CHAPTER 2

Why 3D?

Introduction

Spatial data has been shared as maps for millennia, providing a 2D representation of geography. These maps were drawn and distributed on the best surface available at the time, from cave walls, to animal skins, to paper, and more recently to computer monitors and tablets and phones. The result was a "flat" representation of the world, usually at a specific or logical scale.

As the science and mathematics behind maps improved, they became critical for many purposes—from aiding navigation to defining legal land ownership—but they always worked with a "top-down view," where the world was depicted from above, looking directly down. There were experiments with oblique 3D depictions—especially for cities and small-extent landscapes—but because those maps couldn't be used directly for measurement and analysis, they were often described as art rather than a way to define and deliver authoritative content. Figure 2.1 shows a portion of *Along the River During the Qingming Festival*, a Chinese painting from almost a thousand years ago that shows the layout of buildings in Kaifeng, China. Despite its detail, this 3D map has many limitations—partially obscured roads and buildings, uncertain distances, and a restriction to the artist's chosen viewpoint, to name a few. These limits precluded it from being used in practical work, such as land ownership, city planning, and taxation. While the depiction wasn't accurate enough or flexible enough to use for decision-making, as a method for sharing immersive information, it's an extraordinary piece, and can be viewed as an enlarged and animated digital version at the China Art Museum in Shanghai.

However, with the advent of computer processing power, we can generate accurate representations of geographic content in three dimensions *and* provide methods to interact

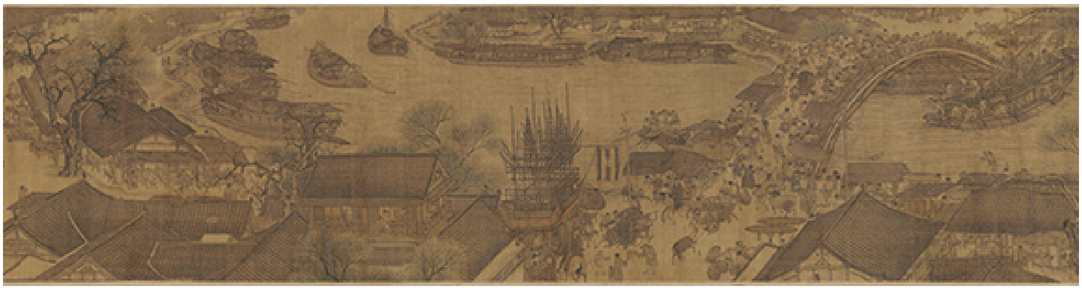

Figure 2.1. This 3D cityscape map from the twelfth century is a section of the painting *Along the River During the Qingming Festival* by Zhang Zeduan (1085–1145). Source: Wikimedia Commons.

with it. Spatial information that's inherently 3D, such as buildings, topography, and subsurface geology, can now be displayed in a way that's both intuitive and measurable. The results can be so useful and so compelling that sharing spatial data in three dimensions is experiencing widespread growth and adoption. The delivery mechanism for spatial data has evolved from purely 2D maps to often also include 3D maps, or *scenes*. A scene is a 3D depiction of spatially or relatively located content in a view with a defined coordinate system, both in x,y and in z. While the extra dimension for positioning and symbolizing data is most often used for measurable, real-world elements such as physical elevations, it can be used for many purposes.

This development has opened many opportunities for taking data that's inherently 3D, such as multiple floors of a building or subsurface earthquake locations, and presenting the content to people in a way that feels logical and natural (figures 2.2 and 2.3).

Maps versus scenes

The key difference between maps and scenes is that the former creates a top-down, constrained view of the content, while the latter creates an entire world to be explored. When GIS users make a traditional 2D map, one of the first decisions they make is the spatial scale, or range of spatial scales, at which the map will be shared. Any interactive navigation within the map, therefore, is either locked to a single scale, like a printed map, or automatically switched between a set of predefined scales, like an online map. To put it another way, there are a limited number of viewpoints at which the map can be investigated, so it's easier for the cartographer to author maps specifically for them.

In 3D, however, it's generally expected that users will explore the world's nooks and crannies, thus requiring a map to contain content for a huge number of scales and viewing directions. This requirement greatly increases the amount of detail needed in a 3D map and relies on user expertise in exploring, or navigating, the world. It's not all bad news—the resulting scene can take advantage of well-understood real-world concepts, such as 3D proximity and size, making the scene vastly more understandable for consumers and justifying all the extra sweat and tears that went into constructing it.

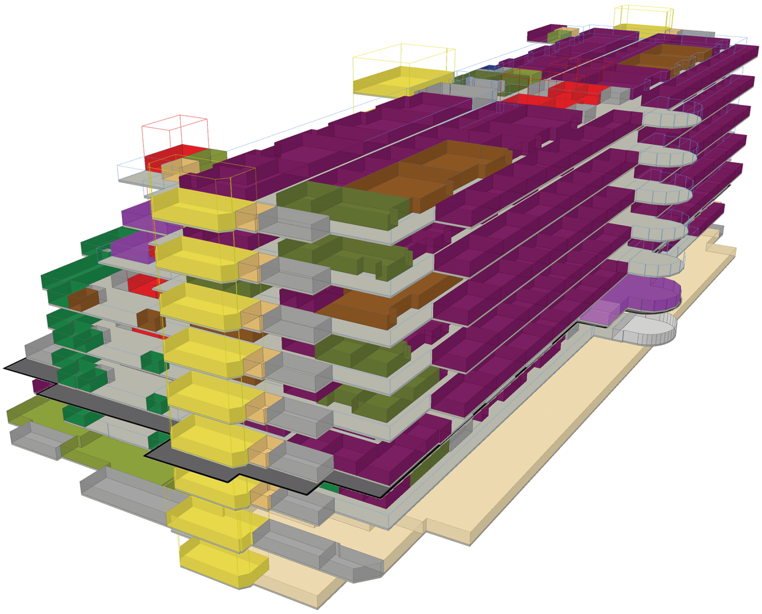

Figure 2.2. Room usage types in a multistory building. Building data courtesy of the US Department of Health and Human Services (HHS) and the National Institutes of Health (NIH) Division of Environmental Protection (DEP).

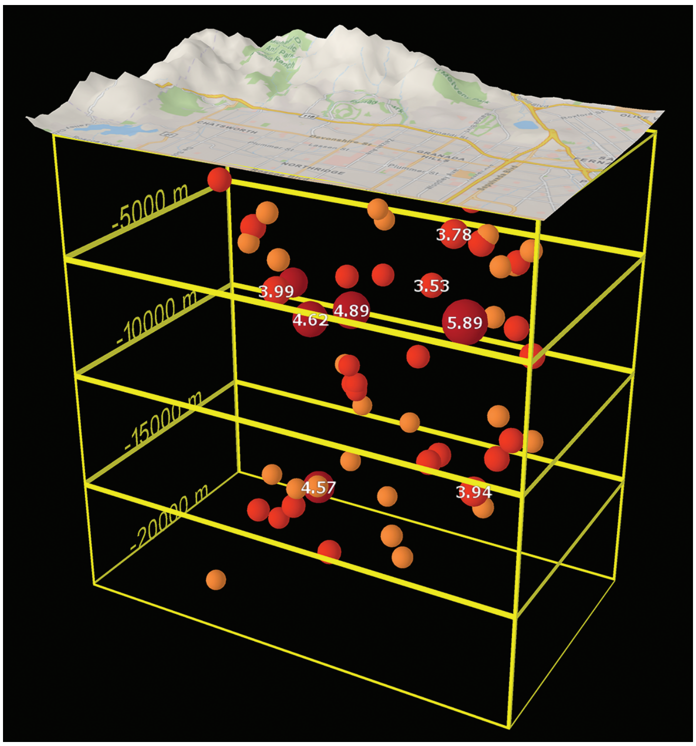

Figure 2.3. Subsurface earthquake points in Northridge, California, in 1994. Earthquake points courtesy of United States Geological Survey (USGS). Topographic basemap from Esri, USGS, National Geospatial-Intelligence Agency (NGA), National Aeronautics and Space Administration (NASA), CGIAR, N Robinson, National Center for Ecological Analysis and Synthesis (NCEAS), National Library of Scotland (NLS), Ordnance Survey (OS), National Mapping Agency (NMA), Geodatastyrelsen, Rijkswaterstaat, Geological Society of America (GSA), Geoland, Federal Emergency Management Agency (FEMA), Intermap Technologies, and the GIS user community.

Opportunities available in 3D

Let's look at some of the opportunities a third dimension provides.

Vertical information

One clear advantage of a scene is that it can incorporate vertical information—the surface elevation of mountains, the heights of buildings, or the positions of orbiting satellites. All these types of geographic data require a vertical component, or *z-value*.

The use of z-values in GIS data is steadily increasing as data capture technologies such as lidar and spherical imagery become more effective and affordable. Subsurface data is being captured using ground-penetrating radar, and both air and water volumes are being modeled as continuous 3D fields of information by scientists and researchers around the world. Even though many analytic operations can be calculated directly against this data without it ever being visualized, viewing it will bring it to life (figures 2.4, 2.5, and 2.6).

The primary goal of most scenes is to display 3D spatial relationships within the data. For example, a scene might show how a one-story house on a hill has an ocean view over the rooftop of a neighboring two-story house, or how line-of-sight microwave transmission networks are linking buildings across a campus. What's more, the structures shown in these 3D maps can be visualized before they are built, thereby supporting the planning process and avoiding problems before they occur. For example, a scene can show whether a proposed underground tunnel will encroach on a building's foundation or how projected vegetation growth will affect the approach path of a runway. The spatial relationships, both current and future, are displayed as they really are—in 3D.

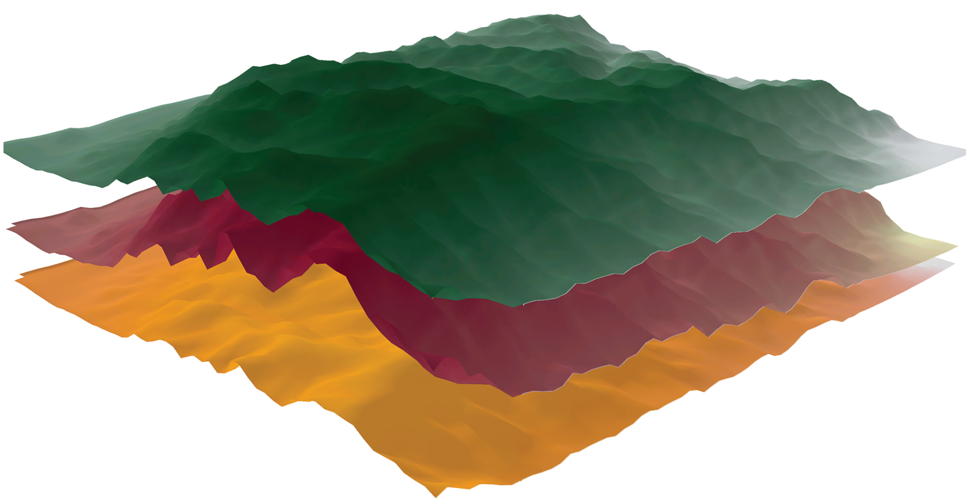

Figure 2.4. Vertically stacked underground surfaces. Simulated data.

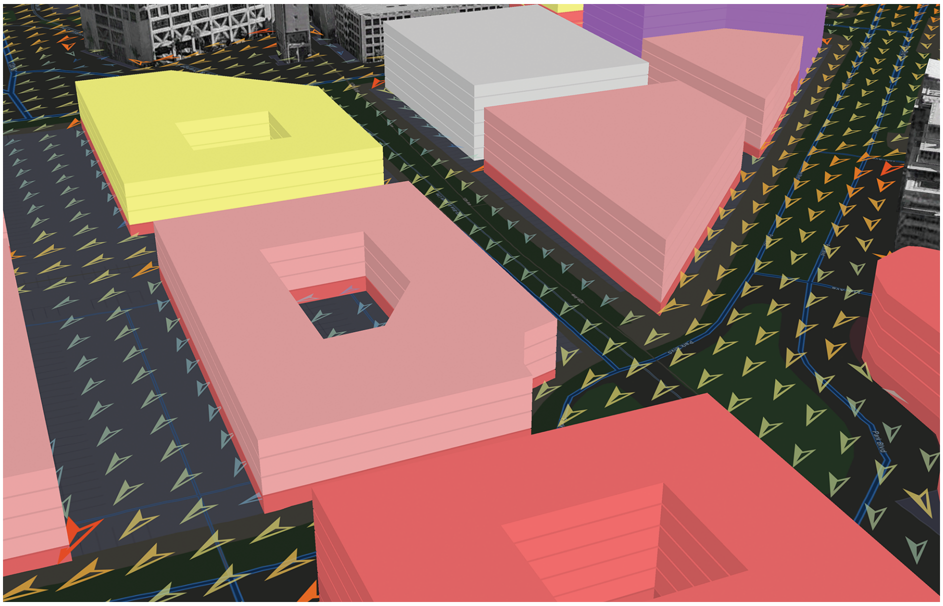

Figure 2.5. Wind strength and direction analysis results for a proposed construction plan. Three-dimensional buildings courtesy of Pictometry and Precision Lightworks (PLW). Analysis objects by Eric Wittner. Scene authored by Eric Wittner and Nathan C Shephard.

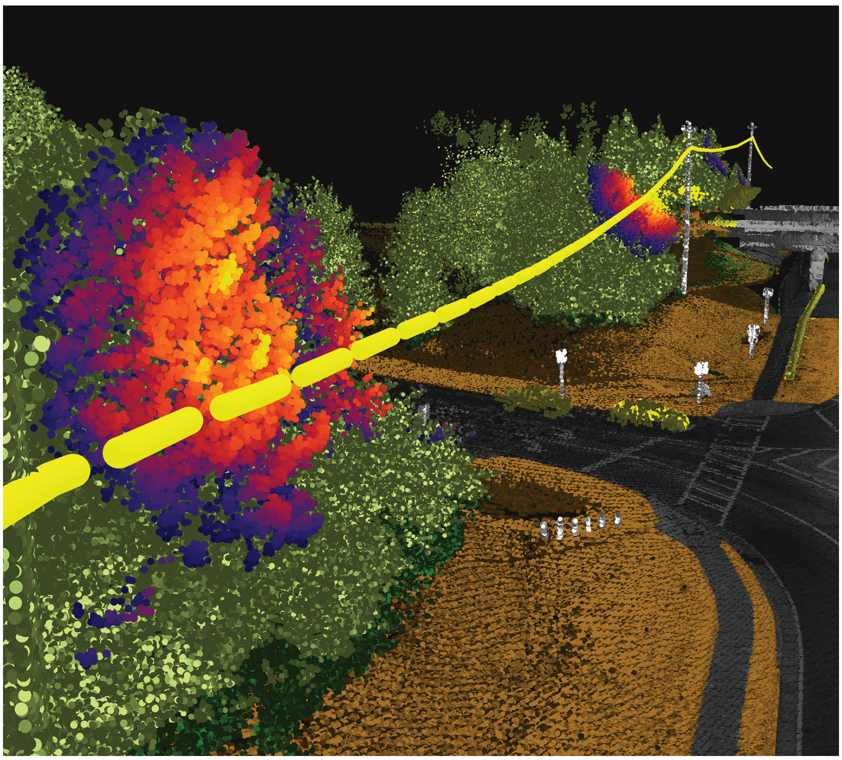

Figure 2.6. Vegetation encroaching on power lines, from lidar. Lidar data courtesy of GMR Aerial Surveys. Analysis and scene authored by Clayton Crawford.

Scenes also support the display of complex data within a volume. Underground, you can represent stacked geological formations in a series of cross sections that reveal soil horizons. In the ocean, you can represent cubes of seawater temperature and predict El Niño and La Niña years. In the air, you can model wind direction and speed at different elevations above the surface of the earth.

One other reason to display features vertically is for a cartographic effect. That is, the data isn't displayed at a real-world elevation but rather at a height that's representative or visually pleasing. Representative heights can be used for data that's naturally ordered and hierarchical, like events through time or the command structure of units in battle. Alternatively, cartographic vertical offsets can highlight features that would otherwise be hidden, such as fire stations in a dense cityscape. In all these cases, feature heights are chosen at the scene author's discretion, and the depiction of the features moves beyond a simple representation of reality into the more complex world of 3D cartography.

Intuitive symbology

Intuitive is a dangerous word to apply to anything. What seems natural and understandable—"intuitive"—to one person might be completely foreign to another. However, for cartographic purposes it is fair to say that every symbol you recognize saves you the effort of referring to a legend to know for sure. A 2D map, for example, might show a fire hydrant as a drawn shape, making it simple to see where these important features are located. However, as features gather more subtypes—such as types of traffic signals or the voltage rating of electrical fuses—the use of individually defined symbols becomes less effective.

In 3D, the familiar feel of a real-world scene allows you to use many readily recognized symbols to make the map simpler to understand. A 3D street furniture layer with park benches, light poles, and trash cans (figure 2.7) is a great example of how recognizable shapes make the scene easy to comprehend without a legend. It's also possible to use stylized symbols or construct features that are wholly representative to help users grasp the content faster (figure 2.8).

Figure 2.7. Real-world objects in a 3D view, such as benches, light poles, and trash cans, don't require a legend.

Figure 2.8. Representative urban zones. Sample scene available with ArcGIS CityEngine®.

The medieval-style city map

Many of the earliest known maps of urban environments were 3D scenes (figure 2.9). These sketched and stylized maps were created as a static 3D bird's-eye view of the world and were successful in providing context through the relative placement of streets, walls, and buildings. The maps' authors would imagine themselves as a bird flying high in the air, and draw the scene using a combination of their understanding of the town and their imagination.

These kinds of medieval city maps were both beautiful and effective because they were works of art that were inherently understandable—there were no symbols or colors to be memorized; they were just "the real world, as seen by a bird." Although the technology of the day (paper and ink) placed significant limitations on the content and functionality of the scene (for example, you couldn't "move the camera" to see the city from a different viewpoint), the fact is that these maps communicated a lot of information efficiently.

However, this stylized view of mapping would fade during the seventeenth and eighteenth centuries as a new, critical use for maps emerged: navigating and measuring real-world distances across many scales. Ships sailed over oceans of endless blue water where reliable positioning became a matter of life and death, and the dominions of empires were oftentimes defining boundaries of future countries. During this age, vast coastlines were surveyed and mapped, and a 2D projected description of areas and distances, required for legal survey, became a primary element of maps, with vast amounts of money riding on the results.

Now, hundreds of years later, the ability to use computers rather than an artist's hand to render a 3D view means we can see a natural, 3D-style representation of our data without having to compromise on data accuracy or limited viewpoints.

Figure 2.9. This 3D cityscape map of Rhodes, Greece, in the fifteenth century is from an illustrated travelogue by Konrad Grünenberg (ca. 1487). Source: Wikimedia Commons.

Human-style navigation

For the vast majority of our lives, we experience the world from a height of two to eight feet off the ground. We walk through streets, we drive our cars, and we look out the windows of our home or office. Occasionally we visit or work in multistory buildings, and even more occasionally we travel in airplanes or helicopters, but even then, we tend to look "out" rather than "down."

To put it simply, human beings are used to being immersed in the world; we see objects in front of us, above our heads, and under our feet. This effect can easily be replicated in scenes by providing a human-style navigation experience. Game engines, in particular, take advantage of this by supporting a walking or running navigation mode that simultaneously allows users to look around (sometimes referred to as a "free look"). In video games such as Quake, Half-Life, World of Warcraft, or Fortnite, there's a strong sense of running down hallways, looking out windows, and being inside a virtual world.

When data is presented in this familiar and immersive way, the sizes and relative positions of objects are intuitively understood by the person wandering through the scene. There's no need to explain that you're in a forest, or that there's a lake blocking your way, or that

10-foot-tall alien life-forms are coming toward you—you can see them from a perspective that immediately makes the situation understandable. Also, once you start running away from the aliens, you'll quickly understand other normally obscure map features such as routes (where to run), topography (where to hide), and line of sight (where to set up your counterattack).

Scenes in 3D let you experience content, not just view and analyze it.

Superhero-style interaction

Superheroes interact with the world in ways most people can only imagine. They can get to hard-to-reach locations, such as deep space, the roof of a skyscraper, or underground. They can look through walls and rip off rooftops. They can sense information beyond the visual spectrum, like heat or sound or impending doom. They can move backward and forward in time. If you can imagine it, there's a superhero who's done it.

With scenes and virtual worlds, you no longer need an interplanetary event or chemical accident to view your data in this way. Interactive scenes will let you fly, or use X-ray vision, or blast away content that gets in your way. You can use transparency and visibility controls to view interior floor plans in a building. You can filter data through time in fast-forward to watch the geologic transformation of Pangaea into today's continents or go back in time to replay the flight path of an airplane arriving at an airport.

It goes further: given that the rules of our everyday world don't apply in the virtual world, it's possible to visualize data that can't be seen in real life. For example, 3D views can visually represent cell-tower coverage or noise propagation from aircraft or truly conceptual data such as the rate of cancer across geographic areas. This is an empowering concept—you can visualize and understand GIS data in 3D and it doesn't have to be an actual real-world object.

Challenges with 3D

If everything is so great with an extra dimension to work with, why aren't all maps 3D?

A 2D map might be superior to a 3D map for many reasons: its simplified representation, in cases where elevation isn't a factor, and the simple fact that it can be delivered without compromises on a flat sheet of paper. Also, as the old saying goes, "Nothing comes for free," and this is particularly true for working in 3D. If you want a beautifully sculpted terrain with crisp boundaries for roads, cliffs, and canals, you'll have to generate, or purchase, the surface data to represent it. The same is true for 3D objects such as buildings—for a faithful representation of the Lincoln Memorial or the Eiffel Tower or the Great Wall of China, someone will have to create it. It can take a lot of time and money to acquire or create great 3D content.

Since data collection challenges are common for both 2D and 3D maps, what are some challenges that are unique to 3D?