# Walk Deserts

by

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BFA Parsons School of Design (2011)

Submitted to the Program in Media Arts and Sciences,
School of Architecture and Planning,
in partial fulfillment of the requirements for the degree of

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## Abstract

This thesis describes a new methodology to identify, measure, and understand "Walk Deserts." This methodology comprises a system for identifying, mapping, and visualizing areas that are ostensibly highly walkable places according to traditional criteria and indicators, but that are also plagued with invisible environmental factors that impede walkability and threaten public health. This research has two principal aims: (1) to better understand and begin to address blind spots in walkability indicators as well as perception-based measurements (that are difficult to quantify and subject to bias), and (2) to present a greater range of environmental data associated with walkability and negative health outcomes in publicly accessible ways in order to facilitate community engagement. Two key contributions emerged from this research: (1) a theoretical re-definition of the concept of "walk deserts" to highlight typically overlooked aspects of walkability, and (2) a creative and technical contribution that focuses on finding "walkable deserts in the City" and visualizing these deserts in immersive ways. Boston's Chinatown district serves as a case study site, a "walk desert" hidden in plain sight. With the presence of greenways surrounded by highways, it appears to be a seemingly walkable and even heavily touristed neighborhood with dramatically poor health outcomes. Digital photogrammetry is used to explore how merging photorealistic, three-dimensional spatial models with environmental data can produce immersive and interactive data visualizations, including a web application, an augmented reality interface, and an interactive installation. These interfaces expose the "walk desert" hidden in Chinatown, and provide a mechanism to engage members of the community, as well as researchers and policy-makers, in the process of transforming degraded urban spaces into healthier and move vibrant ones.


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# Chapter 1

# Introduction

## 1.1 Overview

The COVID-19 pandemic has dramatically changed how people navigate and utilize cities on a daily basis, from working remotely to dining outdoors. This, in turn, has compelled policymakers across the world to pay greater attention to urban "walkability," or how friendly an area is to walking. Paris and Barcelona, for instance, have prioritized policies to transform themselves into 15-minute cities, where urban dwellers can meet all of their daily needs by walking or biking short distances. Further, creating more walkable infrastructure like green spaces, better lighting, and wider sidewalks have been shown to shape residents' walking habits and have substantial effects on a city's carbon footprint, local economy, and public health outcomes [7].

While walkability has been identified as a crucial marker of cities and health, some important questions remain regarding how neighborhoods might become more walkable and communities, in turn, healthier. In particular, researchers and urban planners continue to examine the specific features and dynamics of spaces that render them truly walkable and healthy [8, 9].

Metrics typically used to measure walkability focus on infrastructure and other visible aspects of the built environment. But recent research shows that many of the variables that can impact walkability (such as noise and air pollution) aren't readily perceptible through visual systems. These non-visible factors can also occur in areas that actually and mistakenly score high using typical walkability indices (as discussed later in this thesis). As we continue to develop walkable and high-density cities, it's crucial that we develop public tools that allow communities and urban planners to better visualize, understand, and advocate for more truly walkable environments.

Current methods to map and visualize walkability metrics have two key limitations: First, they often fail to address more subtle or transient ambient factors that impede walkability. Maps and tools like Google Street View provide visible markers of the built environment. However, they are not effective in conveying information about facets of the environment that are non-visual, such as noise, traffic, and air pollution. Second, these approaches often make it difficult to understand the surrounding environments or neighborhoods, so that socioeconomic and health inequities remain obfuscated. As a result, such data visualization can lack crucial contextual information, such as the lived experience of inhabiting a space.

Walkability visualizations are thus often emblematic of larger issues that plague data visualizations in general: multi-faceted human experiences are flattened in ways that leave out important nuances and complexities, and some communities' experiences are rendered more relatable than others'. Who is the issue of (non-)walkability actually impacting, and how? What communities are centered as we define terms like walkability? How do our mapping and data visualization techniques inform our understanding?

Focusing on these questions, I identified areas of the city that look walkable but in many ways are not. I call these areas "walk deserts." The literature on inequalities, specifically, suggests that interdependent effects remain missing or under-examined from dominant definitions and frameworks of walkability, which I discuss later in this paper.

This thesis explores whether, and how, immersive mediums can help us to see typically invisible variables like noise pollution, to see a greater range of variables at once, and to quickly switch between different scales, thus relating a specific location to not only its neighborhood but surrounding areas. In these ways, immersive media can play a role in making data visualizations more relatable and legible.

## 1.2 Contribution

I developed "Walk Deserts" to better understand and begin to address blind spots in walkability indicators and perception measurements, and to present a greater range of environmental data that impact walkability and are associated with negative health outcomes, in publicly accessible ways that may encourage dialogue. With these goals in mind, I conceptualized "Walk Deserts" as a system for identifying, mapping, and visualizing areas that are ostensibly highly walkable places according to traditional criteria and indicators, but that are also plagued with invisible environmental factors that impede walkability and threaten public health. I hope that my thesis makes two key contributions. First, my theoretical contribution focuses on the notion of "walk deserts," especially those hidden in plain sight, to highlight typically overlooked aspects of walkability. This includes an operational definition and ways of identifying such areas. Second, my creative and technical contribution focuses on visualizing these deserts in immersive ways.

I coined the term "walk deserts" using the popular term "food deserts" as a reference point [10]. If food deserts are areas with limited access to affordable and nutritious food, then the most basic definition of walk deserts might be areas with limited access to walkable and healthy spaces. This definition seems straightforward enough, but what makes a space healthy? Beyond questions of whether, say, green spaces and parks or sidewalks exist in the first place, any stretch of sidewalk becomes walkable if there is shade from trees, there are benches to rest on, if there are different sorts of business or buildings nearby with a range of amenities (including restrooms), etc. These sorts of infrastructural factors are well captured in existing walkability indices, discussed in-depth later. In the food desert analogy, comparable factors include distance to a large supermarket carrying a range of produce.

A food desert, however, is not solely defined by whether food exists in the area, but whether it is affordable to local residents, whether it is fresh and of high quality, and whether it provides nutritional value. Thinking about these contextual, relative (food prices being relative to both residents' incomes and to prices of comparable foods in other areas) factors immediately raises issues of nuance, less visible variables, and even contradiction. After all, food deserts are not bereft of food—they are in fact filled with too much unhealthy, calorically rich, processed food that ends up being more affordable than what little fresh produce they do have, contributing to an epidemic of obesity. Likewise, I became intrigued about the potential of the term "walk deserts" when I realized that some of the areas I found to have poor health outcomes did not actually lack spaces where one could put one foot in front of another and walk. They had sidewalks and greenways, but some contextual, relative factors were at play that made these seemingly walkable spaces not. I took this on as a challenge to understand and better engage notions of "walk deserts" and walkability indices writ large.

Given the extent to which policymakers, researchers, and even real estate developers regularly trumpet the importance of walkability and its integral role in public health and well-being, I generated maps of health outcomes and well-being across neighborhoods in Boston. Plotted alongside maps of walkability using existing walkability indices, I found, unsurprisingly, that these maps greatly overlapped. More intriguing, though, were the places where they did not fully do so.

After creating a map that identifies such walk deserts, I realized that 2-dimensional maps could not properly convey the qualitative, subjective, synergistic, and more subtle aspects of "walk deserts" that made them so difficult to identify and properly recognize in the first place. I thus turned to immersive visualizations as a richer and more appropriate tool for investigations of walkability.

Using Boston's Chinatown as a case study of a walk desert, I have built a tool to identify "walk deserts" by performing various analyses on civic data, and coming up with a series of indicators that can help identify them. Specifically, I have built a visualization platform to (1) show 3D models of environments captured via photogrammetry in an immersive environment and (2) convey temporal and environmental data within the environment in a spatialized way.

# Chapter 2

# Background

## 2.1 Understanding Walkability

### 2.1.1 The Walkable Landscape

A number of urban scholars have underlined the importance of critically examining walkability. For instance, in work to codify definitions of walkability across a large dataset of scholarly research, Ann Forsyth helpfully establishes three discrete clusters of how this term is used. First are the technical means and tenets of creating walkability, specifically: easily accessible and traversible environments, dense saturation of amenities and services, public safety, and "physically-enticing" infrastructure that provide pedestrian friendly infrastructure like benches as well as aesthetically pleasing environments. The second cluster consists of definitions of the outcomes that walkability can lead to, which include higher quality public transportation, reduced carbon footprint, and improved public health. Lastly, a group of definitions describes the indicators and metrics used to measure walkability, such as health, safety, and usage of public services. Walkability is thus invoked in both positivist/ empirical and normative terms, and as both means and ends of desirable cities. It is deeply contested and value-laden [11].

Forsyth's framework resonates when we review key, dominant definitions of walkability used by practitioners. What constitutes walkability is especially important to practicing urban planners, who use this to both develop and implement so-called "walkable infrastructure", and also communicate with communities. For instance, in *In Walkable City: How Downtown Can Save America, One Step at a Time*, urban planner Jeff Speck establishes a "general theory of walkability," whereby successful urban design makes a walk "useful, safe, comfortable, and interesting". Speck outlines ten design principles towards achieving "walkability," including factors such as increasing mixed use development and greenspaces, and improving biking and pedestrian infrastructure [8]. While many of these same principles are proposed broadly in urban design literature, they primarily address infrastructural changes and do not account for more nuanced factors, such as varying environmental conditions and socioeconomic inequalities.

Despite seemingly codified rules of walkability, practitioners continue to struggle to operationalize what it looks like in real life. For example, Jannette Sadik-Khan, former commissioner of the NYC Department of Transportation (DOT), radically transformed New York City into a more pedestrian- and bike-friendly city [12]. Her main strategy was using "tactical urbanism," the traditionally bottom-up practice of reclaiming public space through small interventions. Using this approach, Sadik-Khan helped remake Times Square into a multipurpose public park by reducing traffic through the use of elements like paint, lights, signs and planters. This initial, brute-force experiment—and its warm reception from the public and policy-makers—later led to more permanent infrastructural changes like greenspace, pedestrian-only streets, and outdoor cafes [13]. The DOT's practice of tactical urbanism in order to inform infrastructural changes highlights the immense challenge of envisioning and implementing even relatively simple new urban forms, even when proponents are in formal positions of power. While the DOT won praise for its successful use of tactical urbanism, real-life, community-initiated instances of this practice are not only looked down upon, but often criminalized or permitted only when they also serve commercial interests [14]. While tactical urbanism attempts to change the status quo through short-term interventions, most precedents related to walkability only succeed when they are initiated by governmental agencies or by institutions with resources and some political power.

These tensions are also reflected in an attempt by the DOT to address walkability on a neighborhood level. In this initiative, the agency sent out surveys to urban dwellers with a series of questions called the "The Neighborhood Walkability Check." On the form, respondents were encouraged to call 311 to file complaints about any infractions in their neighborhood. Among the various questions, the prompt, "Is it pleasant to walk around my neighborhood?" offers the following potential, pre-articulated problems to choose from: "Not well lit; Suspicious activity; Dirty, lots of litter or trash; Scary dogs; Needs more trees, flowers" [15]. In contexts with deep inequalities, such approaches can raise problematic questions on whose walkability is being defined and exercised. Certain measures, like "suspicious activity" or "broken windows," are now so fraught as to be racially coded. There are hundreds of court cases that debate what behaviors (or who) might be considered "suspicious," long histories of real estate covenants and public health laws against Black and Asian Americans based on perceptions of "dirtiness," and controversial policing techniques and floodlights in the name of well-lit and safe streets [16, 17, 18]. To many planners and urban scholars, simply building better infrastructure fails to meaningfully increase walkability if histories of racial discrimination and persistent socioeconomic inequalities remain unaddressed. If local residents do not have the means to take advantage of new infrastructure, and if jogging or just hanging out is criminalized as loitering or "suspicious activity", communities of color will not accrue the benefits of these changes.

Further, certain definitions of the term "walkability" serve as a key, financialized metric in the real estate market, so much so that it is seen as a reliable arbiter of property values. For instance, the Seattle-based company "Walk Score" provides a commercial walkability index that scores any address in the United States, Canada, and Australia. The product estimates a location's efficiency (via an "automated efficiency model") through criteria such as proximity to public transit and nearby amenities like "businesses, parks, theaters, schools and other common destinations" [19]. Real estate brokers and developers routinely emphasize the profitability of improving walkability, according to these commercial definitions.

These dominant interpretations of walkability highlight the range of stakeholders involved, and raise the point that contextualized, community-driven perspectives remain relatively under-examined, even if not altogether absent. These definitions also highlight specific points of contention, such as the relative weight of different measures as "desirable," and whether different amenities and features are realistically usable by residents with fewer resources or less time [20]. As Forsyth's analysis suggests, meaningful definitions and indices of walkability should make explicit a range of factors in addition to infrastructure, as well as who benefits most from specific visions of walkability.

### 2.1.2 The Era of the "15-minute City"

It is urgent and crucial that we attend to these questions now, because the COVID-19 pandemic has only magnified these issues and inequalities. In a short span of time, it has led to newly emergent and tactical forms of walkability and placemaking across major international cities. A prominent example lies in previously exceptional and now routine street closures to allow for more public space and outdoor dining. This, in turn, has increased discussions about how public policy can both retain these new qualities and build upon them in order to increase urban walkability. For instance, Paris recently prioritized policies to transform itself into a "15-minute city," whereby urban dwellers can meet all of their daily needs by walking or biking. The concept became one of the key issues in the reelection campaign of Paris mayor Anne Hidalgo, who appointed a commissioner to spearhead the initiative. In order to accomplish this goal, the administration outlines that neighborhoods need to serve six social functions: "living, working, supplying, caring, learning and enjoying." [21]

The research group I work with, City Science at the MIT Media Lab, has been heavily invested in these issues for years; the 15-minute city is a core focus for new research projects. Interventions such as hybrid live/work spaces to prevent cross-district commuting, transformable architecture to allow for compact housing, and algorithmic zoning to optimize the placement of local amenities all foster cities where urban dwellers can access the everyday necessities of life within a short walking distance. An ambitious goal of this work by the City Science research group, and arguably the next step for "15-minute" cities, is district-level net zero carbon emissions [22].

The concept of walkability, with all of its purported and desirable effects, now has the attention of policymakers worldwide, and is at a crossroads. However, it is still unclear if can it be implemented in ways that benefit historically marginalized communities.

### 2.1.3 A Walkable Divide: The Intersection of Walkability and Public Health

While "walkability" has been documented as a crucial conduit between cities and health, deeply rooted racial and socio-economic inequalities exist between who currently takes walks, who does not, and why. A recent study published in the journal Nature observed walking behavior before and during the pandemic across 10 major US cities. Three specific findings from this research stand out. First, higher-income city dwellers walked more during the pandemic compared to those in lower-income brackets. Second, lower-income individuals were less likely to take leisurely walks and primarily took utilitarian ones, for instance going to work or the grocery store. Third, extreme income-based disparities exist in contributing factors to walkability, like access to parks and other greenspaces [9].

Throughout my research, it became evident that greenspace is an essential diverging node in the rhizomatic network of environmental public health crises. Greenspace plays a vital role in these issues beyond just being another type of public amenity. It directly tracks with heat, noise, and air pollution, worse health outcomes for residents, and is disproportionately inaccessible by lower income and historically marginalized communities [23, 24]. Given these compounding and hazardous effects, greenspace like trees need to be reframed beyond amenity, towards a vital infrastructure, akin to sewer networks or power grids.

Substantive infrastructural differences can mean that there are deep racial and income inequalities in walkability of neighborhoods within close proximity. Many of these inequities track with the practice of redlining in the 1930s, whereby neighborhoods across the country were assigned color-coded risk grades based on how "hazardous" they were to investment. Neighborhoods assigned with the worst grade (outlined with the color red) had disproportionately higher populations of racial and ethnic minorities. Decades of being rejected from financial services has left these with inadequate infrastructure and are heavily segregated from neighboring areas. Multiple research studies have found that lack of greenspace, elevated levels of noise and air pollution, and higher mortality rates directly track with redlining.

Lack of tree canopy coverage and vegetation have more exposed infrastructure like concrete roads and buildings which strongly retain and emit the sun's heat [25]. For instance, the temperature of lower-income neighborhoods in Baltimore, Maryland can be up to 15-20 degrees (F) hotter than adjacent ones during heat waves [1]. The fact that these hotter neighborhoods are often in close proximity to cooler ones has led them to be called "heat islands".

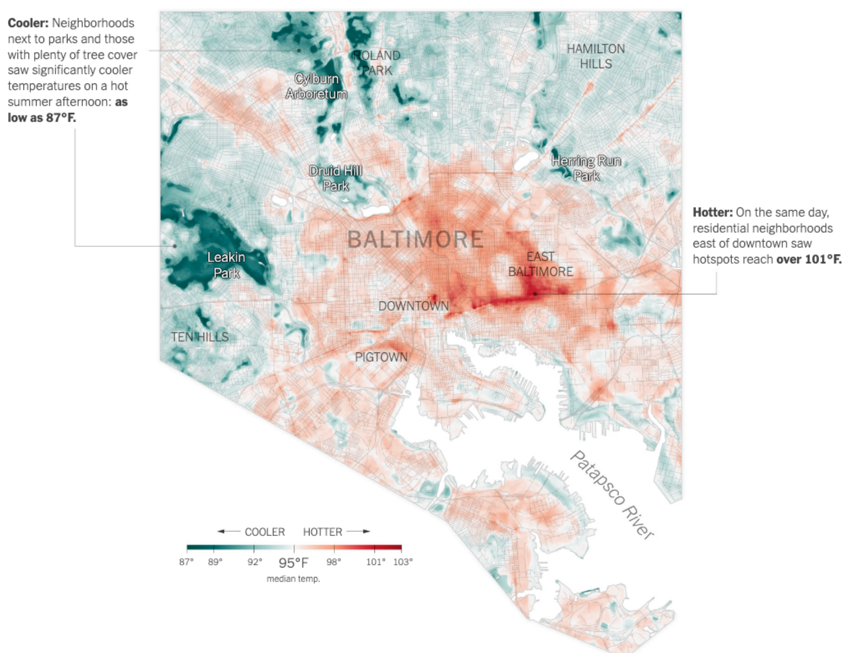


Figure 2-1: Summer afternoon temperature levels in Baltimore [1].

"Heat islands" and redlined neighborhoods also suffer from higher levels of air pollution than nearby higher-income areas. The South Bronx in New York City has one of the highest death and disease rates from asthma in the country, despite being just a 15-minute bike ride from Central Park [26]. Factors such as lack of green space, industrial zoning, and proximity to logistics infrastructures like shipping facilities can be crucial contributors to these health outcomes [27].

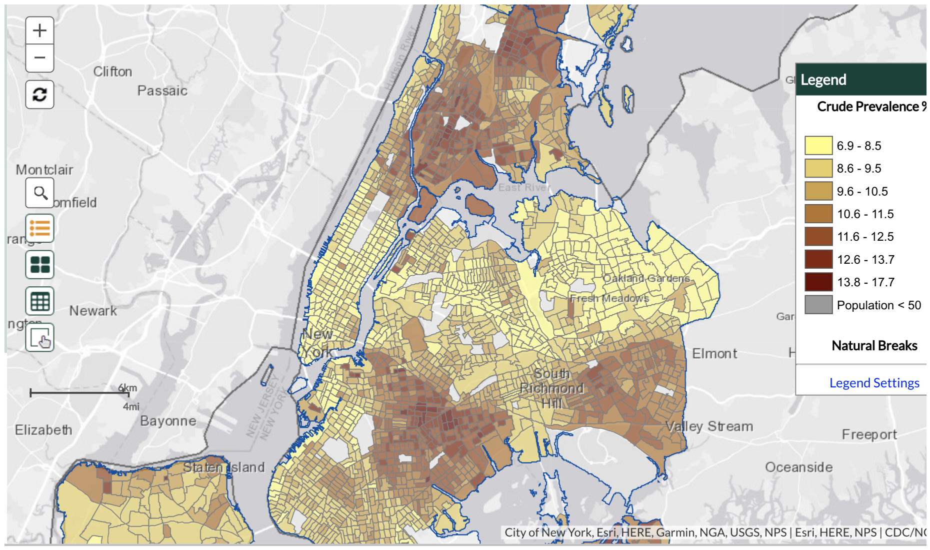


Figure 2-2: Crude prevalence of adult asthma across New York City districts [2].

Unequal access to nutritious, locally-sourced food is also deeply rooted in walkable inequities. Neighborhoods with less local amenities mean residents need to travel further to shop for groceries. These areas, referred to as "food deserts" as discussed above, are sometimes misunderstood to solely imply scarce access to local food [10]. However, a major qualifier here is that these areas often moreso lack access to nutritional, affordable food options. An area can still qualify as a "food desert" even if it has multiple fast-food restaurants that provide unhealthy options or healthy options at a price outside the reach of the surrounding economic demographics.

Likewise, the creation of walkable infrastructure does not necessarily imply positive social and economic impact or equitable access. While many lower-income communities lack access to greenspace, the creation of new greenspace can actually exacerbate socioeconomic inequalities. A 2019 study examining the impacts of new greenspace on gentrification across 10 major US cities found that living within a half-mile proximity to a new long greenway park (such as the High Line in New York City) can increase the chance of neighborhood gentrification by over 200%. Development and access to greenspace directly tracks with real estate prices, increasing the possibility of displacing lower income communities [24]. This highlights the ways in which different aspects of walkable infrastructures are highly interconnected and synergistic, potentially leading to unintended or even harmful outcomes when they are not analyzed and implemented in holistic ways.

Thus, providing traditional statistics, maps, and data visualizations to communities, planners, and governments might fail to address the compounding and intersectional nature of these issues. Providing insights is a crucial step towards advocacy. However, on its own and using traditional methods originally developed by and for institutions, it is not always effective in highlighting the everyday lived experiences and long-term impacts of living and walking in these affected neighborhoods. In addition to giving a voice to advocacy, it remains crucial to explore new visualization methods that convey more nuanced information, especially when multiple dimensions might have synergistic effects, in visceral and contextualized ways.

### 2.1.4 Indicators and Measurements

Traditional methods of measuring walkability, generally called "walkability audit tools," often focus on assessing aspects of physical infrastructure in the built environment. These include features like bike lanes, access to public transit, wide sidewalks, and local amenities. One company that uses these kinds of indicators to provide analytics is "Walk Score". This organization created a walkability index that provides information such as how quickly residents can get from point A to point B, based on available transit options, and whether certain essential businesses, such as grocery stores, exist within a short distance [19]. The tool is primarily intended to help assess local real-estate values. However, their algorithm has been criticized by some for excluding important factors related to walkability, like sidewalks, traffic, and greenspace.

In their paper "Measuring the Unmeasurable: Urban Design Qualities Related to Walkability", Susan Handy and Reid Ewing highlight the importance of perceptual walkability. The emphasis is not solely placed on, for example, how wide a sidewalk is, but whether it makes the space feel easier to traverse or safer and how it impacts one's behavior [28]. In their study, the authors created operational definitions in order to assess an expert panel's perceptions of street images. They identified and included five urban design qualities in their survey: imageability, enclosure, human scale, transparency and complexity.

This focus on perceptual walkability was the impetus of Healthy Streets, a UK-based organization and "human-centered framework for embedding public health in transport, public realm and planning" [29]. Founded by public health specialist and urbanist Lucy Saunders in 2018, the initiative has developed 10 indicators to measure human's perceptions and experience of streets. Among these are qualities like feeling welcome, ease crossing streets, and feeling safe. The organization has also developed interactive maps with a unified health index to specify how healthy a specific street segment is in the greater London area.

### 2.1.5 Walk Deserts Hiding in Plain Sight

Existing work on contested definitions of walkability, 15-minute cities, and issues of equity and walkability divides profoundly shaped and deepened my conceptualization of walk deserts. In particular, this work compelled me to not take any definition of walkability for granted; a street that might look perfectly walkable to a tourist might not appear so to a long-time resident, especially one with mobility issues or from a historically marginalized community. Instead, informed by this work, I emphasize public health outcomes and especially important medical and social determinants of health, such as noise and air pollution, that have often been excluded from analyses of walkability.

As a starting point, I collected and analyzed environmental and civic data in New York and Boston, the cities I am most familiar with (and with high degrees of income and racial residential segregation, and decent public data). I explored how combined and leveraged datasets could be used to create an environmental index for streets throughout the city. Looking especially into aspects of well-being with striking spatial inequalities, such as asthma rates, I began to understand factors like air pollution – currently not represented in existing walkability indices – as important to convey. Some of these investigations highlighted obvious "walk deserts," like those I described in the "Walkable Divides" section above.

But Boston's Chinatown, in particular, emerged as an area with profound, intriguing contradictions: the presence of greenways surrounded by highways, a seemingly walkable and even heavily touristed neighborhood with dramatically poor health outcomes. I was struck by how existing walkability indices might not have flagged the neighborhood as one in need of amelioration, as it would the South Bronx or the areas of Baltimore pinpointed above. Boston's Chinatown is thus a "walk desert" hidden in plain sight.

I came to appreciate how a bench beneath a shady tree did not make a particular space hospitable, if there is roaring traffic noise and smog in the air. If the storefronts are of interest to tourists, they might find the street walkable, but local residents might not. Indeed, while thinking abut the complexities of such contextual data, I learned that some food justice advocates have veered away from naming "food deserts" as their key challenge, instead using the term "food apartheid," in order to place more emphasis on political histories and economic issues [30]. While I still use the term "walk deserts" in this thesis, I hope to do so by centering, rather than sidelining, issues of equity and context in my analysis.

Better understanding existing frameworks of walkability, their strengths and weaknesses, and the historically embedded and multi-faceted dimensions of existing walkability divides compelled me to refine my definition and conceptualization of walk deserts. Whereas my previous notions focused on visible infrastructure, better understanding walkability prompted me to shift to emphasize the invisible aspects of walk deserts and how different, seemingly disparate dimensions—such as sidewalk infrastructure, air pollution, noise pollution—are actually inextricably connected. My next challenge then involved developing a tool to help convey this.

## 2.2 Visualization and Engagement

### 2.2.1 Documenting the Real World in 3D

In this thesis, I explore how merging photorealistic three-dimensional models with environmental data can be used to develop immersive data visualizations. Recreating realistic 3D environments has been a long-researched area in both the film and game industries. Where this process once required extremely powerful computers and an advanced knowledge of 3D modeling software, even people with little technical experience can now quickly convert an environment or object into a model using their phones. However, balancing the accuracy, fidelity, and size of large 3D environments is an intricate process and requires multiple techniques.

Photogrammetry is a process that can create 3D models using multiple two-dimensional photos of an object or scene. In order for photogrammetry software to derive spatial information from the photos, they need to contain overlapping imagery. The differences between two overlapping photos creates "parallax," or the amount of displacement between features in the images. For instance, an object closer to the camera in the scene will have changed position and scale at a faster rate than an object farther away from the camera. Photogrammetry software uses parallax to generate three-dimensional spatial data from these photos using three phases: alignment, reconstruction, and texturing. The alignment phase generates a point cloud (or series of vertices in 3D space) that define prominent features from the images. This point cloud data is then connected together to create a 3D mesh during the reconstruction process. Finally, the software uses the mesh to find matching imagery from the original photographs to generate a texture map, resulting in a model with photorealistic textures.

### 2.2.2 Web-based Extended Reality

A core part of this thesis is an immersive, interactive experience. I designed this component to be flexible and accessible, as I iterated on the concept throughout the process. This

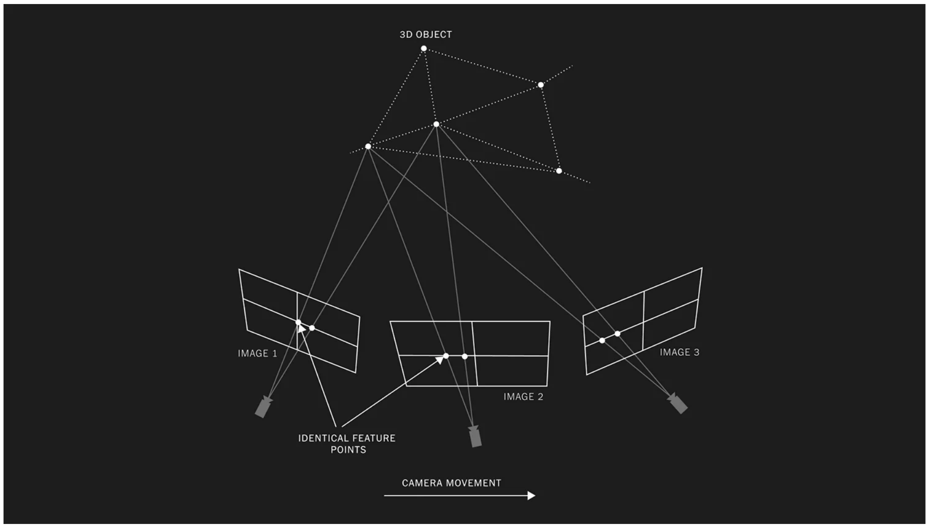


Figure 2-3: Diagram of how to photograph an object in order to capture parallax for photogrammetry [3].

led to the decisions to develop the immersive experience for the web using javascript and implementing the WebXR API.

Extended reality (referred to as XR) is an umbrella term for different technologies that allow us to spatialize digital content within a physical environment. The three main technologies currently used in popular products and visualizations are augmented reality (AR), virtual reality (VR), and mixed-reality (MR). Augmented reality involves overlaying content on top of a 2D image so that it appears to exist within the real-world when looked at through a device (commonly a phone). In virtual reality, content is experienced on a screen within a headset that completely obscures a user's vision of the world around them. Users typically interact with content using a handheld controller. Mixed reality is similar to augmented reality; however, instead of viewing the final augmented scene as a 2D image, overlaid content is projected onto transparent glasses a user is wearing. This adds an extra layer of realism because users are looking directly at the real world around them while still seeing additional digital content [31].

The WebXR Device API provides a standardized way for developers to adapt applications to XR-enabled devices. The application can still be run on a native web browser; however, when viewed on these XR devices, users have the option to enable the immersive features, such as head and positional tracking [32]. In addition to prototyping the "Walk Deserts" visualization for the web, I was able to also experiment with viewing it in AR and VR without writing much additional code.

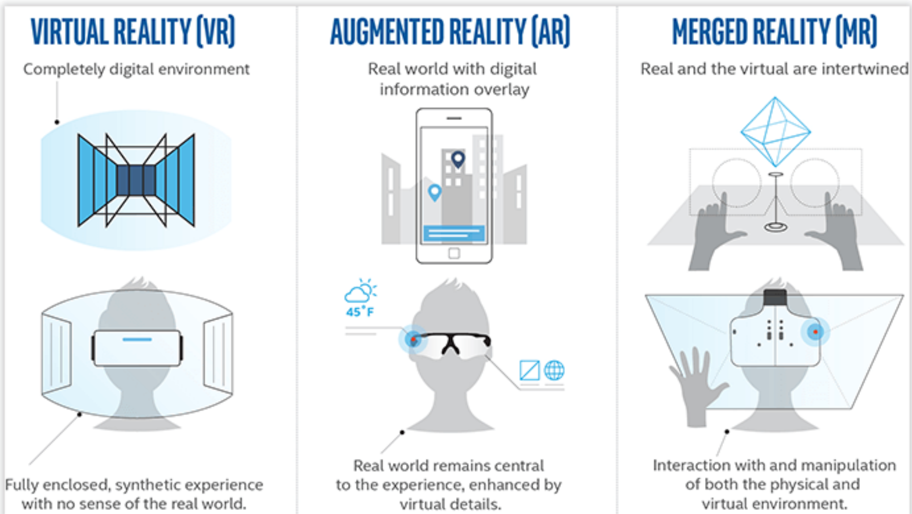


Figure 2-4: Comparison of how users view and interact with XR technologies [4].

### 2.2.3 Immersive Storytelling

In several recent projects, the MIT Media Lab City Science group has been experimenting with extending their research into artistic and qualitative experiences. The first of these projects was "Within," a documentary and installation created by Gabriela Bila Advincula for her thesis. The piece was exhibited at the 2021 Venice Biennale, consisting of a 3-channel video film and interactive table with 3D-printed models of Guadalajara, Cairo, and Port Harcourt. The project description highlights the everyday experiences of those living in informal settlements:

> Through visual storytelling we experience activities from the mundane to the surreal, from the deeply meaningful to the inconsequential. We visit the fringe neighborhoods and community centers of Guadalajara, the vertical slums and bustling streets of Cairo, and the tiny homes and crowded markets of Port Harcourt. In the lives of each individual, we examine the micro and the macro,

from the gentle care of fixing one's hair each morning to the cultural swells of holidays, religious ceremonies, and funerals. In these places, far from our own, we learn and inquire, we gather and we listen, in the hope of better understanding the complexity of the world around us and new possibilities for how we will live together in the future. [5]

Figure 2-5: "With(in)" installation at the Venice Biennale [5].

The second exploration was the "Two Mobility Futures 0∞" installation and film created for the student, future gallery in the "Motion. Autos, Art, Architecture" exhibition at the Guggenheim in Bilbao, Spain. The exhibit "celebrates the artistic dimension of the automobile and links it to the parallel worlds of painting, sculpture, architecture, photography and film" [6]. The film envisions two parallel futures and the impact that their diverging mobility systems have on urban dwellers' lived experiences. In one future, logistics mobilities such as autonomous delivery vehicles lead to a sedentary lifestyle, whereby individuals have no need to leave their homes. In the other future, humans are in perpetual transit, shifting between different mobility infrastructures like trains and teleportation devices. Our exhibition consisted of a 9-channel film, a model of a city constructed out of car parts, and a large led light sculpture that reacted to scenes in the film. I contributed to the concept and light sculpture. The chandelier contained an LED sculpture that responded to moments in the video, and helped me to learn more about how data can be abstracted and visualized in new ways. This made the experience of watching these videos multi-sensorial, and also encouraged people to move their focus around the space, instead of just watching video content from one angle, or in a passive manner.

Figure 2-6: “Two Mobility Futures 0∞” installation at the MIT Media Lab [6].

At the core of the City Science research mission is how technology can help us build more resilient and sustainable urban futures. These investigations span every dimension of urban life: how we navigate cities, where we live and what our homes look like, how information informs policy, and how communities collaborate with the government in policy-making. The group’s immersive explorations provide new, qualitative, and human-centric approaches to visualizing City Science interventions that have traditionally been data-driven and top-down. These explorations, in turn, shift our focus to slightly different but equally urgent questions: For instance, what does the role of micro-mobility look like in our everyday lives, and what is the everyday experience of living in the group’s vision of future cities? And what do these interventions look like when put into practice?

# Chapter 3

# Design and Implementation

This section describes the explorations that led to my final "walk desert" operational definition and immersive visualization. Based on my prior research on walkability, and what issues remain understudied or needed, I began by mapping and identifying regions in the greater Boston area that lack access to walkable infrastructure and that suffer public health issues like higher rates of pedestrian and cyclist fatalities. I then created a tool that uses this geospatial data to help to maximize an urban dweller's exposure to safe and healthy resources, via route recommendations. Finally, after finding areas that suffer from serious public health issues not yet prominently identified on these maps, I created an interactive visualization to better communicate invisible environmental hazards and how they impact walkability.

## 3.1 Methodology

My methodology for this thesis emerged from my explorations. Specifically, I first explored mapping walkability by combining datasets of environmental factors related to walkability and health outcomes, then experimented with different ways to translate this work into health-driven pathfinding, and finally developed a walk deserts visualization, environmental model, and immersive visualization of my case study, Boston's Chinatown. I explain my approach in the following sections.

### 3.1.1 Mapping Walkability

Developing interventions and tools that enhance walkability is a key component to developing safe, efficient, and equitable high-density cities. The City Science group's research makes heavy use of indicators and metrics that can inform and highlight areas that require investment and improved infrastructure. Using a similar approach, I developed a map that combines different public datasets to identify where walkable and unwalkable areas in Boston are located, and what they look like. Instead of creating a complex index in order to score different areas, the intention here was to get a high-level understanding of the geospatial distribution of these issues.

To construct these maps, I incorporated multiple datasets from "Analyze Boston," an open data portal for the city of Boston. Among these were traffic and bike accidents, amount of greenspace (such as parks), tree coverage, sidewalk size and quality, residential complaints, traffic, and bike lanes [33]. A key finding was that residents in the central downtown area of Boston had higher access to greenspace, sidewalks, and bike lanes. They also had less pedestrian and cyclist accidents involving cars than areas that lacked this infrastructure. The areas that were coming up from these analyses were clearly areas that lacked the traditional walkability infrastructure discussed previously, for instance access to nearby greenspace and bike lanes.

I combined datasets to analyze spatial patterns and look for correlations between walkability factors and health outcomes in several maps, such as those pictured below. For instance, it was admittedly no surprise to see that the intersection of Melnea Cass Boulevard and Massachusetts Avenue is associated with less greenspace, wider streets, fewer crosswalks, and more traffic fatalities (Fig. 4). In fact, the intersection is infamous enough as a signifier of economic marginalization that it is also known as "Mass and Cass," "Methadone Mile", and "Recovery Road." This strip of land, which during the COVID-19 pandemic became a

```
In [94]:
fig, ax = plt.subplots(figsize = (25,25))
gf_agg_crash.sort_values(by='counts', ascending=False)
gf_crash_plot = gf_agg_crash.drop_duplicates(subset=['intersection'])
gf_crash_plot['counts_exp'] = gf_crash_plot['counts'] ** 1.5
gf_buildings.plot(ax=ax, cmap="bone")
gf_crash_plot.plot(ax=ax,markersize=gf_crash_plot['counts_exp'],cmap='Reds_r', edgecolor='none'
ax.set_facecolor('white')
plt.show()
```

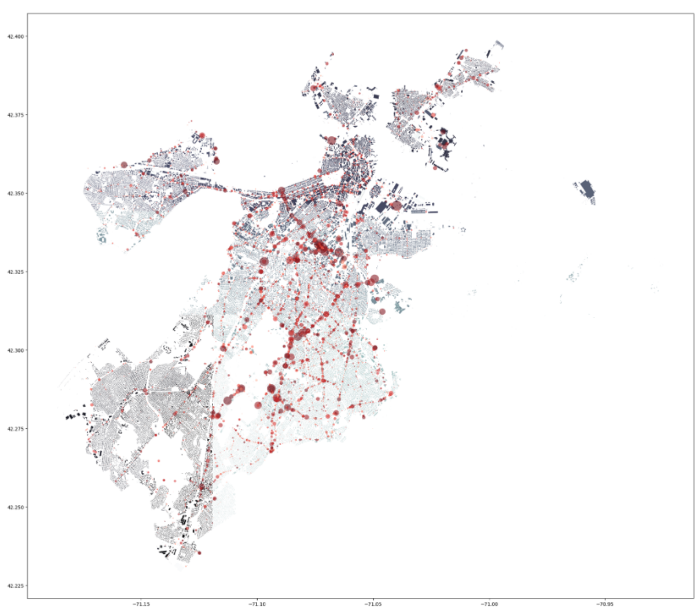

Figure 3-1: Map of cyclist and pedestrian accidents in the Greater Boston Area.

tent city, is characterized as “the epicenter of the region’s opioid addiction crisis” [34].

```
In [107]:
gf_crash['intersection'] = gf_crash['xstreet1'] + " & " + gf_crash['xstreet2']
gf_crash_temp = gf_crash[(gf_crash['mode_type'] == "ped") | (gf_crash['mode_type'] == "bike")]
gf_crash_temp['intersection'].value_counts()[:1]
```

```
MASSACHUSETTS AVE & MELNEA CASS BLVD    30
```


Figure 3-2: The intersection of Massachusetts Avenue and Melnea Cass Boulevard in Boston (Google Street View.)

As I continued to merge datasets, analyze data, and generate such maps, the most striking findings were, like the Mass and Cass example, unfortunately unsurprising. For instance, specific hotspots of pedestrian fatalities on Google Street view, a lack of pedestrian crosswalks, narrow and unmaintained sidewalks, and wide streets multi-lane streets were commonplace and readily apparent on Google Street View. I wondered whether such maps really added value to current campaigns to address walkable divides and increase walkability and well-being in our cities. Where might more information or a different visualization approach make a difference? This suggested to me that, perhaps, aerial maps are not always the most appropriate way to engage with these data. I wondered whether it might be possible to center lived or community experience in more nuanced ways, to combine different sensorial data or multiple walkability factors at once (in a way that is less aggregated than weighted walkability indices, generating a single score for each locale).

Another major clue emerged when I saw that Boston’s Chinatown is associated with quite poor health outcomes, despite having many of the qualities that make an area walkable: nearby access to amenities, narrow streets, and access to nearby greenspace. This helped

```
In [8]: gf_c_t_agg.sort_values(by='ShapeSTLength',ascending=True)['geometry']
```

```
58628    LINESTRING (-71.05898 42.29019, -71.05898 42.2...
63900    LINESTRING (-71.05133 42.28691, -71.05133 42.2...
48254    LINESTRING (-71.06088 42.30669, -71.06088 42.3...
61452    LINESTRING (-71.07061 42.29745, -71.07061 42.2...
53909    LINESTRING (-71.10663 42.30341, -71.10663 42.3...
55879    LINESTRING (-71.08312 42.28681, -71.08312 42.2...
60482    LINESTRING (-71.06369 42.29008, -71.06369 42.2...
48032    LINESTRING (-71.06818 42.30324, -71.06818 42.3...
51021    LINESTRING (-71.11859 42.27574, -71.11859 42.2...
59486    LINESTRING (-71.07332 42.29001, -71.07332 42.2...
```


Figure 3-3: Intersection from analysis of areas with the narrowest sidewalks and least access to greenspace. (Google Street View.)

me to articulate an interesting research puzzle, to conceptualize the notion of walk deserts hiding in plain sight, and to think about immersive technologies as a novel way to convey data, especially those on the invisible and contextual factors of walkability.

### 3.1.2 Health-Driven Pathfinding

During the course of the previous analysis, I began thinking about how this kind of walkability index could translate into an intervention. One significant exploration involved building a navigation tool that optimizes for health and well-being, rather than distance and time traveled. Such a tool aims to combine seemingly disparate, existing datasets on systems of urban assets (like bicycle lanes, numbers and flows of autonomous vehicles, tree-shaded paths, well-lit streets, and street fairs) relevant to a multi-faceted model of personal well-being. For instance, one initial scenario centers on individuals who commute to work each morning, work in an office all day, and often only get to leave the office when it is almost dark. (Not coincidentally, this was my life for a number of years.) Given this, how can the hypothetical commuter maximize their exposure to health-promoting features on their daily commutes? Two freely accessible resources that are hiding in plain are sunlight and shade.

According to a 2018 study, roughly 42% of Americans are Vitamin D deficient, with significant deficiencies among African Americans and Hispanics [35]. Low levels of Vitamin D have been associated with increased risk of cardiovascular disease, diabetes, and certain forms of cancer. Sun exposure is shown to statistically significantly increase Vitamin D levels as well as improve mental well-being [36]. Many of us may have multiple missed opportunities everyday to increase our sun exposure, by walking on a specific side of a street or biking a certain route while commuting to work. Google maps and similar navigation applications maximize time, distance, and traffic efficiency in their routing recommendations. Expanding on this concept, my first prototype routed users based on maximizing shade or sun exposure.

I developed two separate components for this prototype: a solar irradiation index of all streets in New York City (where I was living at the time of development), and a pathfinding tool that optimizes for shade or sunlight given two points. To determine solar irradiation, the length and direction of a building's shadow at any given point of day was calculated based on the angle and height of the sun, and the height of each building in New York City. I then created an index based on what percentage of a street segment was sun exposed at a given hour. To test the index, I generated a map showing the solar irradiation score of all streets for a nearby zip code and took photos along different street segments. The resulting photos revealed that the data was accurate when a street was scored as having high sun exposure or shade.

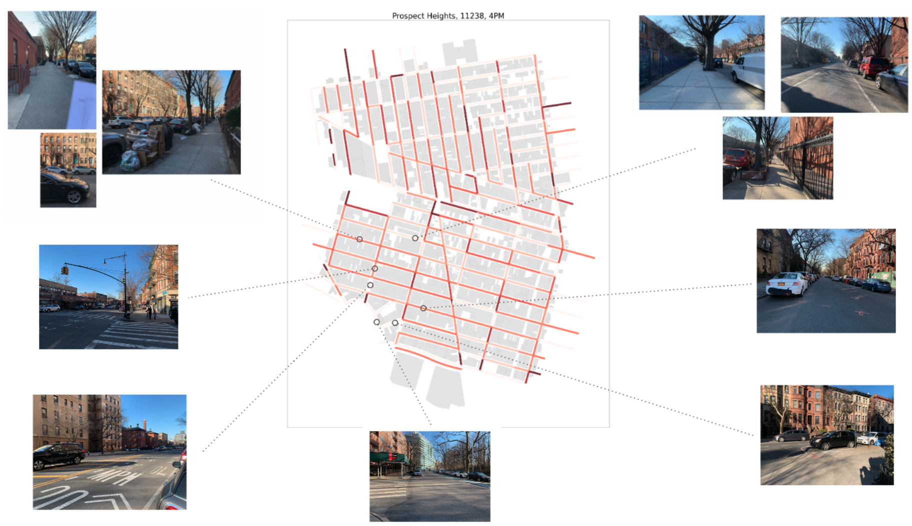


Figure 3-4: Photos of sun exposure in Brooklyn at 4pm.

Using this data, I was able to calculate a path between two points that maintains a relatively short distance while also maximizing sun exposure. I generated two different routes to the same destination and then biked it: One path was optimized for travel time, the other for sunlight exposure. The time difference between the two was negligible, although the overall travel distance was short. I attached a GoPro camera to my bike handlebars in order to qualitatively assess the lighting for the different routes. While biking (both during my experience and in the video footage) the sunlight route as a user tester, my commute was substantially more exposed.

While I was pleased that this prototype indeed made appropriate, complicated calculations

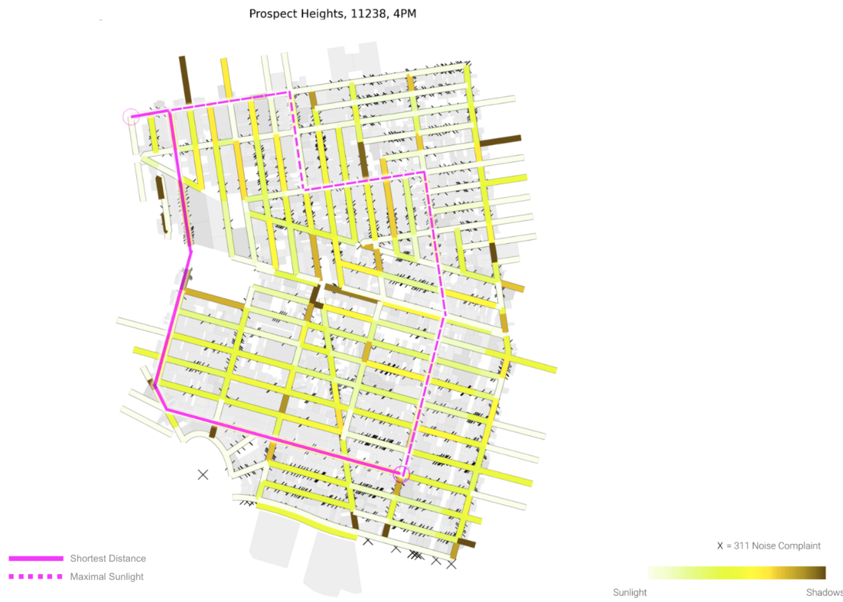


Figure 3-5: Paths optimized for distance and sun exposure between two points in Brooklyn.

and thus "worked," I wanted to research more about complex phenomena such as a sense of community safety, rather than finding a prescriptive formula for sunlight or shade. I also aimed to build a tool that is used not just once (calculating a sunlight-optimal commute, for instance), but more consistently, and that may more directly inform public policy decisions. In particular, this prototype prompted me to think of tools that better conveyed the concept of walk deserts, and which could be better used for community dialogues with planners and policymakers rather than individual users as part of target audiences.

This is in many ways in keeping with my previous research, which highlights individuals' lived experiences in textured ways but aims to generate dialogue rather than prescriptive directions or formulae. This work aims to change systems or policies rather than individuals' behavior.

## 3.2 Walk Deserts Visualization

Focusing solely on physical attributes of the built environment overlooks the lived and bodily experiences within these spaces. Given histories of segregation by design and the differing abilities of people from various communities to leisurely walk with confidence and without a sense of anxiety, it becomes crucial to contextualize these issues within the built environment: "urban design qualities are different from qualities such as sense of comfort, sense of safety and level of interest that reflect how an individual reacts to a place—how they assess the conditions there, given their own attitudes and preferences" [28].

As mentioned earlier, studies assessing qualitative and perceptual aspects of walkability have historically used surveys to understand an individual's emotional responses to videos and images of the built environment. However, these studies focus on what can be easily perceived visually; they typically involve showing survey respondents two or more images of a street block, holding most infrastructural characteristics constant and varying one factor (such as tree density) at a time, and asking respondents which image they preferred. Such studies do not account for invisible factors that impact our perceptions of walkability, such as the amount of traffic or noise. They also do not account for knowledge of a location based on lived experience, such as whether a location feels more (or less) safe at certain times, or policy contestations and social inequities, including inequalities within a purported community. For example, researchers have examined how notions of walkability may be quite different for immigrants with different visas or of different socioeconomic backgrounds [37]. Such contextual data are vital; Boston's Chinatown's traffic flows and fatalities, for instance, have not always abided by rush hour patterns typical in other neighborhoods [38].

### 3.2.1 Case Study: Chinatown

Boston's Chinatown neighborhood, third largest Chinatown in the United States, is a particularly useful area for analysis because it ostensibly embodies many of the desirable characteristics of walkable neighborhoods discussed above [39]. For instance, it is nestled between two of Boston's largest greenspaces, the Public Garden and Boston Common, and Rose

Kennedy Fitzgerald Greenway, both of which are within a short walking distance [40, 41]. At the same time, Boston's Chinatown suffers from a major public health crisis, invisible to visitors and even many residents.

An important factor contributing to Chinatown's walkability is its smaller block sizes. As urban planner Jeff Speck suggests, a major benefit is that there are "more choices a pedestrian can make and the more opportunities there are to alter your path to visit a useful address such as a coffee shop or dry cleaner. These choices also make walking more interesting, while shortening the distances between destinations." Such hyper-local access to everyday needs within a short walking distance is key to walkable spaces and the pursuit of "15-minute" cities. Speck also highlights the importance of safety, in that smaller blocks lead to more, shorter, and narrower streets, which reduces traffic speed and congestion [42].

This kind of network of smaller streets – where more people live, work, or pass through – was a primary factor for writer and activist Jane Jacobs famous phrase "eyes on the streets" from her 1961 book The Death and Life of Great American Cities. Jacobs posited that safe and interesting urban spaces emerge when people are active and present in public space, which creates vibrancy and a sense of social cohesion. This close proximity also reinforces a sense of safety, for instance allowing residents to monitor the street from their apartment windows. A key example she cites is Boston's North End neighborhood, an area she identified as both vibrant and safe as people lived and worked within a close proximity, despite it being a so-called "slum" [43].

Despite its highly walkable features, Boston's Chinatown is also plagued with hazardous levels of air pollution, which has serious material health effects on residents and commuters. Air particulate matter (PM) emissions are measured in micrograms per cubic meter of air. Fine particles (PM2.5) are 2.5 micrometers in diameter or smaller, which (at their largest) is 20 times smaller than the diameter of a human hair [44]. Extended exposure to PM2.5 has been linked to increased risk of heart disease, respiratory conditions, and premature death. A recent study from the Union of Concerned Scientists found that Boston's Chinatown has the worst air pollution of any census tract in all of Massachusetts. The study estimates that, across all of Massachusetts, Asian American residents are exposed to 36 percent more

PM2.5 than white residents; African Americans are exposed to roughly 34 percent more, and Latinx residents breathe in 26 percent more.

According to Tufts School of Medicine's Community Assessment of Freeway Exposure and Health Study (CAFEH), the primary cause of hazardous air quality in Chinatown is the proximity to Interstates 90 and 93, and Route 28 [45]. CAFEH is an umbrella study for multiple research projects focusing on community-based participatory (CBPR) air pollution studies. The group monitored air quality in Chinatown by driving a sensor-enabled van during different times of the day and captured data such as ultrafine particulate matter levels, temperature, and wind direction and speed [46]. Combining this with the traffic volume on the nearby interstates, they were able to construct a model of air quality that had a 20 meter resolution.

CAFEH, in partnership with members of the Chinatown community, also developed an interactive map that allows users to visualize air pollution data across different variables. Their goal was to make their air pollution research accessible to populations of Chinese immigrants with limited English proficiency [47]. They also supplemented this with workshops, presentations, and infographics about the detrimental effects of poor air quality and its causes. The interactive tool provided a macro lens into the systemic issue, while the infographics helped contextualize how it impacts their everyday lives and how they can minimize their risk. Based on pre-post surveys, they found their approach was highly effective.

Another dimension that requires further analysis is the disparity in noise pollution among different neighborhoods in the Greater Boston Area. According to a 2011 World Health Organization European report, "at least one million healthy life years are lost every year from traffic related noise in the western part of Europe." The report cites that long-term exposure to high sound levels have been associated with increased risk of cardiovascular disease and cognitive impairment, among other issues [48]. Dr. Erica Walker, an epidemiologist at the Brown University School of Public Health, developed a comprehensive method of measuring noise in different neighborhoods in Boston. Entitled The Greater Boston Neighborhood Noise Report Card, Walker and her collaborators used three different methods to measure noise levels: sound measurements across different locations, a noise assessment survey given to over 1000 residents, and an analysis of noise complaint data from the City of Boston [40]. This data was used to create, among other things, a series of report cards detailing the amount of noise pollution in different neighborhoods. Based on their data, Chinatown was given an F grade and classified as one of the loudest neighborhoods in Boston [49].

Both of the aforementioned projects provide a nuanced lens into invisible environmental hazards that disproportionately impact Boston's Chinatown, and how to effectively communicate this information to both the general public and local residents. My contribution lies in an attempt to convey multiple walkability factors at once, through an immersive, street-level experience. In doing so, I hope community members can use this as an advocacy tool to accomplish two main goals. The first is to convey the cumulative effects of different factors inhibiting their well-being, drawing upon available scientific data, to policymakers and others in the community. The second is to advocate for specific aspects that should look, feel, and sound different than they currently do, and which are not easily conveyed in other ways.

### 3.2.2 Environmental Model

For the purposes of my thesis, I captured visuals of the iconic Chinatown gate and a section of Beach Street, between Tyler and Hudson Street, using photogrammetry (discussed earlier in this document). This exact location and coverage seemed like enough area to properly contextualize the visualization and make a user feel immersed in the space. Creating a model of this size also requires an immense computer processing power in order to generate a high quality model and textures. I ended up taking around 3,000 photos with a Sony A7SII mirrorless camera to capture the entirety of Beach Street, and 800 photos using a DJI Mini 2 drone to capture the Chinatown gate, plaza, and tops of buildings. Changes in natural light or environments can disrupt the success and quality of a final model. To prevent any issues, I shot the environment over the course of 4 days, starting at sunrise, which gave me a window of about 1.5 hours to photograph with enough natural light and before cars were allowed to park on Beach Street.

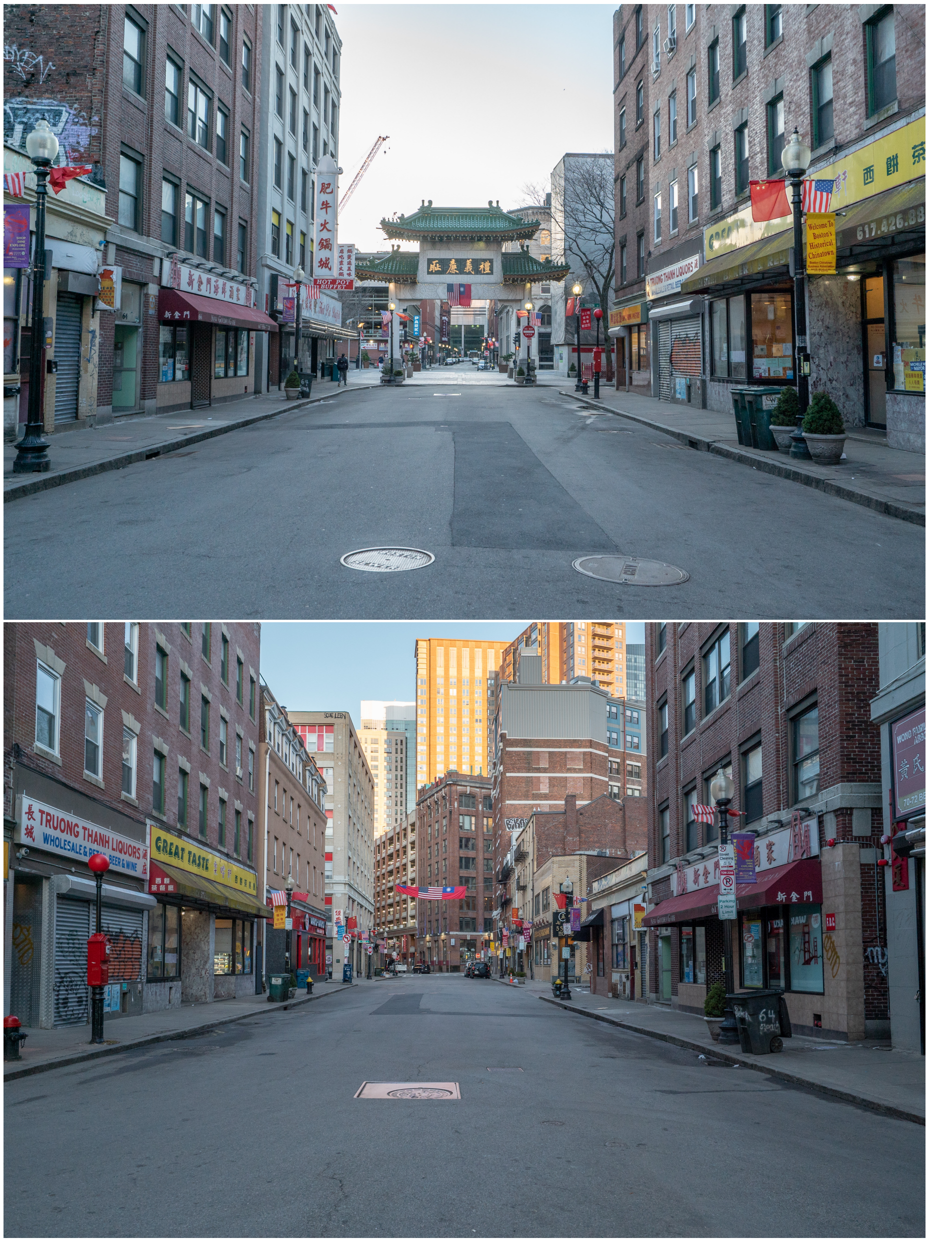


Figure 3-6: Street photos from Boston Chinatown photogrammetry shoot.


Figure 3-7: Drone photograph of Boston Chinatown Gate.

Figure 3-8: Sample of photographs from Beach Street photogrammetry shoot.

Photogrammetry software called Reality Capture was used to generate the final model. Reality Capture is generally regarded as the most robust and high quality photogrammetry software on the market, and thus has become an industry standard. The final high-resolution model I produced was around 800 million polygons with 92 8K texture files, resulting in a 800GB file size. In order to use this model in a game engine or on the web, it needed to be heavily decimated, simplifying the geometry to reduce the number of polygons. Using a process called "texture reprojection," it is possible to simplify the underlying geometry of a model and reuse the original texture files created from the original, undecimated model. This allows for a smaller model file size, while still retaining highly detailed textures. The final decimated model, which had the right balance of compression and fidelity, was around 2 million polygons with four 8K texture files, resulting in a file size of approximately 25MB.

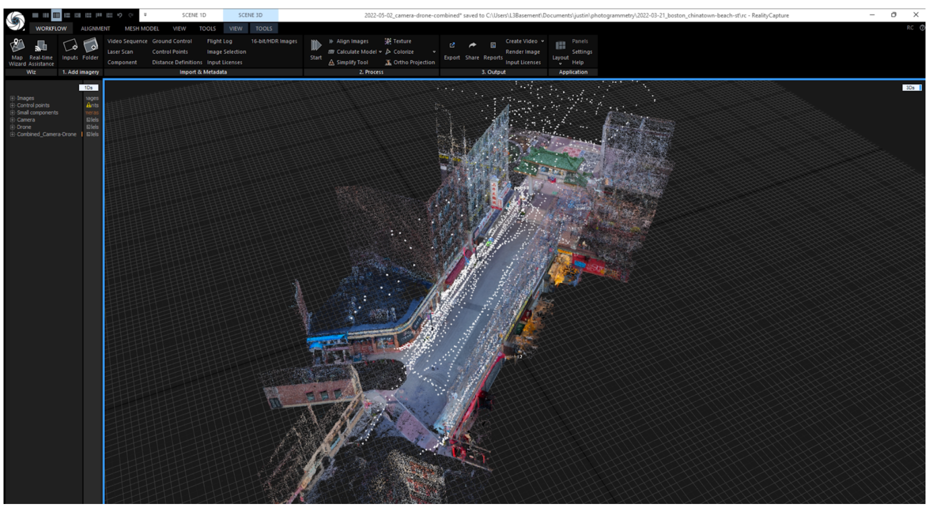

Figure 3-9: A point cloud generated from photos of Beach Street in Chinatown using *Reality Capture.*

### 3.2.3 Immersive Visualization

The visualization tool was originally designed for community members, planners, and city government officials to immersively explore environmental issues impacting a specific neighborhood ("walk desert"). In my case study specifically, it would allow users to view a 3D model of Chinatown from a first-person perspective. To make the tool as accessible as possible, I developed it as a web application and specifically intended the tool to be used on mobile phones. The tool utilized the WebXR browser standard, which allows any device running a web browser that supports WebXR to render the page as an AR or VR experience. It also used Three.js, a JavaScript library for creating 3D experiences for the web [50].

I dedicated a significant amount of development time to rendering high-resolution 3D content on the web, while still maintaining high compatibility and performance. Although the model mentioned in the previous section was small enough to use in a traditional game engine, it was still too large to load into a web browser without significant performance issues. To remedy this, I used a standard called "3D tiles," which is a specification for streaming large 3D geometry files instead of loading them at once. This process breaks a model into a set of compressed files, each one consisting of part of the model at a specific resolution. When viewing the model in a visualization client (in my case, a web browser), higher resolution parts of a model are streamed in based on which areas a user is viewing, and how close they are to that area of the model. The technique is essentially a 3D version of the one used by Google Maps. Exporting these tilesets and serving them into the browser as needed allowed me to visualize a large model while still maintaining a high frame rate (60fps).

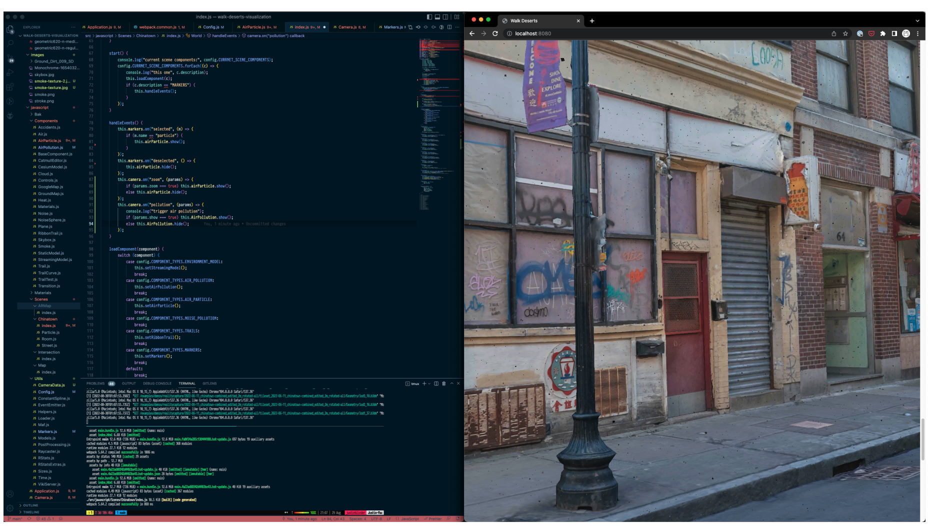

Figure 3-10: Development of the application that loads in the model, overlays data visualizations, and makes them interactive so that users can engage with scenes like the one pictured on the right.

I developed two iterations with different degrees of user control. The first allowed the user complete freedom of movement; the second moved the scene automatically through specific points of interest and then stopped to allow users to look around. The four points of interest provided information about: 1) the spatial distribution of Chinatown vis-à-vis the surrounding interstates and nearby greenspace, 2) the levels of air pollution in Chinatown and how they are impacted by nearby traffic, 3) what PM2.5 particles are and negative health effects from long-term exposure, and 4) how air pollution from the street can also enter apartment buildings. For the final proof-of-concept, the air pollution was visualized as floating 3D particles and the noise pollution was included as spatialized audio using Three.js. Despite conversations with the epidemiologists who constructed them, the air and noise pollution datasets were not adequately prepared for public collaborations by the time development began, so both of these were using testing data that I generated. As a result, because it was easier to simulate mock data, only air pollution data was presented during user testing.

I experimented with converting the visualization into augmented reality and an interactive installation. This aspect of my thesis drew upon my work with the "Two Mobility Futures 0∞" exhibit in the Guggenheim Bilbao, translating people's sensorial experiences into both a video format and an immersive installation, so that people could walk around and engage with the visualization in different ways. In the Guggenheim piece, my contribution focused on building a chandelier that translated data from different mobility futures into an interactive light installation. In my thesis, I worked to translate typically invisible factors like air pollution in similarly visible, visceral ways.

In the augmented reality prototype for my thesis, users viewed the model on their phone and could adjust its size and position to fit it on a surface, or walk around the model in a 1:1, real-life scale. Viewing the model on a table exposed new collaborative possibilities. For instance, multiple people could stand around the model and view it simultaneously, creating a space for discussion for different stakeholders to discuss current issues and proposed solutions. The interactive installation prototype was installed in a room within the group's lab space. As in the Guggenheim Bilbao piece, I worked with adjacent TV screens. The


Figure 3-11: Two views of the immersive visualization on three screens in the City Science lab space.

visualization expanded across each screen and was controllable via a keyboard and mouse, and allowed users to move around the space in a first-person perspective. Expanding the application across three, wide format screens required widening the field-of-view, which distorted content and proved to be very disorienting. For these and for portability reasons, in order to garner feedback from interviewees who might not be able to visit the installation in person, I continued development on the website experience for the user testing evaluations.

Figure 3-12: Scenes from the interactive visualization.


Figure 3-13: Visualization of magnified ultrafine particles.

The final component of the visualization, which has yet to be implemented and will build upon the evaluation, involves visualizing the predicted environmental impact of different interventions. For instance, it might involve showing the impact that a large greenspace barrier between Chinatown and Interstate 93 would have in offsetting air and noise pollution. This feature is a key factor in promoting new solutions to the local environmental issues, as opposed to solely communicating the issues themselves.

# Chapter 4

# Evaluation

I evaluated the "walk deserts" visualization through a series of interviews and user tests with participants working in public health and policy, immersive technology, and art. During the user interviews, participants were given a brief introduction to the "walk deserts" operational definition, as well as background information about air and noise pollution in Boston's Chinatown. They were then shown two versions of the prototype: one version was nonlinear, exploratory, and asked users to select information, while the second version guided the user along, providing pieces of information at specific intervals. After the test, I conducted a semi-structured interview with open-ended questions to elicit feedback about their experience, as well as potential gaps and analyses about the larger theme of walk deserts. At the time of testing, the full pollution and health impacts datasets were not yet publicly available, so the prototype used the best approximated test data available. Participants were informed about this prior to starting the user test.

During the interviews, most participants said they were unfamiliar with the extent of air pollution in Boston's Chinatown. Several stated that the immersive visualization created a visceral response to the environmental data. Among the feedback collected, a few participants expressed surprise by the high level of detail and photo realism of the model. When navigating the visualization, one user expressed, "Whoa, I've eaten at that restaurant before!" and said that being able to explore a photorealistic model created a "strong connection" with the space in a way that did not occur when they were presented solely with a traditional map. Another participant responded, "I don't want to be there," commenting that they felt a strong reaction to seeing ultrafine particles depicted as objects moving towards them.

Participants also provided useful feedback and questions regarding future directions for the prototype. Most of the participants expressed a desire to see more quantitative data combined with the visualization in the form of graphs and maps. A few participants suggested that including personal narratives and interviews with residents in the Chinatown could be a useful way of capturing and communicating the qualitative impacts of air pollution. Another participant stated how exploring a human-scale version of the model would have likely elicited a more emotional response and recommended making a version specifically formatted for a VR experience.

A major finding from the interview process concerned the efficacy of using a traditional data visualization vocabulary when conveying and contextualizing geospatial information. Although situating data within the local built environment in an immersive way seemed effective at increasing relatability, this data needs to be supplemented with traditional maps to increase legibility. Some users still felt more comfortable looking at traditional, aerial view maps in tandem with the 3D visualization, in order to interpret data in more familiar and traditionally legitimate ways. Additionally, creating a linear experience appears to make the content easier to access and understand; however, implementing an exploratory, non-linear approach may work better when used in an XR format (e.g., a virtual reality headset) and requires further investigation. In addition to highlighting areas of improvement, the feedback also informed ideas about future directions for this project.

# Chapter 5

# Conclusion

The United Nations has projected that over 70% of the world's population will live in urban areas by the year 2050 [51]. In order to accommodate this level of urban density, cities need to be planned sustainably, and allow urban dwellers closer access to all of their everyday needs. Using Boston's Chinatown as a case study site allowed me to test an operational definition of walk deserts, hopefully convey contextual data in helpful ways, and explore uses of photogrammetry, WebXR, and immersive storytelling in immersive and interactive data visualizations. The case study highlights some of the potential contributions and drawbacks of immersive visualizations as installations and as web applications, and especially underlines the ways in which typical, aerial view maps and charts of inequities are helpful, but on their own, remain insufficient in conveying multi-dimensional lived experiences and informing good planning. In particular, this thesis underlined the striking ways in which immersive technologies can dramatically shape the way data is conveyed in the future and its potential for visceral impact. Although this is obvious in hindsight, seeing how this happens with multi-dimensional walkability visualizations was nevertheless notable. As with more traditional two-dimensional data visualizations, this raises questions of how data are not just conveyed but constructed via visualizations, how they can flatten or distort complex phenomena, who can access them and whether they are conveyed in publicly accessible ways, and whom they ultimately benefit or serve. Since immersive technologies are poised for widespread adoption in the coming years, such questions are imperative to keep in mind, especially for community-based groups, planners, and policymakers.

A greater range of interventions are needed to address different contexts of walk deserts (and other forms of deserts) hiding in plain sight. Two potential avenues of future work that seem particularly crucial and generative are those of digital twins and community-based modeling and mapping, discussed below.

## 5.1 Community-based modeling and mapping

The scanning techniques discussed in this thesis are capable of generating extremely accurate measurements of spaces. This could provide immense possibilities for informal settlements and informal infrastructure, which lack accurate maps and planning documents. These increasingly ubiquitous capture technologies can enable communities to take ownership of previously inaccessible, and often proprietary, spatial information.

A concept that came up repeatedly throughout development of this thesis was allowing communities to generate models of their own environments. Multiple mobile applications are already extremely easy to convert real-world objects into rough 3D models with a smartphone. Creating a successful model from a space requires more effort and learning a few basic techniques mentioned previously, but it can still be accomplished by almost anyone with a phone in their pocket. This degree of accessibility opens up new opportunities for community-based mapping. For instance, residents in a neighborhood could collectively generate a model of an apartment building or a street. This could, for instance, be used to document and convey disrepair or conditions in ways that are difficult to convey via testimony or at the specific times that city inspectors come by, or to archive an area that is planned for redevelopment or rezoning.

## 5.2 Immersive Digital Twins

Urban digital twins are precise 3D models and simulations of a real city. Both Singapore and Shanghai have developed digital twins to model the future of traffic flows and energy consumption in order to make more informed policy decisions. However, these models typically lack more nuanced perspectives of how these policies appear to urban dwellers from a first-person perspective. Incorporating the XR technologies and spatialized modeling techniques discussed in this thesis into digital twins could inform further insights about how policies transform the built environment for communities, and how this could create a dialogue between communities and government officials.

## 5.3 Concluding Remarks

This thesis introduces "walk deserts" as a new system for identifying, mapping, and visualizing walkability and its relation to public health. The goal is not to replace traditional visualization methodologies, but instead to explore immersive and experiential ways of engaging with urban data that can enhance human empathy and relatability. A major motivation for this project is to raise awareness about aspects of cities that require interventions now in order to have a sustainable future. Given an established literature and policymaker interest on walkability as one concrete dimension of urban sustainability, this thesis built upon critical examinations of the concept to develop and investigate "walk deserts," centering walkable divides, questions of equity, and overlooked aspects of walkability.

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