Application of 3D Cadastres as a Land Policy Tool

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Distinct areas of formal and informal housing densities are evident in Caracas, Venezuela.

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A city's master plan typically describes development goals and objectives through the use of multiple maps and written documents. Most maps and other representations of urban design are built with a two-dimensional (2D) vision and then transferred into regulatory instruments and strategic planning tools. Urban space is treated as being flat and divided up into puzzle pieces such as administrative areas (municipal, rural, urban, growing, expanding, fringe); land use areas (residential, commercial, central business, historic, tourist, informal, recreational); environmentally protected or restricted area (water catchments, floodplains, landslide-prone hills); and other categories.

When urban space is described through digital maps integrated with databases in a geographic information system (GIS), many additional layers of information can be considered in a three-dimensional (3D) platform. However, when real 3D urban space is managed by laws and other conventions based on a 2D vision, the physical and legal cities are operating in quite different and incompatible dimensions. This discrepancy was accepted in the past, when 2D maps were the primary resource available to represent the real city, but nowadays computer graphics can handle more complex objects in space.

Rethinking the legal and economic aspects of urban society by shifting from the traditional 2D vision to a 3D approach will be necessary to develop, implement, and control urban land policies more efficiently. A 3D cadastre is one of the tools that can facilitate that process through spatial databases and representations. The institution of a territorial cadastre is familiar in many countries, but does not exist in the same way in the United States. A modern cadastre is an integrated database system that holds information on land registration and ownership, physical characteristics, econometric modeling for property valuation, zoning, geographic information, transportation networks, infrastructure and services, and environmental attributes, all of which are linked to socioeconomic and demographic information on property owners.

Creating a New 3D Framework

Google Earth has popularized geographic information by allowing users to visualize a virtual 3D location at the desired level of detail and in a global environment. Google Earth and other geographic software can be used quite easily to change the viewpoint of reality. Moving from a top-down view, which shows the city as a flat area, to an oblique perspective permits the viewer to see the relief and height of buildings, trees, aerial utility networks, and other objects in space.

This type of 3D visualization can identify undeveloped spaces, buildings of different heights, scattered suburban housing, structures in isolated rural areas, and precarious slum construction, thus helping to infer changes in land uses. Even when 3D images are represented on a flat screen or printed surface, they show details that are hard to identify in a 2D map, such as shadow movements during the day, views from an apartment window, and spatial relationships between buildings.

The constantly evolving 3D technology is changing the paradigms of urban planning and land policy because it impacts not only how the city is viewed but the way property rights and other restrictions in space are described. As a result, a new urban legal framework based on 3D laws and 3D property registries will be needed to describe objects in space instead of just flat contours. The 3D laws affect rights in space, not in a plane of projection, and in this context it will be possible to define 3D land policies.

For example, a 3D image of the basic, maximum, and actual floor-area-ratio (FAR) for a set of land parcels would facilitate the use of land management instruments such as charges for the purchase of building rights for new development. To support a 3D legal framework it is necessary to have spatial data systematized on 3D cadastres, which create and maintain up-to-date spatial databases and volumetric representations of cities, as well as a 3D property registry in which every property and its restrictions are identified and documented.

Land surveyors, geologists, biologists, and engineers are accustomed to determining the location of physical objects in space by specifying attributes such as mineral deposits, water bodies, contamination or fumes in the air or underground, or restricted spaces around power lines, but legislators, urban planners, assessors, and others are not used to describing the intersections of more than two attributes in space. The increasing complexity of infrastructure and densely built-up areas requires the proper registration of their legal status (private and public), which can be provided only to a limited extent by the existing 2D cadastral registrations.

Despite its promise as a tool for urban planning and the extensive research and progress in practice to date, no country has a true 3D cadastre with complete functionality. The evolving concepts involved in this new process should be based on the ISO 19152 Land Administration Domain Model (LADM), which provides support for 3D representations (van Oosterom 2011).

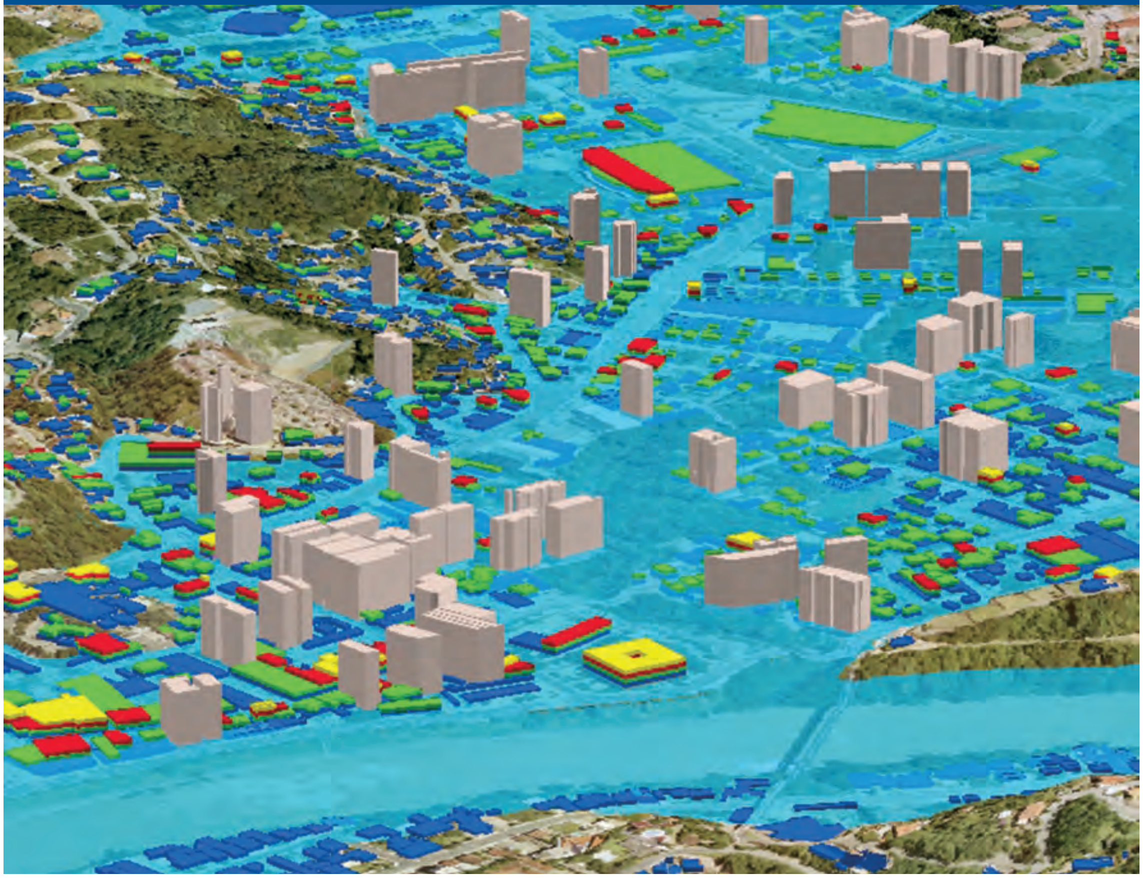
The Virtual 3D City

The first idea that usually comes to mind regarding a 3D image is its representation in regular shapes such as cubes, prisms, and cylinders, but these simple forms have proved insufficient to analyze urban space. Seeking a closer match with reality, researchers and designers have developed techniques to overlay photographs of building facades on building contours, and to represent all architectural characteristics of a building using 3D computer-aided design (CAD) software.

However, even these types of virtual 3D buildings typically were placed on a flat reference plane, which created a false image because it showed all buildings at the same level. By adding relief through digital perspectives based on digital terrain models, virtual 3D buildings could be placed at the correct altitude relative to sea level. The next step was to overlay aerial orthophotos on digital relief images, resulting in much more realistic 3D images of the real (physical) city (figure 1).

Presently, 2D and 3D urban models continue to be built with points, lines, polygons, and images.

FIGURE 1
Virtual 3D City Representation of Blumenau, Santa Catarina, Brazil



Note: The blue, green, red, and yellow colors show different floor levels of low-rise buildings, and the light blue overlay indicates the level of flooding in 1983.
Source: Aeroimagem S/A *(www.aeroimagem.com);* prepared by Everton da Silva and João Norberto Destro.

These models are useful but still insufficient for detailed urban analyses because, as noted by the Brazilian geographer Milton Santos, "Geometries are not geography" (Câmara 2000). In fact, several kinds of geographic information are used to develop land policies—human, physical, economic, and environmental—and all of them occur in space.

GIS contributes to the process of building a virtual 3D city by permitting linkages between statistical data and geometric shapes to generate thematic information images that can be applied to a variety of land policy issues. The 3D image created in a GIS platform is frequently more useful for urban planning purposes than a photograph of the same sector because the 3D platform makes it is possible to highlight certain information of interest, create prospective scenarios that anticipate the economical effects of certain land policy decisions, or evaluate the environmental impacts of new development.

Formal and Informal Virtual 3D Cities

The virtual 3D city represented geometrically is useful in several types of analyses, such as vehicle traffic studies, propagation of cell phone waves, or any type of infrastructure network analysis. For other kinds of analysis, even the virtual 3D city is not sufficient, as when a lawyer needs to visualize the legal 3D city as defined by urban and environmental regulations. Figure 2 shows two sets of virtual 3D city blocks, one representing existing buildings and the other indicating the development potential of those buildings based on the applicable urban regulations. These two images show different densities and consequently variable land and property values, but in both cases the property tax base and potential value capture charge can be estimated precisely.

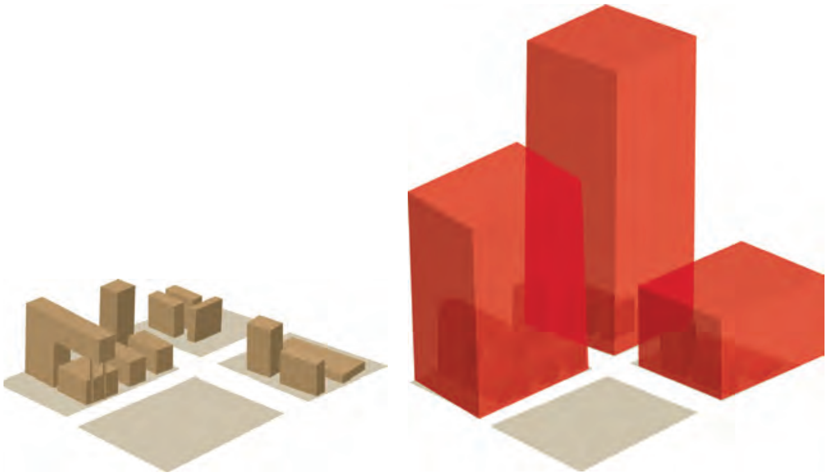
In Latin America, where the incidence of informality is emblematic of the urban landscape, it is important to visualize and define the informal as well as the legal dimensions of the city. Informal settlements develop when households cannot afford housing supplied by the market or by social programs. People must find a place to settle, which is often on hazardous or protected land that is inappropriate for housing, or on vacant public or private land. The magnitude of the need for housing often surpasses the amount of land available, thus forcing informal settlers to build taller structures at higher densities (figure 3).

Every occupied space is a part of the city and should be considered in the urban databases of the cadastre. The task of connecting the virtual informal city with the rest of the virtual city is a bigger challenge in 3D than in 2D due to complexities in dealing with parcels where owners and occupants are different but may share the same space. Infrastructure is also organized differently in these areas. In the formal city, for example, public infrastructure networks consisting of fixed pipes, cables, roads, and rails are regularized and stable. In the informal city, infrastructure networks are often self-built and change constantly as the settlement expands. A 3D cadastre can inform planners of the gaps between the characteristics of the population demanding shelter and the effective supply of land and its attributes, thus helping define policies to address unplanned informal settlements.

FIGURE 3
Improvised Housing Units in an Informal Settlement in Caracas, Venezuela

Source: © Martim Smolka; rendering by Diego Erba.

FIGURE 2
Representations of the Virtual 3D Formal City and the Virtual 3D Legal City



Note: The existing buildings on the left are incorporated into an expanded legal city on the right.
Source: Prepared by Diego Erba and Anamaria Gliesch-Leebmann.

3D Dynamic Cities

Changes taking place in cities can be visualized and measured in several ways, for example through studies of densification, migration, and expansion of infrastructure networks. These studies assume that social, economic, and environmental variables are constantly changing although the land is static. However, other forces that produce change in the city can cause dislocations of different intensities that can be measured in space (3D) and time (4D). For example, the continental plates are moving South America, its cities, public and private properties, and infrastructure networks slowly toward the west at the rate of 2 centimeters (cm) per year. These movements, which seem insignificant, have consequences for urban policy if one considers that in 50 years a property could be moved as much as 1 meter from its current position.

Even more extreme movements are the consequence of the dynamic nature of our planet. The earthquake in February 2010 impacted the Chilean region of Bio-Bio at many different scales. Measurements by the Transportable Integrated Geodetic Observatory (TIGO) in the city of Concepción recorded that the entire territory moved initially toward the northwest and then ended with a displacement of 3 meters toward the southwest, all within 30 seconds. During this event, the height

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Port au Prince, Haiti, after the earthquake of January 12, 2010.

of land shifted by 50 cm. The telluric movement carried away properties and destroyed urban infrastructure and buildings, and the damage was compounded by the subsequent tsunami. A similar pattern was observed during Chile's 1960 earthquake, the most severe ever registered in the world, when the ground moved with such velocity that some properties disappeared into the sea and other land areas emerged.

The January 2010 earthquake in Haiti produced an estimated 20 million cubic meters of debris in 35 seconds, even though significant land displacements were not registered. From the point of view of the cadastre, however, these two disasters had very different impacts. If the urban information had been structured in thematic layers and integrated in a GIS platform, the earthquake in Haiti would have affected the construction layer and several representative building types would have disappeared. In Chile, the construction layer was modified mainly by the tsunami, but the land itself was affected by the spatial displacement and shifts resulting from the telluric movement. Fast-moving natural disasters like these change the environment and people's lives radically, and have important implications for government priorities, including definitions and implementation of land policy, both before and after such events.

Predictable climate change events, underground contamination, air pollution, and other such data can be mathematically modeled before they happen. By connecting these models with the spatial databases of a 3D cadastre, it is possible to create prospective 3D scenarios of the potential impacts and identify the neighborhoods and properties that could be affected. Unpredictable phenomena such as earthquakes and sudden flooding can be represented much more quickly if the measurement instruments tracked by environmental institutions or government agencies are connected to the spatial databases of 3D cadastres. The spatial representation of the impact can be made available soon after the event.

In sum, the 3D representation can help define preventive land policies to address predictable changes and also enable the readjustment of current land policies after unpredictable natural events.

3D Networks and Infrastructure

Infrastructure and transport networks move through 3D parcels in different ways and allow the city to remain active and fluid. Some of these

© Regional Government of Bio-Bio, Chile.

Aerial views of Dichato, Chile, before and after the tsunami on February 27, 2010.

networks are invisible by nature, such as the microwaves of cellular phones; others are invisible because they are located underground, such as infrastructure tunnels and pipes; and others are easily visible because they are built on the surface, such as roadways or utility lines. Figure 4 illustrates some of the complex spatial intersections that occur in the overlapping layers of infrastructure and transportation networks within 3D parcels.

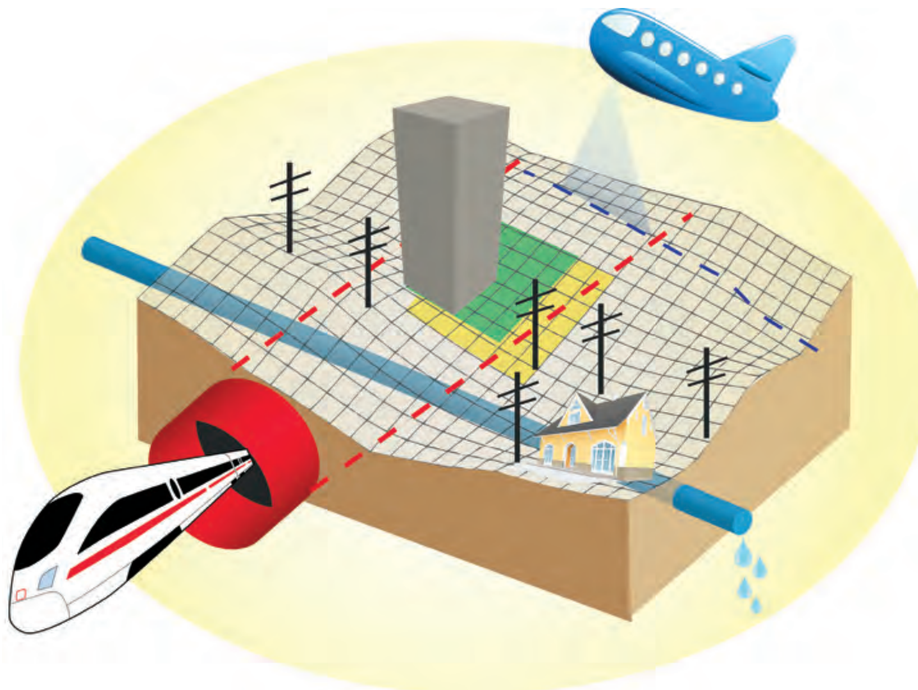
These spatial relationships among networks and public and private properties, environmental reserves, mineral deposits, water bodies, and other features have been treated inefficiently through 2D cartographic norms, but they require the development of specific, new 3D norms to enforce the social function of property with equity and justice. For example, Article 1.286 of Brazil's Civil Code states that a landowner is obligated to provide a right of way through her property for cables, pipes, and other underground conduits that serve the public at large and could not be built elsewhere. The law also outlines the need to determine the amount of area affected by public works projects in each parcel and its corresponding value in order to calculate the compensation due to the owner. 3D cadastral records can be an important contribution to facilitating such transactions.

3D Land Market Value

One of the functions of a territorial cadastre is to provide information to determine the value of the parcels with respect to property taxation and urban planning policies. In Latin America, land values generally have been based on ad hoc valuation methods (such as the replacement value of buildings) that use construction data and land values for each cadastre sector (Erba 2008). This practice does not always produce reliable valuations because it is difficult to keep the cadastral databases up-to-date, and the implementation of the valuation methods may be arbitrary from place to place.

An alternative valuation method now being implemented across the region is the use of spatial econometric models to determine property values with the desired level of statistical precision. This is important because land values change across urban space and depend on variables such as urban regulations, environmental restrictions, scenic views, infrastructure, and other features associated with the property, such as underground or airborne elements.

FIGURE 4
Urban Infrastructure and Transportation Networks in Space

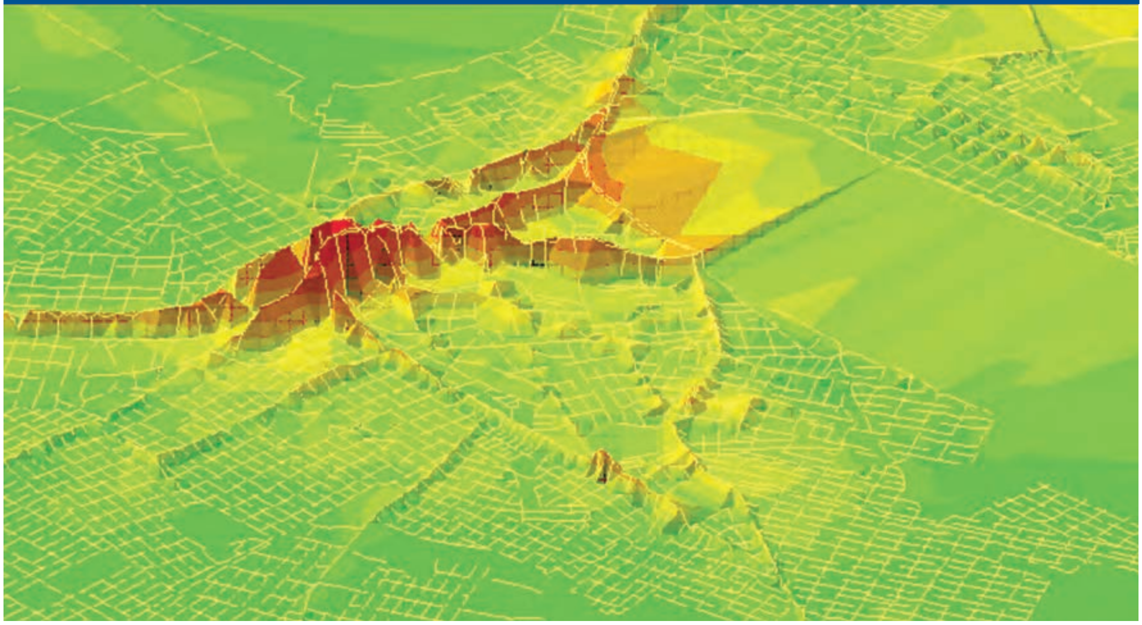


Source: Prepared by Diego Erba and Anamaria Gliesch-Leebmann.

The most modern GIS platforms developed for 3D cadastres even allow the assessor to "stand" inside a building at any given altitude before the building is constructed. The software allows the assessor to see the view that will be available from the window of the dwelling, identify relationships to other buildings, perceive the natural landscape, and note other relevant characteristics of the property. Such data help determine the relevance of externalities to the value of the property, an aspect often neglected in valuations based on traditional replacement value methods.

Figure 5 shows a perspective of the surface gradient of land values per square meter obtained from sample points corresponding to properties for sale. The surface has the same coordinate reference system (x, y) as the entire city. Even when the spatial third dimension (z) is not related to the geographic space, it is possible to put the surface under the legal virtual city (as shown in figure 2) and analyze the spatial correlation between the land value per square meter and relevant urban regulations. Such an application is another possible contribution to the development of land policies based on 3D cadastre techniques.

FIGURE 5
Land Values per Square Meter on a Continuous Surface



Note: The colors emphasize the variation of the land value, which is represented by the movement of the surface.
This illustration shows the city of Várzea Grande, Mato Grosso, Brazil.
Source: Aeroimagem S/A *(www.aeroimagem.com)*; prepared by Everton da Silva and João Norberto Destro.

Conclusions

While the technologies used to measure, represent, and store information are now evolving toward 3D platforms, urban legislation and land policies continue to approach the city as a flat land surface. To visualize the buildings and the restrictions imposed on properties in 3D is a considerable advancement for those responsible for urban decision making. Nevertheless, there is a long way to go before 3D information is integrated as part of urban legislation and property titles.

The consolidation of a 3D cadastre, which registers how 3D parcels intersect with the corresponding legal norms and regulations, would contribute to more effective urban and environmental planning, infrastructure network design, and the prevention of informality by permitting the construction of future scenarios showing the impacts of land policies in space. Changing the term *area* to *space* would be a first step in giving urban and environmental legislation a 3D connotation, and would be a simple and relevant way to start the process of introducing this new paradigm. Structuring a 3D property registry is still under development, but when it is established landowners will understand that they own cubic feet instead of only square feet.

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