ArcGIS for Land Records: Current Status and Future 3D Considerations

Carsten BJORNSSON, USA and Nick LAND, UK

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SUMMARY

3D cadastre is necessary to display and manage complex spatial relationships. To support a full 3D cadastral implementation, object boundary definitions, object topologies and their legal representations will have to be further defined. A hybrid approach combining 2D and 3D using GIS represents a feasible, economical and extensible approach. Using the ArcGIS parcel fabric model, allows for the legal boundary definition of parcels while at the same time maintaining the topologic relationship between parcels and to other spatial objects. By representing multi floored buildings each containing one or many parcels, overlapping parcels topologies can be maintained through least squares adjustments and joins. Overlapping polygons can be represented as 3D objects in ArcGIS allowing for identification, search, analysis and visualization of parcels. The paper also highlights some additional capabilities within ArcGIS for extending the use and value of 3-D cadastral data in related areas such as city planning, design of new buildings and minimizing environmental impact.

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1. SOME CHALLENGES FOR THE 3D CADASTRE

A cadastre is built to support the land registration process and traditionally contains one or more of the following:

- the means of identification of a land unit; maps displaying each land unit;
- legal survey measurement defining the boundary of the land unit; and
- legal rights associated to the land unit.

Behind each of these, procedures are established to create, aggregate or remove land units and associated legal rights (Skrubbeltrang, 2004).

While establishing definitions for ownership, rights and interests, the cadastre is also used for serving many purposes within land management: as an address identifier, tax assessment, land valuation, permitting, expropriation, land consolidation, environmental impact assessments, onshore/offshore oil and gas leases, national security, disaster management, subsidies etc. Having a multi-purpose functionality the cadastre is challenged with managing and mapping complex relationships between land units as well as their relation to other spatial objects.

Moving the cadastre from a 2D representation to 3D representation is a rewarding concept and has attracted much research and development over the last decade. Although advances have been made there are still multiple challenges confronting anyone considering implementing 3D cadastre. In managing 3D cadastral objects continued challenges exists with respect to measuring and displaying land units in 3D as well as defining their relationship to other types of spatial objects.

1.1 Creation and management of 3D objects

By representing a land unit as a 3D object, existing procedures supporting the ‘legal survey measurement’ of the land unit will have to be extended. A land unit is spatially defined by a legal description, which can be either survey based measurements or through some other means of description outlining the perimeter of that individual land unit.

Creating 3D objects from technical specifications using GIS or CAD has been feasible for several decades but mostly for support of volume analysis or surface display. To have a legal representation of 3D objects, measurement procedures will have to be developed and written into a legal framework supporting the definition of the land unit. If measurement techniques like LIDAR and radar scanning are used for data collection, then automated procedures to extract specific 3D objects from the data cloud will have to be developed and integrated into the ‘legal survey measurement’ to legally define the boundary of the object.

To ensure that no ambiguity exists between land units and their individual definitions, a cadastre usually contains rules for maintaining their topologic relationship. A topological relationship can be maintained through either a survey network or through a set of cartographic rule sets.

For a 3D object space the survey network will have to be extended into supporting a volume space, with the ability to perform adjustments while at the same time maintaining its topology. Procedures to uniquely express reliability of each individual land unit in relation to other land units in a 3D space will have to be expanded from current 2D operations.

Much research has gone into maintaining topologic relationships between 3D objects through a set of cartographic rule set applied in a 3D object space. Once objects are defined, their individual relationship can be verified and corrected by following e.g. a proximity rule for maintaining a certain distance, exactly in the same way as is currently done with 2D representations.

1.2 Maintaining relationships to other 3D objects

Additional layers, in a 2D space, containing other objects correlated to the land unit can be related through either positioning via a common coordinate system, directly linked to the land unit or related through cartographic rules (topology). As the definition and location of the land unit gets updated, the spatial relationship with the associated data can be maintained to ensure continued correlation between the land unit and other data. This is essential for the maintenance of accuracy of the related data, which otherwise would get quickly out of synchronization.

In a 3D space similar rules will have to be applied for maintaining these relationships. When a 3D land unit object moves two considerations will have to be made. Firstly e.g. the land unit of a building moves due to updated surveys. Being a 3D object all associated floors of that building will have to move as well to avoid skew in the buildings spatial alignment. Secondly associated data e.g. the neighboring building, easements, tax parcels etc. will have to move as well to avoid topological inconsistencies.

2. CONCEPTS OF 3D CADASTRE

Today several authors have identified and proposed a nomenclature for representation of the 3D cadastre and ontologies are underway to further define the content and relationship in a 3D object world. In principle three approaches can define the 3D (Stoter et al 2002):

1. full 3D cadastral registration, where all space is subdivided into volumes with associated measurements and legal definitions and maintained as such;
2. a hybrid solution, where all the cadastral layouts are maintained in a 2D space with associated measurements and legal definitions and established relationships to 3D physical objects;
3. 3D tagging, where all cadastral layouts are maintained in 2D with associated measurements and legal definitions and external references are made to the 3D data.

There has also been mention of 4D cadastre, involving handling of time as a dimension, but in practice this is more usually handled using dates of applicability as attributes.

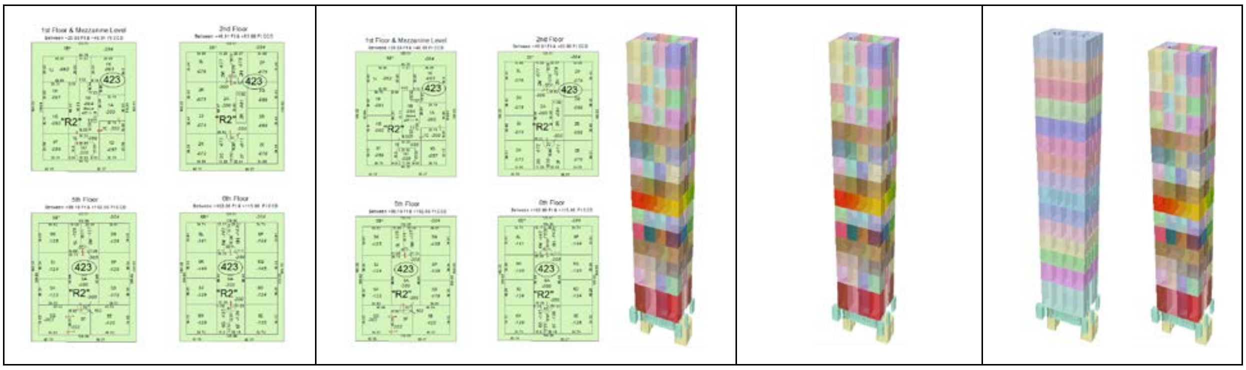


Figure 1a. 3D tags **Figure 1b. Hybrid** **Figure 1c. Full 3D** **Figure 1d. 4D?**

2.1 The hybrid solution

Given the challenges with a full 3D cadastre the most feasible approach is to implement it as a hybrid solution. In doing so geometries and spatial relationships are maintained via 2D objects as well as maintaining their individual and external topologic dependencies. Relationships are defined between 2D and 3D objects to provide the 2D cadastre with 3D analytic, search and display capabilities to support illustration of complex problems.

The ArcGIS software package introduces the concepts of parcel fabric and feature topology. The parcel fabric allows for definition of land units (parcels) through delineation of the boundary from legal survey measurements. Being a part of the geodatabase model, the parcel fabric is maintained by the core parcel editing tools. These allow for editing and maintaining unique identification of the land unit, display of land units, definition of the boundaries and associate legal rights to the land unit. With the inclusion of the land unit as part of the geodatabase object model, land units can be referenced, analyzed and displayed in a 3D space. The feature topology provides topological models and rules to maintain spatial relationships between objects in the geodatabase.

3. PARCEL FABRIC

The parcel fabric is a dataset for the storage, maintenance and editing of parcels. It is created within a feature dataset and inherits its spatial reference from the feature dataset. The feature dataset can contain other related spatial objects.

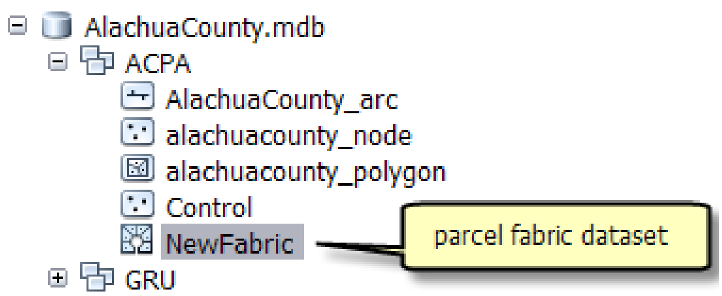


Figure 2. The Parcel Fabric dataset

A parcel in the parcel fabric is composed point features, line features and polygon features. A series of individual lines close to form a polygon and each line has a 'from' and a 'to' point that are also the parcel corner points. Parcel points can have up to one line point and one control point. A parcel is always associated with one plan (record of survey).

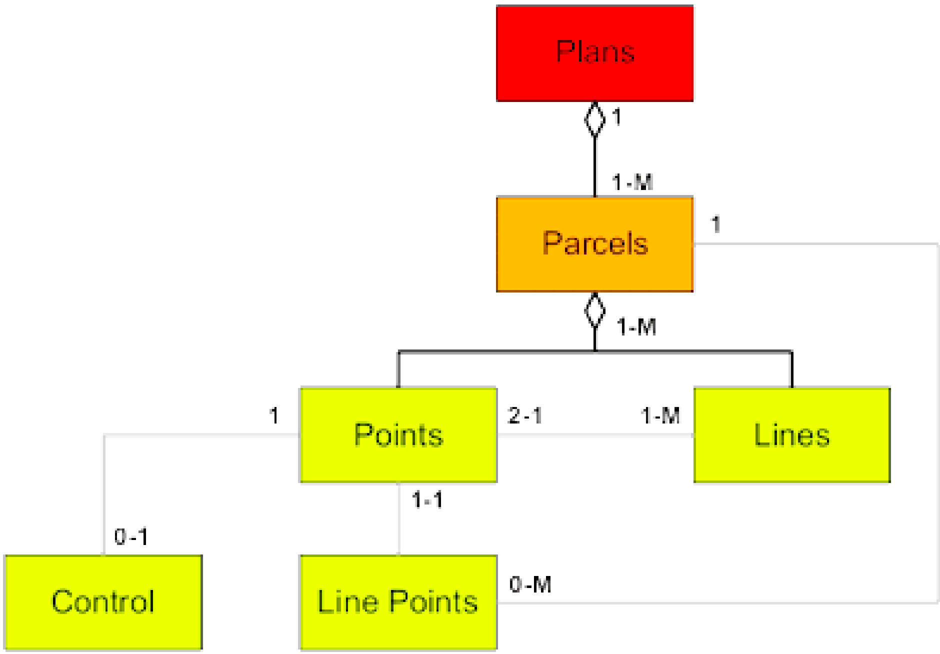


Figure 3. Parcel fabric parcel data model

Each parcel is defined from a sequence of boundary lines which store dimensions as attributes to the line to maintain the legal survey information. To maintain relationships between parcels the fabric is stored as a continuous surface of connected parcels through the parcel network.

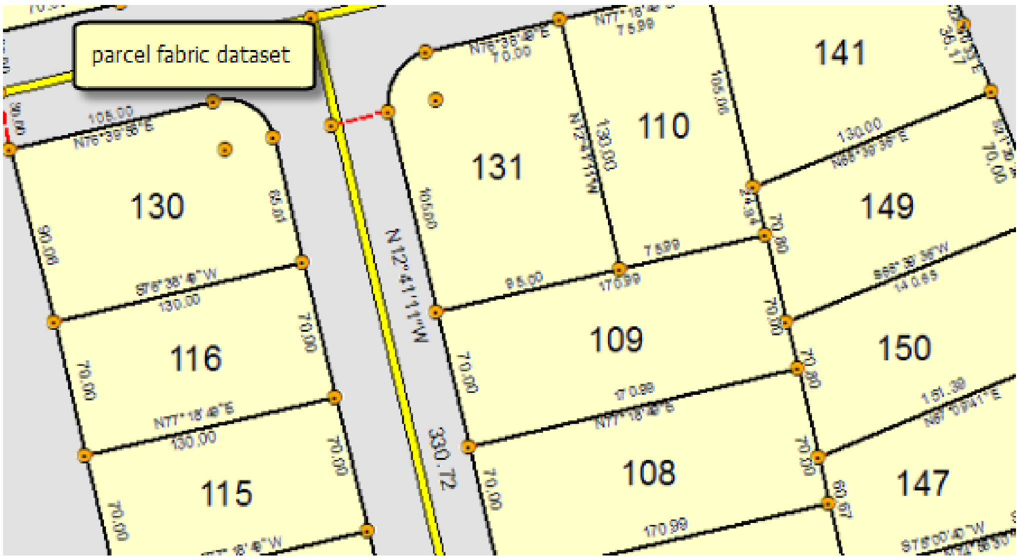


Figure 4. Map fragment showing the content of a parcel fabric dataset

Spatial accuracy in the fabric is maintained through a least-squares adjustment. Control points are processed together with recorded dimensions to derive new, more accurate coordinates for parcel corners. Line dimensions are not changed, but fabric point coordinates are updated. The result is an accurate coordinate-based cadastral system. As they share common boundaries, adjacent parcels are always kept in the same relationship.

3.1 Modeling parcel relationships

As relationships exist between parcels, lines, and points in the parcel fabric, relationships exist between parcel features and other parcel fabric data elements such as plans. The following list summarizes the relationships between parcel features themselves and between parcel features and other tables:

- a parcel polygon is related to many lines;
- a parcel line has two endpoints;
- a parcel line is related to only one parcel, resulting in two lines representing common parcel boundaries;
- a parcel point is related to one control point;
- a parcel point is related to one or more lines;
- a line point is related to one or more parcel polygons;
- a line point is related to one parcel line;
- a parcel point is related to one line point;
- a parcel polygon can have many line points;
- a parcel polygon is related to one plan;
- a parcel can have one or more historic parcels (lineage);
- a parcel point can have one or more adjustment vectors (from a fabric adjustment).

3.2 Maintaining external relationships

The parcel fabric acts as a basemap for overlying feature classes in the geodatabase. Feature classes such as building polygons and utility lines are constructed in relation to parcel boundaries. Feature classes using parcel boundaries as a basemap will fall out of alignment when a parcel fabric is adjusted. To bring standard features back into alignment with the parcel fabric, coordinate shifts resulting from the least-squares adjustment are captured and stored as displacement vectors in the geodatabase. Displacement vectors are then applied to overlying features in a rubber sheeting process to bring them into alignment with the parcel fabric. The result is features that are aligned with an accurately coordinated parcel fabric.

Because each set of displacement vectors is associated with an adjustment level, feature adjustments can be applied ad hoc. Since feature classes are tracked by their last adjustment level, previous displacement vectors are never reapplied and vector sets are always executed in sequence and not omitted.

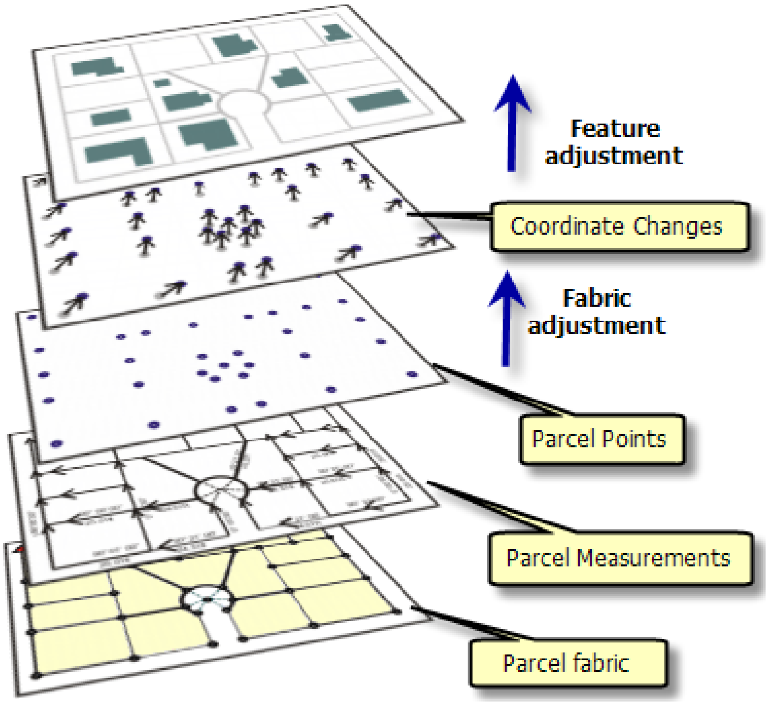


Figure 5. Feature adjustment based on parcel fabric adjustment

3.3 Parcel history

A parcel fabric is a representation of the record of survey for an area of land. Parcel boundary line dimensions in the parcel fabric match the dimensions on the survey record. Dimensions in the parcel fabric are edited in response to a change in the survey record, for example, a parcel split or resurvey. Parcels that are edited or replaced by new survey records are retained as historic, thus always preserving the original survey record.

3.4 About topology

In ArcGIS, topology is the model used to describe how features share geometry and is the mechanism for establishing and maintaining spatial relationships between features. An example of a topological relationship is the one between building polygons and parcel polygons: a rule might be that building polygons are always contained within parcel polygons. A topology is stored in a geodatabase as a set of rules on how the features in one or more feature classes within a feature dataset share geometry.

When a topology is validated, features participating in the topology are evaluated against a set of defined rules, and violations of the rules are treated as errors. For example, if the building polygon overlaps the parcel polygon, this is a violation of the rule specifying that building polygons should always be contained within parcel polygons.

3.5 The 3D reference

The parcel fabric supports multi layered parcels allowing parcels to overlap. The base parcel can be duplicated into multiple layers each representing e.g. a building floor. Each layered parcel is duplicated as a joined parcel to the original parcel hereby maintaining its original spatial relationships during least squares adjustments of the base parcel. Each duplicated parcel can be reshaped or subdivided using survey measurements into lesser units representing e.g. condominiums or apartments. Each sub-unit represents a parcel record in the geodatabase.

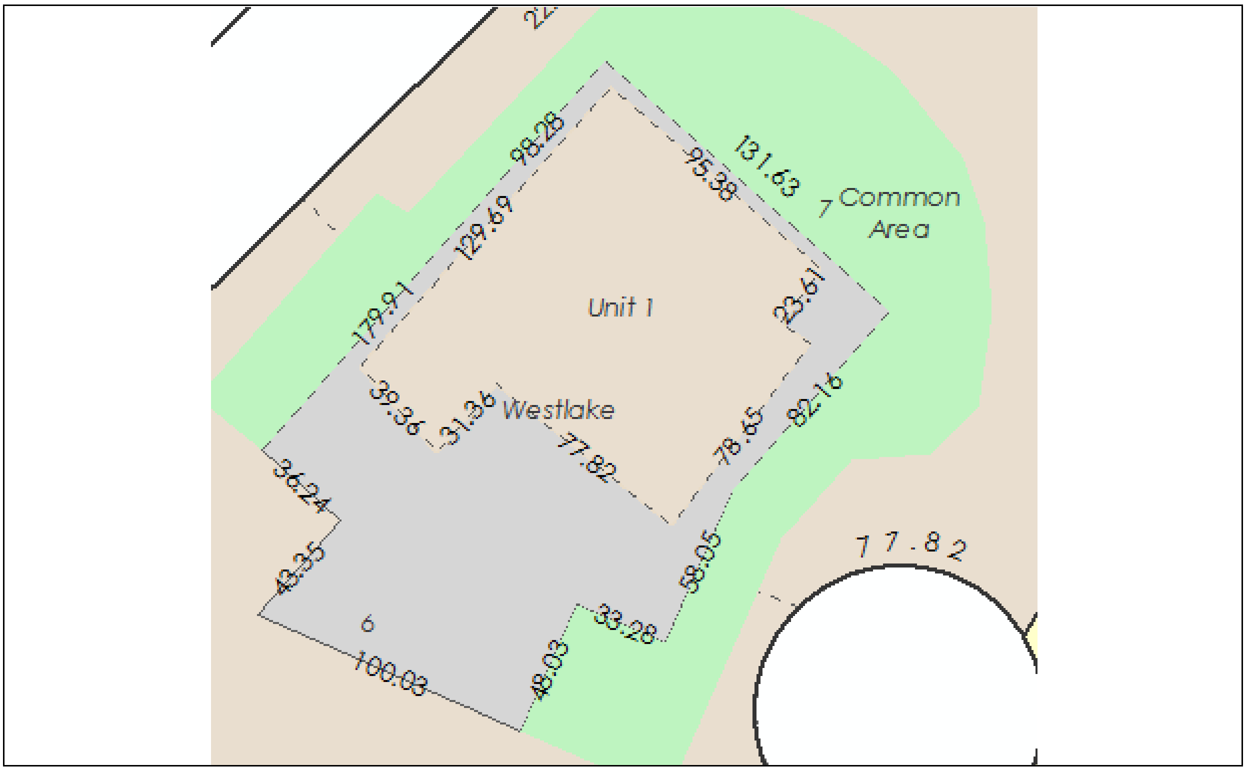


Figure 6. The parcel fabric with two overlapping parcels belonging to the same two story building

Given the accurate building floor areas are effectively stacked polygons, it is simple to use vertical offsets and extrusion (based on an average floor height) to display a single, seamless 3D building. These 3D objects are representations of the records in the parcel fabric and can be queried, searched, selected and displayed in the 3D representation.

The derived 3D representation of the cadastral fabric not only provides a visual representation of 3D space ownership, it also provides access to the 3D spatial relationships between parcels. These relationships can be analyzed to support other elements of 3D cadastre - for example, line of sight analysis can support tax assessment, while shadow and proximity analysis can be used for zoning and planning purposes.

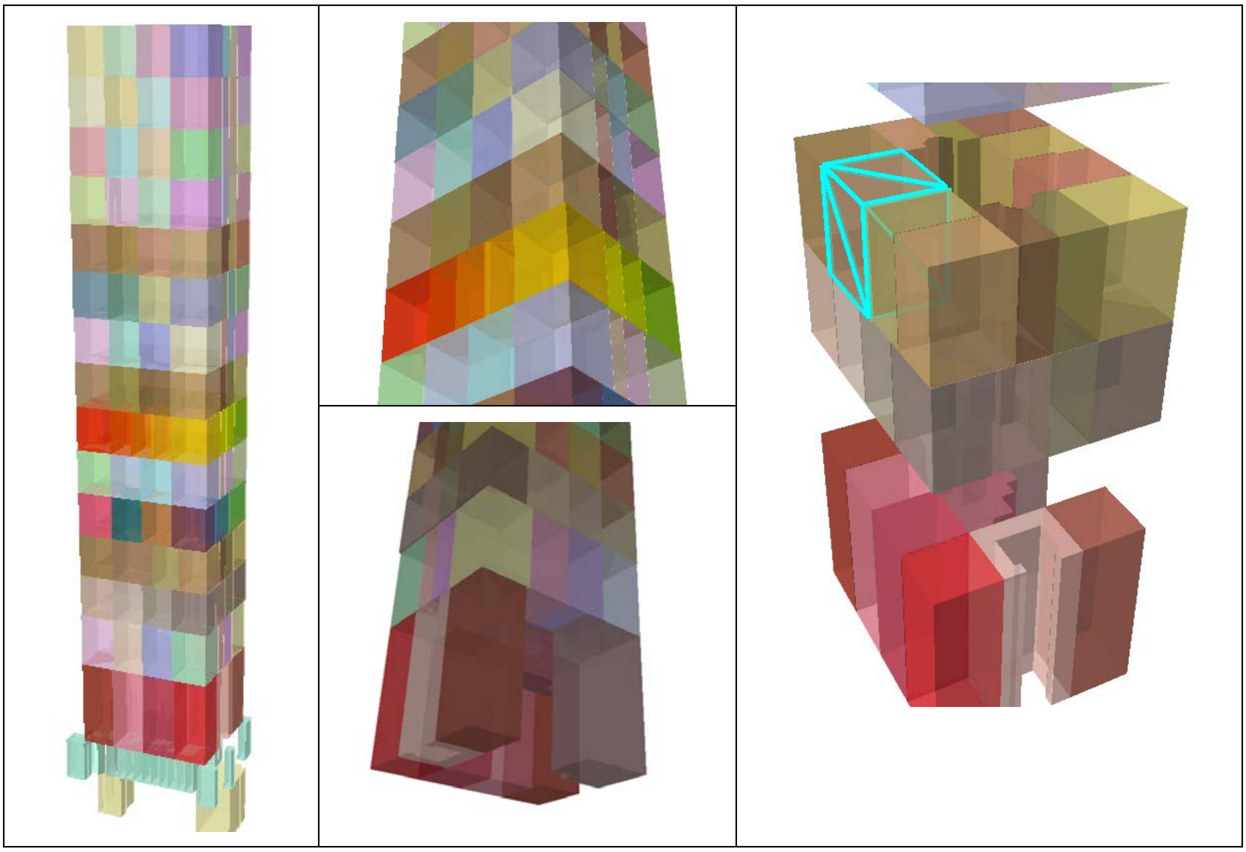


Figure 7. 3D display of 2D cadastre 15 story building with parcels and intermediate space from the Parcel Fabric

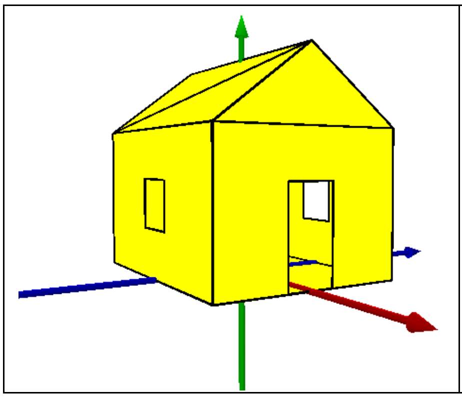
4. 3D CITIES

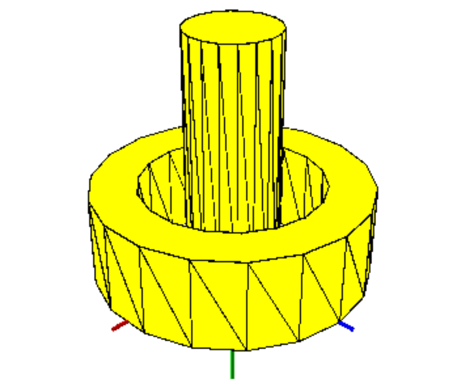
Esri is active in 3D in a multitude of fields beyond the management of 3-D cadastre, and many of these are likely to contribute capabilities which will be useful for 3D cadastre in the future. These capabilities will extend the use and value of the 3-D cadastral data in related application areas, such as city planning, building design, and environmental impact assessment. In particular there have been recent advances in multipatch textured 3D buildings for city models, in 3D analysis, in handling of LIDAR data, and in rule-based 3D rendering.

4.1 3D multipatch datatype

ArcGIS includes a multipatch datatype as standard in the ArcGIS geodatabase data model. This allows the modeling of complex 3D structures at high levels of detail.

The volumetric models are made up of collections of 3D geometric primitives: triangle strips, triangle fans, triangles, and rings. The geodatabase model also allows storage of texture image, color, transparency, and lighting vector information within the geometry.





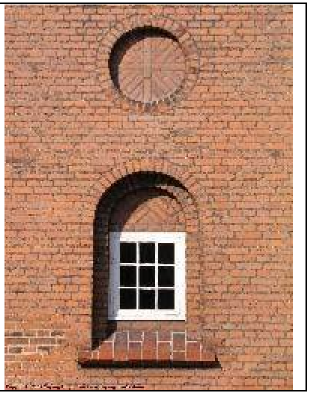


Figure 8a. 3D volumetric model	Figure 8b. Made of triangles and rings	Figure 8c. With surface textures

These datatypes can be used in many 3D applications, such as virtual city models like 'Virtual Philadelphia' shown below.

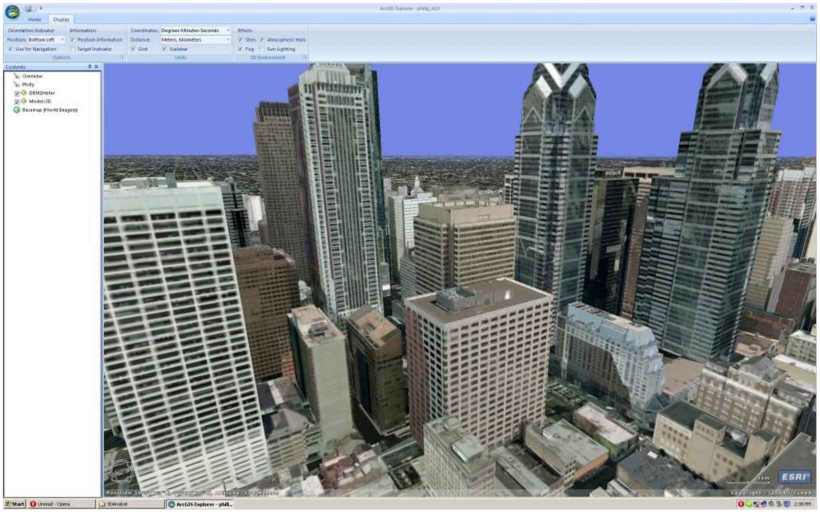
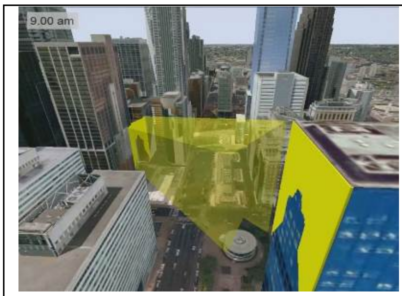
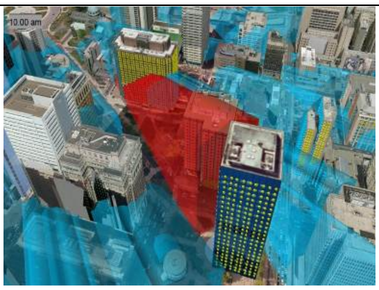


Figure 9. Virtual Philadelphia

4.2 3D analysis

Many of the traditional 2D analysis algorithms work in 3D, but there are also a set of new 3D analyses for shadow, glare, skyline etc., which will be very relevant to applications related to the cadastre, such as planning the design of new buildings in cities.





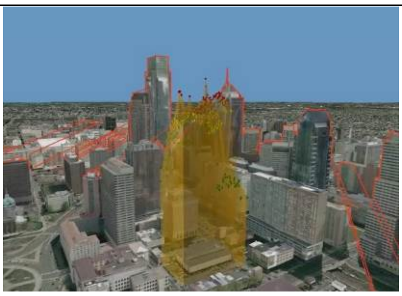


Figure 10a. Volumetric Glare	Figure 10b. Volumetric Shadows	Figure 10c. Skyline visibility

4.3 LIDAR

LIDAR is becoming a major source of 3D data for use in 3D cadastre and other 3D applications. ArcGIS has supported LIDAR for a while, but the next release (10.1) includes extra support for on the fly mosaicking of raw LIDAR datasets

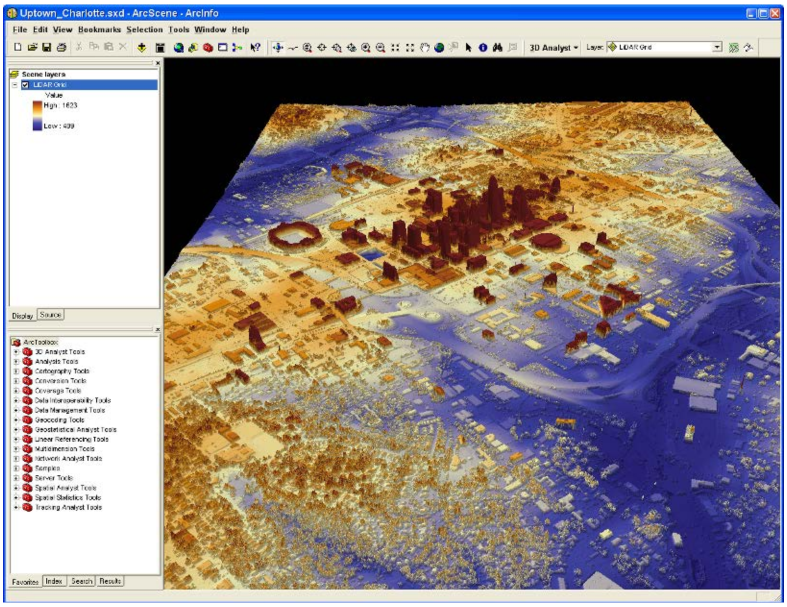


Figure 11. LIDAR data as in input into 3D Cadastre

4.4 Rule-based 3D rendering

Esri recently acquired Procedural, whose product CityEngine has exciting capabilities for generating rule-based 3D constructs from basic cadastral data, allowing realistic visualizations at increasing levels of detail.

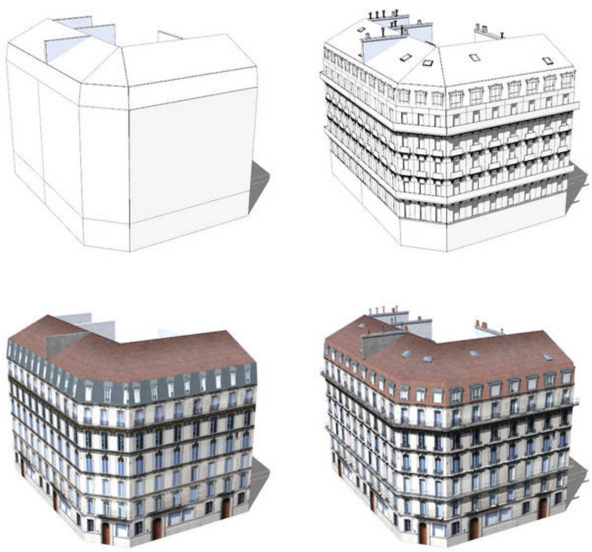


Figure 12. 3D visualizations of same object at increasing levels of detail

5. CONCLUSION

3D cadastre is necessary to display and manage complex spatial relationships. To support a full 3D cadastral implementation, object boundary definitions, object topologies and their legal representations will have to be further defined. A hybrid approach combining 2D and 3D using GIS represents a feasible, economical and extensible approach.

Using the ArcGIS parcel fabric model, allows for the legal boundary definition of parcels while at the same time maintaining the topologic relationship between parcels and to other spatial objects. By representing multi floored buildings each containing one or many parcels, overlapping parcels topologies can be maintained through least squares adjustments and joins. Overlapping polygons can be represented as 3D objects in ArcGIS allowing for identification, search, analysis and visualization of parcels.

This paper has largely concentrated on managing 3-D parcels, but it also provides an insight into other ArcGIS 3-D capabilities which extend the use and value of cadastral data. For example, in areas such as city planning and sustainable land management, as well as tools for processing important 3-D data sources such as LIDAR.

ACKNOWLEDGEMENTS

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BIOGRAPHICAL NOTES

Carsten Bjornsson is Project Manager at Esri Professional Services, specializing in Land Administration. Before that he was Associated Professor in GIS and Surveying at the Royal Veterinary and Agricultural University of Denmark. Mr. Bjornsson holds a Masters Degree in Surveying and LIS from Aalborg University.

Nick Land is Esri's Business Development Manager for National Mapping and Cadastre in Europe. He has previously been the Executive Director of EuroGeographics – the association of Europe's National Mapping & Cadastral organizations.

CONTACTS

Carsten Bjornsson and Nick Land
Esri Inc.
380 New York St
Redlands
CA 93273
USA
E-mail: cbjornsson@esri.com; nland@esri.com
Website: www.esri.com