Bentley's Support for 3D Cadastre Development[1]

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SUMMARY

Cadastre has been playing a huge role in the development of our society since it aims at registering legal status and property rights associated to land. Cadastre is usually based on a 2D parcel description with associated land information. Although 2D representation simplification of our 3D reality offers advantages (e.g.: it can be easily represented on paper) it also involves several limitations when the existing situation is too complex to describe.

There are many cases where infrastructure density leads to complex interleaving (overhanging structures; above and below ground infrastructures…). Furthermore, demographic forecasts expect urban population to double between 2005 and 2050. This assessment of current and coming challenges has been made several times and motivated numerous research activities suggesting the adoption of 3D Cadastre. This research identifies some of the technological limitations in implementing a 3D cadastre.

The geospatial and engineering industries have evolved very quickly over the past few years. The development of 3D GIS technologies offers new methods to represent property ownership in 3D and to associate detailed attribution to those representations. The objective of this paper is to present a benchmark exercise in which Bentley Geospatial software was used to implement several scenarios in a 3D Cadastre. The results describe an architecture (a combination of desktop GIS applications with server based RDBMS) to implement different scenarios for a 3D Cadastre (Full 3D and Hybrid). The results illustrate how it is possible to combine advanced CAD technologies, such as Solid Modeling and Constructive Solid Geometry, to create and update intelligent objects corresponding to both 3D objects (infrastructure components) and 3D property units. Technology evolves very quickly providing new methodologies to present and manage land information. This paper provides an overview of the latest 3D GIS capabilities as applied to cadastre.

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[1] This paper is an extension of the paper was previously presented at FIG Working Week 2011, Benoit Frédéricque, Keith Raymond and Kees van Prooijen, 3D GIS as Applied to Cadastre - A Benchmark of Today's Capabilities, FIG Working Week 2011, Marrakech.

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1. INTRODUCTION

Cadastre has played a huge role in the development of our society since it aims at registering legal status and property rights associated to land. Cadastre is usually based on a 2D parcel description with associated land information. Although 2D representation\simplification of our 3D reality offers advantages (ex: can be easily represented on paper) it also involves several limitations when the existing situation is too complex to describe. It can become difficult to accurately document ownership in a way that is easy to understand for practitioners.

There are many cases where infrastructure density leads to complex interleaving (overhanging structures; above and below ground infrastructures…). Figure 1 which corresponds to London Tottenham Court Road subway station illustrates particularly well this complexity. Several infrastructures with different owners and rights are interleaved in a limited 3D space.

Figure 1. 3D Information Model of Tottenham Court Road subway station. Data courtesy of Crossrail

Also in less complex situations a 3D presentation helps to understand the situation between the various building rights and objects.

Despite organizational and legal challenges, implementing a 3D Cadastre involves technical difficulties in order to create, maintain and share 3D information for cadastral registration. As an example, in Pouliot et al 2010 the authors identify the requirement for efficient tools to create, manage and exchange 3D data. In their research, they conclude that the time required to create 3D data was one of the main barriers to the adoption of 3D cadastre.

Geospatial and engineering technologies have evolved very quickly in the past few years. The development of 3D GIS technologies offers new methods of representing property ownership in 3D and associating detailed attribution to those representations. The objective of this paper is to present an overview of what can be achieved using Bentley products to implement 3D Cadastre today. The first section describes different techniques to model 3D property units. The second addresses data management within a scalable framework using spatial databases. The last section provides a description of presenting 3D cadastre via 3D PDF and a web based solution.

2. CREATING VALID 3D GEOMETRIES CORRESPONDING TO 3D PROPERTY UNITS

When implementing a 3D Cadastre it is necessary to establish 3D geometries defining ownership volumes. Data can be available from a variety of sources. In developed countries with existing cadastral systems and a structured legal process for the management of building processes we can expect to find 2D cadastral data. Often, plans defining as-built or proposed buildings are also available. In countries adopting standard Building Information Models in their building permit process we can even expect to have 3D Building models available.
On the other hand, when limited data are available, building 3D cadastre property units can be seen as a process starting from scratch.

2.1 Problems to avoid
The process of building 3D volumes must be done carefully in order to guarantee topological consistency of the result. Following are a few typical examples identified from previous research.

We can see two types of problems. The first one relates to the spatial relationship between two volumes (extrinsic topology). In this case, by zooming in, it appears that the 2 volumes overlap. As noted by the authors, this could be deliberate if the overlapping area is indeed shared by two owners but could also be a problem with modeling.

Another problem illustrated by Figure 2 relates to the geometry of the object itself (intrinsic topology). In this example, independent polygons are used to describe each face of a closed volume. The problem identified by the authors is a snapping issue between the different faces which leads to an unclosed volume and consequently does not allow for volume computation. Using such geometry to define a 3D property would be invalid since it wouldn't adequately describe the property.
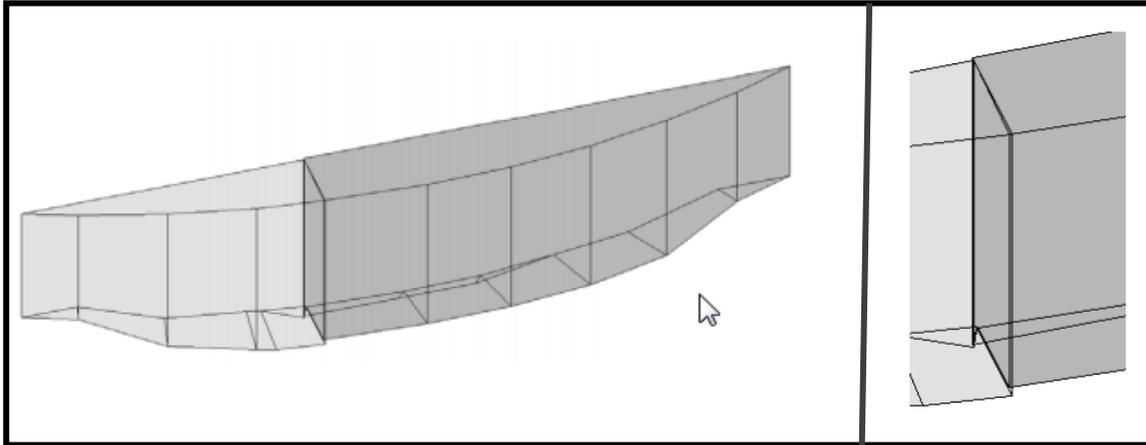
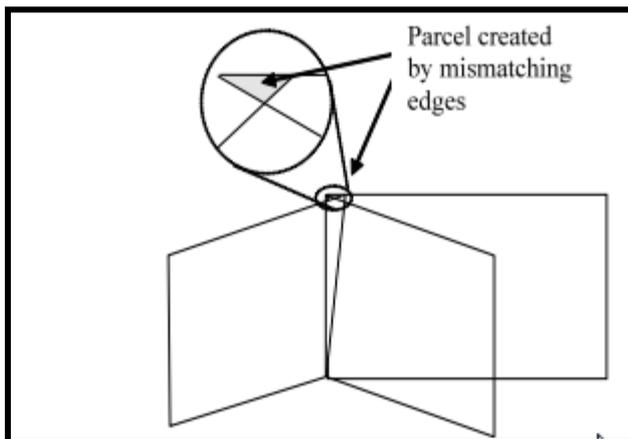**Figure 2. Example of extrinsic topological inconsistency from Karki et al (2010)**

Figure 3. Example of intrinsic topological inconsistency from Stoter et al (2004)

These problems illustrate several challenges:
- How to create a valid closed object
- How to create objects that do not overlap
- How to detect overlap issues
- How to detect snapping issues
- How to automatically fix such issues

2.2 How to create valid geometry and to detect problems?
One very efficient solution to create valid volumetric geometries is to use "solid modeling" techniques which, by nature, manipulate closed volumetric objects. It is possible and straightforward to create a solid from a 2D shape (floorplan) by extruding it. The result is a solid which can be edited easily and accurately with push\pull operations. Push/Pull modeling allows drawing on a solid, selecting faces, vertices and edges and extruding or moving them. It is very efficient and always creates a closed solid which guarantees intrinsic topology (consistency between all faces of the same object).

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The extrinsic topology (consistency between two solids that are side by side) can be guaranteed with a different strategy. First, validate the topology of the two polygons before the extrusion, next perform the extrusion in the same direction. This idea was proposed in Ledoux et al (2010) and can be implemented in Bentley Map using parcel tools usually used for 2D Cadastre. The solid modeling tools are then used for the extrusion.

Another approach is to adjust the two solids after the extrusion using Boolean operations (subtraction), a basic solid modeling operation. These are part of the Smart Editing tools in Bentley Map.

Detecting snapping issues in a group of faces that define a closed volume can be performed by using advanced CAD techniques. These tools convert a group of faces to solid geometry objects. In the case of Bentley for example, MicroStation provides a function called, "Stitch Surfaces", which will perform such a conversion *if and only if* all the faces are well connected. This tool can clearly act as a quality control test.

Detecting overlap in 3D is challenging but can be achieved automatically using a "clash detection engine" which is used in engineering workflows to detect interference between objects.

As far as we know there are no automatic tools today to automatically fix snapping issues between a group of faces.

2.3 From existing 2D raster

As it is described and tested in Pouliot et al (2010), creation of 3D geometries defining 3D property registration can be achieved by integrating 2D plans and descriptive information. 2D floor plans can indeed be combined with section plans or with floor height information to define the 3D volumes corresponding to the 3D properties. In the context of the Quebec cadastre analyzed by the authors the 2D plans are available as raster in the Cadastre administration.
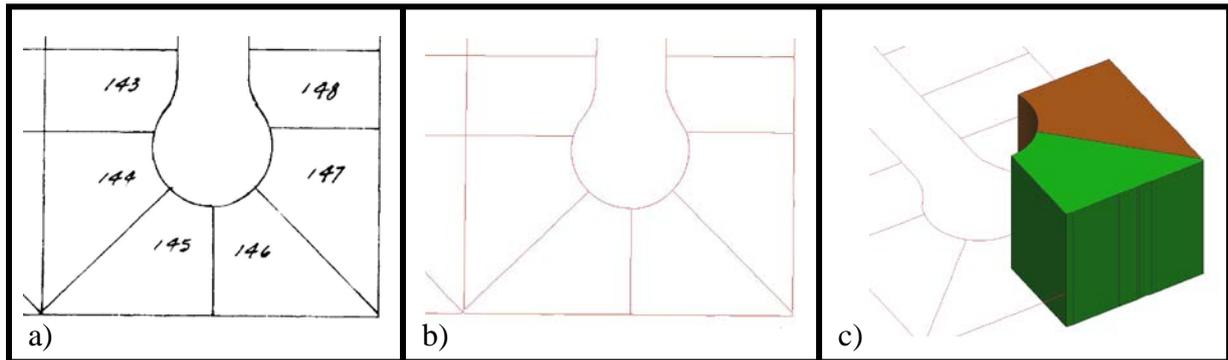
An additional step is required to convert 2D raster plans into 2D vector. Based on our own experience as technology providers we can state that this workflow is repeatable in other countries.
A significant amount of time can be saved using image processing software combining OCR and automatic vectorization techniques. The performance of such technologies has greatly progressed in the last decade even if the quality of the result is dependent on the quality and complexity of the raster imagery.
In addition to the time required to perform the extraction and quality control of the result, the authors stress the need for better interoperability to reduce time spent in file conversion. Indeed, even if there is a direct conversion between two formats, such processing requires management and time.
An efficient strategy to reduce raster conversion and data exchange is to combine the software inside the same platform. For example, Bentley Map (Enterprise version) contains tools for extracting automatically and semi-automatically geometries from raster (Vectorize tools). Figure 4 represents the original raster 2D building floor plan and the extracted geometries.

The results are produced directly in Bentley Map and can be stored inside Bentley Map files as well as the Oracle Database. Integration with the Oracle database will be more fully described in the next sections.

Figure 4. From 2D Raster (a) to 2D Vectors (b) to 3D Solids (c)

As soon as 2D polygons describing the footprint of the properties are obtained, solid modeling tools can be used to extrude and edit the geometries according to the available elevation information.

2.4 From 3d building information models

The increasing prevalence of BIMs (Building Information Models) means that we can expect to see very detailed building models available in the planning stage. Consequently these models can be used to generate 3D volumes for properties. This approach works if tools are available to obtain an "as-built" model from an "as designed" model. For example, in Finland, land surveying techniques are used after construction to validate the "as-built" is consistent with the original design. In this context, land surveying measurements act as "check" points so that the 'as-designed' model does not have to be completely rebuilt.

When detailed engineering models describing the "as built" model are available, they can be used to create the 3D property registration volumes. The issue then becomes one of cost. Is it cheaper to automate the extraction process from the model or to build the model from scratch? BIM models are very detailed and bring a level of information which is definitely higher than that required for a 3D Cadastre. Details such as wall thickness, rooms and type of material are superfluous. Consequently going from a BIM model to 3D property registration requires an abstraction/simplification process which is challenging to automate. Automation of BIM model simplification has already motivated several research efforts and several issues still need to be addressed before full automation can be expected. For example researchers Van Berlo Léon and De Laat Ruben (2010) note that the geospatial standard CityGML and the BIM standard IFC rely on different paradigms to model geometries. This is illustrated in Figure 5.
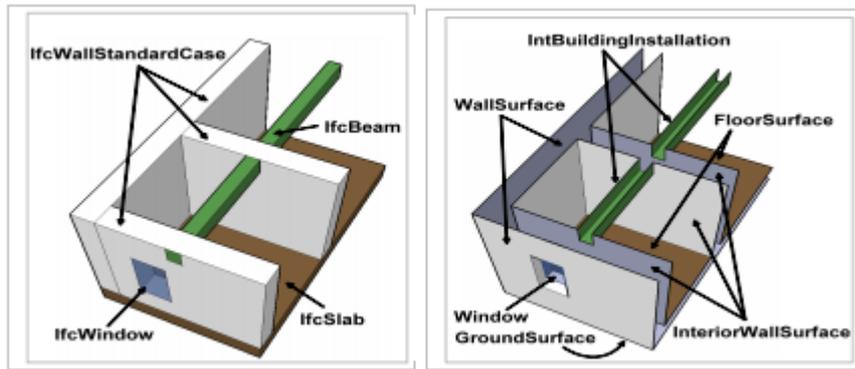
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Figure 5. Different modeling paradigm used in IFC and CityGML standards from Nagel et al (2009)
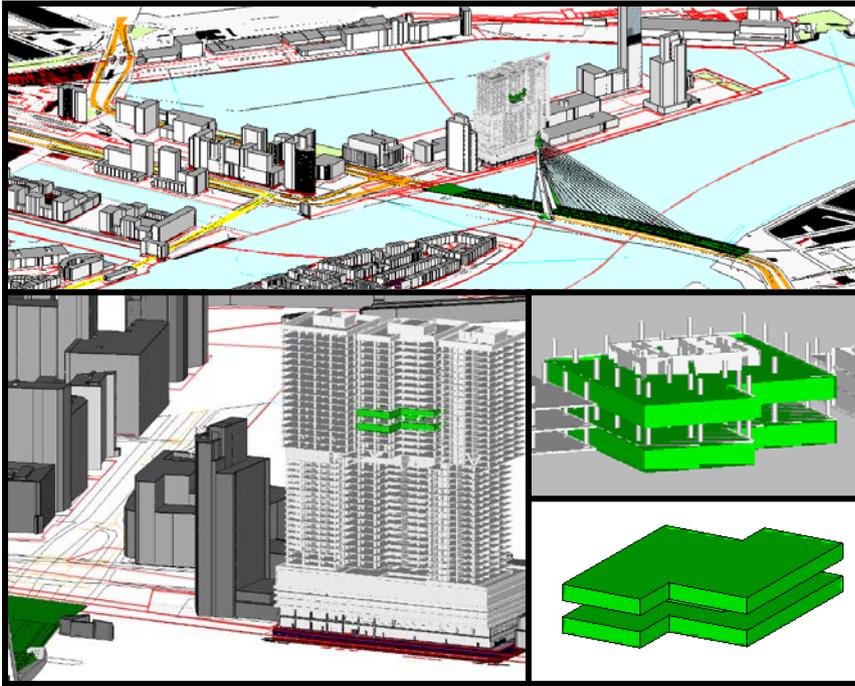
Another challenge clearly identified by researchers Nagel C et al (2009); Umit Isikdag and Sisi Zlatanova (2009) is a semantic mismatch between IFC schema and a geospatial schema such as CityGML. In other words in some cases there is no one-to-one relationship between a concept in IFC and a concept in CityGML.

Automatically extracting 3D geometries to define 3D properties is, as far as we know, not possible today and still requires much research. Despite this automation limitation, it can be beneficial to use existing 3D building models to reduce field operations. This requires two successive steps: 1) reference it in a 3D GIS environment 2) use it as a background model to manually build the 3D Cadastre model

The first can be achieved directly if the Building Model file format is supported by the GIS and the model is georeferenced properly. Reading most file formats is rarely a problem but georeferencing can be an issue. Architects and engineers frequently work in a local coordinate systems which means that an extra-georeferencing step may be required. Characteristic points are frequently available in Building Models and the referencing process is used to map these points to the right geospatial location.

The second can be achieved by using advanced CAD techniques combined with a GIS paradigm to quickly create 3D volumes with semantic information. The geometry integrity is particularly crucial in a 3D cadastre context and again requires particular attention to guarantee 3D topology consistency. The previously discussed solid modeling tools would help in this regard.

Figure 6 shows a 3D model of *Kop van Zuid* in Rotterdam. As a backdrop a topographic map is used that has been draped over a DTM model using Bentley's PowerCivil. A detailed 3D Building Model of a newly created building *De Rotterdam* is transformed from a local coordinate system to the national coordinate system and placed on the correct height. From this reference some cadastre 3D objects have been created below ground and on the 20th till 22nd floor. In this case Bentley Map is used to define closed volumetric geometries and to associate semantic information.

Figure 6. 3D Properties manually extracted from a building model georeferenced inside 3D city model of Rotterdam

2.5 From scratch using point cloud or land surveying techniques

In the case where no existing information is available field survey techniques can be used to acquire the 3D property data. The last decade has seen the development of laser scanning technologies as a new land surveying technique which permits fast acquisition of 3D data from aerial or multiple ground points. Such a point cloud can be used as a reference to support the direct drawing of the 3D property.

The process of modeling the 3D properties therefore becomes similar to what has been described in the previous section. Point cloud or land surveying points are used as reference to draw the solid geometries. In the case of the point cloud, one approach is to section it at a given elevation to extract a profile similar to a 2D floorplan. Such a section can be generated in real time using the clipping capabilities of Bentley Map or MicroStation. Figure 7 illustrates a section of a 3D Point Cloud and a polygon extracted from this section.
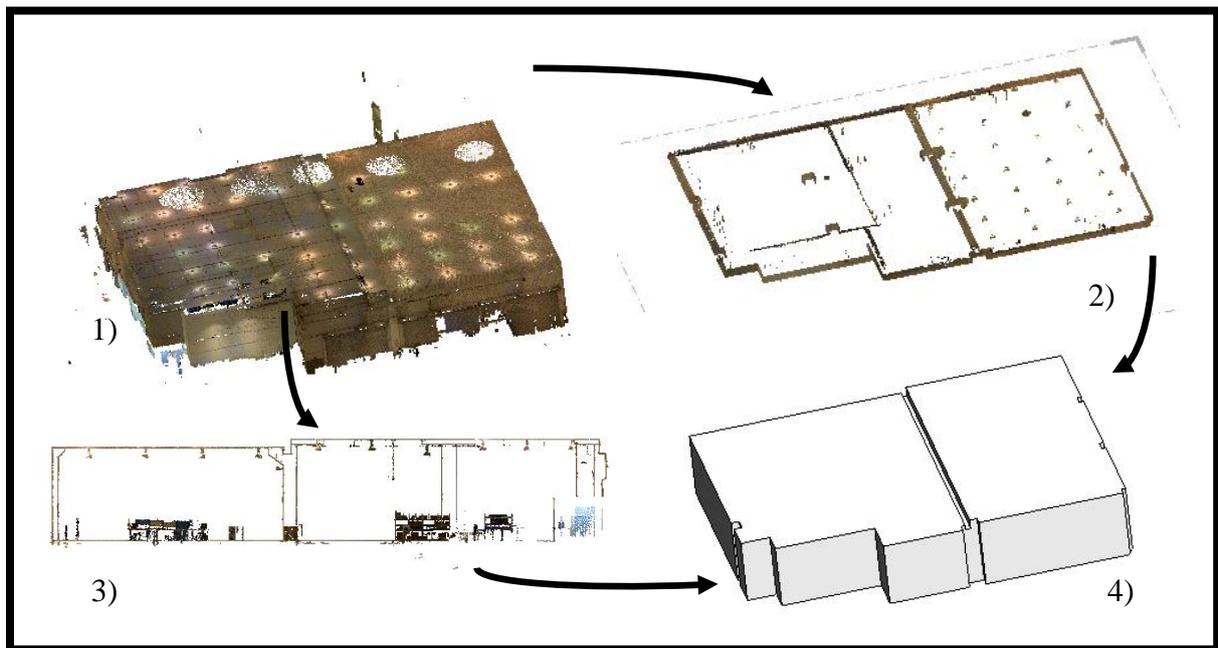
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Figure 7. From Point Clouds (1) to Building Sections (2 and 3) to Solid geometry (4) (Point Cloud courtesy of Faro)

3. COMBINING 3D OBJECT WITH SEMANTIC INSIDE A SCALABLE FRAMEWORK

3.1 XFM & smart editing

We described in section 2 different ways to generate valid 3D geometries for a 3D Cadastre. As in 2D cadastre a 3D Cadastre requires the definition of properties such as the parcel ID, the name of the owner and other attributes.

It is, therefore, required to have a mechanism to associate 3D geometries with properties in a 3D GIS. Bentley Map allows storing a group of 3D polygons as a single 3D GIS object to which the user can attach properties by using a mechanism named *XML Feature Modeling*.
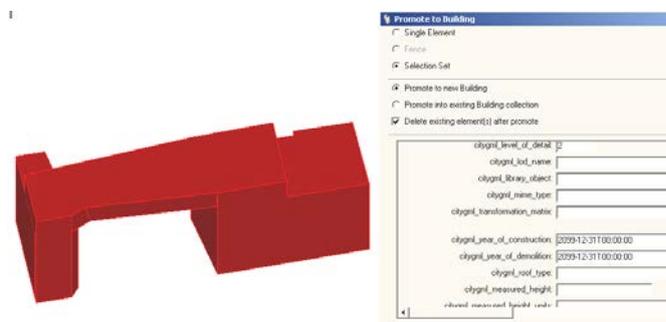

Figure 8. Create a 3D GIS object from polygons and attach properties

The reader should notice that the storage data type used is a set of faces and not solids. Solids can be created on-the-fly to support any new editing with all the benefits previously

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mentioned. This on-the-fly creation of solids from faces maintains all the attributes and is referred as Smart Editing in Bentley Map. Storing a collection of faces and not a solid offers two main advantages: performance and interoperability.

The solid data type in the Bentley framework is very powerful and supports many advanced editing tools and geometric complexity. This power has a cost in term of data size about 4-5 times a similar geometry stored as faces. Another aspect is interoperability. The GIS industry has limited experience in using 3D solid models and the definition of a solid can vary from one system to another leading to data exchange issues. Storing and exchanging faces reduces data size and simplifies data exchange.

3.2 Managing 3D cadastre information with 3D spatial database
Geospatial databases have been used for years in the geospatial industry and offer numerous advantages such as scalability, security, standardization etc. The reader can refer to this podcast in which use cases and benefits of combining Oracle Spatial Databases with Bentley tools are discussed.
(http://streaming.oracle.com/ebn/podcasts/media/8489151_Bentley_022210.mp3) .

In the context of 3D cadastre these aspects are very important and suggest the use of a Geospatial Database. The development of spatial databases now support 3D objects in much the same way as 2D types. Oracle Spatial 11g, for example, introduced different 3D data types such as Solid and MultiSurface. It is therefore possible to store, as a unique row in a database table, a feature with properties and a 3D volumetric geometry. This distinction is very important since, in the past, storing 3D volumes in a spatial database required one row for each geometric element and a method to relate them. (ex: a cube involved 6 rows).
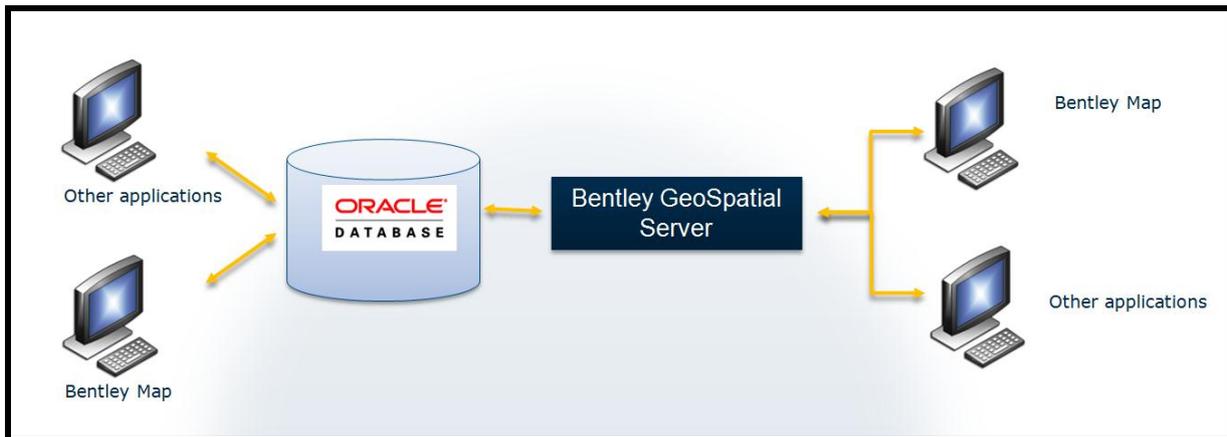In Figure 6 the two green solids were created with Bentley Map and stored as 2 rows (Surfaces with gtype: 3003/3007 + etype: 1006) in Oracle Spatial 11g using a direct connection.

Several ways to interact with spatial databases exist (short vs. long transaction; optimistic vs. pessimistic modes) and can involve different architectures. As illustrated in Figure 9, connection to a database can be achieved directly and allow a 3D GIS user to extract information, edit and then update it. Such an architecture allows collaboration between people using different software and the database can act as an interoperability component. In Figure 9 we use Oracle as the spatial database and several different client applications including Bentley Map.

To tackle cases with numerous users, more elaborate architectures (3-tier or multi-tier) can also be implemented with different mechanisms to access the database. It can be beneficial to add intermediate layers on the server side allowing management of the user's access. Figure 9, show a multi-tier architecture in which some users (e.g.; GIS administrators) have direct access to the database and some others (ex: technicians) access Oracle Spatial data through Bentley's Geospatial Server.

This architecture allows creating, updating and managing 3D features. It does the same for 2D features as well as a hybrid of both. In Figure 6 the reader should notice that several 2D

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features are integrated in the 3D model. These include the existing 2D cadastre. This means that the tools and architecture we described to create 3D cadastre can be used to implement full 3D cadastre as well as a hybrid cadastre combining 2D and 3D content.

Figure 9. Example of multi-tier architecture combining Oracle Spatial 11g and Bentley Geospatial Server to serve data to different desktop applications

A 3D Cadastre system is not only about managing 3D property features with geometries and attributes. Many other documents such as legal documents, urban plans and documentation as well as existing scanned plans are all part of the cadastre record and require efficient management processes. These documents are in different forms such as PDF, doc, txt, tiff files etc and are frequently managed with Content Management Systems. One major benefit in the management of these heterogeneous documents is the ability to integrate them with geospatial data. This can be achieved by associating spatial locations to these documents. Documents can therefore be represented on a map and found through a spatial query.

Another way to integrate images and documents is to link them to existing spatial objects such as a cadastre parcel. Figure 10 shows documents managed within the Bentley Geospatial Server. In this illustration we can see on the left a tree view, similar to Windows Explorer, which supports a file/folder based navigation of the data. The second part of the interface shows a 2D representation of the geospatial data (e.g.: top view of a 3D model). By clicking on an object (e.g. a parcel) a user can access all of the documents that are linked to that parcel. In this case, by following the link, a user can access a 2D scan of an old legal document. Bentley Map allows creating links between features and documents stored on Bentley Geospatial Server. These links are attached to the features and stored in Oracle Spatial. Therefore, a multi-tier geospatial server allows users to not only create, manage and provide access to 3D Cadastre objects but also to efficiently manage all related documents.
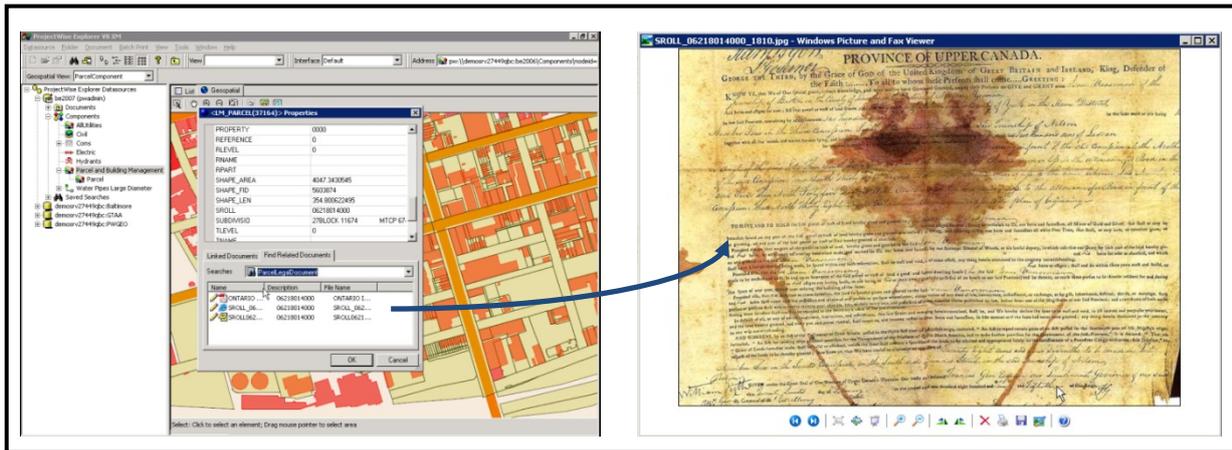
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Figure 10. Managing different documents such as PDF or jpeg in a geospatial framework with Bentley Geospatial Server

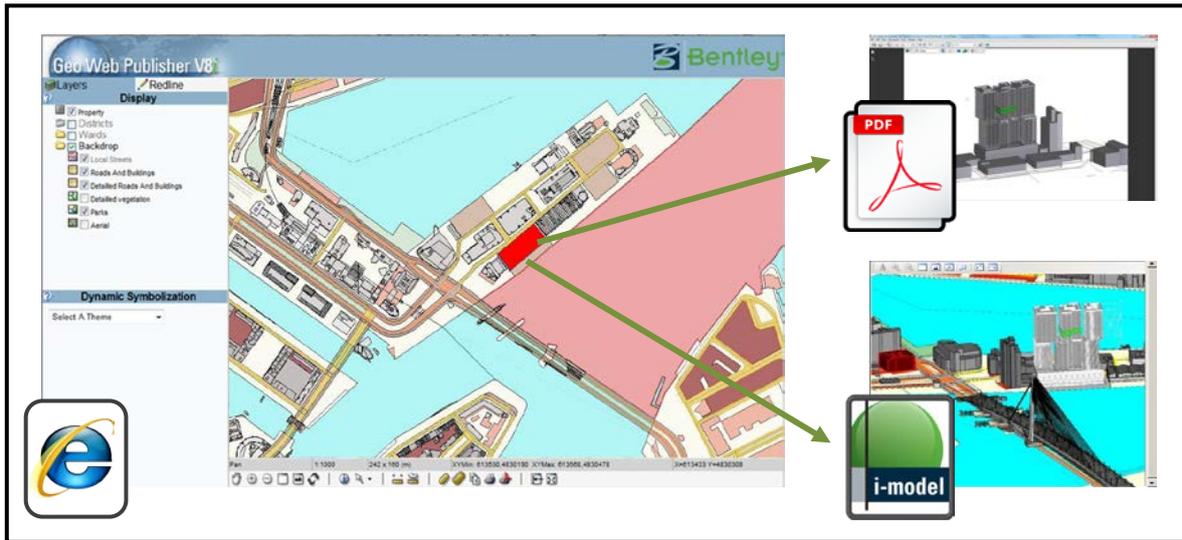## 4. SHARING 3D CADASTRE INFORMATION WITH THE 3D SPATIAL DATABASE

Previous sections described how it is possible to create, maintain and manage 3D Cadastre spatial data as well as the associated documentation.

A 3D Cadastre can simplify communication of complex cases by providing 3D visualization tools to city staff, legal personnel and the public. These people are typically not 3D GIS experts and need simple tools to access the required information. Such an application needs to be very simple, work on a variety of hardware and operating systems and be easily maintained.

3D information can be presented in 3D PDF files. PDF is a very common format and is readable on most devices with a free viewer. Indeed, PDF supports full 3D objects in a compact form and requires only Adobe Acrobat Reader. It offers the possibility to view the objects from all angles and all details. In next paragraph a use case with 3D presentation is described.

An efficient way to address a wider audience is to implement a simple web GIS application as illustrated in Figure 11. This application uses a 2D background map to support very simple and intuitive navigation across the service area. 3D information can be accessed on demand and delivered as a downloadable 3D PDF file.

Another option is to download 3D content as i-model file. i-model is a 3D standard developed by Bentley which allows exchanging detailed and rich 3D Models with properties. A free dedicated viewer or web plug-in is required.

Figure 11. Implementing a WebGIS application to provide access to 3D Cadastre information

4.1 3D Ccadastre use case

In a use case for the Dutch cadastre, the possibility was examined to create 3D drawing of cadastre registration. The current NMAs and Cadastral/Registries administrations are usually able to present (mainly as hardcopies but also as softcopies) their documents only as 2D products. The common format 3D PDF makes the complex plans readily available to those involved in the design and approval process. This reduces the chance of errors in planning and registration. Finally the electronic document can be stored in the public register together with the deed and paper drawing.

In the first step using the Bentley Map tools an accurate drawing is created with a 3D registration object from various 2D and 3D sources: cadastral and topographic maps, 3D objects (LoD1) and 3D Building model, aerial photo. In Figure 12 several sources are presented.

Figure 12. Sources for creating a registration object

At this stage the object can be exported to CityGML and/or stored into a spatial database (see Figure 8). Next, all relevant objects and geometries are selected and a 3D PDF document is

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created. Optionally, a digital signature can be added to the PDF document to prove the authentication of the document. In Figure 13 a PDF reader shows the registration from different angles and background layers such as topography, parcel and parcel numbers can be switched on and off.
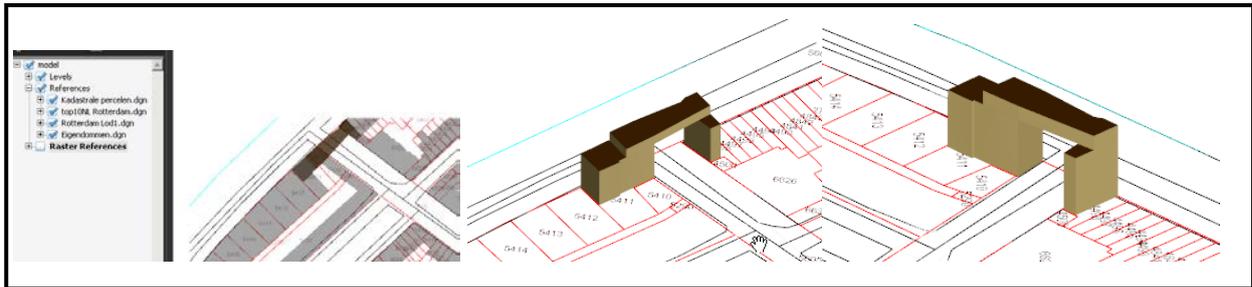

Figure 13. Various 3D presentation in the same PDF document.

5. CONCLUSION

This paper provides an overview of what can be achieved using Bentley products to implement 3D Cadastre today. The results describe an architecture (a combination of desktop GIS applications with server based RDBMS) to implement different scenarios for a 3D Cadastre. The results illustrate how it is possible to combine advanced CAD technologies, such as Solid Modeling and Constructive Solid Geometry, to create and update intelligent objects corresponding to both 3D objects (infrastructure components) and 3D property units.

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BIOGRAPHICAL NOTES

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