energy requirements of machine-to-machine communication shows promise but must be weighed against the energy needed to truly process Big Data. While the European Union, for instance, has committed to making all data centers net zero in carbon emissions by 2030 (EC, 2021), the path toward achieving this goal will be made more difficult by the growing amounts of data to store generated by and for smart cities.

6.8 CONCLUSION

In Chapter 6, we discussed new directions for future research that can leverage the spatial-analytical prowess of GIS to examine housing issues. Post World War II suburban morphologies have been created through an alliance of landowners, real estate developers, builders, car manufacturers, and politicians who believed that they were addressing the housing crisis of their time. We propose that GIS can be used by individual activists, nonprofit organizations, and housing policy professionals who want to explore various ways to transform and retrofit existing suburban neighborhoods to ameliorate and alleviate the problems of living in suburbia. GIS tools can be deployed to identify ways to make suburban environments walkable and bikeable, create safe routes to transit stops, or carve out shared open spaces. While beyond the scope of this book, we argue that GIS used alongside community organizing and mobilizing can be a powerful way to engage citizens in the physical transformations of residential environments in suburban contexts (Ramasubramanian, 2010).

GIS also provides housing policy experts and advocates alternative ways to engage the public on a series of housing related issues, by linking housing affordability and quality to public and environmental health, and to address the problems created by a changing climate. At the other end of the spectrum, digital twins allow planners and policymakers to model the impact of changing policies and changing physical interventions in real time within smart and senseable cities. While these innovations are still in a testbed phase, it's critical that we examine how access to data, data quality, and coherent communication pathways across disciplines are established. Housing is a key indicator in the evolution of smart city concepts with the idea that we advance 20-minute neighborhoods – neighborhoods that support a range of residential living choices, work opportunities, and recreation facilities, not to mention support services like educational and health care facilities. GIS anchors smart city modeling, especially as we strive to address societal concerns related to access and equity.

NOTE

1. Some of these numbers are simply the result of the most populous states; others are a function of urbanization (homeless people tend to move from surrounding areas to urban centers), and climate (it is easier to survive in a non-freezing environment). Under-reporting is a function of acknowledgement/politics, i.e., the low numbers reported for Phoenix/Maricopa county don't withstand closer scrutiny.

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7 Conclusions

7.1 INTRODUCTION

In the United States, academic conversations related to housing have appropriately focused on affordable housing and public housing – in other words – how to provide housing for those who are unable to successfully participate and thrive in the private property or rental markets (e.g., Schuetz, 2022) In large part, scholarly inquiry and public conversations about housing have challenged lawmakers to enact policies and programs that support the homeownership ideals while also mitigating risks (e.g., Belsky et.al, 2014). We encourage and support these conversations. Housing policy experts have examined the impacts of federal policies, and programs and many scholars want the federal government to be more involved in the provision of housing (e.g., Colburn and Aldern, 2022). Yet, the crisis remains.

Housing seems awash with data produced by academic think tanks, city agencies, nonprofit organizations, and advocacy groups. Yet, all these data don't appear to be producing new residential living units or preserving the housing stock we have. We came to the conclusion that academic housing experts have highly specialized and valuable knowledge about specific federal and state policies and programs; the historical and social context within which these housing policies are created, enacted, and sustained; and in-depth analyses of the impacts of housing policies on the lives of everyday people. It is these in-depth case studies and ethnographic narratives that reveal that it is very difficult to understand housing challenges, without simultaneously considering many other factors including demographics, health, education, and more specifically, *where* people live.

As authors who collectively have professional and practical expertise in the fields of architecture, urban planning, and Geographic Information Science (GIS), we are eager to directly assist those individuals, nonprofit groups, philanthropic organizations, and housing advocates who are doing the work of creating alternatives to avert the housing crisis – the acute shortage of housing alternatives that currently exists for all but the very wealthy. Chapter 1 articulates these challenges and provides a geographical framework to explain how everyone who is interested in solving housing challenges in their community can use GIS and spatial analysis to support and expand their sphere of influence. GIS allows end users to demystify housing policy and draw in those stakeholders whose engagement is sorely needed to create new housing alternatives. Chapters 2 and 3 speak to GIS professionals who are currently developing interesting analytical methods and using them to ask housing-related questions without having the historical context of how demographic change, urbanization, and federal policies and practices shaped the contemporary housing landscape.

The private housing and rental markets understand the power of location all too well. The infamous – location, location, location – mantra that every real estate broker makes when they present a property for sale short-circuits policy conversations and brings home the essential truth – the geographical (socio-spatial) context is critical

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and implicit in any housing conversation. Yet, the geographical context that a realtor creates for the prospective buyer is a purpose-drawn "map" of an imaginary ideal; realtors typically tout the opportunities of any location under consideration, while downplaying constraints or limitations. Unlike a realtor's map, the GIS concepts we discuss in this book are rigorous and scientific. In Chapters 4 and 5 in particular, we provide you with a primer on how to build a GIS project from scratch – from data acquisition to the use of basic and advanced spatial analysis methods that encourage those who care about the quality of life in their cities and neighborhoods to participate thoughtfully in housing conversations.

Presently, housing policy experts tend to be isolated, often speaking within an echo chamber of like-minded people. In Chapter 6, we propose a different approach to drawing attention to our current crises of housing shortages and lack of affordability by encouraging research, analysis, and advocacy at the local level, where land use and zoning decisions are made. The reality is that contemporary housing policy is reactive and critical, more than it is visionary or even pragmatic. Since housing policy decisions reside within an interconnected framework of policy choices made by government and private entities, it may be prudent for housing specialists to engage and build alliances across disciplines and domains in creating new housing alternatives – whether it be accessory dwelling units, multi-family medium-rise housing units, co-housing models, or transfer of unused public land to create new affordable housing. GIS can support and facilitate the establishment of these connections.

We do not offer GIS as a panacea to address entrenched biases, including mistrust in government, racism, and prejudiced attitudes about who we want as our neighbors. We are also not favoring one set of housing policy or programmatic interventions over another. Our desire is to use GIS maps and associated analyses to communicate socio-spatial narratives to advance well-reasoned policy agendas. We are well aware that the United States in the 2020s is a hyper-polarized political landscape in which civil debate over ideas seems all but impossible. But we must try nonetheless. The alternatives are dire – rising housing costs, sprawl, environmental degradation, increased travel time, and overall reductions in the quality of life.

7.2 THE POWER OF GIS

Although GIS has been available as a set of tools since the 1970s, its initial promise to advance decision support was not fully realized until recently. We are now facing a split into two separate GIS communities: end users who have basic GIS functionality at their fingertips, be it in office software or web-based mapping on one side vs. power users, who mash up terabytes of data accessible through cloud services. GIS tools and functionalities have co-evolved alongside computational advances. We have been aiming for the middle. The power of GIS lies in its ability to combine data across departments and provenance. Some visualization packages such as Tableau have added an amazing array of mapping tools to their software. Linking disparate datasets is now often as easy as drag and drop. Yet, similar to the lament of statisticians, with powers come responsibilities. The distinction between basic and advanced GIS operations in Chapter 6 mirrors the separation between "democratized" GIS functionality now widely available and those operations that will remain the domain of GIS and related software (such as the R ecosystem). We might characterize the former as small letter gis to describe simple forms of communicating with maps and tell the difference from capital letter GIS, which requires conceptual models for the development of indicators and a keen eye on what is special about spatial analysis methods.

The conceptual models have to come from the application domain, whether this is housing proper or economic development, transportation, environmental protection, etc. We propose that housing policy analysts engage critically[1] with the use of GIS as they begin conversations about increasing density, for example, or about the siting of new affordable housing in residential neighborhoods. While there is a nascent Yes, in my backyard (YIMBY) movement emerging in areas of high unaffordability, the nation as a whole is largely resistant to high-density residential development.

None of the challenges listed in Chapter 6 can be solved without GIS. They require the collaboration between GIS novices, intermediate, and expert users with the housing policy analyst sitting in the middle. They need to be able to talk to Jane Public using storymaps, create her own analysis of policy interventions, and make conscientious use of datasets created by climatologists, epidemiologists, or economists. As useful as putting things on a map is from an exploratory perspective, the mere production of an atlas of all the different stakeholder perspectives (the "gis" from above) would be a severe short-selling of GIS's potential. GIS can be a communication platform that provides access to multiple expert knowledge bases and allows stakeholders to engage in constructive arguments about local decisions that in their multitude have regional impacts. It is the housing policy analyst's responsibility to use the advanced techniques discussed in 5.4 to put the relationships on a scientifically defensible quantitative basis. When stakeholders present their perspectives and lay open the data and methods used, decision making becomes transparent and the housing policy analyst fulfills her democratic mandate.

7.3 THE ROLE OF GEO-ARTIFICIAL INTELLIGENCE (GEO-AI)

We are taking a balanced view of the role of artificial intelligence (AI) in GIS in general and its application to housing research in particular. The term AI has been around for many decades and left a bad memory on most information scientists because of many broken promises and predictions that have proven to be wrong. The community has therefore been learning towards the adjective "computational" to connote the application of AI methods such as cellular automata, agent-based models, neural networks, or genetic algorithms in many disciplines. As of late 2022, so-called large language models have caught the attention of the general public, mostly by allowing them to retrieve facts and instructions in a conversational mode. A more technical audience has been using neural networks for object recognition in remotely sensed images or even video streams to update cadastral maps or provide live updates for crowd control.

"Segment Anything" (*Facebook 2023*), for instance, is the combination of a Python library and a carefully selected dataset that can be locally installed and for which there are numerous plugins to geospatial software packages (e.g., Wu and Osco 2023) that identify objects in images and depending on the tool that has been built on top of it, creates features in a variety of geospatial formats. Depending on the local hardware, this can be accomplished in real-time – a feat that eluded a generation of image processing and remote sensing researchers. The development of a customized model based on in-house imagery is probably beyond the brief of a housing researcher. But in collaboration with GIS staff, housing researchers can now develop their own customized deep learning models (MapFlow 2023[2]) based on multiple generations of imagery, possibly using a range of sensors (e.g., post-war black-and-white aerials, current drone photography, multi-spectral satellite imagery, and LiDAR) to perform analyses that would have sounded utopian a decade ago.

The GIS unit of the *Province of Cantabria* (Spain), for instance, has applied such object recognition techniques adapted to their own data holdings to create a story-map of *(sub-) urbanization*, to derive *3-D building objects*, or to perform *real-time crowd detection on their beaches* during the coronavirus pandemic.

In Section 6.2, we discussed the parametric generation of housing objects based on CGA rules. Podrasa *et al*. (2021) demonstrate how this can be scaled from individual objects (buildings) to the development of land use scenarios for generative urban design. The same way large language models such as GPT-4 work with so-called transformers that are capable of understanding the context of sequential data by analyzing the relationships between the words; their neural network uses generative approaches to implement what Cantrell and Mekies (2018) call "relational urbanism". Using building and neighborhood typologies parameterized as per our discussion in Section 6.2, their neural network worked through millions of possible combinations to create design solutions that outperformed every expert and Charette solution based on the criteria developed for a planning exercise in Berlin (Christ et al. 2017). Figure 7.1 illustrates the workflow of this generative approach.

7.4 EDUCATING THE NEXT GENERATION OF HOUSING ADVOCATES

Housing is an important area of specialization in graduate planning education in the United States. However, given the broad scope of topics covered within this subject area, students are unlikely to have a deep and immersive understanding of all aspects of the field unless they are getting a doctoral degree. Housing policy classes cover topics such as demographic trends, housing finance, public housing, fair housing, and community reinvestment, but they may not cover zoning for housing, design, and construction issues because those topics may be covered in a land use class or in an urban design class. While most graduate planning students in the United States now take at least one GIS class as they acquire their master's degree, their knowledge of "GIS" may be limited to basic mapping and analysis. This does not address the lack of GIS expertise among many of the housing planning or policy professionals and is exacerbated by the fact that many local authorities lack GIS experts in any department. Given the ubiquity of GIS functionalities built into housing related apps like Zillow, students may not even notice that they are being guided to explore housing problems in a market-driven way, rather than to consider variables that may result in a more equitable and community-oriented outcome.

21st century challenges like climate change or addressing income inequities require that policymakers use robust data to support integrative solutions.

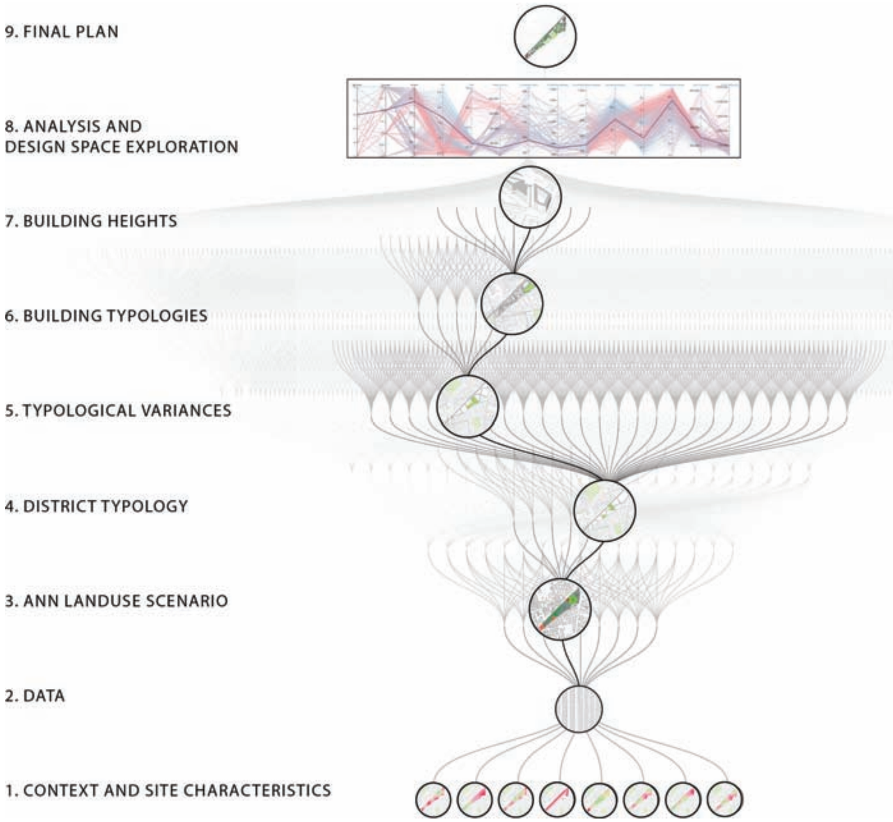

FIGURE 7.1 Generative typology

For example, advocates of dense housing and advocates for public transportation can both come together to address climate change by advocating for dense housing to be built close to transit hubs. This thinking is not considered novel within academic planning circles – planning scholars have been advocating for such actions for many years. Yet, the case needs to be made to other groups of decision-makers, especially investors who are looking for solid returns on their investment. In addition to prospective home buyers and renters, engaging with the real estate industry about location decisions requires that housing policy professionals take a regional view, challenging the site-specific view that most real estate professionals use to push their projects through. GIS, as discussed in earlier chapters and Section 7.2, can support this shift in perspective.

7.5 WHERE TO FROM HERE?

We have to confront the sobering reality that there is a serious housing supply and affordability crisis in the United States, one of the wealthiest countries on the planet. The fragmented nature of land use planning and land management is one of the reasons that the United States struggles to produce a high volume of affordable housing. As we look at the socio-political landscape in 2023, it is hard to imagine a national consensus about tackling these housing crises. The most optimistic way forward is for a bottom-up approach of an intentional large-scale social transformation, anchored by creating walkable/bikeable and environmentally sustainable neighborhoods, cities, and states.

The pathway to creating meaningful changes to serve diverse housing needs and diverse populations requires that we do not adhere to a single ideology or a single planning strategy to move forward. We can continue to innovate by advancing the use of sustainable building materials, as well as promote the salvage and reuse of construction materials, and explore advances in environmentally friendly construction techniques. In the design sphere, creating housing using adaptive design and universal design principles to support healthy aging and aging in place is essential.

In policy terms, we must continue to have conversations about increasing residential building density, including a commitment to densifying suburbia. While it is challenging to undo the unsustainable suburban landscapes created in the 1950s to the 1990s, it is also critical. Densifying suburbia cannot simply focus on the housing infrastructure; by necessity, we have to also consider the capacity of street networks, water and sewer infrastructure, and services. Housing in already dense neighborhoods and communities requires that we address different policy challenges, including solving the burdens of housing affordability and consequent displacement and housing precarity. Recently, Democrats in California have proposed what is perceived as a bold move to advocate for a Viennese model of "social housing" we discussed in Section 2.13 where the city owns about 25% of the city's housing stock for low-income residents. Assembly Bill, AB 309 advocates for social housing to be used as a way to address the shortage of affordable homes for all income levels in California. There is a need to build more housing, build it quickly, and build it to accommodate low-income families so that they can live there if not in perpetuity, for a period of time to create stability for their families and allow for the creation of a sense of community. We are not opposed to the government getting involved in the housing construction and management business just as they were over a half century ago. Yet, we have to learn from the mistakes of the past to avoid repeating them.

GIS is often referred to as the science of "where" and in this book, we have described the power and promise of geographical analyses. We have taken a unique perspective and set of approaches to engage you, the reader, to explore how the use of Geographic Information Science concepts and methods can advance applied research and policymaking in housing. GIS tools can provide a bridge to establish connections between different fields and disciplines by connecting different conceptual frameworks using spatial anchor points that are familiar – building, neighborhood, city, and region to advance more equitable and just housing policies and practices.

NOTES

1. We use the term here not in the sense of critical theory but in the sense of a spatially aware citizen who does not uncritically fall victim to the gospel of GIS vendors or blindly applies GIS functionalities because there is a button for that.
2. MapFlow and UrbanMapping projects of the GeoAlert company, online resource available at https://github.com/Geoalert, last accessed 28 May 2023.

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Appendix 1

TABLE A.1

Housing Tenure Variables of the American Community Survey

Table	Title
B07013	Geographical Mobility in the Past Year by Tenure for Current Residence in the U.S.
B07413	Geographical Mobility in the Past Year by Tenure for Residence 1 Year Ago in the U.S.
B08137	Means of Transportation to Work by Tenure
B08537	Means of Transportation to Work by Tenure
B17019	Poverty Status of Families by Household Type by Tenure
B25003	Tenure
B25007	Tenure by Age of Householder
B25008	Total Population in Occupied Housing Units by Tenure
B25009	Tenure by Household Size
B25010	Average Household Size of Occupied Housing Units by Tenure
B25011	Tenure by Household Type (Including Living Alone) and Age of Householder
B25012	Tenure by Families and Presence of Own Children
B25013	Tenure by Educational Attainment of Householder
B25014	Tenure by Occupants Per Room
B25015	Tenure by Age of Householder by Occupants Per Room
B25016	Tenure by Plumbing Facilities by Occupants Per Room
B25020	Tenure by Rooms
B25021	Median Number of Rooms by Tenure
B25022	Aggregate Number of Rooms by Tenure
B25026	Total Population in Occupied Housing Units by Tenure by Year Householder Moved Into Unit
B25032	Tenure by Units in Structure
B25033	Total Population in Occupied Housing Units by Tenure by Units in Structure
B25036	Tenure by Year Structure Built
B25037	Median Year Structure Built by Tenure
B25038	Tenure by Year Householder Moved Into Unit
B25039	Median Year Householder Moved Into Unit by Tenure
B25042	Tenure by Bedrooms
B25043	Tenure by Telephone Service Available by Age of Householder
B25044	Tenure by Vehicles Available
B25045‡	Tenure by Vehicles Available by Age of Householder
B25046	Aggregate Number of Vehicles Available by Tenure
B25049	Tenure by Plumbing Facilities
B25053	Tenure by Kitchen Facilities
B25106	Tenure by Housing Costs as a Percentage of Household Income
B25115	Tenure by Household Type and Presence and Age of Own Children
B25116	Tenure by Household Size by Age of Householder

(*Continued*)

TABLE A.1 (*Continued*)

Housing Tenure Variables of the American Community Survey

Table	Title
B25117	Tenure by House Heating Fuel
B25118	Tenure by Household Income
B25119	Median Household Income the Past 12 Months by Tenure
B25120	Aggregate Household Income by Tenure and Mortgage Status
B25123	Tenure by Selected Physical and Financial Conditions
B25124	Tenure by Household Size by Units in Structure
B25125	Tenure by Age of Householder by Units in Structure
B25126	Tenure by Age of Householder by Year Structure Built
B25127	Tenure by Year Structure Built by Units in Structure
B25128	Tenure by Age of Householder by Year Householder Moved Into Unit
B25129	Tenure by Year Householder Moved Into Unit by Units in Structure

TABLE A.2

Housing Value Variables of the American Community Service

Table	Title
B25075	Value
B25076	Lower Value Quartile (Dollars)
B25077	Median Value (Dollars)
B25078	Upper Value Quartile (Dollars)
B25079	Aggregate Value (Dollars) by Age of Householder
B25080	Aggregate Value (Dollars) by Units in Structure
B25082	Aggregate Value (Dollars) by Mortgage Status
B25083	Median Value (Dollars) for Mobile Homes
B25096	Mortgage Status by Value
B25097	Mortgage Status by Median Value (Dollars)
B25100	Mortgage Status by Ratio of Value to Household Income
B25107	Median Value by Year Structure Built
B25108	Aggregate Value (Dollars) by Year Structure Built
B25109	Median Value by Year Householder Moved Into Unit
B25110	Aggregate Value (Dollars) by Year Householder Moved Into Unit
B25121	Household Income by Value

TABLE A.3
Mortgage-Related Variables of the American Community Survey

Table	Title
B25027	Mortgage Status by Age of Householder
B25081	Mortgage Status
B25082	Aggregate Value (Dollars) by Mortgage Status
B25087	Mortgage Status and Selected Monthly Owner Costs
B25088	Median Selected Monthly Owner Costs (Dollars) by Mortgage Status
B25089	Aggregate Selected Monthly Owner Costs (Dollars) by Mortgage Status
B25090	Mortgage Status by Aggregate Real Estate Taxes Paid (Dollars)
B25091	Mortgage Status by Selected Monthly Owner Costs as a Percentage of Household Income
B25096	Mortgage Status by Value
B25097	Mortgage Status by Median Value (Dollars)
B25098	Mortgage Status by Household Income
B25099	Mortgage Status by Median Household Income
B25100	Mortgage Status by Ratio of Value to Household Income
B25101	Mortgage Status by Monthly Housing Costs as a Percentage of Household Income
B25102	Mortgage Status by Real Estate Taxes Paid
B25103	Mortgage Status by Median Real Estate Taxes Paid (Dollars)
B25120	Aggregate Household Income by Tenure and Mortgage Status

TABLE A.4
Variables Related to Home Ownership Costs in the American Community Survey

Table	Title
B25087	Mortgage Status and Selected Monthly Owner Costs
B25088	Median Selected Monthly Owner Costs (Dollars) by Mortgage Status
B25089	Aggregate Selected Monthly Owner Costs (Dollars) by Mortgage Status
B25091	Mortgage Status by Selected Monthly Owner Costs as a Percentage of Household Income
B25092	Median Selected Monthly Owner Costs as a Percentage of Household Income
B25093	Age of Householder by Selected Monthly Owner Costs as a Percentage of Household Income
B25094	Selected Monthly Owner Costs
B25095	Household Income by Selected Monthly Owner Costs as a Percentage of Household Income

TABLE A.5
Variables Related to Rent Costs in the American Community Survey

Table	Title
B25031	Median Gross Rent by Bedrooms
B25057	Lower Contract Rent Quartile (Dollars)
B25058	Median Contract Rent (Dollars)
B25059	Upper Contract Rent Quartile (Dollars)
B25060	Aggregate Contract Rent (Dollars)
B25062	Aggregate Rent Asked (Dollars)
B25064	Median Gross Rent (Dollars)
B25065	Aggregate Gross Rent (Dollars)
B25066	Aggregate Gross Rent (Dollars) by Units in Structure
B25067	Aggregate Gross Rent (Dollars) by Meals Included in Rent
B25070	Gross Rent as a Percentage of Household Income
B25071	Median Gross Rent as a Percentage of Household Income (Dollars)
B25072	Age of Householder by Gross Rent as a Percentage of Household Income
B25074	Household Income by Gross Rent as a Percentage of Household Income
B25111	Median Gross Rent by Year Structure Built
B25112	Aggregate Gross Rent (Dollars) by Year Structure Built
B25113	Median Gross Rent by Year Householder Moved Into Unit
B25114	Aggregate Gross Rent (Dollars) by Year Householder Moved Into Unit

TABLE A.6
Variables Describing Housing Characteristics in the American Community Survey

Table	Title
B25031	Median Gross Rent by Bedrooms
B25041	Bedrooms
B25042	Tenure by Bedrooms
B25068	Bedrooms by Gross Rent
B25016	Tenure by Plumbing Facilities by Occupants Per Room
B25047	Plumbing Facilities for All Housing Units
B25048	Plumbing Facilities for Occupied Housing Units
B25049	Tenure by Plumbing Facilities
B25050	Plumbing Facilities by Occupants Per Room by Year Structure Built
B25051	Kitchen Facilities for All Housing Units
B25052	Kitchen Facilities for Occupied Housing Units
B25053	Tenure by Kitchen Facilities
B25054	Kitchen Facilities by Meals Included in Rent

TABLE A.7

Esri's Tapestry Segmentation Categorized by Racial/Ethnic and Housing Characteristics and Their Geographic Distribution

Market Segment	Dominant Geography	Renting %	Households Total	White %	Asian %	Black %	Hispanic %
High-rise renters	Poor, multi-generational dense cities	96.3	622,500	23.8	4.9	36.5	57.4
Fresh Ambitions	Multi-generational immigrants in older major city neighborhoods	72.9	794,600	35.2	5.7	24.4	55.2
Farm to Table	Hispanic agricultural, mostly in CA and WA	55.6	299,600	44.6	2.6	3.4	82.9
Family Extensions	Older Hispanic neighborhoods Periphery of West Coast metros, NYC and CHI	64.3	912,400	43.7	4.2	6.3	84.7
NeWest Residents	Recent immigrants in large metros in South and West	83.4	970,800	44.4	4.5	11.3	72.2
City Commons	Low-income mid-sized buildings in metro cities	77.0	1,106,600	14.3	1.3	75.9	9.1
Southwestern Families	Hispanic older neighborhoods in SW city centers and suburbs	46.3	1,021,400	69.8	82.5	5.9	1.6
Forging Opportunity	Urban periphery of larger metros in South and West	40.5	1,289,900	56.2	2.4	7.9	72.5
Modest Income Houses	Older urban neighborhoods in the eastern half of the country	55.3	1,627,600	10.1	0.5	84.7	4.8
Hometown Heritage	Old neighborhoods in central cities in South and Midwest	60.0	1,507,700	53.2	2.3	28.0	20.8
Social Security Set	Older housing in high-density metro cities	86.2	1,001,400	49.7	7.1	31.2	18.6
Diverse Convergence	Dense urban peripheries on the Coasts and CHI	72.4	1,528,100	44.0	11.3	11.7	57.6
Metro Fusion	Urban periphery apartments	76.0	1,753,500	42.7	5.2	30.8	34.2
City Strivers	Dense city neighborhoods Bos-Wash and Chi	68.1	962,900	12.2	3.0	71.3	19.4
Down the Road	Semi-rural mobile homes in metro areas in South and West	34.8	1,406,700	67.7	1.8	10.7	27.5
Downtown Melting Pot	High-density apartments in CA and Mid-Atlantic	68.6	814,000	43.0	39.1	4.3	20.1
Rural Bypasses	Ultra-rural South	30.1	1,646,400	56.5	0.5	34.7	5.6

(Continued)

TABLE A.7 (*Continued*)

Esri's Tapestry Segmentation Categorized by Racial/Ethnic and Housing Characteristics and Their Geographic Distribution

Market Segment	Dominant Geography	Renting %	Households Total	White %	Asian %	Black %	Hispanic %
Urban Villages	Older homes in urban periphery of larger metros	19.9	1,319,200	49.5	11.2	7.4	63.4
Family Foundations	Stable low-income neighborhoods in cities S and W	34.3	1,299,600	13.2	1.1	79.8	7.4
Urban Edge Families	Urban periphery of larger metros in South and West	36.3	1,824,900	52.1	5.4	20.0	44.4
Small Town Sincerity	Small towns and semi-rural neighborhoods	50.3	2,305,700	76.5	1.3	13.2	10.4
Front Porches	Old neighborhoods	53.5	1,960,300	63.7	4.8	15.0	24.0
Set to Impress	Suburban apartments	72.3	1,714,100	64.7	3.7	18.5	16.7
Traditional Living	Low-density urban areas in Midwest and South	41.1	2,395,200	74.3	1.7	13.4	12.7
Dorms to Diplomas	Older small apartment buildings	92.5	630,300	70.6	12.9	9.8	8.5
Economic Bedrock	Ultra-rural mining and mobile homes	24.5	810,000	84.2	0.6	6.3	11.7
Senior Escapes	Seasonal rural homes in CA, AZ, and FL	24.8	1,116,000	93.9	1.6	4.4	13.9
College Towns	Dense student housing in mid-sized cities and towns	75.4	1,176,200	71.6	7.8	12.4	10.2
Young and Restless	Dense city neighborhoods in non-coastal areas	86.9	2,131,500	53.3	8.0	23.9	22.5
Southern Satellites	Rural exclaves in Southern metros	22.3	3,856,800	84.1	0.8	7.9	8.8
Rooted Rural	Rural Appalachia, TX and AR	20.2	2,430,900	88.4	0.5	5.8	5.1
Heartland Communities	Rural areas from Rustbelt to Great Plains	30.6	2,850,600	88.4	0.9	4.7	6.8
City Lights	Dense urban but not apartment	48.3	1,813,400	60.2	13.5	10.6	25.7
Old and Newcomers	Gentrifying city neighborhoods	54.8	2,859,200	76.5	3.9	10.9	11.9
Retirement Communities	No particular geography	54.9	1,501,100	79.2	4.6	9.2	11.6

(*Continued*)

TABLE A.7 (*Continued*)

Esri's Tapestry Segmentation Categorized by Racial/Ethnic and Housing Characteristics and Their Geographic Distribution

Market Segment	Dominant Geography	Renting %	Households Total	White %	Asian %	Black %	Hispanic %
Trendsetters	Cores of high-rent cities	75.5	1,319,400	57.7	14.8	11.4	24.3
Bright Young Professionals	Apartments in urban periphery of larger metros	57.2	2,750,200	65.1	6.4	16.6	17.4
Rustbelt Traditions	Dense fringe of metros in South and Midwest	28.8	2,716,800	81.2	2.1	8.8	11.5
Pacific Heights	Urban periphery of CA and Northeast metros	27.6	889,400	34.7	48.6	3.1	15.6
Parks and Rec	Older suburban neighborhoods	30.3	2,449,600	78.7	3.7	0.6	12.3
Middleburg	Semi-rural places within metros	26.6	3,511,200	79.5	2.4	10.0	11.2
The Great Outdoors	Rural areas in West, South and Northeast	22.5	1,908,600	87.4	1.7	3.0	8.7
Home Improvement	Low-density suburbs	20.6	2,114,500	69.3	5.7	13.8	19.7
Up and Coming Families	New suburban peripheries	26.1	2,901,200	63.7	6.9	15.3	27.3
Midlife Constants	Older suburban periphery of small metros	27.3	3,068,400	86.0	2.1	6.6	7.7
Salt of the Earth	Rural areas in OH, PA, IN	16.9	3,545,800	93.0	0.7	2.6	3.8
Rural Resort Dwellers	Scenic rural, often seasonal	18.9	1,227,200	92.0	0.8	2.1	5.1
Prairie Living	Ultra-rural in the Midwest	20.7	1,323,200	92.8	0.6	1.1	6.6
Pleasantville	Suburbs of larger coastal metros	16.9	2,718,100	73.1	8.5	8.8	17.6
Enterprising Professionals	Suburbs all over	48.8	1,737,200	54.1	23.3	12.1	14.7
Emerald City	Low-density neighborhoods in all urban areas	51.5	1,748,600	77.7	5.2	9.3	11.1
The Elders	Suburban periphery of warm metros	18.6	910,100	93.1	1.8	2.7	5.6
Military Proximity	Metro suburbs South and West	97.0	186,600	65.3	4.6	16.9	18.5
Metro Renters	Urban cores	79.8	1,911,500	66.9	14.5	10.8	11.7

(*Continued*)

TABLE A.7 (*Continued*)

Esri's Tapestry Segmentation Categorized by Racial/Ethnic and Housing Characteristics and Their Geographic Distribution

Market Segment	Dominant Geography	Renting %	Households Total	White %	Asian %	Black %	Hispanic %
Golden Years	Large metro areas but not central cities	37.3	1,657,400	81.3	7.0	6.6	8.8
Green Acres	Rural areas within metros	13.9	3,923,400	90.8	1.6	3.3	5.5
In Style	Older neighborhoods in metro cities	32.2	2,764,500	83.5	4.6	6.1	7.8
Comfortable Empty Nesters	Suburbs and small towns	13.1	3,024,200	87.2	2.7	5.8	6.6
Workday Drive	Suburban peripheries	15.1	3,541,300	78.0	6.2	8.7	11.7
Silver and Gold	Seasonal suburban near metro cities	16.8	942,900	92.3	2.2	2.3	5.8
Urban Chic	Suburbs of larger coastal metros	33.8	1,635,200	79.1	9.7	4.3	10.2
Boomburbs	Suburbs of larger metros	16.0	2,004,400	68.1	15.6	8.0	15.0
Laptops and Lattes	Cities in larger metro areas	62.7	1,307,500	76.1	12.8	4.7	9.3
Exurbanites	Suburbs of larger metros	15.1	2,398,200	86.3	5.7	3.3	7.4
Savvy Suburbanites	Suburbs of larger metros	9.4	3,664,200	85.5	6.0	0.3	7.2
Professional Pride	Suburbs of larger metros	8.4	1,982,300	78.7	12.6	4.3	6.9
Top tier	Suburbs of larger coastal metros	9.8	2,113,000	82.8	11.2	2.2	5.9

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