EMERGING TRENDS IN GEOSPATIAL TECHNOLOGIES FOR STUDY OF URBAN LANDSCAPE

LEE, MING-CHUN
University of North Carolina at Charlotte, ming-chun.lee@uncc.edu

1 ABSTRACT

GIS has been an effective tool to study urban landscape. Recent developments in geospatial technologies offer new possibilities with new toolsets for spatial analysis and data visualization. This paper traces recent major trends in GIS and discusses their implications to the field of urban landscape study. These trends include the following: 1) increase in dimensions with 3D GIS; 2) integration with remote sensing; 3) cloud-based GIS; and 4) integration with virtual reality. This paper discusses a recent project and demonstrates the potential of these new emerging GIS tools applied to the study of urban landscapes. Many GIS applications were incorporated in this urban design project, including 2D mapping, remote sensing, scenario planning, 3D procedural modeling, virtual reality, and cloud-based tools. This paper details technical specifications and workflows used in the project. In spite of several advantages of these tools, their applications are not without drawbacks, such as high costs due to their proprietary *nature, limited data availability, and inconsistent data schema and quality. This paper concludes with a brief discussion on their pros and cons for applying these tools in urban landscape study.*

1.1 Keywords

Geographic Information System, Urban Form, 3D GIS, Remote Sensing, Virtual Reality

2 INTRODUCTION

Geographic Information System (GIS) has been a useful tool to study landscape and urban form since its inception in the 1960s. It is particularly effective to measure quantitative variables of built environments, such as density, clustering, proximity, accessibility, etc. (Song and Knaap, 2004; Tsai, 2005). GIS as its own field has continued to evolve in a rapid pace (Goodchild, 2011). Recent developments in the area of geospatial technologies offer new possibilities with new toolsets for spatial analysis and visualization (Kumar, 2015).

This paper traces recent major trends in GIS and discusses their implications to the field of urban landscape study. These include: 1) Increase in dimensions with 3D GIS: conventional 2D maps are being replaced by interactive 3D models generated by procedural rules stored in GIS. Along with locations and associated attributes, vertical elevation and architectural details are also represented. 2) Integration with remote sensing: remote sensing not only enables 3D visualization with imagery processing but also provides other spatial information to create meaningful analysis results. For instance, LiDAR point-cloud data allow extraction of built forms and identification of physical features and land cover. 3) Cloud-based GIS: web-based GIS services allow centralized access to location-based information. Yet through distributed mobile platforms, real-time data collection, sharing, and collaboration are done seamlessly in the cloud. 4) Integration with virtual reality: virtual reality creates immersive experiences with a perception of being physically present in a non-physical world. GIS can greatly enhance the accuracy and realism of virtual scenes with up-to-date terrain models, street networks, and 3D features.

This paper identifies these major developments in geospatial and visualization tools, discusses their key features, and concludes with a discussion on a class project and demonstrates the potentials of these new emerging GIS tools for study of urban landscape. Many GIS applications were incorporated in this urban design project, including 2D mapping, remote sensing, scenario planning, 3D procedural modeling, virtual reality, and cloud-based tools. Technical specifications and project workflows are detailed in the paper.

3 LiDAR

LiDAR (light detection and ranging) is an optical remote sensing technology that uses laser light to densely sample the surface of the earth. It is an active remote sensing technology. LiDAR sends a pulse of near infrared light and waits for the pulse to return. LiDAR can produce highly accurate x-y-z measurements and mass point cloud datasets that can be visualized and analyzed using GIS software programs (Esri, 2016). Spatially organized LiDAR data is known as point cloud data. The initial point clouds are large collections of 3D elevation points along with additional attributes such as GPS time stamps. The specific surface features that the laser encounters, such as the ground, buildings, tree canopy, roadway structures, bridges, etc., are classified after the initial LiDAR point cloud is post-processed (GISGeography, 2017).

Recent developments in LiDAR are increasing the pace of our transition to true 3D GIS. Earlier LiDAR systems emit a pulse of laser energy and measure the time it takes for that energy to travel to a target, bounce off the target, and return to the sensor. These systems are called linear-mode because they generally only have a single aperture, and so can only measure distance along a single vector at any point in time. Newer more recent Geiger-Mode and Photon-Counting LiDAR systems are based on focal plane-based LiDAR design. These systems are able to collect data with sampling rate of more than 200 MHz, versus the maximum 800 KHz of the current linear-mode LiDAR and point cloud density of up to 100 points per square meter. Such LiDAR systems collect data from an altitude up to 30,000 ft. above ground resulting in wider ground coverage. Another important aspect that these newer LiDAR technologies offer, beside the density, is their focal plane design aspect, which results in a raster-style data acquisition and in turn produces an accurate elevation for the intended survey area. Overall, LIDAR has become the inevitable technology to provide accurate 3D data fast and reliably (Abdullah, 2015; Ullrich and Pfennigbauer, 2016).

4 3D PROCEDURAL MODELING

Procedural modeling is a generic term for a class of techniques in computer graphics to create 3D models and textures from sets of rules. Procedural modeling focuses mainly on generating 3D models based on rules, or enhancing models automatically (Andrews, 2017). Procedural modeling is often applied when it would be too cumbersome to create 3D models using conventional 3D modeling programs, or when more specialized tools are required. This is often the case for vegetation, architecture or landscapes (Muller, et al., 2006; Nishida, et al., 2016).

CityEngine, developed by GIS Company Esri, is a desktop application for the modelling of large-scale urban environments in 3D. With the procedural modeling approach, CityEngine facilitates users to quickly generate 3D city models from existing 2D GIS data. Designers can conduct conceptual design in 3D based on GIS data and procedural rules. CityEngine also allows professionals in the filming and gaming industries to model virtual 3D urban environments for simulation, game development, and entertainment (Ribeiro, et al., 2014).

A single procedural rule can be used to generate many 3D models in CityEngine. With the integration between CityEngine and GIS, a rule set can make use of feature attributes stored in GIS data, such as numbers of floors, floor heights, roof type, or wall textures, to generate different 3D models that represent properties of different features. A 3D model generated in this way is basically a 3D object resulting from a 2D shape extrusion according to the rules defined in a rule set. The origin of these 2D shapes can either be imported from GIS or built manually in CityEngine (Jin, et al., 2015; Ribeiro, et al., 2014).

5 CLOUD-BASED GIS

The rise of cloud computing has been one of the most significant advancements in computer science. It only seems logical that GIS is also heading into the cloud. Some of the broad advantages of cloud-based GIS include: 1) data access can be through any Internet connection, anytime, anywhere; 2) For an organization with a range of remote users, cloud-based GIS makes the distribution of GIS data, analysis and systems simple to implement and manage; 3) cloud-based GIS allows data capture in real or near real time to be displayed directly onto a centralized system (Chappell, 2010).

Esri's ArcGIS Online is one example of cloud-based web GIS. It provides users with access to many data sources that have already been made available to subscribers, such as Esri's Living Atlas of the World. Users can also use many templates to create their own maps or apps. ArcGIS Online also includes a suite of basemaps that provide reference maps for the entire earth and context for local jurisdictions (Esri, 2017). These maps are built using available data from a community of authoritative data providers and presented in multiple cartographic styles. ArcGIS Online also includes detailed imagery of the world, which reveals both the present state of the earth and changes over time. It also includes a comprehensive set of demographic and economic data of the United States through its online-based systems: Business Analyst and Community Analyst. With these ready-to-use basemaps and data, users can then add their own GIS data and create mashups that serve their own purposes. Esri's Story Maps, another web-based platform with a set of templates, allows ArcGIS Online users to combine authoritative 2D maps and 3D scenes with narrative text, images, and multimedia content for sharing and presentation purposes (Esri, 2018).

6 VIRTUAL REALITY

Virtual reality (VR) creates immersive experiences with a perception of being physically present in a non-physical world. To experience VR, users hold a screen mounted to a headset, which is typically powered by a gaming console, a mobile phone, or a computer to their eyes. Then through specialized software and sensors, users are immersed in an artificial world where they interact with various virtual objects (Manly, 2015; Parisi, 2015; Rubin, 2014).

The immersive nature of VR, which allows viewers to encounter a simulated 3D landscape from multiple points of view, can be a very useful tool for urban planners, designers, or researchers in the field of urban morphology. They can use VR to redraw streets and neighborhoods, offer real and imagined views of existing and proposed developments, or study historical events related to urban transformations.

VR has already drawn attention from the GIS industry, considered to be the next frontier to broaden the capabilities of GIS. For example, Esri has created a mobile VR solution for urban planners, architects, and GIS professionals. With their latest release of CityEngine, users of CityEngine have the option to quickly convert their 3D models into VR experiences on mobile devices. Esri's ArcGIS 360 VR allows users to quickly immerse themselves through a mobile phone with VR headset into 3D city models by teleporting to static viewpoints and comparing different urban design scenarios. These VR experiences can be created in CityEngine and are hosted on ArcGIS Online (CityEngine, 2017).

In addition to this streamlined approach offered by Esri, users can also use commercial third-party 3D game engines (game development software programs, such as Unity of Unreal) to create VR experiences. Esri CityEngine allows users to export their creations in various formats, including .fbx, which can then be imported into 3D game engines. Users then can add VR support to their models in these game engines (Singh, et al., 2014; Smelik, et al., 2014).

7 DEMONSTRATION PROJECT

To explore the potential of these geospatial tools and visualization media, an urban design project was conducted by the author and his students. The Graduate Program in Urban Design in School of Architecture at the University of North Carolina at Charlotte took on the challenge to re-envision the future of Buttermilk Bottom, an old urban renewal site in the City of Atlanta. The main idea for this academic project was to learn from the City of Savannah about how the class might use those lessons to redo what was badly done three decades ago in Buttermilk Bottom. The assignment was to re-design the Buttermilk Bottom neighborhood according to the design principles observed in the plan for Savannah’s Historic District and their quantifiable traits.

To assist in both the site analysis and urban design processes, GIS was used by the class to explore physical structures in both two cities, including street networks, block configurations, open spaces, distributions of land uses, demographic data and their related socio-economic characteristics. Many GIS applications were incorporated in this urban design project, including 2D mapping (ArcGIS Desktop, ArcGIS Pro), remote sensing (Esri Local Government 3D Basemaps), 3D procedural modeling (Esri CityEngine), and cloud-based tools (ArcGIS Online).

7.1 Data Acquisitions

The GIS analysis started with collecting data. The class relied on online open-source GIS databases to acquire the needed datasets for their analyses. For the study area in Savannah, SAGIS (Savannah Area Geographic Information System) Open Data site was the primary source, which provides free access to geospatial data in a standardized format to the public. For the site in Atlanta, two sources were used by the class: DPCD (Department of Planning and Community Development) Open Data and ARC (Atlanta Regional Commission) Open Data.

A series of basemaps were created by combining GIS datasets in both ArcMap and ArcGIS Pro to create a digital representation of the existing urban structure for both two cities. The datasets used in these basemaps included the following: streets, parcels with land use information, building footprints, parks, landmarks, points of interests (such as schools, churches), waterbodies, contours, and census tracts. Demographic data were collected from Census Bureau website (American FactFinder) and linked to the census tracts dataset.

7.2 LiDAR Processing

After the basemaps were created, the next step was to create 3D models for both sites in Savannah and Atlanta. These models were intended to display the existing buildings, trees, and accurate terrains to represent the landforms. This was done by extracting 3D features from LiDAR point cloud data (Figure 1).

For the site in Savannah, the LiDAR data was acquired from Department of Architecture in Savannah College of Arts and Design (SCAD). 8 LiDAR tiles were obtained in the .las file format (version 1.1). They were commissioned in 2009, each covering an area of 5,000 ft by 5,000 ft with a point spacing of 1.5 ft. These tiles had been classified into 5 classes: unassigned; ground; building; noise; water.

For the site in Atlanta, the LiDAR tiles were downloaded from the website USGS Earth Explorer. 2 tiles were obtained in the .las file format (version 1.0). The tiles were created in 2006, each covering an area of 5,300 ft by 5.300 ft with a point spacing of 4.6 ft. Since these two LiDAR tiles were not classified, the first step was therefore to reclassify them. ArcGIS Pro was used to process this step. The reclassification was performed by applying the following two methods: classify building and classify by height. After this step, the class used Esri’s Local Government 3D Basemaps tools to process all LiDAR tiles for both two cities to extract buildings and trees in 3D. This step also produced digital terrain models (DTM) in the .tiff file format to represent the bare ground terrain for both two sites.

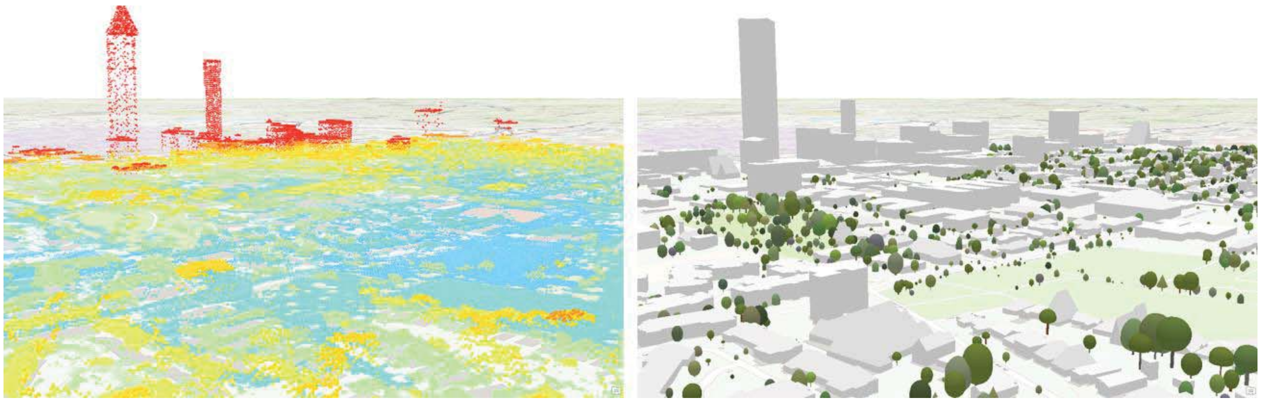

Figure 1. The class used ArcGIS Pro and Esri's Local Government 3D Basemaps workflow to reclassify LiDAR point cloud data and extract 3D features from the LiDAR for City of Atlanta (Broyles, et. al., 2017)

7.3 3D Modeling

The 3D models created by extracting features from LiDAR data were considered simple representations of the existing urban structures for both sites. To enhance their visual qualities and model appearances, Esri's CityEngine was used by the class to add details to the 3D models. These details included architectural structures and textures, landscape features, roadway signs and pavements, transportation features, vehicles and human figures. Lighting effects were also added to enhance the level of realism in the models.

Before using CItyEngine, a GIS data package in the .gdb file format (Esri's File GeoDatabase) had to be prepared in ArcGIS Pro. This package included the following items: 3D buildings extracted from LiDAR by Local Government 3D Basemaps; DTM as .tiff images; tree points (also from LiDAR), street centerlines, building footprints, and aerial photos of the site as .tiff images.

The street-creation tool in CityEngine was used to generate streets. This step was done based on street types that were identified by the class. All the details associated with the streets, such as vegetation, signs, pavements, vehicles and human figures, were added by using Esri's Complete Street rule package. The class then used Esri's Urban Design rule package to generate 3D buildings with architectural details and textures.

Overall, the class was able to use the 3D models by CItyEngine to examine the physical qualities of the areas, such as: overall land use distributions by color-coding building footprints; potential ways of urban transformations by urban design; and streetscape configurations with fully rendered details (Figure 2).

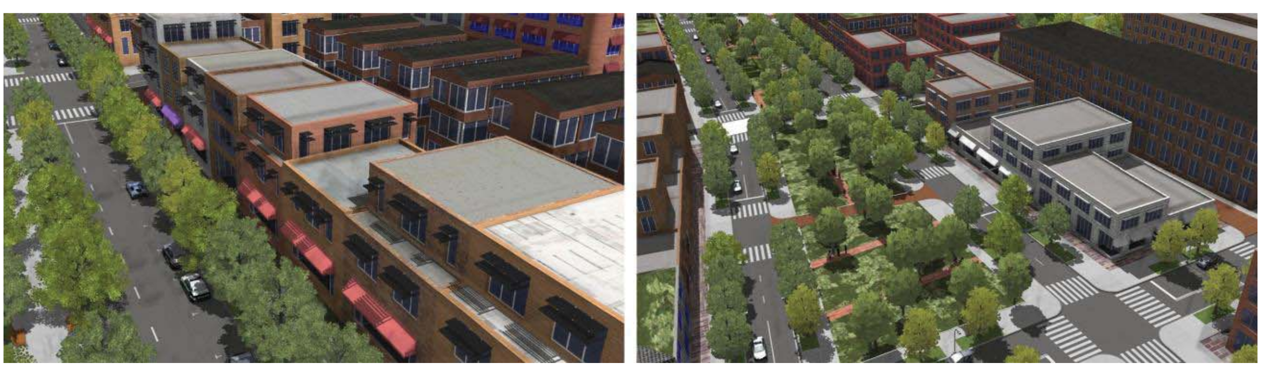

Figure 2. CityEngine allowed the class to create a large-scale model with details to render future urban design solutions (Broyles, et. al., 2017)

7.4 Cloud-based GIS

In addition to relying on online open data sources to acquire GIS data, the class also took advantage of Esri's cloud-based platform, ArcGIS Online, for the following activities and purposes:

1) Data and content sharing: An online user group was created to include all the students as well as the instructor of the class to enable sharing of GIS data, processed map layer and scene layer packages, and maps and 3D scenes that were generated by the class.

2) Data processing and analysis: the class also used some of the analysis capabilities offered by the platform to perform some basic analysis, such as walkability analysis and hot-spot analysis.

3) Map and web scene generation: the class used this online platform to generate maps and 3D web scenes, which included detailed streetscapes, buildings, spatial analysis, and to visualize and explore urban structures and design solutions.

4) Project presentations: the class used the template provided by the online platform to create story maps to present project outcomes. Each story map contains multiple forms of media, including static images, text narratives, interactive maps and 3D scenes that reveal urban structures of the two sites. These story maps were made available to the general public online through the Internet (Figure 3).

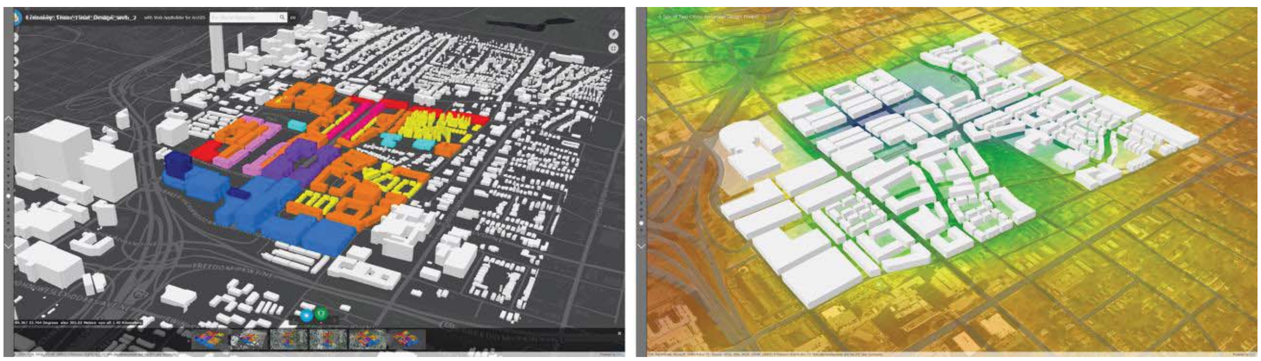

Figure 3. The class created a story map to organize a series of web scenes for documenting their analyses and design solutions, including land use mix analysis and walkability analysis (Broyles, et. al., 2017)

7.5 VR Development

The class also tested the potential of using virtual reality as a way to study urban form and explore urban design solutions. Their 3D CityEngine models were exported as .fbx files (Autodesk), which were then imported into Unity, a game development platform, or game engine, to be further converted into virtual reality scenes. Unity allows additional lighting effects and environment rendering options to enhance the appearance of the models. It also enables virtual reality settings that allow a user to use a typical game controller, such as Xbox controller, to walk around 3D scenes generated by the CityEngine models. During the class final review meeting, a computer was set up to allow guest critics to experience the virtual reality scenes in person and offer comments for students' design projects (Figure 4).

8 CONCLUSION

This class project offered an opportunity to explore the possibilities to use new geospatial tools and visualization media to study urban form and its related topics. These tools and media, including 3D procedural modeling with GIS, LiDAR remote sensing, cloud-based GIS platform, and virtual reality, represent four of the many major development trends in the geospatial technology industry and its related fields.

This project reveals potential advantages of these geospatial and visualization tools for the study of urban form, including: 1) quick 3D form extraction from LiDAR; 2) urban structure exploration with 3D procedural modeling; 3) easy access to accurate terrain elevation data and global satellite imagery; 4) easy data sharing and presentation over the Internet through cloud-based platform; and 5) a new way to experience urban spaces through virtual reality.

Figure 4. Virtual reality scenes, converted from CityEngine models, allowed reviewers to experience students' urban design solutions in an immersive way (Broyles, et. al., 2017)

However, noticeable disadvantages or issues still present and hinder the adaption of these tools, including: 1) proprietary software license; 2) limited data availability and unreliable quality; 3) inconsistent data schema; 4) multiple software programs and platforms with a steep learning curve; and 5) high cost of hardware devices.

Though an in-depth evaluation on the exact effectiveness of these software tools or media for the study of urban form is out of scope for this paper, which can certainly be an important next-step for advancing this particular practice, this project allowed for a quick glimpse of the current development trends in the GIS world. As these digital tools are becoming more and more advanced, we researchers, scholars, or designers interested in understanding the dynamics of city building processes should explore new methods and establish new workflows to utilize these tools to advance our work.

9 REFERENCES

Abdullah, Q. (2015) 'The Emerging Signs of 3D GIS', LiDAR News Magazine, Vol. 5, No. 4.

Andrews, C. (2017) '3D at Esri: 2016 in Review', ArcGIS Blog (https://blogs.esri.com/esri/arcgis/2017/01/04/3d-at-esri-2016-in-review/)

Broyles, C., Huan, Y., Prioleau, B., Young, V. and Lee, M.-C. (2017) Re-envisioning Buttermilk Bottom: Learning from Savannah (http://unccharlotte.maps.arcgis.com/apps/MapJournal/index.html?appid=6fe203d7f08749dcae454136b50e1f48), accessed 15 June 2017.

Chappell, D. (2010) GIS in the Cloud: the Esri Example (http://www.esri.com/library/whitepapers/pdfs/gis-in-the-cloud-chappell.pdf), accessed 23 May 2017.

CityEngine Help (2017) Introduction: The 360 VR Experience (3VR) (http://cehelp.esri.com/help/index.jsp?topic=/com.procedural.cityengine.help/html/manual/export/vr360/export_formats_3vr.html), accessed 23 May 2017.

Esri (2016) What is LiDAR data? ArcGIS Help 10.1 (http://resources.arcgis.com/en/help/main/10.1/index.html#//015w00000041000000), accessed 23 May 2017.

Esri (2017) What is ArcGIS Online? ArcGIS Online Help (http://doc.arcgis.com/en/arcgis-online/reference/what-is-agol.htm), accessed 23 May 2017.

Esri (2018) Get Started with Story Maps (https://learn.arcgis.com/en/projects/get-started-with-story-maps/), accessed 23 September 2018.

GISGeography (2017) A Complete Guide to LiDAR: Light Detection and Ranging, (http://gisgeography.com/lidar-light-detection-and-ranging/), accessed 23 May 2017.

Goodchild, M.F. (2011) 'Looking Forward: Five Thoughts on the Future of GIS', ArcWatch (http://www.esri.com/news/arcwatch/0211/future-of-gis.html)

Jin, X., Wang, F., Hao, L., Duan, Y., and Chen, L. (2015) 'Analysis of the Modeling Method and Application of 3D City Model based on the CityEngine', International Conference on Advances in Mechanical Engineering and Industrial Informatics (AMEII 2015), pp. 34-39.

Kumar, M. (2015) ‘Evolution of the Geospatial Industry: From GIS to Spatial Computing’, GeoAwesomeness (http://geoawesomeness.com/evolution-of-the-geospatial-industry-from-gis-to-spatial-computing/)

Manly, L. (2015) ‘A Virtual Reality Revolution, Coming to a Headset Near You’, The New York Times, November 19, 2015.

Muller, P., Wonka, P., Haegler, S., Ulmer, A., and Van Gool, L. (2006) ‘Procedural modeling of buildings’, ACM Transactions on Graphics (TOG), Vol. 25 (3), pp. 614-623.

Nishida, G., Garcia-Dorado, I., Aliaga, D. G., Benes, B., and Bousseau, A. (2016) ‘Interactive Sketching of Urban Procedural Models’, ACM Transactions on Graphics (TOG) - Proceedings of ACM SIGGRAPH 2016, Vol. 35 (4).

Parisi, T. (2015) Learning Virtual Reality: Developing Immersive Experiences and Applications for Desktop, Web, and Mobile, O'Reilly Media, Incorporated, 2015

Ribeiro, A., Duarte de Almeida, J.-P. and Ellul, C. (2014) ‘Exploring CityEngine as a Visualization Tool for 3D Cadastre’, 4th International Workshop on FIG 3D Cadastres, 9-11 November 2014, Dubai, United Arab Emirates, pp. 197-218.

Rubin, P. (2014) ‘The Inside Story Of Oculus Rift And How Virtual Reality Became Reality’, Wired Magazine, May 2014.

Singh, S. P., Jain, K., and Mandla, V. R. (2014) ‘Image-based Virtual 3D Campus modeling by using CityEngine’, American Journal of Engineering Science and Technology Research, Vol. 2, No. 1, pp. 1-10.

Smelik, R. M., Tutenel, T., Bidarra, R., and Benes, B. (2014) ‘A survey on procedural modelling for virtual worlds’, Computer Graphics Forum, Vol. 33, pp. 31-50.

Song, Y. and Knaap, G.-J. (2004) ‘Measuring Urban Form: Is Portland Winning the War on Sprawl?’, Journal of the American Planning Association, Vol. 70, No. 2, pp.210-225.

Tsai, Y.-H. (2005) ‘Quantifying Urban Form: Compactness versus Sprawl’, Urban Studies, Vol. 42, No. 1, pp.141-161.

Ullrich, A. and Pfennigbauer, M. (2016) ‘Linear LIDAR versus Geiger-mode LIDAR: Impact on data properties and data quality’, Laser Radar Technology and Applications XXI, Proc. of SPIE, v. 9832.