

# Chapter 16

## Digital City: An Urban Perspective on Digital Earth



Davina Jackson and Richard Simpson

**Abstract** Digital Earth and many other satellite and semiconductor-enabled cartography advances imply the need for a globally useful schema for more scientific and eco-ethical management of cities. How should we plan an internationally cohesive and locally effective system for understanding and managing urban stocks and flows around our planet? The answer to this question depends on new systems for managing geodata to underpin increasingly automated systems for evidence-based decision making. The current concept of Digital Earth as a “self-aware nervous system” is being advanced by urban proto-projects that are supported or followed by globally applicable initiatives including Singapore’s new Geospatial Masterplan, the International Standards Organization’s City Standards, Denmark’s Open Public Life Data Protocol, and the City-GML data model. These recent ventures are progressing a movement that extends far beyond the 1990s concepts of “smart cities” enabled by wireless telecommunications. In the Digital Earth science paradigm, cities must simulate their key situations and scenarios and analyze Earth observation data obtained via satellite-enabled devices that remotely detect and interpret all the light and radio waves of the electromagnetic spectrum.

**Keywords** Data cities · Geospatial · Digital urbanism · GEOSS · Digital earth · Earth observations · Smart cities · Urban modeling · Geodesign

### 16.1 Introduction: Satellites Meet Cities

The Digital Earth project (Gore 1992, 1999; Goodchild et al. 2012; Craglia et al. 2012; Jackson and Simpson 2012) is aligned with the intergovernmental program for a Global Earth Observation System of Systems (GEOSS was launched in 2005, the same year as the online commercial globe Google Earth; Group on Earth Observations (GEO) 2007, 2015; Jackson and Simpson 2012). These and many other satellite

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and semiconductor-enabled cartography advances imply the need to produce a globally useful schema for more scientific and eco-ethical management of cities (Ratti and Claudel 2016). This aspect of Gore’s Digital Earth dream remains far from reality and was promoted earlier by Richard Buckminster Fuller, beginning with his 4D Air-Ocean World Town Plan concept diagram (Fuller 1928; Fig. 16.1), followed by various urban synergetics proposals and prototypes. These contributed to his influential late-career book *Operating Manual for Spaceship Earth* (Fuller 1969), which was published exactly fifty years before this *Manual of Digital Earth*.

How should we design an internationally cohesive and locally effective system for understanding and managing urban stocks and flows around our planet? This question requires comparisons and integrations of significant concepts published and prototyped by key scientists, technology innovators, architects and other leaders of the urban informatics revolution; especially since Fuller died in 1983.

His original World Town Plan sketch was invented when “computers” were mathematically minded people, more than a decade before German engineer Konrad Zuse invented the first electromechanical, stored-program computing machine; his Model Z3 was first demonstrated in 1941. Fuller expired shortly after *Time* magazine named “The Computer” instead of a human recipient for its annual “Man of the Year Award” cover feature (Brosan and Segal 1982).

**Fig. 16.1** Fuller’s air-ocean world town plan diagram, 1927–28 (Estate of R. Buckminster Fuller/John Ferry)



Although his vision of an electronic infrastructure to operate Spaceship Earth was inspired by radar and airplane autopilot systems, satellite navigation was not commercialized widely for terrestrial vehicles until the early 1990s. Accompanying the advent of GPS (global positioning system) devices linked to American NAVSTAR satellites were magazine and newspaper reports forecasting commercialization of the internet as a “new information superhighway” and revolutionary television and telephony advances (Negroponte 1993, 1995; Gates 1995). Leading professors of town planning and architecture expected computers to accelerate “smart cities” (Gibson et al. 1992) and the MIT Smart Cities Lab was founded by William J. Mitchell in 2003. Other urban prophecies included “fractal cities” (Batty and Longley 1994), the “city of bits” (Mitchell 1995) and “intelligent environments” (Droege 1997). At the time of writing this chapter, the world’s main satellite navigation systems were GPS (US), BeiDou (China), Galileo (Europe) and GLONASS (Russia; Hunter and Hartcher 2019). We suggest that all of these 1990s terms emerged in response to global commercialization of wireless and mobile telecom infrastructure—and that this century’s Digital Earth and GEOSS planetary systems simulations vision demands a new emphasis on the cruciality of satellite-enabled remote sensing data; thus, we now use the term Data Cities when considering the urban aspects of Digital Earth.

All of those end-of-century writers (and others before and since) highlighted that “wireless” (actually extensively cabled) telecom technology was unlocking a crucial new way to understand cities: not as static compositions of buildings and streets but as dynamic, unpredictable and increasingly networked flows of activity and connections. However, until recently (Jackson 2018) there was little emphasis on how satellites have become essential to what Batty called “a science of cities” (Batty 2005, 3; 2013) and Stephen Wolfram termed “a new kind of science” (Wolfram 2002) that would interpret fractal and cellular automata principles of evolutionary growth and behavior.

Satellites allow for today’s environmental scientists and designers to use increasingly sophisticated machines and programs to monitor and simulate various processes that Jay Forrester termed “urban dynamics” (Forrester 1969). City monitoring and modeling are being accelerated by increasing numbers and constellations of Earth-observing (EO) satellites, including squads of tiny CubeSats carrying miniature remote sensing instruments. These include scanners and sensors to scrutinize atmospheric and ocean conditions for meteorological and marine agencies (producing data that are visualized dramatically for television weather reports). They also include many devices that use all the wavelengths of the electromagnetic spectrum to continually survey the world.

Earth observation methods such as SAR interferometry, GNSS reflectometry (GNSS-R), radar altimetry and lidar sensing are revealing many structures and activities that normally cannot be viewed by humans or have been long obscured. Some dramatic recent examples are digital heritage discoveries and detailed 3D mapping of various ancient cities that were lost for centuries under tropical jungle foliage or

catastrophic floods. Specialists in digital archaeology can study early stone carvings under thick coats of dirt and moss, and explore fabled burial grounds, perhaps without touching a spade (Venkataramanan 2014).

For professionals developing and managing contemporary cities, satellite-enabled land surveying has become vital to understanding existing circumstances with unprecedented accuracy—allowing designers, decision makers and stakeholders to share the same eyewitness evidence in discussions of proposals and problems.

To understand how satellite technology and data are being applied to solve today’s environmental planning and management challenges, Davina Jackson (coauthor of this chapter) devised a matrix diagram of five research themes and their flow-on priorities and projects in government, commerce and public sector contexts. Drafted from 2008 to 2011, it was published in a GEO-sponsored snapshot report on the scope of the GEOSS/Digital Earth project (Jackson and Simpson 2012, 5; Fig. 16.2). All five research themes are being pursued concurrently towards the ideal of a global model of complex environmental systems. They are natural systems modeling (NSM; projects simulating certain area-defined environmental behaviors), building information modeling (BIM; creating virtual models of structures and testing the viability and defects of each design before on-site construction), city information modeling (CIM; 3D mapping, satellite and aerial imagery, remote sensing and data analytics at scales from street corners to megalopolises), virtual nations and networks (VNN; data management and mapping the environmental conditions of countries,

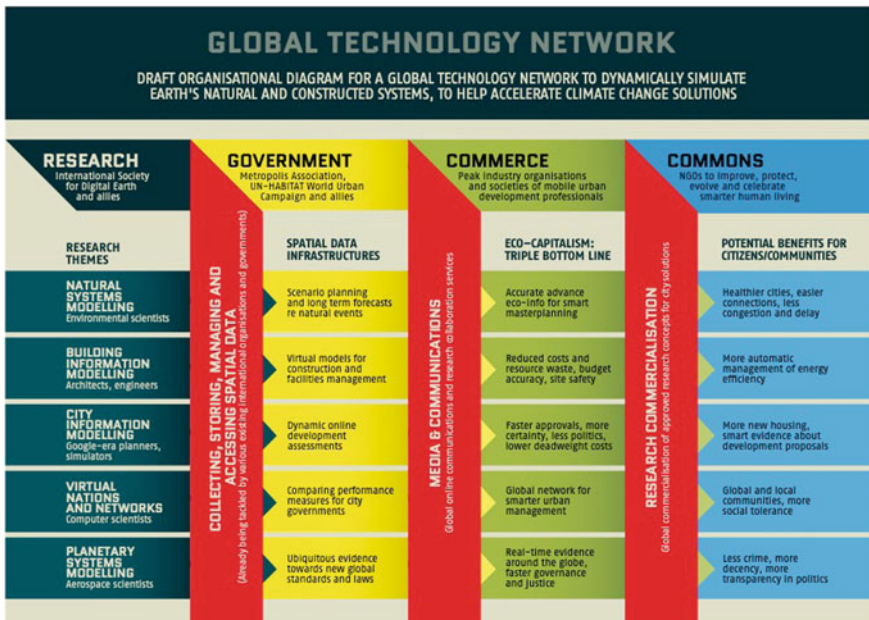


Fig. 16.2 Jackson’s global modeling network concept diagram, 2008–2011 (Jackson and Simpson 2012)

multinational regions or continents—e.g., Virtual Singapore) and planetary systems modeling (PSM; integrated 3D data mapping of environmental conditions around the Earth).

All five scales of Earth observations and simulations must be integrated to achieve the concept of a global EO system of systems but the diagram identified them separately to reflect the reality that most researchers operate within specific professional disciplines and domains of study (Fuller 1980). The following sections explain current activities and recent projects that contribute to the integration of data and modeling that is transforming urban development.

## 16.2 Global and Dynamic Data Mapping of Cities: A New Cartography Paradigm

The Digital Earth vision and GEOSS program are both evolving through collaborations between several hundred international governments, space agencies, science, research and standards organizations, and United Nations entities (UN Global Marketplace n.d.). These groups are organizing different advances towards the system of systems that has begun to allow users to access, analyze, visualize and exploit the data collected by Earth observation instruments aboard or networked with satellites. In this section, we identify how this system is being progressed in ways that may help reform obsolete, insular and ecology-damaging practices by millions of influential actors in urban development and city governance roles.

Today's collaborations are underpinned by shared understandings of the imperative to scientifically tackle the deadly impacts of climate change, including extreme weather events (natural catastrophes), loss of biodiversity, rising sea levels, and extreme heat and drought (UNDP n.d.). Two key UN bodies are leading the task of broadly communicating information and strategies to deal with these wicked problems: the Intergovernmental Panel on Climate Change (IPCC), which releases five-yearly scientific reports recording the world's environmental threats and performance, and the UN Framework Convention on Climate Change (UNFCCC), which organizes annual conventions where relevant organizations discuss, and participating governments agree, how they will reduce ecology-damaging practices in their countries.

Another UN organization, the UN Development Programme (UNDP), globally promotes seventeen sustainable development goals (SDGs) that include climate action and sustainable cities and communities (UNDP n.d.) and other, mainly urban, agendas. Its urban targets for 2030 include upgrading slums, increasing the resilience of communities that are vulnerable to disasters, reducing the environmental impacts of cities, improving air quality and waste management and providing affordable, useful public transport and housing.

Certain places are evidently dangerous to occupy—flood plains, fire and earthquake zones, or countries prone to war. Vast land areas, especially deserts or polar regions, are shunned because they seem inhospitably dry or frozen. Should they be invigorated via hydro- and geo-engineering? This matter is being debated by ambitious scientists and engineers through their academic and professional organizations.

Many properties near water—cliff-top mansions on New York’s Long Island or entire island states such as Tokelau and Nauru—risk subsidence and submersion through the same forces (freak waves, storms and rising sea levels) that caused ancient monumental cities such as Thonis (Egypt) and Harrapan (India) to slide into the sea. Cyclones sometimes destroy popular resorts on South Pacific islands and towns along Asian coasts, and fires seasonally burn through leafy suburbs in southeast Australia and southern California. Residents of large hillside cities in Central America and South America—like La Paz in Bolivia—understand that their homes suddenly might slip down their slopes of clay. All these dangers appear to be escalating with the global warming that Swedish scientist Svante Arrhenius first predicted in 1896. He calculated that global temperatures would rise by 5 °C with the doubling of carbon dioxide burned into the atmosphere. This prediction seems consistent with today’s UN forecasting of a 5 °C temperature increase globally by 2050 (UNDP n.d.).

In Geneva, the International Centre for Earth Simulations (ICES Foundation) archives scientific and press reports of environmental disasters on its website (Bishop 2018). Its articles from September 2017 to March 2018 included photographs of a hotel tower falling after a Taiwan earthquake, bridges collapsing in Colombia and Florida, homes buried under mudslides in southern California, a volcano erupting in Bali and Hurricane Irma battering Caribbean countries and Miami. ICES, led by Bob Bishop, a scientist expert in high-performance, real-time computer simulations, aims to establish an advanced computing facility in Switzerland for modeling complex environmental systems. His foundation offers a worldwide QLARM message service that promptly predicts and maps likely building damage and human casualties after earthquakes (Wyss n.d.). More than 1000 alerts have been issued since 2002 using geological data from the Swiss Seismological Service, settlement records from the *World Housing Encyclopedia* and population statistics. ICES also completed earthquake vulnerability studies of Haiti (for the Swiss Department of Foreign Affairs) and Kyrgyzstan (for Médecins Sans Frontières).

In recent lectures, Bishop analyzed the challenges and potential for building “an open, integrated, wholistic model of Planet Earth for decision support, disaster reduction and public good”—the same vision as the GEOSS, Gore’s 1990s Digital Earth and Fuller’s 1960s Spaceship Earth. He warned that quantities of data—mostly unstructured data—are growing far faster than global computing power—and that both are insufficient to crunch solutions for the world’s many serious environmental and sociopolitical threats. He predicted that, as well as quantum computing systems, global simulations projects will ultimately be improved by neuromorphic computing to imitate information processing by human brains. Recent projects to develop neuromorphic chips include TrueNorth by IBM, SpiNNaker by Manchester University and BrainScaleS, initiated by Heidelberg University. The two academic ventures have transferred to Europe’s Human Brain Project (HBP), which aims to substantively

upgrade today's energy-guzzling computers built with von Neumann architectures (Modha n.d.). Bishop (a former chair of the HBP advisory panel) suggested that, while these computing capacity ambitions are being pursued, current projects can reduce energy consumption by installing processor-in-memory (PIM) technologies to use big data, preferably without moving it. While computer architectures would be global, the data should be applied to solve local urban and regional problems.

European scientists recently published the first sophisticated satellite mapping of the world's human settlements, depicting four decades of population statistics and machine-analyzed Landsat data, including some information on building heights, footprints and materials. Launched in 2012 as the Global Human Settlement Layer (GHSL dataset for GEOSS; Pesaresi et al. 2016), this project is included in the GEO Human Planet initiative that was announced at the 2016 United Nations Habitat III conference on settlements. As well as identifying several major new cities in Asia that were not UN-recorded, it applied astrospatial (developed for space exploration), geomatics (terrestrial monitoring) and telematics systems to the formerly paper-centric domains of land surveying, cartography, architecture and town planning. Outstanding 3D and 4D visualizations of the GHSL data, depicted as "population mountains", were produced by Alasdair Rae (Rae 2016, 2018) and Matt Daniels (Daniels 2018a, b).

The first example of global 3D video-mapping of urban population (including growth) statistics was Japan's PopulouSCAPE project, which included a 10-minute *Night Flight Over an Urbanizing World*, providing aerial views of cities as surging towers of population (visualizing UN Figures) and intercity transport and communications connections (Ito et al. 2005; Team PopulouSCAPE 2005). Another historically significant example of planet-scale modeling of cities was the *Pulse of the Planet* real-time video visualization of AT&T data recording telephone and internet traffic between New York and other cities. Produced by a Carlo Ratti-led team at MIT's SENSEable City Lab, it was shown in the *Design and Elastic Mind* exhibition at New York's Museum of Modern Art (MIT SENSEable City Lab 2008). These two projects were perhaps history's first world-scale depictions of the data cities movement (Jackson 2008; Jackson and Simpson 2012)—following some important mid-2000s video simulations of specific cities such as the *Virtual London* model (showing flood and shadow simulations) by University College London's Centre for Advanced Spatial Analysis (2002–2005) and the *Real-Time Rome* mobile phone data-mapping show at the Venice Biennale by MIT's SENSEable Cities Lab (2006).

One notable new world urban mapping project is the Global Urban Footprint (GUF), led by Thomas Esch's team at the Earth Observation Center of the German Space Agency (DLR, Fig. 16.3). Scatters of tiny black dots show settlement patterns with unprecedented detail and precision, using radar data from the TerraSAR-X and TanDEM-X pair of satellites operated by the DLR and Airbus Space and Defence. Although only depicted in 2D, the GUF shows the global distribution of human settlements with an unprecedented spatial resolution of 0.4 arcsec (~12 m), using 180,000 satellite scenes expressed in grayscale: black dots for urban areas, white for land and gray for water (DLR n.d.; Fig. 16.4). This instantly informative data visualization (seen on-screen via a swirling sphere) refreshes the adage that new technology



**Fig. 16.3** Global Urban Footprint map by the German aerospace center (DLR/Thomas Esch)



**Fig. 16.4** Sunlight control modeling for Auckland city (1988), with the operative envelopes visualized as “stained glass” windows (Cadabra)



paradigms (such as 3D time-series video-mapping) are not the only, or always the best, tool for communicating specific information in certain circumstances. As an obvious example, audio remains preferable to video when people are walking or driving cars.

## **16.3 Global Advances in Computer Design, Analysis and Construction**

This section highlights five significant advances in data modeling solutions for major challenges in designing and managing built environments.

### ***16.3.1 Environmental Performance Control Envelopes***

New Zealand's Resource Management Act, passed in 1991, was ground-breaking legislation for the nation to conserve and sustainably manage its natural resources: land, air and water. It was underpinned by one of the world's first cases of using architectural computer modeling (then known as CAD, computer-aided drawing, now updated as BIM, building information modeling) to pretest the potential environmental impacts of new building proposals. Approval by a New Zealand court of law for uses of 3D computer models as evidence was first granted for the appeal of a planning decision that delayed construction of Auckland's Sky Tower. As the tallest freestanding structure in the Southern Hemisphere, Sky Tower was a radical departure from the city's conservative urban landscape and would not have been publicly acceptable without using computer simulation and 3D visualization to articulate the regulatory, design and environmental impacts (Fig. 16.4).

Before the Resource Management Act, basic prescriptive rules were used by NZ planning authorities to maintain unimpeded sunlight for specific open spaces. This approach was refined during the years after the 1987 stock market crash, when city property values slumped. In 1988, the Auckland City Council commissioned Cadabra, an applied computer graphics consultancy led by Richard Simpson (coauthor of this chapter) to develop one of the world's first performance-based 3D virtual city models to allow for patterns of sunlight to be more specifically and accurately simulated.

Cadabra's approach was to calculate an overarching operative control envelope (OCE) for the central city. This performance-based envelope was generated from an accurate 3D terrain model of the city, including twenty-seven designated public places (mostly parks) that were to maintain access to sunlight and views. The sunlight controls for these places were evaluated for every moment of the year to determine the overall impact that each would have on the city height limits. The result was a set of twenty-seven envelopes that intersected in complex and dramatic ways in 3D

and 4D space above the virtual city skyline. The overarching operative envelope was determined by overlaying all the place-specific envelopes and defining the combined surface minimum to define the OCE.

This operative surface had the appearance of an exaggerated rugged terrain in the sky. It defined a “battle” between ground-based controls. In one place, one control might have a sweeping influence on the height of a potential new building, then would be overridden by another control. The hilly nature of the inner city, protection criteria, and eclectic formats of park boundaries all contributed to this complex expression through controls on the generated operative envelope. Visually, this model appeared like a paint-by-number on a wildly rumbled canvas.

The operative envelope was visualized as a contour plot of heights above a datum. The model enabled performance-based sculpting of the city’s urban envelope and regeneration of the individual sunlight controls to ensure solar irradiation for any place for specific periods of the year and times of day. It was also rendered in 3D with proposed and existing 3D CAD models of buildings. If a building complied with the control, it would be visually obvious as it would not breach the envelope. The rendering treated each control as a differently colored “stained glass” window and thereby visualized the volumetric influences of controls in the airspace and throughout any day. Colored light for a specific control might flood the ground to clearly show the influence of any specific control through a day or year.

The final design of Auckland’s OCE was published as a set of regulatory contour maps in the 1991 district scheme. This work defined the aesthetic balance and shape of Auckland’s skyline and enabled a paradigm shift from obsolete prescriptive controls to more evidence-precise and context-responsive performance controls. The modeling removed legal ambiguities and provided more clarity and certainty for citizens to enjoy maximum sunlight and views when using public spaces.

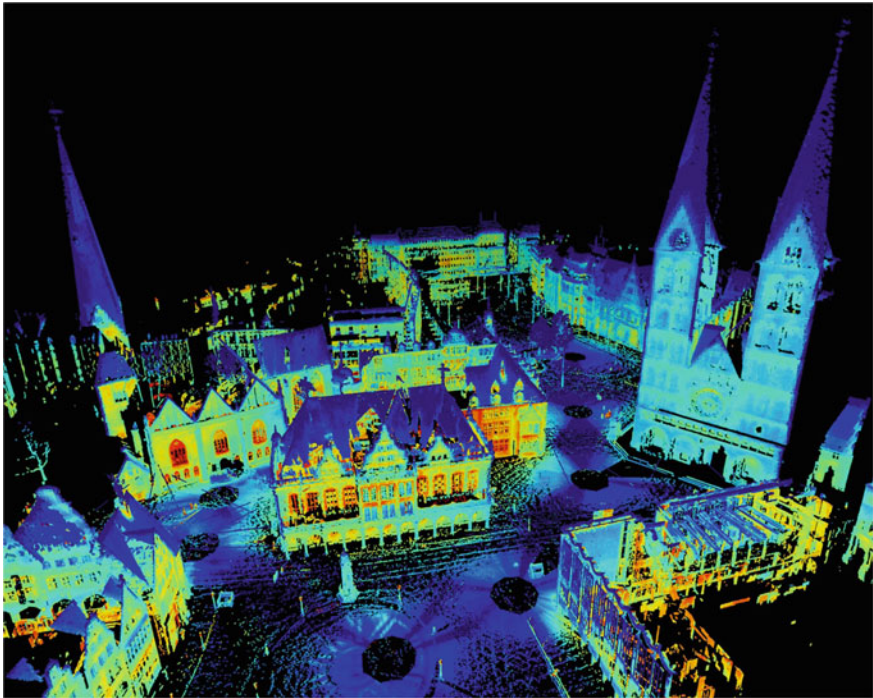
### ***16.3.2 Geodesign***

In 2001, Pascal Mueller, then a postgraduate student at ETH-Zurich’s Future Cities Lab, introduced CityEngine, a procedural modeling program to rapidly generate and modify basic forms of buildings in urban scenes. It offered designers flexibility to change the heights and floorplates of specific buildings on the fly, using process scripts rather than the prescriptions of parametric modeling. When commercially launched in 2008, it could generate a realistic 3D online (flythrough) depiction of Venice’s Gothic-Byzantine building stock in a few minutes. Users could transform the heights and areas of one or various buildings, and simulate shadows cast at different times of day and year. Since 2011, CityEngine has been owned and updated by Esri, the world’s largest commercial GIS mapping software supplier, to integrate with its formerly offline and 2D (pre-Google Earth) suite of ArcGIS mapping tools. Esri’s transition to online 3D dynamic modeling and what-if design tools, and its SYMAP-derived

topographical data mapping, catalyzed a new educational-promotional venture that the company's founder, Jack Dangermond, launched with the name Geodesign in 2010 (Steinitz 2012, 2013; De Monchaux 2016).

Until recently, the GIS packages needed by surveyors and land-planning professionals have been used separately from the building design (BIM and CAD) programs required by architects and building engineers. However, some surveying firms such as Britain's Severn Partnership are marketing "Scan2BIM" skills to provide point clouds of 3D laser-scanned, geotagged data about existing buildings and landscapes, giving precise bases for modeling structural alterations. Another example is the *ThermoMapper* project in Bremen, where Dorrit Borrmann and Andreas Nüchter from Jacobs University recorded a 360° aerial point cloud of the city square with temperature data from nine thermal images overlaid on eleven 40° laser-scanned poses of the historic buildings, plaza and streets. They used a Riegl VZ-400 3D laser scanner and an Optris PI infrared camera, with the pose files calculated using 3DTK based on odometry information (Borrmann and Nüchter n.d., Fig. 16.5).

In 2017, Autodesk and Esri announced a new collaboration to integrate their building design and environmental data modeling tools. Patrick Janssen, with the Singapore ETH Future Cities Lab, was skeptical that this partnership would resolve all



**Fig. 16.5** *ThermoRathaus*, a point cloud of Bremen's city square, overlaid with temperature data from a thermal imaging camera (Borrmann and Nüchter, Jacobs University)

the aspirations of architects but recognized opportunities to resolve significant deficiencies in Esri's GIS and Autodesk's BIM and graphics packages. Janssen praised GIS software for providing data online and downloadable in tiles and criticized BIM programs for not providing online access to data and fine-grain imagery. He said advanced architects were eager for open semantics, "where you can compute your own stuff"; a capability now available to some extent in Houdini but likely to be more prevalent soon with new developers using Amazon Web Services or Web Assembly (Wasm). He said that most sophisticated modeling programs remain too complex in their structural routines—generating too many links and nodes in their data graphics. He was developing a new online geometrical design application, Vidamo, which he expected to be more efficient and more comprehensible for users without advanced programming skills (Jackson 2018, 37).

At the 2018 Geodesign Summit, Dangermond's presentation emphasized "the science of where" as being crucial for "understanding and managing our world" through "integrating people, processes, things and data about them" via three types of information infrastructure: records, insights and engagement. He also highlighted three major groups of trends that would evolve WebGIS during coming decades (and which are applicable to other types of software needed for urban planning and design). For professionals concerned with *data*, relevant advances include drones, lidar, scientific measurements, real-time video, crowdsourcing and much more detailed information on traffic, demographics, weather and locations. For experts developing *computer infrastructure*, he highlighted mobile communications, big data, machine learning, distributed computing, SaaS (software as a service), the IoT (Internet of Things), cloud storage and parallel computing, web services, microservices and networks. For *GIS innovation*, he focused on "expanding the power" via advanced analytics, open APIs, dynamic image processing, online content, apps, 3D modeling and smart mapping, data exploration, hubs, real-time visualization, Python programming and portals (Dangermond 2018).

As a corporation led by landscape architecture graduates from Harvard, Esri is focused on how to use computer tools to eco-sensitively integrate buildings and urban infrastructure with natural environments. Echoing three of the five research themes identified in Jackson's 2007 GEOSS-DE network diagram (Jackson and Simpson 2012, 5; Fig. 16.2), Dangermond identified four main types of modeling that should be increasingly integrated: landscape information models (LIMs; another term for natural systems modeling), building information models (BIMs), city information models (CIMs) and zoning information models (ZIMs; a CIM subset of particular value to government planners; Dangermond 2018).

### 16.3.3 *Digital Engineering and Digital Twinning Standards*

Also called virtual engineering, digital engineering is a shorthand reference to the consistent use of digital methods and tools throughout product development and production processes to improve planning quality and process controls over an asset's

entire life cycle. Digital twinning involves modeling and simultaneously sustaining all the virtual systems associated with a physical entity. These terms emerged with computer modeling and autopiloting systems developed for aerospace, ship and car manufacturing and operations. Now these labels have transferred to BIM and geospatial environmental modeling—which evolved from different 2D paradigms (CAD drawing and GIS mapping) that depend on different methods of structuring data.

To establish interoperability, the buildingSMART International (bSI) group and the Open Geospatial Consortium (OGC) established a joint working group in 2017 to prepare a roadmap towards a global standards framework named the Integrated Digital Built Environment (IDBE). BSI administers Open BIM standards, including Industry Foundation Classes (IFCs), and the OGC administers OpenGIS, including geospatial data interoperability, and the Reference Model and GML standards. The IDBE is intended to underpin digital engineering and enable digital twinning of physical conditions with corresponding records held in digital repositories. The physical twin may be represented in the digital twin (virtual model) at any level of detail (LOD). However, there are new moves beyond formerly prescriptive notions of LOD to a more agile, performance-based, level of information needed (LOIN) approach, which specifies why data are required, what specific data are required, when they are required, and who is responsible for the transfers and uses.

### ***16.3.4 Astrospatial Architecture***

Architecture's ancient history switched tones around the turn of the third millennium. In May 2000, Aaron Betsky published *Architecture Must Burn*, a critique of late-twentieth century architectural culture and a “manifesto for architecture beyond building” (Betsky and Adigard 2000). This book preceded, by just eighteen months, the explosions that collapsed America's twin towers of modern capitalism, the World Trade Center, in September 2011. Five months later, Manhattan architects Diller Scofidio+Renfro revealed an unprecedented anti-icon: the Blur pavilion, a wide cloud of clean water vapor hovering low across Lake Neuchâtel during the 2002 Swiss National Expo. Solar-powered and with sensors dotted across its fog-obscured steelwork, this work symbolized two novel impulses: to evaporate architecture's antiquated focus on merely crafting static structures using weighty materials dug from the Earth and to steam-clean a world remaining stubbornly reliant on carbon-belching fossil fuels.

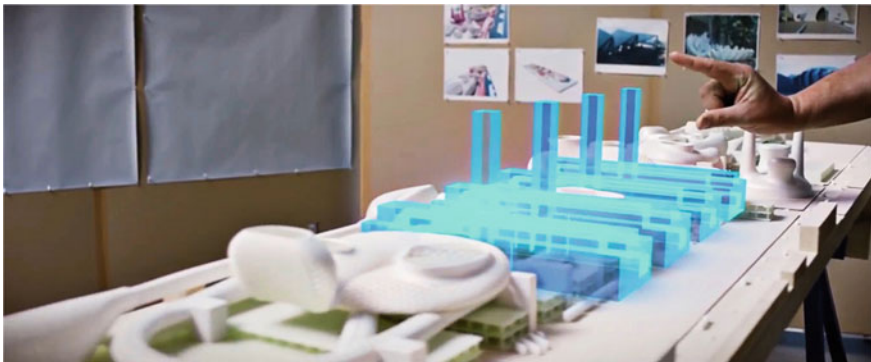
Blur catalyzed a post-internet design movement that was later named astrospatial architecture (Jackson 2016). Protagonists now intend to design extraordinary compositions of solids and voids and devise memorable interpretations and experiences via light and data. For example, in 2011 Joseph Paradiso's Responsive Environments group at MIT's Media Lab revealed perhaps the world's first video simulation of invisible atmospheric dynamics inside a building—using temperature, humidity,

light, sound, human movement and other data, streaming from RFID and other sensors around floors of the real building. Visualized with the Unity game engine, the *DoppelLab* showed how space pulsates with unseen information (Paradiso 2011).

Architectural technology has evolved from computer-aided drawing (CAD) tools (beginning with light pens drawn on tiny screens in the late 1950s) to BIMs that are derived from aerospace engineering software and can script algorithms to operate fabrication machinery such as 3D printers and construction robots. Professors leading this international revolution tend to be involved in three overlapping design movements: Parametricism (Schumacher 2008), Smartgeometry (Smartgeometry n.d.; Peters and Peters 2013) and the more recent Advanced Architectural Geometry (AAG) group (Adriaenssens et al. 2016).

Building models created in programs such as Autodesk's BIM360 or Revit, or Trimble's Tekla BIMsight or Connect, can be exported for viewing with headsets using plug-ins such as Modelo, Prospect, Enscape, Umbra or AUGmentecture. Another capability was demonstrated by Greg LynnFORM at the 2016 Biennale of Architecture in Venice, where Lynn and his team used Microsoft HoloLens goggles and augmented reality (AR) software to compare multiple holographic scale models of the Tate Modern building in London with a physical scale model of a giant former car plant in Detroit (Fig. 16.6). HoloLens wearers could look inside the physical model and walk around full-scale virtual rooms defined by lines of ephemeral light. The team also highlighted and overlaid the history of the building being redesigned and showed different road and aerial vehicles flowing around the site (Jackson 2018, 19–20).

Beyond the design studio, VR, AR and nonimmersive 360° viewing systems are valuable tools for the property industry (Stanley 2017). They help clarify building proposals to stakeholders influencing council development approvals. They help in marketing buildings and apartments prior to completion or to inform remotely located investors. For example, spherical imagery captured by drones can clarify views from different floor levels of an unbuilt tower. The industry expects continuous



**Fig. 16.6** Greg Lynn finger-snaps holographic (AR) building models of London's Tate Modern onto his physical model for car plant redevelopment in Detroit (Microsoft)

improvements to VR and AR experience kits and 360° cameras over the coming decade. Better graphics (pixel densities and spatial resolutions), audio, haptics (more touch-sensitive handset interfaces), and tracking speeds are still needed.

Another way to represent architecture and cities is with holographic images. These are data-coded recordings of light fields (waves of particles scattered off illuminated objects). Like sound recordings, holographic recordings can be reproduced later—but usually with considerable loss of fidelity, so the representations seem ethereal. Virtual building and city models can also be converted into 3D holographic imagery printed on film. When illuminated from above, these renditions seem to pop in three dimensions from their glossy sheets. If not precisely lit and viewed, holographic images appear spectral and chromatically fragmented.

Holographic glasses and headsets underpin augmented reality (AR)—a domain alternatively named “metasensory augmentation” by wearable computing visionary Steve Mann. At MIT in 1978, he prototyped the first AR spectacles, Digital Eye Glass, and later versions could be finger-tapped to convey holographic data. Those precedents inspired Google’s Glass smart specs (sold generally from 2013 to 2015), Microsoft’s HoloLens system (launched 2016) and the Vuzix Blade smart glasses (previewed in 2018, Statt 2018). The HoloLens has been surpassed technically by another of Mann’s creations, Metavision’s Meta 2 visor, released to Unity game developers in late 2017.

LiFi (light fidelity) is another emerging technology expected to energize built environments. Demonstrated by Harald Haas in a TED talk in 2011, a LiFi system uses the semiconductors of LED lamps (such as downlights) to transmit data (Haas 2015). In some early tests, LiFi networks transferred data at much faster speeds than is currently possible over WiFi networks conducting low-frequency radio waves and microwaves. This is because LiFi uses the higher frequencies and bandwidths that come from the visible light, infrared and near-ultraviolet waves that share the mid-range of the electromagnetic spectrum. Since Haas and his partner Mostafa Algani set up the pureLiFi company to commercialize his discoveries, several dozen startups and corporations have begun developing LiFi applications using next-generation LEDs with signal processing capabilities. In Dubai, Zero 1 used LED streetlights for networking data—exploiting pre-Haas research on urban transport-logistics telematics. In Dresden, the Fraunhofer IPMS research center has developed industrial automation solutions for several corporations. All major electronics manufacturers—General Electric, Panasonic, Samsung, Philips, Osram, Qualcomm and Cree—are racing to market with LiFi data-and-light product suites.

People in polar countries often feel depressed by the long nights of winter—needing treatment with mood-elevating colors and wavelengths of light. This affliction, called seasonal affective disorder (SAD), seems to emerge from changes to a body’s circadian rhythm and serotonin and melatonin hormone levels. Some local governments in near-Arctic latitudes encourage their citizens to take therapy sessions and cheer their communities with winter light festivals (that also magnetise tourism). From 2012 to 2016, Oslo artists Christine Istad and Lisa Pacini responded to SAD in Norwegian towns (where there is no daylight during January) by trucking around a night sun—a 3 m-diameter circular panel crusted with hundreds of color-changing

LEDs (Anon 2013). A popular, three-dimensional, night sun is Rafael Lozano-Hemmer's *Solar Equation* aerostat (helium balloon), which is video-mapped with layers of computer-generated imagery and data derived from NASA's sun-monitoring instruments (Fig. 16.7). These are just two examples of creative urban (outdoor) applications advancing this century's revolution in 'electroluminescent' technology, based on semi-conductor controls of electric pulses (Neumann and Champa 2002; Jackson 2015).

### 16.3.5 Artificial Intelligence

Artificial intelligence was ignored by most built environment professionals until the internet caused widespread apprehensions during the 1990s, systemic disruption during the 2000s, and now, inevitably, new ways of understanding and doing things. Today, AI brings another wave of unfamiliar technologies and terms—including augmented intelligence, where machines are intended to improve human abilities to decide and perform. This seems less threatening than artificial intelligence, where machines are presumed to increasingly replace humans to a tipping point that Ray Kurzweil termed the Singularity (Kurzweil 2005).



**Fig. 16.7** *Solar Equation*, a “night-sun” (helium balloon) designed by Rafael Lozano-Hemmer and mapped with NASA sun-monitoring data (Marcel Aucar)



All intelligence, artificial or natural, flows from competent processing of information. Most AI researchers have abandoned their early reliance on preprogrammed rules to solve problems. Instead, they are evolving machine learning, where computers use statistical learning algorithms to gradually teach themselves how to intelligently process big data. The more data that computers are given, the more capably they can perform complex tasks; partly through their supra-human powers of pattern recognition (*New Scientist* 2017).

Dacheng Tao at the University of Sydney has developed a classification system to help understand different concepts, methods and challenges that are being advanced in AI and robotics. His taxonomy highlights four basic functions performed by machines: perceiving, learning, reasoning and behaving. Devices fueled by data from sensors and cameras must perform one or more of these functions to help solve humanity's ultra-wicked problem of how to sensibly manage our planet.

Machine learning is a new field that is being divided into different specialties: unsupervised learning (training machines to identify untagged images), supervised learning (training using labeled or annotated information), reinforcement learning (training via rewards for correct actions) and deep learning (using complex neural networks). Neural networks are software circuits inspired by flows of information through human brains. They can deliver general artificial intelligence (solving various tasks) or narrow AI (expertise in one or two specific tasks).

One of the most promising potentials in AI is for robots to replace humans in performing extremely dangerous tasks: such as exploring nuclear power plants after an explosion, entering narrow cavities to replace damaged wiring or recording stress points in unstable structures. Czech writer Karel Čapek first coined the term robot in his 1921 play *R. U. R: Rossum's Universal Robots*, and today's humanoid versions such as Boston Dynamics' Atlas and Honda's Asimo are agile and realistic. Most of Boston's robots, being developed with the US Defense Advanced Research Projects Agency (DARPA), emulate fleet-footed animals and are intended to replace soldiers on topographically rugged battlefields. Swiveling, fixed-footed robots (mounted on a floor or ceiling) can print small masonry dome structures and assemble timber-framed houses (Jackson 2018, 42–48; Kohler et al. 2014).

Researchers developing computer vision systems are evolving improved ways for cameras, sensors and software to detect, recognize and track moving objects, including people, analyze environments by segmenting items of interest in changing scenes, estimate distances between cameras and objects in view, and enhance the clarity of images. Face-detection software can discern and frame almost every head in crowds of thousands. Any newly scanned face can be matched instantly with the same face from a digital archive. Data analysts can also clarify blurry, hazy, too-dark, wrongly colored and low-resolution images using smarter versions of the photoenhance tools found on standard laptops and smartphones. As these perception technologies improve, CCTV is becoming all-pervasive, with predictable reductions of both public crime and personal privacy.

Machine vision scientists depend on open-source datasets comprising images of objects that are classified and labeled to allow for comparisons with new images containing similar objects. The world's largest object dataset, ImageNet, contains

more than 14 million crowd-labeled thumbnails, which can be downloaded to help identify different types of natural places, buildings, rooms, products such as fridges or dishwashers, furniture, fabrics, clothes, and apparel such as hats or sunglasses. Vision experts classify database images according to whether they depict “things” (box-frameable objects such as chairs, people or windows) or “stuff” (matter with no clear boundaries such as a patch of sky, an office corridor, a wall, a hillside or a street) (Stanford Vision Lab 2016).

Ironically, the image databases now being assembled to support AI analytics all depend on the “artificial intelligence” (i.e., the non-electronic knowledge of humans working online) to label and cross-check the images uploaded by database compilers. One busy conduit is Amazon’s Mechanical Turk (AMT) portal, which matches employers (such as public research groups) with freelancers to contribute to specific human intelligence tasks (HITs). One recent HIT, to assemble and correctly label 328,000 thumbnail images of “common objects in context” for the Microsoft COCO dataset, required 70,000 h of work by Microsoft-funded AMT participants (Lin et al. 2015).

Cameras and scanners capture images that can be analyzed, compared and manipulated, increasingly automatically and accurately. Some powerful processes are becoming common practices for owners and managers of major buildings and public places. For example, different faces, facial expressions, poses and walking gaits can be transferred or morphed between source videos featuring one or more people and “target” videos involving other people. Security cameras can detect licence plates and simultaneously track clusters of moving vehicles, even at night. All these observation systems are being integrated gradually with traffic lights, smartpoles and building heating, ventilation and cooling (HVAC) systems.

Data networks underpin the sensing and imaging infrastructure that is necessary to deliver key goals for the Global Earth Observation System of Systems. These include improving urban and disaster resilience; public health; energy, mineral and water resource management; infrastructure and transport systems; food security and agriculture, and healthy, biodiverse ecosystems. These domains overlap—integration of information and technology solutions is the main point of the GEOSS.

Caution pervaded a recent editorial for *Environment and Planning B*, in which Michael Batty warned readers not to expect too much sophisticated intelligence from “intelligent” machines. He said that machine learning through highly repetitive schemes of pattern recognition is “not much more than sophisticated averaging” but because machines could rapidly process vast quantities of data, they would continue to be useful for automated tasks such as monitoring and prediction of energy uses, delivery of location-based services, and transport. He suggested that machines would not be capable of replacing humans in planning long-term development of cities because they could not compute “the hard choices” of how a city functions economically and is organized in terms of social equity. He suggested both exploration of the limits of AI in understanding cities and “a concerted effort” by planners to invent new ways of automating urban functions (Batty 2018).

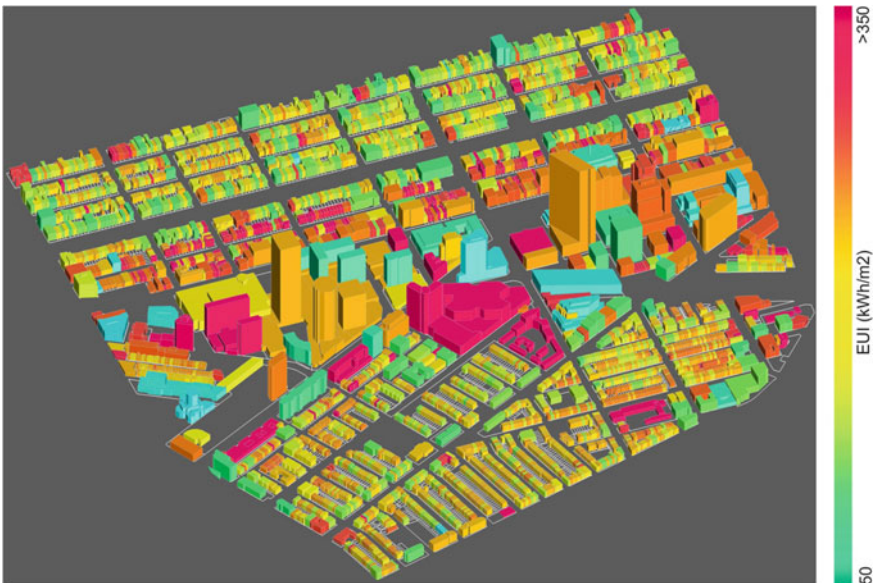
## 16.4 Some Recent Urban and Regional Case Studies with Global Potential

This section highlights seven projects and research groups that have advanced urban environmental simulations with methods that could be applied in many other cases and places.

### 16.4.1 MIT Media Lab Projects, United States

Carlo Ratti's SENSEable City Lab worked with government leaders in Cambridge, Massachusetts to prototype the *City Scanner* project to acquire weather and air quality data for different precincts using sensors fixed to garbage trucks. Christoph Reinhart's Sustainable Design Lab developed an urban modeling interface (*umi*) program that evaluates key environmental performances of neighborhoods and cities. First, the area being studied is architecturally modeled in Rhino 3D, and then the model is analyzed for walkability, daylighting and several types of energy consumption (Fig. 16.8).

Kent Larson's City Science group is continuing its *CityScope* project to model city precincts using color-coded Lego bricks, which are sensor-tagged and plotted on screens as data units. Users rapidly move the data bricks to reveal different ways



**Fig. 16.8** Energy use analysis of a Rhino 3D city model in the urban modeling interface (*umi*) developed by MIT's sustainable design lab

to improve the density, proximity to services, and demographic diversity (vibrancy) of each area. City Science researchers have also prototyped ingenious “mobility on demand” (MOD) solutions. Their latest persuasive electric vehicle (PEV) can drive autonomously, even following its human passengers slowly if they decide to walk themselves; can be driven in bike lanes without the driver requiring a vehicle license; could be suitable for public sharing and can move both people and goods. In another project, Larson and Hasier Larrea showed how five hundred people could be housed in a medium-rise block of 25 sqm “action apartments” with the same footprint as forty-five conventional car spaces. Since graduation, Larrea has established a company, Ori, to make and sell these robotically mobile furniture suites.

### 16.4.2 *Almere 2030, the Netherlands*

In the Netherlands, one of a few countries noted for consistent innovations in urban spatial planning, architects MVRDV (Maas van Rijs de Vries) designed a 2030 vision plan to help the municipality of Almere plan polycentric growth on 250 sq km of polder land reclaimed in the 1960s (Fig. 16.9). The terrain is three meters lower than the water level of the adjacent IJseelmeer (lake) so Almere is constantly at risk of flooding, protected by a system of dykes and sluices. MVRDV’s plan, gradually underway now, contradicted the popular Western strategy of transport-oriented development (TOD), where high-rise apartment buildings are clustered around suburban metro stations and new ribbons of low-to-medium-rise housing and commercial development are encouraged along main bus routes and rail lines.



**Fig. 16.9** MVRDV masterplan for four “carpet cities” at Almere, the Netherlands

Instead, MVRDV proposed four “carpet cities”. IJ-Land, designed with California architect William McDonough, will be a series of new island nature reserves in the lake, including 5–10,000 homes. Pampus will be a high-density, medium-rise village of 20,000 partly floating homes, with all streets leading to a lakefront boulevard. Almere Centre will extend the current city center with development of Almere Floriade, a compact and ultragreen neighborhood intended to be the horticultural campus for the World Expo in 2022. The public arboretum will contain 1,600 new homes, offices and facilities. In Oosterwold (Freeland), the first residents have begun to build their own neighborhood, with up to 15,000 new homes to be set in agricultural fields east of central Almere (MVRDV 1999, 2007, n.d.).

### 16.4.3 *Jade Eco Park, Taiwan, China*

French architect Philippe Rahm redesigned an obsolete airport in Taichung to provide a “meteorological” recreation landscape, Jade Eco Park, where vegetation and paths are interrupted by freestanding structures comprising white pipes, air ducts, sensors, filters and other electronic devices (Fig. 16.10). These were designed to mitigate Taichung’s generally hot, humid climate and air pollution: they blow cool breezes, release mists or patches of rain, or clean local air to generate three types of artificial and contained atmospheric experiences: Coolia (four cool zones), Clearia (four areas of clean air) and Dria (three areas of dry air). Rahm’s team first monitored and mapped the existing temperatures, humidity and air pollution conditions across the site and then used computational fluid dynamics to create an atmospheric map of the site. The

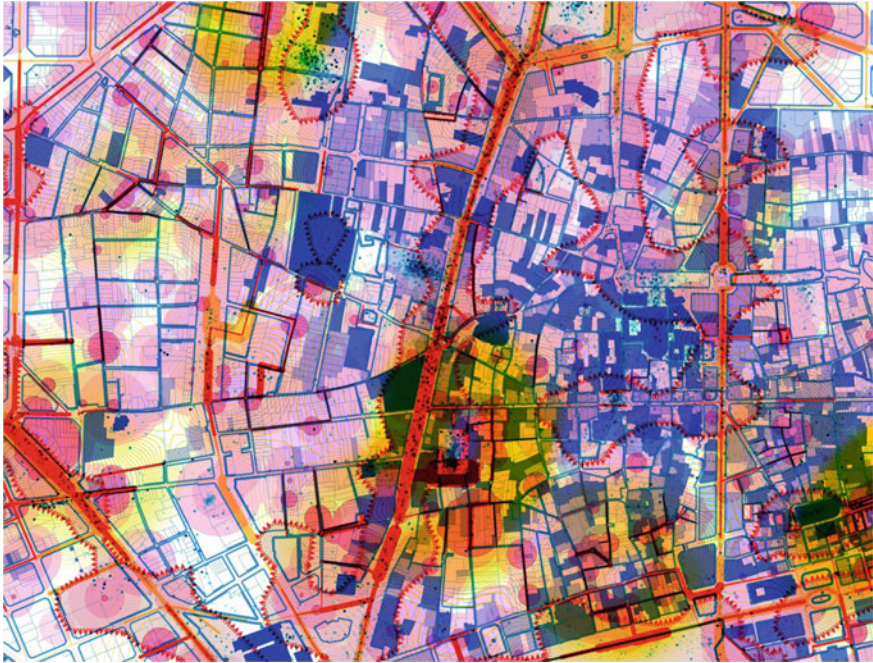


**Fig. 16.10** Illustration of clean, cool and dry atmospheres generated across the Jade Eco Park in Taipei, designed by a team led by Philippe Rahm

new atmospheric zones overlap each other to allow for different sensory experiences to be selected at different times of day or during the year (Jackson 2018, 54; Rahm n.d.).

#### ***16.4.4 Nocturnal Barcelona, Spain***

In Barcelona, the “datatecture” studio 300.000 km/s (speed of light) mapped the city’s current and potential night-lighting of streets and public squares in a 2017 report for the city council’s Municipal Institute of Urban Landscape and Quality of Life (Fig. 16.11). The project included analyses and visualizations of data on mobility, citizens’ activities and business types in each location. The report also included comparison pairs of day and night photographs of city scenes, a satellite image of light pollution and the city’s lighting regulations.



**Fig. 16.11** Map of night lighting around central Barcelona by 300.000 km/s

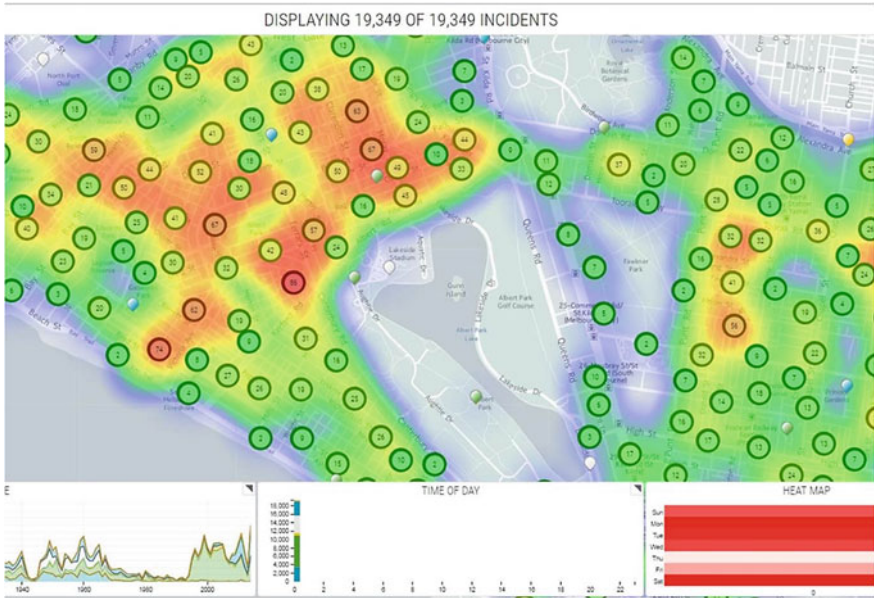
### ***16.4.5 Spatial Information Management Platform, Australia***

Cities are complex, adaptive systems (CAS), where various dynamic systems evolve in interdependent ways. To “digitally twin” (computer-simulate) a city successfully in the Digital Earth context, this complexity needs to be represented accurately within the digital framework. Each component of the model must be able to evolve independently of the whole. Any viable CAS invariably evolved from a simple system that worked. Any complex system designed from scratch typically fails and cannot be repaired.

Modeling the behaviors of real-world complex systems with counterpart digital systems deepens our knowledge and improves our control of real-world scenarios. Recent projects undertaken by a Brisbane geospatial planning consultancy, Meta Moto, have adopted a CAS framework so that complementary systems of record, engagement, and insight can interact through a common semantic ecosystem supporting master data management and spatial data transformation functions. By adhering to open standards and exchange formats, the complementary systems can be made agnostic to one another. For example, graphics library transmission format (glTF) is a royalty-free specification for the efficient transmission and loading of 3D scenes and models by applications. This format defines the sizes of 3D assets and the runtime processing needed to unpack and use those assets. It defines an extensible, common publishing format for 3D content tools and services that streamlines authoring workflows and enables interoperable use of content across systems of engagement (such as web base viewers). Adopting this as a pipeline within a CAS framework ensures that the uses determine the engagement tools, and the semantic data model drives the user experience and presentation of the data in these tools. This approach removes the risks of vendor lock-in and ensures that the system has continuous opportunities to evolve. Meta Moto recently used glTF for data visualizations supporting Brisbane’s Cross River Rail project and the next-generation spatial platform for South East Water in Melbourne (Fig. 16.12).

### ***16.4.6 Greening Greater Bendigo, Australia***

Bendigo, a regional city of 100,000 people in central Victoria, Australia, recently began to use EO imagery from Europe’s Sentinel satellites to regularly monitor changes of vegetation around its towns and suburbs. A Melbourne landscape consultancy, Office of Other Spaces, analyzed sixteen multispectral Earth observation images (captured at 10 m resolution and stacked as a time-series ‘data cube’) to monitor seasonal and area-specific changes in vegetation throughout the city during the summer from December 2018 to February 2019. This pilot project allowed the city council to create new a vegetation cover benchmark (named the consolidated



**Fig. 16.12** Heat mapping of incidents over time is an example of a system of insight for South East Water, Victoria

mean value, CMV) to clarify the measure of its vegetation cover and determine any site-specific risks of new building developments destroying existing vegetation (Fig. 16.13).

### 16.4.7 *Happy, Smelly and Chatty Maps, Britain*

Computer scientists with the Cambridge node of the Nokia-Bell Labs network are advancing a Good City Life program that is intended to support happier citizens—not necessarily the prevailing corporate-governance agenda of ‘smart’ (time- and cost-efficient) cities (Aiello et al. 2016; Quercia et al. 2016). Led by Daniele Quercia, the Bell-Cambridge social dynamics team has been surveying, analyzing and mapping how people are enjoying—or could better enjoy—the sights, smells, sounds and other atmospheric experiences of public places that they navigate regularly (Fig. 16.14). With other computer scientists at Yahoo Labs in London, and with the Universities of Turin and Sheffield, they analyzed diverse social media tags and developed sophisticated algorithms which allow users of mobile devices to generate navigation routes on their GPS map apps (initially tested via OpenStreetMaps for specific zones of London and Barcelona). The paths they calculate are usually longer than the quickest journeys but can provide happier scenes, smells and sounds along the





Fig. 16.13 Time-stacked EO images of Bendigo, analyzed for urban vegetation changes by Melbourne’s Office of Other Spaces

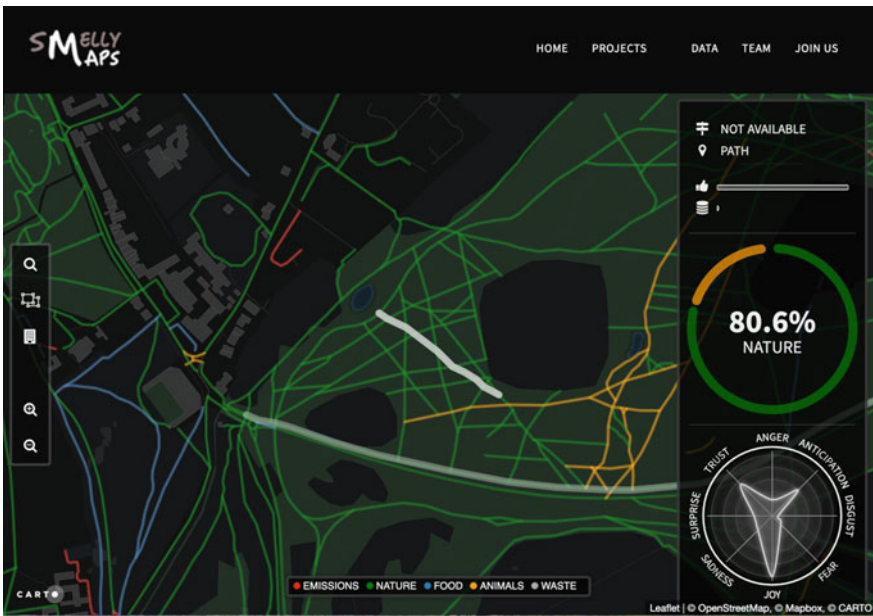


Fig. 16.14 Data-visual street map indicating five types of smells and likely emotions for people navigating an urban area, by Nokia-Bell Labs, Cambridge, UK

way. In recent papers, Quercia's team noted that urban planners and local government officials tend to focus on unpleasant odors and acoustics (signaling air or noise pollution) and mostly ignore desirable smells and sounds.

## 16.5 Urban Criteria, Process and Standards Taxonomies and Platforms

Many of the world's most intelligent and experienced urban professionals are not digital natives, sometimes refer to themselves as Luddites, and still use hand-inked diagrams, lists, tables and grammatical sentences to express their ideas. Some of these thought-leaders have devised schema for systems that could someday be programmed to analyze development proposals and building performance. This section reviews some taxonomies (matrices of criteria, goals, procedures and standards) that should be integrated into the future GEOSS-Digital Earth world-management system. These develop Fuller's concepts for what he initially named the 4D Air-Ocean World Town Plan then termed the World Game and Spaceship Earth. In one of his last books, Fuller said:

This design revolution must employ a world-around, satellite-interlinked, data-banks-and-computer-accomplished conversion of present-day, exclusively geocentric, Spaceship Earth wealth accounting [... to a system where ...] computers fed with all the relevant energy-efficiency facts will be able to demonstrate which uses will produce the greatest long-term benefit for all humanity (Fuller 1980, 199, 225).

Two critical factors lie at opposite ends of today's project to deliver Fuller's vision. One is the need to decide what data to collect to understand the world's conditions and how to organize it effectively (the main concern of UN-GGIM and other UN technical agencies, the Group on Earth Observations (building the GEOSS Common Infrastructure, GCI), CODATA, the Open Geospatial Consortium (OGC) and the (now disbanded) Global Spatial Data Infrastructure Association (GSDI; Crompvoets et al. 2008). The other challenge is for leaders of international land development organizations to clarify how to identify and deliver all data relevant to future modeling of eco-ethical developments. This agenda is being led by the World Bank (Global Platform for Sustainable Cities), the C40 Large Cities for Climate Change group, the Council on Tall Buildings and the Urban Habitat (CTBUH), the World Federation of Engineering Organizations (WFEO), the World Green Building Council (WGBC) and the OGC-buildingSMART alliance.

Guiding the collection and organization of satellite data are the essential climate variables (ECVs) for all three domains of our planet's environment: atmospheric, hydrographic and terrestrial. The ECV datasets are intended to underpin future eco-ethical practices in land development, and include river discharges, water use, ground-water and lake levels, snow cover, glaciers and ice caps, permafrost and seasonally frozen ground, albedo (surface reflectance), land cover (vegetation types), photosynthetically active radiation, leaf area, biomass, fire disturbance and soil moisture.

Geodata, urban planning and natural resource administration agencies will need to collaborate to obtain the ECV data relevant to their domains of governance and to integrate it with the cadastral and other topographical datasets that they administer. Also valuable are the lidar and radar scanning and 3D city modeling data that are obtained by commercial EO satellite operators (including DigitalGlobe, Airbus and UrtheCast), aerial survey companies (such as AAM, Nearmap and Borbas), and locality-diverse providers of terrestrial environmental imaging and remote sensing services.

### ***16.5.1 CityGML and 3D Cadastre***

CityGML is an XML-based, 3D vector, open data model for storing and exchanging 3D city and landscape models that is based on the geography markup language (GML) produced by the Open Geospatial Consortium (OGC) and the International Standards Organization (ISO TC211). It defines the objects, properties, aggregations and relations contained in models, allowing for them to be readily compared and for correctly classified data to be reused. The platform allows for sophisticated analysis tasks and thematic inquiries relevant to most urban professions and management functions. CityGML is evolving continuously to improve 3D and 4D city modeling. Dynamic variations of the properties of a city object can be represented using the Dynamizer feature type. This enables specific objects in the 3D model to be linked with simulations or time series data. This can be used to trigger dynamic behaviors such as transformation of the geometry, thematic data, or the appearance of a specific object. This event-driven dynamic sentience of a city model is a foundation for advancing digital twinning of the physical world.

Current urban development approaches require more sophisticated conceptualizations of spatial data and new tools to holistically facilitate four key spatial planning tasks: urban management, impact assessment, site and road selection, and strategic planning. Sabri et al. (2015) developed a new framework to leverage current 3D geospatial and data model technologies in urban modeling and analysis. This framework, including recent insights by Biljecki et al. (2014), adopts a new conceptualization for CityGML that covers most 3D city modeling requirements. Sabri's team demonstrated how complex 3D urban scenarios enable city designers to have a greater understanding of existing and proposed urban forms and potential urban heat islands. The study showed how 3D analysis plays a critical role in examining the impacts of urban consolidation strategies and the densification of inner cities. Nevertheless, the 3D level of detail should be enhanced to support more accurate decision making.

In a recent study, Agius et al. (2018) explained how rule-based 3D city modeling enables planners to measure the physical impacts of building controls (e.g., heights,

shadows, setbacks) and the functional impacts (e.g., mixes of land uses). This might be useful for land administration (including subdivisions) but, if strata title properties are to be visualized or the public and private ownership of future developments needs to be analyzed by stakeholders, today's tools must be improved.

The ability to measure the capacities and implications of underground infrastructure (Qiao et al. 2019) and the above-ground services needed for huge future developments can be added through combinations of 3D cadastre data and BIM methods. Adopting a 3D cadastre (Aien et al. 2013) will enable users to more accurately evaluate future changes in land and property values, which is a major concern for many stakeholders involved in inner city redevelopment (Shin 2009).

### ***16.5.2 Graph Databases: Lossless Processes for Data Cities***

Graph databases have nodes, edges and properties to represent and store data. They aid in analysis of many-many relationships and have applications in machine learning, fraud detection, social media, semantic harmonization and master data management. Graphs are a key enabler of next-generation spatial platforms for the integrated digital built environment (IDBE).

Recent Singapore research demonstrates potential for multidirectional lossless transformation of semantic and geometric data across the paradigms from design models to open standard formats. With traditional methods, there may be significant loss of data integrity and content at each step in the transformation from the proprietary design files (native BIM) into various OpenBIM standards (IFCs), and then into CityGML and a city model. This journey wrangles data between multiple paradigms. By adopting a triple graph-based framework for semantic and geometric conversions a “complete and near-lossless” mapping between the models can be achieved (Stouffs 2018). This framework can be applied to bulk and incremental updates between these models and may be applicable to lossless transformations between IFC versions (for example, IFC2x3 to IFC4x2) and pivoting from project information models (PIMs) to asset information models (AIMs) at handover.

Also significant for cities and major infrastructure projects and operations are graph application platforms for master data management (MDM). Property type graphs (with metadata at nodes and edges) will also become increasingly important for building asset registers and to enable sophisticated twinning of a sentient virtual model with its physical counterpart in the real world.

### ***16.5.3 Open Public Life Data Protocol***

Denmark's Gehl Institute, founded by Jan Gehl and now led by Shin-pei Tsay, has collaborated with city government agencies in Copenhagen, San Francisco and Seattle to produce a data protocol for assembling and comparing metrics about how

people use and enjoy public environments. Launched as a beta version in late 2017, it includes a choice of eight components relevant to any public life survey: gender, age, mode of mobility, groups, posture, activities, objects (accompanying people) and “geotag” (which parts of a location are preferred). The protocol document explained how to structure the survey to record all the information in data tables, to be saved as CSV files that could be compared with the results of any similarly assembled survey. Although this project was focused on using digital tools to collect and process the survey information, it appears to be strongly influenced by Christopher Alexander’s pattern language classifications (published before personal computers) to help design comfortable indoor and outdoor places at different scales and for different times and purposes (Gehl 2017; Alexander et al. 1977).

#### ***16.5.4 City Standards: ISO 37120***

In 2014, the International Organization for Standardization (ISO) launched its first suite of indicators to measure and compare the performance of cities across seventeen general themes including the economy, energy, governance, health, telecommunications and innovation, transport, waste and water. Developed by the Global City Indicators Facility (GCIF) at the University of Toronto and promoted by the related World Council on City Data (WCCD), the ISO 37120 standard for sustainable cities and communities was updated in 2018. Two subset standards documents, *ISO 37122: Indicators for Smart Cities* and *ISO 37123: Indicators for Resilient Cities*, were also produced (ISO 2018).

#### ***16.5.5 Data Cubes***

Launched in 2013 by the national EO team at Geoscience Australia, the Australian Geoscience Space-Time Data Cube is a system that stacks matching Landsat scenes in time sequences (currently up to fifteen years) to allow for faster analysis of changing conditions. The dataset for the whole of Australia amounts to almost four million scenes and 110 TB of compressed geoTIFF files, which are analyzed by the Raijin high-performance computing lab in Canberra. Technicians can access the dataset with a Python API that can generate specific mosaics and stacks of image files, which can be interpreted via users’ own algorithms (Jackson 2013). The Data Cube system is the foundation of the Digital Earth Australia national satellite mapping project. It is supplied freely to research agencies in other countries under the name Open Data Cube (ODC), under the auspices of the Committee for Earth Observation Satellites (CEOS n.d.). One ODC was repurposed as the Africa Regional Data Cube, providing satellite surveys to an initial group of five African nations; it was later expanded to all 54 African countries as the Digital Earth Africa project (Digital Earth Africa n.d.)

In 2018, Peter Baumann at Jacobs University in Bremen received German research funding to lead a BigDataCube project to improve Rasdaman (raster data manager) software for data cubing satellite imagery from the European Space Agency's Sentinel constellation (source of the six terabytes per day of new satellite image files that are stored in Germany's CODE-DE archive). In addition to the commercial and free/light versions of Rasdaman, Baumann is developing data cube standards for the Open Geospatial Consortium (OGC), which works with the International Standards Organization (ISO; Anon 2018).

### ***16.5.6 Compact Cities***

In 2012, the Organization for Economic Cooperation and Development (OECD) released a list of fourteen characteristics of compact cities, which could be used as indicators to compare and improve operations. Compact and often high-rise cities such as Manhattan, Hong Kong and Paris are more efficient than sprawling low-rise cities with wide traffic thoroughfares, such as Los Angeles and Dubai. The criteria are high residential and employment densities, mixtures of land uses, a fine grain of land uses (small sizes of land parcels), strong social and economic interaction, contiguous development (rather than vacant land or street-level carparks), contained urban development within demarcated limits, good urban infrastructure (especially sewage and water mains), multimodal transport, high connectivity of streets (including footpaths and bicycle lanes), extensive coverage of impervious surfaces and a low ratio of open space (OECD 2012).

### ***16.5.7 EcoDesign***

Malaysian architect Ken Yeang pioneered ecological strategies for commercial towers and urban precincts. He clarified an "endemic" (climate and place-responsive) design system that is now standard practice in urban development. He rejected key modernist routines for tall buildings to look the same on all four sides, be built around a central lift core, have sealed windows and be mechanically air conditioned throughout. Instead, he designed buildings to respond to their different compass aspects and sun and wind conditions; positioned lift cores on the sides of buildings where they could best block excessive sun and wind and would allow for courtyards or atria to be landscaped in the center; introduced natural sunlight and ventilation via openable windows to the foyer, lift lobbies, fire stairs and toilets; and designed sky gardens and sunny courtyards on upper levels. By working closely with engineers on climate-response tests of his building models, he discovered that sky gardens could break the flows of winds down the surfaces of his towers to reduce gusts for pedestrians walking on nearby streets and plazas. On upper floor levels, some winds could be deflected into the buildings to ventilate spaces and cool the structures.

Yeang first applied green architecture principles to his tall buildings in tropical cities—beginning with Menara Mesiniaga, an office building in Kuala Lumpur (1992). His most substantial book, *EcoDesign* (Yeang 2006), was the first to clarify an eco-scientific system to design site-sensitive architectural projects anywhere in the world. His method requires understanding the natural context of each site by identifying its biome (regional community of diverse species sharing the same climate and terrestrial conditions). His system also included an “interactions matrix” that requires four sets of data to be gathered to assess four main ecological impacts of a building scheme: its relations to its environment, its internal relations, its inputs (of energy and matter) and its outputs. He urged architects to plan developments to avoid destroying healthy ecosystems or to rehabilitate damaged ecosystems. He also described three criteria for modeling any design: a description of the built system, a description of its environment and a mapping of interactions between the building and its environment (Yeang 2006, 59–73).

### ***16.5.8 Positive Development***

Counterproductive practices in the “sustainable urban development” movement have been targeted by Janis Birkeland, author of an evidence-based ecological building theory that she named “positive development” and “net-positive design” (Birkeland 2008). She proposed that every building should be expected to sequester the amount of carbon used in its operations and the amount of carbon emitted through resource extraction and consumption. Every building project destroys many tons of the Earth’s natural resources and the link between mining and construction is the major global cause of excessive carbon emissions. The nature and extent of this problem are obscured by green building assessment practices that “measure the wrong things in the wrong ways”—and that measure negative impacts only up to zero without measuring positive impacts. Birkeland suggested that buildings that support substantial and permanent planting (green walls and roofs) will amortize carbon far earlier in their life cycles than if they are only operated with renewable energy sources. She expected machine-analyzed data to allow for much more comprehensive and accurate analyses of buildings before and after construction, but the issues being recorded and assessed must be changed and expanded.

### ***16.5.9 Cities and the Digital Earth Nervous System***

In a 2010 article for the *International Journal of Digital Earth*, European scientists explained Digital Earth as a “metaphor for the organisation and access to digital information through a multiscale, three-dimensional representation of the globe” (De Longueville et al. 2010). They extended that vision by forecasting a “self-aware nervous system” to provide decision makers with improved alerting mechanisms for

crisis prediction and situational awareness. This goal may prove the most beneficial for governments and citizens in urban areas—and strategies are essential to clarify how the relevant officials and stakeholders can contribute to and usefully exploit such a sophisticated system of automated operations.

New international protocols are essential to give urban authorities rapid access and accurate, automatic analyses of the data sets relevant to their challenges. Several international corporations—including Mapbox, Orbital Insight and OmniSci—are managing and analyzing very large quantities of geodata for government customers which cannot afford or do not find it feasible to apply the necessary resources and infrastructure to maintain such sophisticated operations.

One geospatially advanced city (and nation) is Singapore, which ranked fourth in the 2018 countries geospatial readiness index—not far behind the United States, United Kingdom and Germany, and ahead of China (Geospatial Media and Communications 2018). Its extraordinarily integrated government created a national spatial data infrastructure (NSDI) system in 2009, is locally training urban geotech specialists through joint research programs with Switzerland’s ETH Future Cities Lab and America’s MIT SENSEable Cities Lab (with centers located at the National University of Singapore), has accelerated a Smart Nation policy since 2014, launched the Virtual Singapore project in 2016 and released the Singapore Geospatial Masterplan in 2018. Singapore aims to foster “geosmart government”, “geoempowered people”, and “a thriving geoindustry”.

## 16.6 Summary

International scientists supporting the Digital Earth and GEOSS visions are applying satellite and semiconductor-enabled technology to accelerate delivery of Fuller’s visions for a “4D Air-Ocean World Town Plan” and efficient management of resources on “Spaceship Earth”. Many governments have been promoting “smart city” policies and programs since the 1990s, when wireless and mobile telecommunications began to be commercialized internationally. The authors of this paper suggest it is now important to not only emphasize systems that enable humans to communicate worldwide but also next-generation infrastructure for societies to be accurately informed about our planet’s environmental conditions and challenges.

At the urban scale of today’s planet-simulation project, there is a need to integrate area-specific modeling of natural environmental systems with current best practices in building information modeling and city information modeling. All three methods must be improved to incorporate real-time streaming of Earth observations data obtained via sensing and scanning the light and radio waves of the electromagnetic spectrum. This satellite and semiconductor-enabled movement has been labeled “the new science of cities”, “geodesign”, “senseable cities”, “digital cities”, and “data cities”. As De Longueville et al. clarified in 2010, it seems crucial for the Digital Earth “nervous system” to become self-aware and be able to obtain and respond more automatically to unprecedented quantities of environmental information—far too much



to be processed by humans. This chapter highlighted some urban advances, strategies, issues and case studies that are significant contributions to this millennium's Digital Earth/GEOSS imperative.

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