Digital Cartographic Model of 3D Cadastre: An Initial Design and Implementation

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Key words: 3D cadastre, visualization, symbology, digital cartographic model

SUMMARY

Despite the abundant research discoveries in 3D cadastre visualization, there still lacks a synthesis method of concreate symbology instructions and 3D graphical content as an easy entry for designers, implementors, and visualization systems. In cartography domain, introducing DCM (Digital Cartographic Model) on top of DLM (Digital Landscape Model) is a method that could enable unambiguous depiction of portrayal and improve the visualization interoperability. Currently, no investigation has explored the applicability of this method in 3D cadastre visualization. The aim of this research is to evaluate the applicability of using DCM for 3D cadastre visualization regarding symbology encoding, graphic content creation, and 3D content exchange. In this research, the 3D cadastre DCM contains 1, a 3D symbology encoding module to structurally describe the employment of 3D design features; 2, a 3D graphic content module to represent the symbology result. We first investigated the current 3D cadastre visualization features. According to these features, we then designed a tentative 3D symbology encoding model and select COLLADA and glTF as 3D content models. We invited scholar and student participants to learn, use, and judge 3D SE for the description of 3D cadastre visualization instructions. We constructed a prototypical program that can read 3D symbology encoding and then convert DLM data automatically to COLLADA and glTF encoded 3D graphic content. Finally, we export the COLLADA and glTF files to multiple visualization platforms and evaluate the visualization result. The work of this research shows that applying DCM in 3D cadastre is applicable and improves the visualization interoperability. It enables structured symbology description, automatic graphic content creation, and promotes the 3D content exchange. Current design and implementation are still at an early stage. It may have improvement in multiple parts, including the more advanced feature filtering of XML based data, and the finer rendering control.

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1. INTRODUCTION

Cadastre map is a critical material for cadastre legal and administration practices and has long been a main part of modern cadastre system. Its objective is to help the user unambiguously perceive cadastre related spatial and non-spatial information that may otherwise be difficult to understand with only tables and description. As cadastre moving from 2D to 3D, many researchers believe that moving cadastre map from 2D to 3D may bring a series of benefits (Pouliot et al., 2018). 3D visualization could provide more intuitive presentation (Biljecki et al., 2015), interactive navigation (Shojaei et al., 2012), extra symbology design choices (Wang, 2015) and so on. However, 3D visualization also brings challenges. For readers, 3D scene interaction and reading may require experience (Wang et al., 2017), and the occlusion may hinder perception (Ying et al., 2016). For designers, the existing cartographic knowledge and experience may no longer be viable in 3D (Wang et al., 2012).

Existing investigation yields useful knowledge about the user, visual tasks, visualization design, and usability of 3D cadastre visualization (Wang et al., 2017; Shojaei, 2014). Despite the abundant discoveries, there still lacks a synthesis method of concreate symbology instructions and 3D graphical content as an easy entry for designers, implementors, and visualization systems. The visualization design principles and the resulting 3D graphic content are not readily interchangeable. This impedes the unambiguous transfer of the visualization design instructions and 3D graphic contents. Currently, the guidance and principles communicated between designers are encoded as a natural language in the forms of oral communication, documents, research papers, and regulations. The designers have to understand the guidance first. Then they should carefully apply these principles to specific scenarios and manually construct visualization scenes. The overall process is not only time consuming but may contain subjective-bias.

Introducing Digital Cartographic Model (DCM) on top of Digital Landscape Model (DLM) is a method employed by many cartographers in both 2D and 3D geo-visualization for structured portrayal description, interoperation, and automation (Semmo et al., 2015; Stoter et al., 2010). The cartography visualization pipeline could then be modeled as a symbology process from DLM to DCM, and a rendering process from DCM to final output on display devices. In this process, DLM is the model to describe the geospatial reality, for example, the topological model that describes the structure of a railway network. On the other hand, DCM is the model that describes the cartographical visualization. It has the visualization-related data, like the symbology instruction and the graphic content. DCM could also be a medium through which designers, researchers, system implementors, and even computer system communicate.

From DLM and DCM point of view, 3D cadastre research domain devotes a significant portion of efforts to the development of 3D cadastre DLM, say, building semantic-rich and topologic sound data models to register the cadastre related spatial and non-spatial information. However, there are still very few explicit applications of DCM in 3D cadastre domain despite that it has been mentioned in Stoter (2004)'s 3D cadastre thesis. The prototypical visualization system proposed by Shojaei et al. (2012) uses KML for visualization on top of LandXML based ePlan data. Their prototype could be evaluated as a simple DCM and DLM separating design.

Based on current research, design, and implementation of DCM, we evaluate that introducing DCM to 3D cadastre visualization may enable unambiguous depiction of 3D cadastre portrayal and may improve the 3D cadastre visualization interoperability. It may also bring other benefits. For example, it could facilitate the automation of visualization content construction (Semmo et al., 2015). It could also provide better performance by using widely supported and optimized data format, compared with the direct rendering of burdensome 3D cadastre DLM (e.g., LandXML, GML, CityGML, or a relational database).

In this paper, we present proof-of-concept research of 3D cadastre Digital Cartographic Model. We designed and tested a tentative 3D cadastre DCM to access its applicability and interoperability. We first show the inventory of relevant symbology features of 3D cadastre. In section 3 we present the design of 3D DCM. It has a 3D Symbology Encoding module to describe the design features and a 3D graphic content module. Section 4 presents the application and evaluation of the tentative 3D DCM in 3D cadastre visualization. We give the conclusion and discussion in the last section.

2. THE INVENTORY OF 3D CADASTRE SYMBOLOGY FEATURES

Collecting an inventory of current 3D cadastre symbology design features is the starting point of a 3D cadastre DCM design. It could inspire the creation of DCM since the DCM should have the capability to describe a large portion of these features. We collected and reviewed all the 3D cadastre related papers since 2001 with an emphasis on 3D cadastre visualization figures. Both the 3D and 2D figures are considered. There are two types of visualization figures in these papers: the snapshot of a 3D visualization system or 3D scene, like those in Vandysheva et al. (2012)'s manuscript, and the manually draw demonstrative plot, like the Isometric diagram, Cross-section diagram, and the 2D demonstrative plot in Wang et al. (2012)'s paper. The snapshot could represent those design features that have been realized in a 3D scene. Besides, we evaluate that the manually draw plot may also contain some preferable symbology features that have not yet been realized in an interactive 3D situation.

Table 1 gives an inventory of current 3D cadastre symbology features. For visualization primitives, the area primitive is the most popular in current 3D cadastre visualization. Applying visual variables like color hue and transparency over the area primitive to differentiate property units is the most common design feature. The area could be the boundary faces of a 3D property unit volume. It could also be the representation of the boundary lines of a 2D property unit terrain. The popularity of area may due to its ease of technical realization. This feature could be readily realized in 3D content creation software like SketchUp and Blender. The suitability of area primitive has been evaluated. For some visual variables, for example, color hue, and transparency, the results are promising (Wang et al., 2017; Wang 2015). Moving area from its original geometry location is also a common design feature to reduce the occlusion effect (Ying et al., 2016).

In contract with the widely used area primitive, the line primitive is less touched in interactive 3D scene. Some 3D cadastre prototype systems use lines, often colored red, as a highlighting technique to increase the saliency of a selected surface or volume (Vandysheva et al., 2012). Despite the limited application in the interactive 3D scene, line symbol has been extensively employed in manually draw plots. Some researchers also add extra line symbol on top of the original snapshot of 3D cadastre prototype to better demonstrate the situation to the reader. The most common visual variables used with the line symbol are color hue, width, and shape (solid line, dash line, etc.). We evaluate that line primitive is also favorable in 3D cadastre visualization. However, line primitive is difficult to realize in common 3D content creation software and may require special rendering settings.

The point primitive is seldomly employed in interactive 3D scenes. However, it has appeared in some cross-section diagram and isometric diagram, which normally are drawn in CAD (Computer-Aided Design). It is also a frequently used feature in 2D cadastre map. In these diagrams and maps, the point primitive is normally used to symbolize a surveying point or to represent landmarks whose shape is too little to be explicitly represented. We evaluate that using point primitive in 3D may also be valuable since representing surveying point and landmarks are still relevant in 3D cadastre visualization.

There is also the application of the solid primitive in 3D cadastre visualization. Li et al. (2016) demonstrated the feasibility of a direct volume texture rendering to visualize voxelized 3D cadastre data. Despite its higher demand for computational resources, volume primitive could also be an interesting design feature in future.

Text annotation is frequently employed to demonstrate the non-spatial information like the ownership and the official measurement. However, we notice that the application of annotation has been limited by the functions of 3D content creation software. It appears more in CAD and SketchUp platform.

Table 1. The inventory of 3D cadastre visualization design features

Visualization Primitive and graphic elements	Visual variables	Corresponding data	Visualization scenario
Point	Shape, size, brightness	Survey Point, Landmark	2D cadastre map Isometric diagram, Cross-section diagram
Line	Shape, size, hue	The boundary line of legal/physical objects (solid, area)	2D cadastre map Isometric diagram, Cross-section diagram, highlighting in 3D cadastre scene
Area	Location, brightness, hue, texture, transparency,	The boundary area of legal/physical objects (solid), land parcel (area), the boundary line of legal objects (line)	2D cadastre map Isometric diagram, Cross-section diagram, highlighting in 3D cadastre scene
Solid	Hue, brightness	The closed space of legal objects	Interactive 3D scene
Annotation	Size, Location, shape	Ownership, Official measurements	2D cadastre map Isometric diagram, Cross-section diagram, 3D cadastre scene in SketchUp and CAD

We spot three characteristics of current 3D cadastre visualization:

1. The type of visualized spatial and non-spatial data is limited. Despite the semantic-rich 3D cadastre data that researchers have been developing, the data visualized are still very limited. The typical spatial data involved in 3D cadastre visualization are spatial boundaries of legal objects, spatial boundaries of physical objects, landmarks, and survey points. The common non-spatial data are ownership, official measurements, and so on. The common encoding formats of 3D cadastre DLM are in XML and relational database.
2. The visualization primitives may not in accordance with the spatial feature. For example, an area could be used to represent a boundary line of a 2D property units. Similarly, property unit could be visualized with survey points, outlines, boundary faces, and solid.
3. The 3D visualization design features are deeply influenced by the functions provided by current visualization platforms. The 2D cadastre map, isometric diagram, cross-section diagram, which are often drawn with CAD, uses point primitive, line primitive, and text annotation more frequently. On the other hand, the 3D content created and visualized in SketchUp seldomly uses line and point primitives. The text annotation is scarcely spotted in interactive 3D maps except as a tooltip for information query.

3. DIGITAL CARTOGRAPHIC MODEL OF CADASTRE

Based on the analysis of current visualization design features, we proposed a 3D cadastre DCM. It contains two modules: 1, a 3D symbology encoding model (3D SE) to structurally describe the employment of 3D symbology features; 2, a 3D graphic content model to describe the symbology result. The 3D cadastre DCM should be platform independent and be encoded in a human and machine-readable manner. Figure 1 shows the role of DLM and DCM in 3D cadastre visualization process.

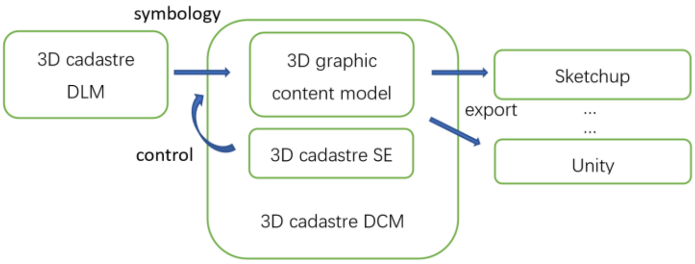


Figure 1. The role of DLM and DCM in 3D cadastre visualization process

3.1 3D symbology encoding model

Since the separation of DLM and DCM, multiple symbology encoding models have been proposed. Some data models tightly attach to a certain technical platform, like OGC SLD (Standard Layer Descriptor), ESRI ArcGIS layer style, Tilemill's CartoCSS, and Mapbox style specification. On top of these platform dependent model, OGC has proposed a platform-independent Symbology Encoding Specification (OGC, 2006), and International standard organization demarcates ISO 19117 Portrayal (ISO, 2012), a conceptual symbology encoding schema. There are also experimental models. Bocher and Ertz (2018) proposed a redesigned OGC SE to enhance its flexibility. Rylov and Zipf (2012) proposed improvement of label placement in OGC SE. However, there are only a limited number of research publications of 3D symbology encoding, like that of Neubauer and Zipf (2009), and Haist et al. (2007). Current symbology encoding models provide a rich knowledge base for structured symbology encoding description.

We evaluate that current models, even those proposed for 3D visualization, could not meet the need of 3D cadastre visualization. The primary deficiency is that existing 3D symbology encoding is not flexible enough to describe the relationship between the visualization primitives and their geospatial feature counterparts. For example, using solid primitive to visualize the line boundaries of a land parcel, or using point primitive to visualize the vertex of a polygonal property unit.

Aiming current deficiencies, we proposed a new 3D symbology encoding model for 3D cadastre DCM. The design contains a conceptual 3D symbology encoding model and an XML encoding schema (XSD). Figure 2 shows the simplified UML class diagram of the conceptual 3D SE model. We tested and improved the model multiple times during the development to ensure it has the capability to express a large portion of the existing symbology designs.

The main idea behind the design is separating the symbolizer with its symbol component and differentiating the symbol component from the scene element. The symbolizer is the abstract type that defines the symbology of a feature. It has four sub-types according to the geometry of the underlying feature type. The symbol component is the abstract type that defines the graphic representation of symbols. It has four sub-types that corresponding to the four visual primitives. The scene element is the abstract type that defines the perceivable element in a 3D scene. Such design is largely in accordance with the definitions in ISO 19117.

Separating symbolizer, symbol component, and scene element could enhance the flexibility of the model. For example, a SolidSymbolizer represents the symbolizer of a solid geometry. Its symbol component could be: a solid representing the space it occupied, a series of the area representing its boundary faces, a series of the line representing the edge of its boundary faces, or a series of the point representing the vertex of the boundary edge. Furthermore, each symbol component could also connect with one or several 3D scene elements. For example, the line component could contain a graphic stroke, or composed of a series of geometry3D along the line.

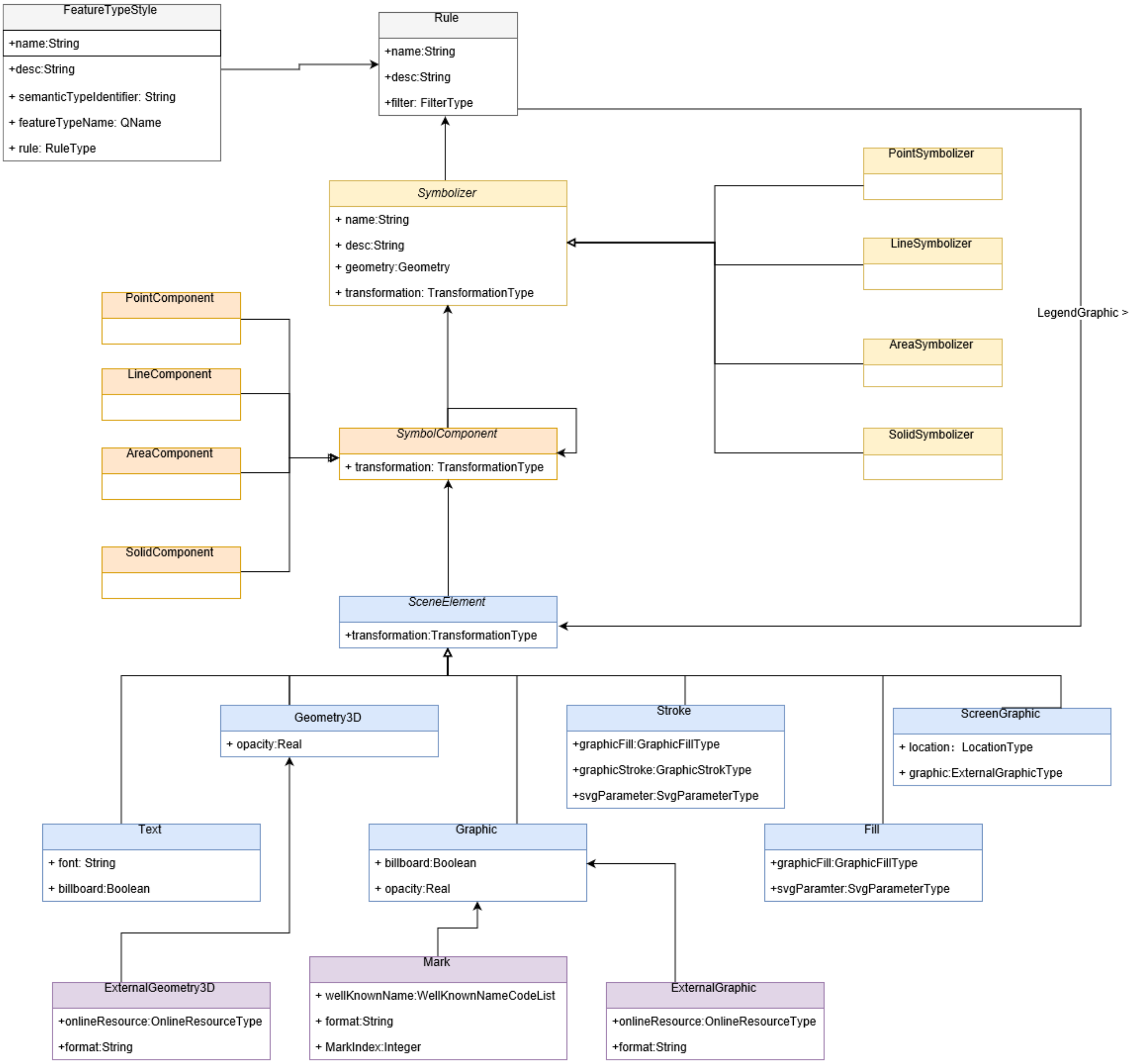


Figure 2. The UML diagram of the tentative 3D symbology encoding model

We keep the name of classes in the conceptual model largely the same with existing classes in OGC SE and those in Bocher and Ertz(2018)'s design. For example, we use Stroke to represent the linear graphics. We also introduce new concepts. ExternalGeometry3D represents the external 3D geometry in the scene. It could refer to a COLLADA geometry. ScreenGraphic represents the graphic on the screen panel, not in the 3D scene. Considering the natural of cadastre data, we do not contain LOD (level of detail), scale, and RasterSymbolizer in 3D SE. In order to better model the geometry rotate, scale, and translate from the original spatial feature, we introduce geometrical transformation property in Symbolizer, SymbolElement, and SceneElement. The filter in the Rule class control the selection of cadastre features for visualization. Its syntax follows the OGC Filter Encoding Specification. For the DLM that is encoded in XML format, like CityGML, LandXML, an XPath expression could be used to point to one or a series of elements or values in the DLM.

The proposed 3D SE conceptual model may lead to many encoding choices, such as XML, JSON, or a relational database schema. In this paper, we encode the 3D SE in XML format and translate the conceptual model to an XML schema (XSD). Figure 3 shows a snapshot of the 3D SE XSD. The destination XSD follows the style of OGC SE XSD, so the user of OGC SE could easily understand the proposed 3D SE.

```
<!-- ======================Graphic ================================================== -->
<element name="Graphic" type="se3d:GraphicType" substitutionGroup="se3d:SceneElement"/>
<complexType name="GraphicType">
    <complexContent>
    <extension base="se3d:SceneElementType">
    <sequence>
        <element ref="se3d:Opacity" minOccurs="0"/>
        <element ref="se3d:Size" minOccurs="0"/>
        <element ref="se3d:Rotation" minOccurs="0"/>
        <element name="billBoard" type="boolean"/>
        <choice minOccurs="0">
            <element ref="se3d:Mark" minOccurs="0"/>
            <element ref="se3d:ExternalGraphic" minOccurs="0"/>
        </choice>
    </sequence>
    </extension>
    </complexContent>
</complexType>
```

Figure 3. A snapshot of 3D SE XSD

3.2 3D graphic content model

We use a 3D graphic content model to store the result of symbology process. Such model should have the capability to store all potential scene elements and be supported by a large amount of visualization and rendering platforms. Also, its encoding should be non-proprietary, so we can use a series of free/open source middleware to create the application that converts DLM to 3D graphic content.

Since creating an ad-hoc 3D graphic content model may not be readily supported by existing 3D visualization platforms, we decide to use existing 3D asset format as the 3D graphic content model. The format like .3DS,. blender, .fbx are proprietary, thus may not meet our needs. OBJ (ASCII)，COLLADA, glTF, and X3D are the most common non-proprietary formats. We evaluate the four formats by their geometry capabilities, 3D scene information, acceptance by visualization platforms(popularity), and encoding methods. Table 2 shows the results.

Table 2. The comparison of four non-proprietary 3D graphic content format

Format	Geometry capability	Appearance information	3D scene information	Popularity	Encoding methods
Obj	All the common geometries	All the common appearance settings	Not applicable	Highest	Ad-hoc grammar, ASCII encoding
COLLADA	All the common geometries	All the common appearance settings	Camera, Lighting and animation	High	XML
X3D	All the common geometries Direct visualization of text	All the common appearance settings	Camera, Lighting and animation	Low	XML/JSON/Binary
glTF	All the common geometries	All the common appearance settings	Camera, Lighting and animation	Medium	JSON

The comparison shows that X3D format provides the richest features. However, X3D has not received wide acceptance. In contrast, obj is the most popular 3D asset format, yet, it lacks the necessary scene information like lighting. Finally, we choose COLLADA as the 3D graphic content model in 3D cadastre DCM. COLLADA has been accepted as an ISO standard (ISO, 2012) and is widely supported by 3D content creation platform, rendering engine, interactive 3D visualization platforms, and geospatial 3D platform. As a digital asset exchange model, it enables the expression of common 3D graphic contents and 3D scene settings. Since it is encoded in XML, it is both human and computer readable. We also test glTF because it is closely related to COLLADA and is more compact.

4. IMPLEMENTATION AND EVALUATION

We implement and evaluate the 3D cadastre DCM with a LADM based, GML encoding tentative cadastre DLM of Anhui Province, China. We use the data of two real cases and four simulating cases of condominium. These cases contain the common 3D cadastre phenomenon including 2D cadastre parcel, 3D building unit above the ground and underground, party, party group, and so on. The data contains only ownership right, and the overlapping situations involved are relatively simple.

Three parts of the visualization pipeline use 3D cadastre DCM: the symbology design process, the graphic content creation process, and the visualization process. Thus, the implementation of 3D cadastre DCM may contain three consecutive parts, and each part involves different user groups. First, the visualization designer may use the 3D SE in DCM to describe the symbology design features of 3D cadastre. Second, the 3D content creator may construct the 3D graphic content in DCM according to the regulations demarcated in 3D SE model. Finally, visualization system implementor exports the 3D graphic content to different software platforms and in multiple types of device.

4.1 Symbology design encoding

During the design process, the proposed 3D SE has been tested multiple times to ensure that it could express the design features collected from the 3D cadastre literature. Thus, the implementation and evaluation of 3D SE model are concentrated more on using the model to describe new visualization designs and communicate the settings between designers. We first construct a series of examples about how the symbology design could be conceptually described by 3D SE, and how the description could be encoded in XML format correctly. Many of these examples are based on existing 3D cadastre visualization designs. Then, we invite the research scholars and undergraduate students with cartography and GIS background in the school of Resources and Environmental Engineering, Anhui university to learn the proposed 3D SE model with the help of these examples. Based on the data of four simulating scenarios, they are encouraged to propose new 3D cadastre symbology design and describe their designs by 3D SE. We designed a prototypical SE design program to provide a certain level of automation to the SE encoding process. Participants could select the desired attribute in a computer-user interface, and the program will construct the SE XML file automatically. We also encourage the participants to read and interpret the design principles from the 3D SE XML file built by other participants. Figure 4 shows a snapshot of encoded 3D SE SolidSymblizer.

```xml
<se3d:SolidSymbolizer>
  <se3d:name>symbolizer for spatial units</se3d:name>
  <se3d:description>This Symbolizer contains a LineComponent and an AreaComponent</se3d:description>
  <se3d:LineComponent>
    <se3d:Stroke>
        <se3d:SvgParameter name="stroke-width">4</se3d:SvgParameter>
        <se3d:SvgParameter name="stroke">#0000ff</se3d:SvgParameter>
    </se3d:Stroke>
  </se3d:LineComponent>
  <se3d:AreaComponent>
        <se3d:Fill>
            <se3d:SvgParameter name="fill">#aaaaff</se3d:SvgParameter>
        </se3d:Fill>
  </se3d:AreaComponent>
</se3d:SolidSymbolizer>
```

Figure 4. A snapshot of XML encoded SolidSymbolizer

4.2 3D content creation

We construct a prototypical program to automate the 3D graphic content creation. The program, based on FME, interprets the symbology instructions in XML encoded 3D SE and then convert 3D cadastre DLM to COLLADA files accordingly. The interpretation and translation are straight forward since all the files involved are coded in XML with clear XSD.

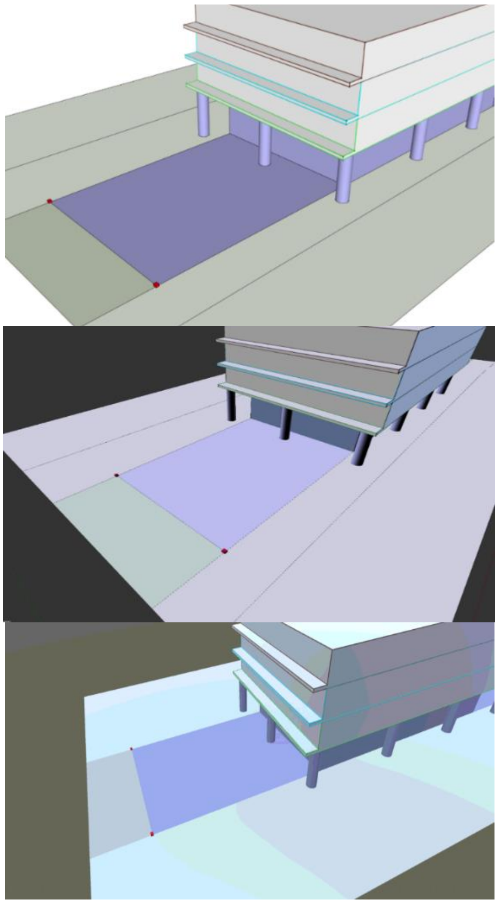
The exported COLLADA file is then converted to glTF file automatically by free converting tools. The participants of the previous symbology design step are also invited to try the program for 3D content creation.

The automatic program translates some of the scene elements to a volume realization, like Stroke. This guarantees these elements could display evenly in different visualization platforms. When encounter well-known mark, such as square and circle, the program will replace them with corresponding 3D geometries like tube and sphere. Also, the program will use a 3D cylinder or other pipeline style 3D geometries to represent stroke defined in the 3D SE. Text, billboard, and screen graphic have not yet been realized since COLLADA lacks the direct support for these features.

Till now, we tested the prototypical program with 3 visualization designs on 6 DLM, resulting 18 graphic contents encoded in 36 files (18 COLLADA, 18 glTF). The prototypical automation program is still at a stage of testing, debugging and improving.

4.3 Visualization

We export the automatically constructed COLLADA files to a series of 3D platforms to examine the visualization result. Currently, these 3D platforms including SketchUp, Blender,



a.
b.
c.

Figure 5. The comparison of the model appearance of a same 3D graphic content (encoded in COLLADA) in different platforms. a. SketchUp, b. Blender, c. Unity

and Unity. The models are firstly visualized in the 3D content editing interface of SketchUp, Blender, and Unity. Then, we export the scene to SketchUp 3D warehouse and visualize it in a browser. With the help of unity, we also visualize the 3D scene in an interactable 3D scene, and on mobile devices. Figure 5 shows the desktop snapshot of the results of an output COLLADA file in SketchUp, Blender, and Unity. In this file, the 3D property unit is symbolized by two primitives: the line and the area. The hue of the area encodes the type of the property unit: private parts(gray), common parts (dark blue), and 2D terrain (light green and light brown). The hue of the edging line represents the different party of the private units. The survey points are represented by red cubes on the land surface.

4.4 Result

Generally, the test shows promising results: 1, the 3D SE in the proposed DCM could describe the symbology instructions of 3D cadastre visualization and encoding them in XML, a machine and human readable format. 2, The 3D graphical content of DCM could be imported and rendered in multiple 3D visualization platforms. 3, The invited user participants, either students or experts, could design and produce 3D cadastre visualization effectively and efficiently with the help of DCM. Some users also express that using DCM in 3D cadastre visualization is preferable.

The implementation and test have also exposed some deficiencies of current 3D cadastre DCM implementation. First, the filter in 3D SE, which follows OGC Filter Encoding Specification and employ XPath to retrieve XML elements, may not be able to support some of the complex symbology encoding instructions. For example, setting diversify colors for each of the spatial units in a 3D scene. Second, reading and writing visualization instructions requires the knowledge of 3D visualization, UML, and XML. A large portion of participants in this research spends significant long time (a few weeks) to acquire the basic understanding of UML and XML before they could read and use 3D SE. The most difficult part is learning and applying XPath in the 3D SE to select desired XML elements in DLM. Without suitable design assistant program, like that of Mapbox Studio, it is still hard for an ordinary user to read and use 3D SE. Third, COLLADA lacks the direct support of some scene elements, like screen graphic, billboard graphic, and 3D text. Whether these elements could be realized, and how to realize them could be the next investigation topics. Fourth, the 3D cadastre DCM achieved the standardization and interoperability of 3D cadastre visualization at both symbology instructions and 3D graphic scene content level. However, it may not guarantee the visualization uniformity from the reader's perception perspective. Due to the different underlying rendering process and realization strategies of each platform, the same COLLADA data may have a similar yet diverse appearance in different platforms and visualization devices (see figure 5). Specify fine-tuned visual variables and rendering settings for each platform could be a possible solution.

5. CONCLUSION

Despite focusing on the interoperability of 3D cadastre data (a cadastre DLM), this research, in turn, focuses on the interoperability problem of 3D cadastre portrayal and proposes a DCM solution. The proposed DCM contains a 3D symbology encoding model to describe portrayal instructions and uses COLLADA and glTF formats to encode 3D graphic scene. The implementation and tests prove that this solution is feasible, improves the portrayal interoperability, and enables portrayal automation. The proposed DCM also has the potential to serve as a starting point of a nationwide 3D cadastre portrayal specification. We believe that such portrayal specification, if well designed, tested and implemented, may also be beneficial for 3D cadastre legal and administration. The reader from cadastre legal and administration sections may have limited cartographic knowledge and 3D reading experience. With the help of a standardized 3D cadastre visualization, they could build a stable experience of how the visual appearance represents the underlying data, thus could read the 3D cadastre more efficiently and correctly.

This work is one part of the ongoing 3D portrayal development in the geospatial domain. The result, though ad-hoc in cadastre, may also inspire similar research in other application domains. It advocates the detaching of graphical content and symbology encoding instructions from semantic-rich data in 3D geo-visualization for better portrayal interoperability and performance. The investigation of 3D DCM is also relevant to the development of 3D portrayal service, which already has a newly published OGC standard (OGC 2017). The standard advocates the development of 3D SE for better 3D styling capabilities. Also, the evaluation, implementation, and test of the 3D graphic content model in 3D DCM could yield a clear conclusion about the pros and cons of each particular 3D graphic format. Such information is useful for designers and system implementors since the OGC standard doesn't give a particular endorsement.

This work is an initial design and implementation. There are still a lot of challenges yet to be addressed. The 3D SE editing tools are very elementary, and the 3D graphic content creating program is still at a stage of prototyping. In future, we will keep developing supportive programs and improving the 3D cadastre DCM in numerous ways, including better feature filtering capabilities for XML based data, ontological symbology knowledge model, rendering control, and so on.

REFERENCES

Biljecki, F., Stoter, J., Ledoux, H., Zlatanova, S., & Çöltekin, A. (2015). Applications of 3D city models: State of the art review. ISPRS International Journal of Geo-Information, 4(4), p.2842-2889.

Bocher, E., & Ertz, O. (2018). A redesign of OGC Symbology Encoding standard for sharing cartography. PeerJ Computer Science, 4:e143.

Haist, J., Ramos, H., & Reitz, T. (2007). Symbology Encoding for 3D GIS–An approach to extend 3D city model visualization to GIS visualization. In Urban Data Management: Urban Data Management Society Symposium 2007, Stuttgart, Germany, 10-12 October 2007, p. 121-131.

ISO. (2012). ISO 19117:2012. Geographic Information Portrayal. Geneva, Switzerland.
ISO (2012). ISO/PAS 17506:2012. Industrial automation systems and integration -- COLLADA digital asset schema specification for 3D visualization of industrial data. Geneva, Switzerland.

Li, L., Wu, J., Zhu, H., Duan, X., & Luo, F. (2016). 3D modeling of the ownership structure of condominium units. Computers, Environment and Urban Systems, 59, p. 50-63.

Neubauer, S., & Zipf, A. (2009). 3D-Symbology Encoding Discussion Draft. OGC Document Number: OGC, 09-042. Available at https://portal.opengeospatial.org/files/?artifact_id=32904.

OGC. (2006).OGC Symbology Encoding Specification 1.1.0. Available at http://www.opengeospatial.org/standards/se.

OGC(2017). OGC 3D Portrayal Service 1.0. Available at http://docs.opengeospatial.org/is/15-001r4/15-001r4.html.

Pouliot, J., Ellul, C., Hubert, F., Wang, C., Rajabifrad, A., Kalantari, M., ... & Ying, S. (2018). Chapter 5. Visualization and New Opportunities. Best practices 3D cadastres: extended version, FIG publication, p. 183-230.

Rylov, M., & Zipf, A. (2012). Solutions for limitations in label placement in OGC symbology encoding (SE) specification. In:Geoinformatik 2012, Heidelberg.

Semmo, A., Trapp, M., Jobst, M., & Döllner, J. (2015). Cartography-oriented design of 3D geospatial information visualization–overview and techniques. The Cartographic Journal, 52(2), p. 95-106.

Shojaei, D., Rajabifard, A., Kalantari, M., Bishop, I. D., & Aien, A. (2012). Development of a 3D ePlan/LandXML visualisation system in Australia. Proceedings of 3rd International

Workshop on 3D Cadastres: Developments and Practices. Shenzhen, China. 25-26 October 2012. FIG.

Shojaei, D. (2014). 3D cadastral visualisation: understanding users' requirements. Doctoral dissertation. University of Melbourne.

Stoter, J. E. (2004). 3D cadastre. Doctoral dissertation. Delft University of Technology the Netherlands.

Stoter, J., Meijers, M., van Oosterom, P., Grünreich, D., & Kraak, M. J. (2010). Applying DLM and DCM concepts in a multi-scale data environment. In Proceedings of GDI 2010: symposium on generalization and data integration, p. 1-7.

Vandysheva, N., Sapelnikov, S., van Oosterom, P., de Vries, M., Spiering, B., Wouters, R., et al. (2012). The 3D Cadastre Prototype and Pilot in the Russian Federation. In Proceedings of the FIG working week 2012, Rome, Italy.

Wang, C. (2015). 3D visualization of cadastre: assessing the suitability of visual variables and enhancement techniques in the 3D model of condominium property units. Doctoral dissertation. Laval University.

Wang, C., Pouliot, J., & Hubert, F. (2017). How users perceive transparency in the 3D visualization of cadastre: testing its usability in an online questionnaire. GeoInformatica, 21(3), p. 599-618.

Wang, C., Pouliot, J., & Hubert, F. (2012). Visualization principles in 3D cadastre: A first assessment of visual variables. In Proceedings 3rd international workshop on 3D cadastres, p. 309-324.

Ying S., Guo R., Li W., Yang J., Zhao Z., Li L., (2016). Visualization for the Coherent Set of 3D Property Units. 5th International FIG 3D Cadastre Workshop, 18-20 October 2016, Athens, Greece, p. 361-372.

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