# Visualization for the Coherent Set of 3D Property Units

**Shen YING, RenZhong GUO, WeiYang LI, Jie YANG, ZhiGang ZHAO and Lin LI, China**

**Key words**: 3D Cadastre, Visualization, Topological Relationship, Distort Visualization, Coherent Set, Spatial layout

**SUMMARY**

There are many 3D objects with denser aggregation that they are fully/partly coherent touched with each other through shared facets, which we called coherent set of 3D objects. Visualization for 3D property unit is an effective way to understand 3D spatial occupation, location and relationship in urban space, particularly in the coherent set of 3D property units. We present a novel method to visualize coherent set of 3D property units with application in 3D cadastre. We innovatively utilise deforming or distorting technique to visualize them, taking account of both the focused 3D objects and the coherent set. This visualization approach can illustrate not only the relative locations, spatial relationships of/between them, but also the highlighted shape, location of the focused/selected 3D object. Also we try to display spatial relationship explicitly between 3D objects to preserve our spatial cognition about the spatial layout and distribution.

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## 1. INTRODUCTION

Visualization is an efficient way to recognize the phenomena and obtain further spatial knowledge because of their morphology and layout. There are many 3D objects with denser aggregation that they are fully/partly coherent touched with each other via shared faces, which we called coherent set of 3D objects. These situations include not only the spatial morphology of the macroscopic galaxies but also that of the microscopic proteins. The common realities that we can often meet are, for instance, the tiles of container on the cargo and the apartments in condominium as Figure 1. For denser coherent set of 3D objects, we can only see the outer appearances and have no idea about the interior. Sometime we may image there may be similar structure inside without clear impression. Apparently, 3D objects in coherent set touch or connect with each other. To visualize the coherent sets of these 3D objects, it is impossible to see the object inside the set directly because of the visual occlusion with the outer or neighbour objects.

3D cadastre is a special field that includes many coherent 3D spatial objects. The 3D space is divided into many 3D property units with coherent boundary faces, no matter where they are located, either above or under earth surface. Effective visualization can manifest the locations of the boundary points, lines and faces of the 3D property unit, and also display spatial layout of the 3D property units and their relationships. For single 3D property unit, visualization methods are sufficient; but for coherent set of 3D objects, seldom methods are available. The visualization and human-computer interaction with 3D cadastral units have attracted attentions, but, in some way, they are quite different from the well-known superficial visualization of 3D city models (Wang, Pouliot, &Hubert, 2012; Van Oosterom, 2013). Consider the visualization of an apartment located inside a building in Figure 1b and how we can represent its correct locations, shapes spatial relationship with others.

a b

**Figure 1. Coherent set of 3D object: a) containers; b) apartments**

The paper describes the methods of visualization techniques and methods to support the visualization of 3D coherent property units. The paper is organized as following. After the introduction in Section 1, the requirements of visualization of coherent set of 3D objects is analysed in Section 2. Normal visualization techniques that can partly support the visualization of the set of 3D coherent property units are stated and analysed in Section 3. Our novel method, named distortion visualization, is detailed in Section 4, and at the last conclusion is given in this paper.

## 2. REQUIREMENTS OF VISUALIZATION FOR COHERENT SET OF 3D PROPERTY UNITS

To discuss the visualization of coherent set of 3D property units, we first distinguish it with single 3D object visualization. The coherent set of 3D property units is first as a whole set and each 3D property unit in the set is a basic element. 3D property units touch each other through topological constructions or share boundaries. It is easy to understand the visualization of individual object, and normally they look dense. Because of their overlay and occlusion with each other, it is difficult to visualize the set and each unit effectively and clearly. Also it is quite difficult to highlight the individual object inside the coherent set. The visualization of coherent set of 3D objects requires:

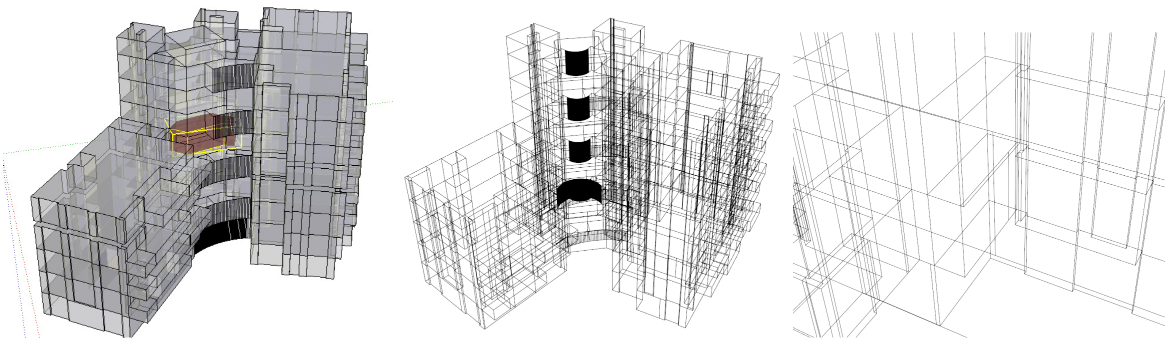
- Supporting common visualization functions, including zooming, rotation, panning.
- Ensuring the visibility of the coherent set. That means ability to visualize the whole coherent set of 3D objects. The visibility of all 3D objects should be preserved and spatial distributions of them are remained to maintain the user's cognitions and understandings regarding the coherent set. Displays of the coherent set provide the foundation, context and reference of visualization of focus object.
- Ensuring and highlighting the focus object in the coherent set. The focus object, no matter where it locates and no matter what shape it has, should be highlighted prominently.
- Ensuring that spatial relationships between 3D objects in the coherent set can be expressed and maintained, and that spatial relationships are stable and equivalent.

## 3. COMMON VISUALIZATION TECHNIQUES

Because of the physical occlusion between 3D property units inside the coherent set (as showed in Figure 1), it is not available to interpret the locations and depths of 3D property units using cross depth references. Common visualization techniques, like zoom in/out and pan, cannot browse the inner objects inside the coherent set. To solve this problem, there are normally three methods in 3D modelling field: wireframe model or certain transparent display, cross-sections and slide-out object techniques (Van Oosterom, 2013), or their combination

### 3.1 Transparent mode

Colour (hue) is the first element to distinguish the difference of the objects. In order to show the objects behind the others, transparent display is used to indicate the depth and display the boundaries of/between 3D objects in the coherent set. This transparent visualization (Figure 2a and 2b) can mostly display the occluded objects (Livingston, Swan, Gabbard, et al, 2003). Fully transparent visualization, wireframe or x-tray model (Figure 2b), is a special way to show the strokes and the outlines of 3D object and their coherent set. However, it cannot show the depth sequence correctly and give the visual disorder and chaos when we try to focus on local object or one object inside the set of 3D objects (Buchman, Nilsen, Billinghurst, 2005) (Figure 2c). Also it cannot provide the functions to highlight the focused object.



a b c

**Figure 2. Visualization of coherent set of 3D property units with transparent**

### 3.2 Cross section mode

Cross section profile or slice profile is another effective way in 3D engineering field to display 3D buildings. Coherent set of 3D property units is similar with 3D buildings, can section profile can also be used to show spatial relationships of 3D property units in one cross plane. For a condominium in Figure 3a, with the vertical cross section, we can clearly judge the locational relationship and topological relationship between 3D property units (Figure 3b) and horizontal cross section is well known as planar map of building (Figure 3c). Also cross sections at other direction (Figure 3c) can show the boundary lines and boundary faces of the sliced units. The shortcomings of cross section are also obvious. First, the absence of the sliced objects results in the lack of the wholeness about the surrounding context, which decrease the user understandings and cognitions of the real environment. Second, cross section only show the certain profile of coherent set of 3D property units, and cannot provide the objects in perpendicular direction. This would lose spatial (neighbour) relationship and spatial layout in that direction.

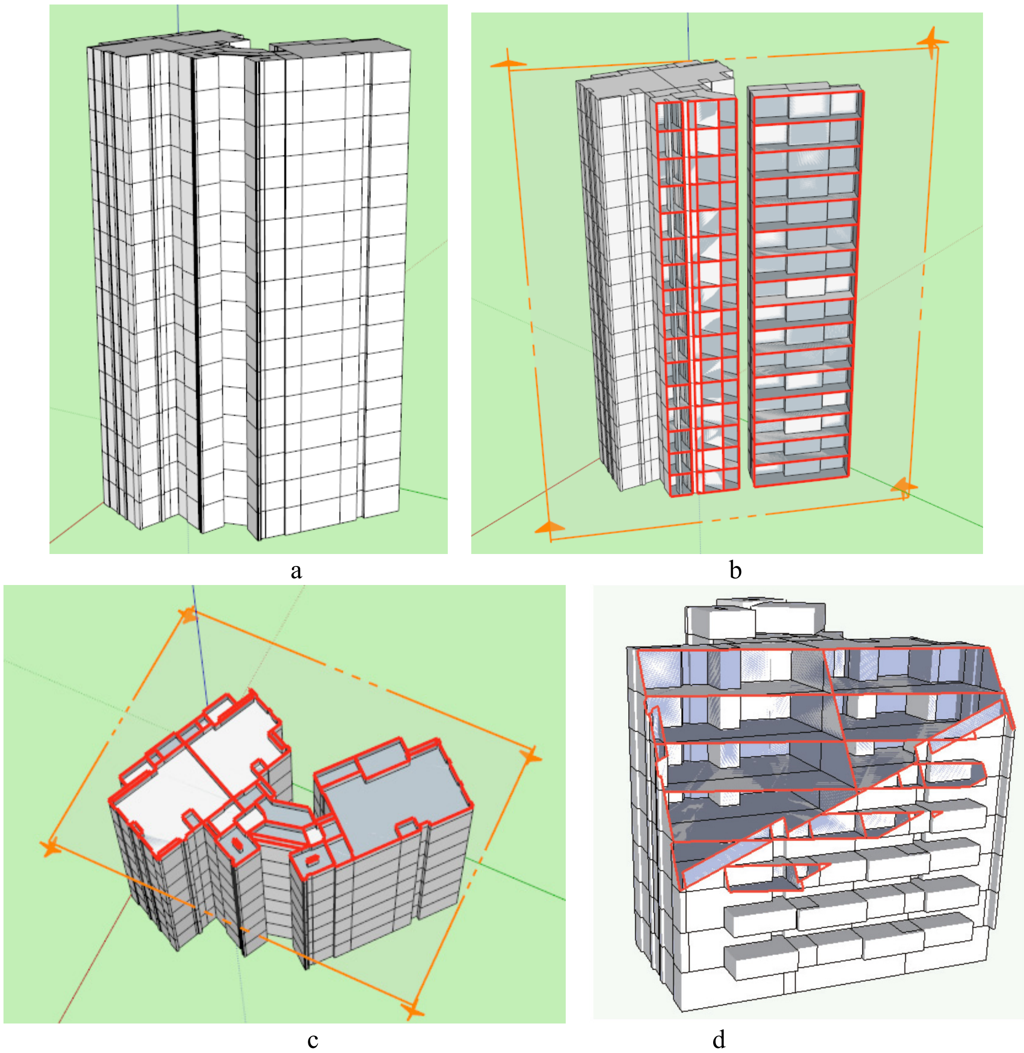


Figure 3. Visualization of coherent set of 3D property units with cross-section mode

### 3.3 Slide-out object mode

Slide-out object mode separates the selected objects from the left parts and displays them clearly as Figure 4. Visualization with slide-out object mode fits the floor-to-floor real property, especially the building and condominium, and it demands the property space should be divided vertically. Galina Elizarova et al (2012) used "move floors" to depict the floor out of the building. Also this visualization model can picture the individual object at the outer boundary of the coherent set of 3D property units. On the contrary, if there are horizontal divisions of 3D space, more precisely, pure inner 3D property unit that completely bounded by other units, cannot be selected and visualize.

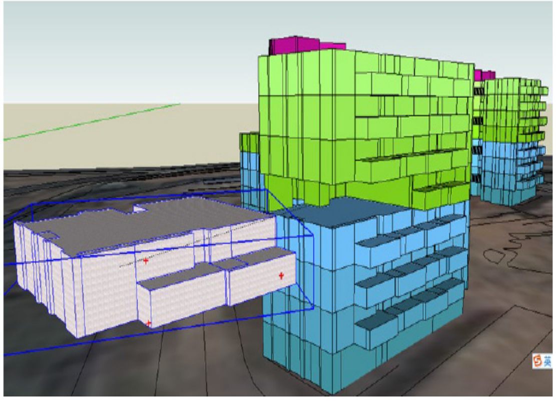


**Figure 4. Visualization of coherent set of 3D property units with slide-out object mode**

### 3.4 Voxel visualization

Voxel visualization is a branch in computer graphics, which is quite different with visualization from the view of object. Voxel visualization is implemented based voxel representations of the 3D spatial objects (Nourian et. al., 2016), and it has broad applications in medical image processing and volumetric phenomenon simulation. Volumetric lenses (Kruger et al, 2006; Trapp, Glander and Buchholz, 2008) can show both the focus object and the context at the same time. Li et al (2015) provided semantic volumetric texture model for direct illustration of the 3D buildings. Semantic volume texture of a LoD4 building model is showed in Figure 5, and rooms are rendered totally transparent. Unlike the physical architectural structure with certain texture, the 3D property unit is always an abstract 3D space. Through multi-pass volume rendering, different density colour can be used for foreground and background 3D property unit to show their difference as showed in Figure 6. However, this effect produces the excessive display to indicate the depth and spatial relationship at the far-end.

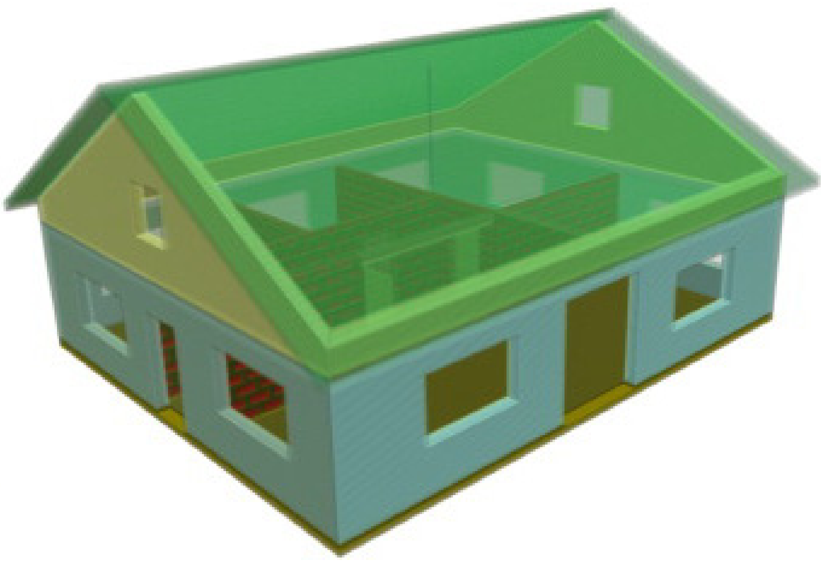


**Figure 5. Semantic volume texture of a LoD4 building model (Li et al, 2015)**

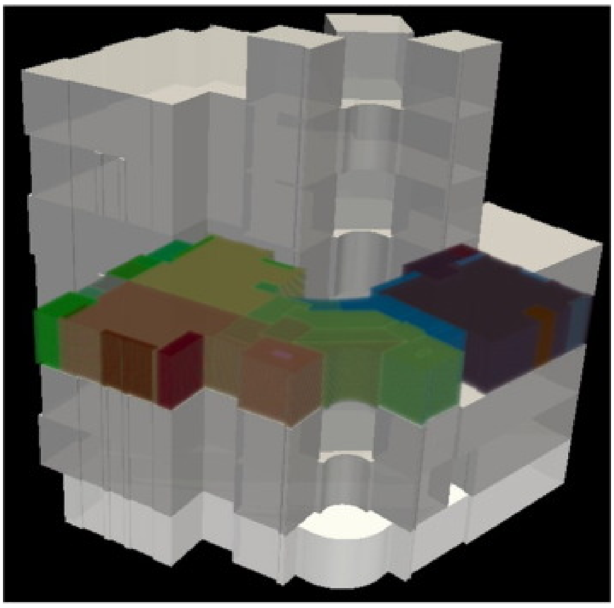


**Figure 6. Volumetric visualization of object Highlighted semantic objects with contextual sur-roundings (Li et al, 2015)**

# 4 DISTORTION VISUALIZATION OF THE COHERENT SET OF 3D PROPERTY UNITS

Distortion method first discretizes the coherent set of 3D property units to give the potential visibility of all the units and uses Poincare duality to deliver the spatial relationship between the 3D property units.

Before we fulfil the distortion visualization of the coherent set of 3D property units, we suppose: 1) the coherent set of 3D property units can be discretized into separate units; 2) each 3D property unit is rigid and cannot deform, but it can be enlarged or shrunken as a part; 3) the coherent set of 3D property units should be discretized according to certain function, and the displacements of 3D property units should be continuously propagated and propagation directions should be controllable; 4) the spatial direction relationships and relative locational relationships between 3D property units should be maximally preserved; 5) the spatial topological relationships between 3D property units should be kept or be equally represented.

The discretization of the coherent set of 3D property units would result in distorting its whole spatial layout and distribution by exploring the set and displacing each unit. The displacement and its propagation of/between the 3D property units are implemented and are transferred by the neighbourhood of 3D property units. There are many mathematical functions that can be used to discretize the coherent set of 3D property units. Different functions will produce different spatial distortions of the set, and spatial layout and locations of the 3D property units are also different.

To give the details of the distortion visualization, suppose there are coherent 9*9 rectangle set in Figure 7a, and each rectangle is a basic unit. An orthogonal function is used to discretize the coherent rectangle set and to displace each rectangle:

$$T_x = \begin{cases} 0 & if\ x_b = x_a \\ -d_x & if\ x_b > x_a \\ d_x & if\ x_b < x_a \end{cases} \qquad T_y = \begin{cases} 0 & if\ y_b = y_a \\ -d_y & if\ y_b > y_a \\ d_y & if\ y_b < y_a \end{cases} \tag{1}$$

If there is a focus unit, the discretization centre will locate on it and the surrounding context units will be displaced (Figure 7b); otherwise, the default original point will be the left-bottom corner point. If we extend 2D rectangle set to 3D cube set (Figure 7c), the corresponding orthogonal distortion with centre focus cube are showed in Figure 7d. This method can keep the orthogonality of/between the 3D unit, especially for 3D property units because of their orthogonal shapes. Also the focus unit can be enlarged and be coloured to highlight, accompanying by the surrounding context.

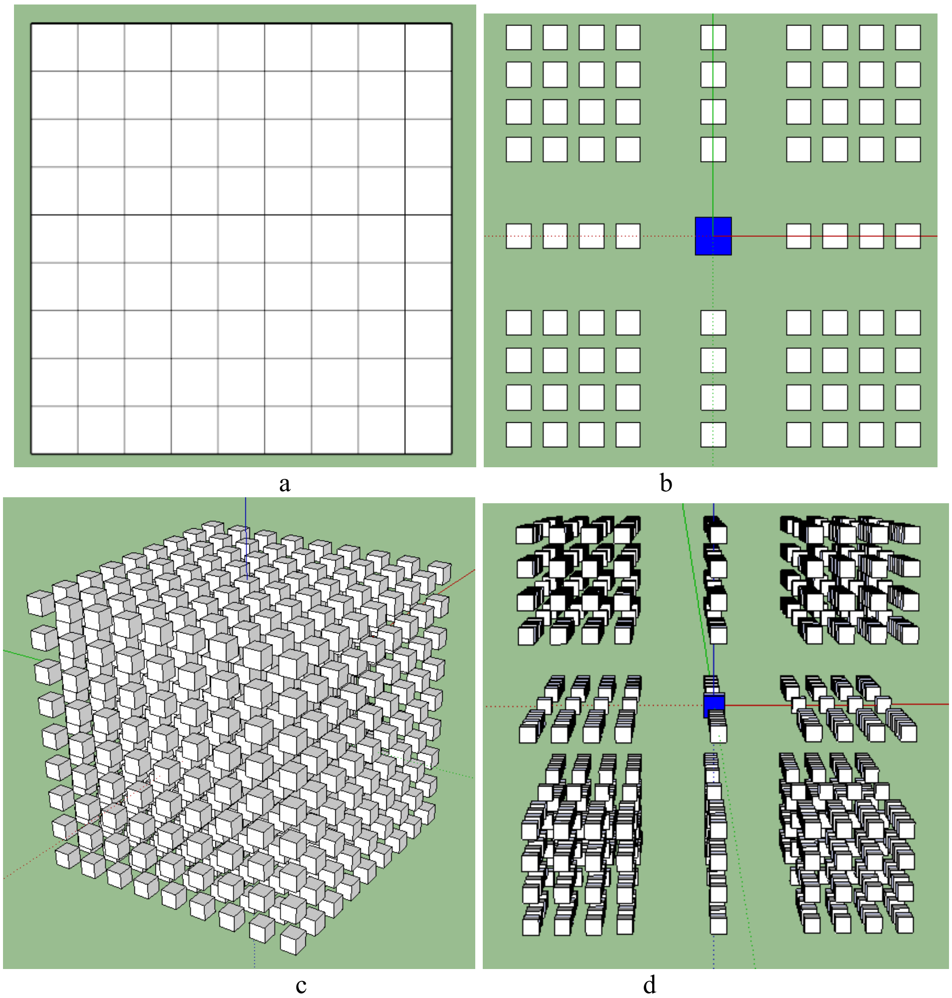



**Figure 7. Orthogonal distortion of the coherent rectangle/cube set**

Visualization select can pick up the outer objects of the coherent set and cannot select the inner objects with penetrate the outer objects. Of cause, the inner objects can be selected through the attribute query if known. However, even so, the selected inner object cannot be effectively visualized or highlighted. The discretization and distortion visualization can separate each unit of the coherent set, which provides the possibility to make them visible. Various distortion functions can be used to highlight the focus and give the surrounding context at the same time.

An actual coherent set of 3D property units located in Shenzhen, China (Figure 8a) are tested. We discretize the coherent set with certain distance to make them selectable and visible (Figure 8b). Then a distortion function is carried out on this set and the focus unit is further highlighted as well as the surrounding context that shows the set spatial distribution. To represent the spatial topological relationship, Poincare duality is implemented. Each edge depicts the topological relationship and connectivity link between 3D property units (Figure 8d). Also colours and transparent techniques can be used in illustration to compare and highlight the focus and context of the coherent set of 3D property units (Figure 8e).

Discretization and distortion visualization of the coherent set of 3D property units take whole spatial distribution, relative locations and spatial topological relationships into consideration. Any 3D property unit can be selected and be visualized through this method, and both focus 3D property unit and its surrounding context can be visualized simultaneously, which can effectively enhance the user understanding about the focus and coherent set of the 3D property units.

Distortion method are still facing the following questions: 1) 3D hole objects are moved out of their containers, which may give wrong understanding about relative locations; 2) if there are other references existed (e.g. digital orthogonal map), this distortion method also make chaos about spatial locations of each 3D objects because their footprint is inconsistent with the ground reference.

## 5 CONCLUSION

Visualization for 3D property units, particularly in the coherent set, is an effective way to understand 3D spatial occupation, location and relationship in urban space. Visualization plays an important role to strengthen 3D space management and enhance the user to interpret his property as well as its relationship with his neighbours.

Regarding the coherent set of 3D property units, the paper discusses coherent set visualization with normal visualization techniques and provides a novel discretization and distortion visualization to illustrate the coherent set of 3D property units. This visualization method can effectively express the whole set context with locations, spatial distribution and relationships, as well as the selected focus object highlighted.

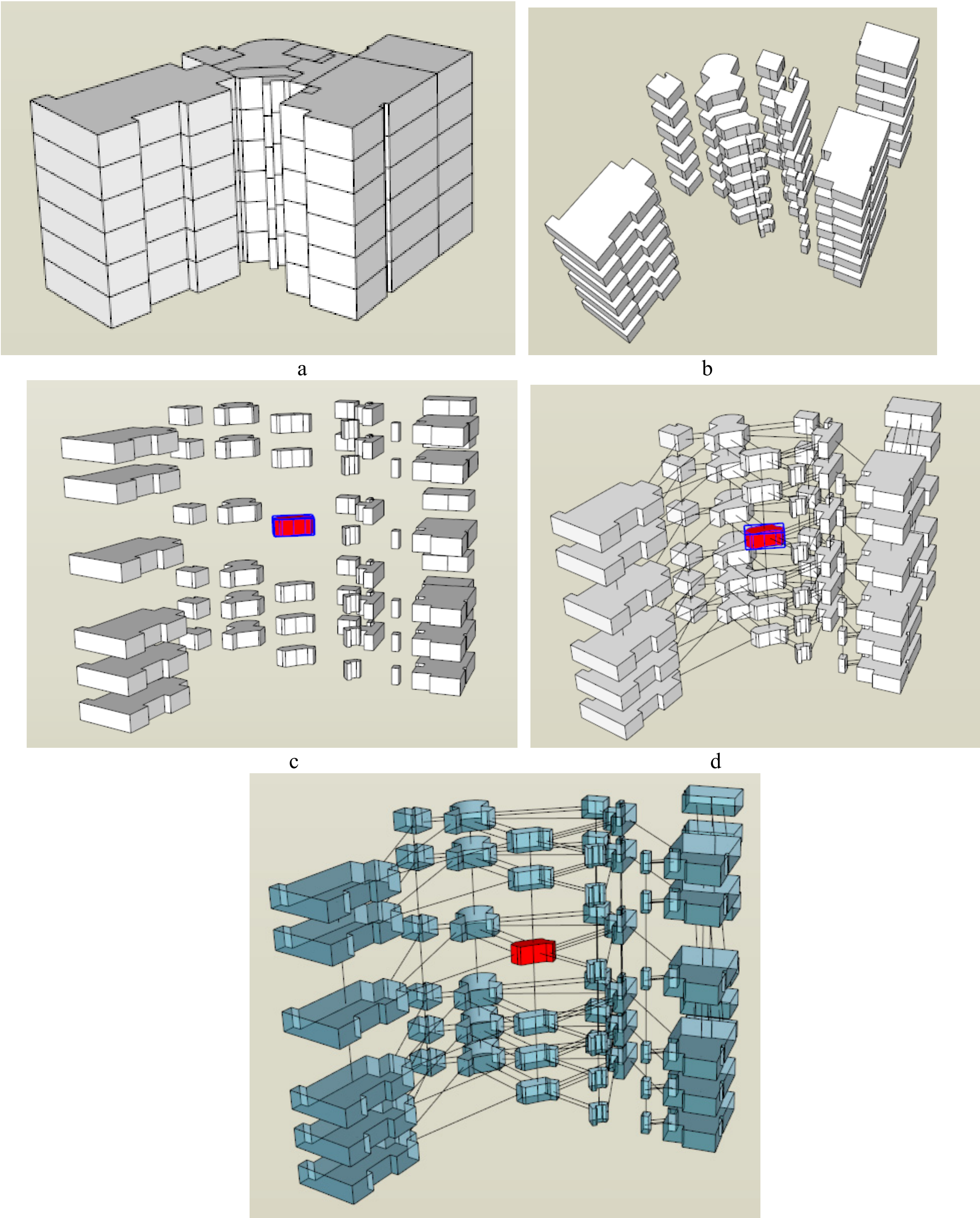



**Figure 8. Distortion visualization of the coherent set of 3D property units: a) the coherent set; b) discretization; c) distortion and focus; d) representation of topological relationship; e) different colours and different transparent**

## ACKNOWLEDGEMENTS

The work is partly supported by the National Natural Science Foundation of China under Grants 41371369, 41671381 and 41531177 and is partly supported by Open Project fund of Key Laboratory of Urban Land Resources Monitoring and Simulation Ministry of Land and Resources. The authors thank the reviewers for their helpful comments.

## REFERENCES

Buchman V., Nilsen T., and Billinghurst, M. (2005). Interaction with partially transparent hands and objects. Proceedings of the Sixth Australasian conference on User. 40: pp. 17-20.

Elizarova, G., Sapelnikov, S., Vandysheva, N., Pakhomov, S., van Oosterom, P., de Vries, M., Stoter, J., Ploeger, H., Spiering, B., Wouters, R., Hoogeveen, A. and Penkov, V. (2012). Russian-Dutch project “3D Cadastre modelling in Russia”. 3rd International Workshop on 3D Cadastres: Developments and Practices. 25-26 October 2012, Shenzhen, China.

Kruger, J., Schneider, J. and Westermann, R. (2006). Clearview: an interactive context preserving hotspot visualisation technique. IEEE Transactions on Visualisation and Computer Graphics, 12, 941–948.

Li, L., Duan, X.Q., Zhu, H.H., Guo, R.Z. and Ying, S. (2015). Semantic volume texture for virtual city building model visualisation. Computers Environment & Urban Systems. 2015, 54, 95–107.

Livingston, M.A., Swan, I.I.J.E., Gabbard, J.L., Höllerer, TH, Hix, D., Julier, S.J., Baillot, Y. and Brown, D. (2003). Resolving multiple occluded layers in augmented reality. In: Proc. ISMAR 2003. IEEE, Tokyo, Japan, pp. 56-65.

Nourian, P., Gonçalves，R., Zlatanova，S., Ohori，K.A and Vo, A.V. (2016). Voxelization algorithms for geospatial applications: computational methods for voxelating spatial datasets of 3D city models containing 3D surface, curve and point data models. MethodsX. 2016, Volume 3, pp. 69－86.

Trapp, M., Glander, T.and Buchholz, H. (2008). 3D generalization lenses for interactive focus + context visualisation of virtual city models. 2010 14th International Conference Information Visualisation (pp. 356–361). IEEE.

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, May 2012, Rome.

van Oosterom, P. (2013). Research and development in 3D cadastres. Computers, Environment and Urban Systems, 40: 1–6.

Wang, C., Pouliot, J. and Hubert, F. (2012). Visualisation principles in 3D cadastre: a first assessment of visual variables. 3rd International Workshop on 3D Cadastres: Developments and Practices. 25-26 October 2012, Shenzhen, China.

## BIOGRAPHICAL NOTES

**Shen YING** is a professor in School of Resource and Environmental Sciences, Wuhan University. He received a B.S.(1999) in Cartography from Wuhan Technique University of Surveying and Mapping(WTUSM), and MSc and PhD degree in Cartography and GIS from Wuhan University in 2002 and 2005, respectively. His research interests are in 3D GIS and cadastre, updating and generalization in multi-scale geo-database and ITS.

**Renzhong GUO** works at the Urban Planning, Land and Resources Commission of Shenzhen Municipality. He is also a member of the International Eurasian Academy of Sciences and guest professor at Wuhan University. He received his B.S. and MSc in Cartography from Wuhan Technical University of Surveying and Mapping (WTUSM) (now Wuhan University) in 1981 and 1984, respectively. In 1990 he received his PhD in Geography from University of Franche-Comté. His current interests include 3D cadastre, land administration, map generalization and spatial analysis.

**Lin LI** is a professor at the School of Resource and Environmental Sciences, Wuhan University, and the chair of the Department of Geographic Information Science. He received his PhD in photogrammetry and remote sensing from Wuhan University in 1997 and has worked on cartography and GIS for many years. His current interests include 3D cadastre, computer-aided cartography, geographic ontology, and LBS.

## CONTACT

Shen Ying
Wuhan University
School of Resource and Environmental Sciences
430079 Wuhan
PR CHINA
Tel.: +86 27 68778294
Fax: +86 27 68778893
E-mail: shy@whu.edu.cn
Website: http://sres.whu.edu.cn/teacher.asp