

Beyond Visualisation in 3D GIS

James Milner^{*1}, Kelvin Wong^{†1} and Claire Ellul^{‡2}

Department of Civil, Environmental and Geomatic Engineering, University College London, London, UK, WC1E 6BT

November 02, 2014

Summary

Although 3D visualisation is becoming more common in GIS, as of yet, there has been relatively little in the way of 3D editing and analysis functionality especially in the web. This research describes a first attempt at addressing this deficit, documenting a 3D Web GIS with the ability to select, edit, 3D buffer, measure and retrieve attributes. A small user evaluation was undertaken to assess aspects such as usability, consistency and responsiveness. The system developed was implemented using Three.js as a frontend 3D framework and PostGIS as a backend database. The GIS was successful in its execution but detected some issues in requirement of addressing in order to progress. It concludes with recommendations to improve performance and go further with 3D editing.

KEYWORDS: 3D, Web, GIS, WebGL, Editing

1. Introduction

The progression of 3D geographic information systems (GISs) has perhaps never been more necessary. The ever increasing demand for 3D GISs and 3D geographical data has been acknowledged (Gröger and Plümer, 2012) and recent research has evidenced real-world applications for 3D GIS such as visualisation of dynamic urban landscapes (Yin & Shiode, 2014), and mineral resource exploration (Wang et al., 2014). The primary aim of this research was to develop, implement and document fundamental functionality such as visualising, selecting, editing, measuring, 3D buffering and attribute revival in a 3D web GIS.

2. Background

2D GISs struggle to represent the three-dimensional world, unable to express multiple height values at one 2D point (Abdul-Rahman and Pilouk, 2008). 3D GISs are needed that are able to visualise, capture, structure, manipulate and analyse 3D data (Abdul-Rahman and Pilouk, 2008). Many 3D systems currently lag behind 2D oriented systems (Ellul and Haklay, 2009). This is even more prominent in browser based 3D web GIS (Ming, 2008), with most modern 3D web GISs (e.g. Esri CityEngine Web Viewer) focusing predominantly on visualisation and/or navigation, and not editing and analysis. Recent technologies such as HTML5 and WebGL, have made the possibility of 3D GIS natively in the browser a real scenario, however they present new problems such as handling various coordinate systems in these environments.

3. Data

The research uses 3D data for Newcastle (Table 1 and Figure 1) which was provided in Esri Shapefile format by Ordnance Survey. All layers were 3D (x, y, z), with the data being originally derived by the

* james.milner.13@ucl.ac.uk

† kelvin.wong.11@ucl.ac.uk

‡ c.ellul@ucl.ac.uk

OS from aerial imagery using photogrammetric techniques. The ‘Walls’, ‘Roofs’ and ‘Bridges’ layers are at LoD2 with the ‘Iconic_Buildings’ layer at LoD2 with some LoD3 elements.

Table 1 Feature Details for the Newcastle Dataset

| Feature Name | Feature Geometry Type | Number of Features | Shapefile Size (kilobytes) |
|-----------------------|-----------------------|--------------------|----------------------------|
| HeightedITNRoadNode | Point | 1470 | 64 |
| HeightedITNRoadLink | Line | 2086 | 762 |
| Vegetation | MultiPatch | 139 | 10,476 |
| HeightedOSMM_TopoLine | Line | 8998 | 2,008 |
| HeightedOSMM_TopoArea | Polygon | 21469 | 22,506 |
| Walls | MultiPatch | 300 | 2,830 |
| Roofs | MultiPatch | 300 | 1,968 |
| SimpleBuildingHeights | Polygon | 5080 | 2,547 |
| Bridges | MultiPatch | 3 | 132 |
| Iconic_Buildings | MultiPatch | 4 | 1,784 |



Figure 1 The Newcastle dataset layers displayed in ESRI's ArcScene 10.2.1

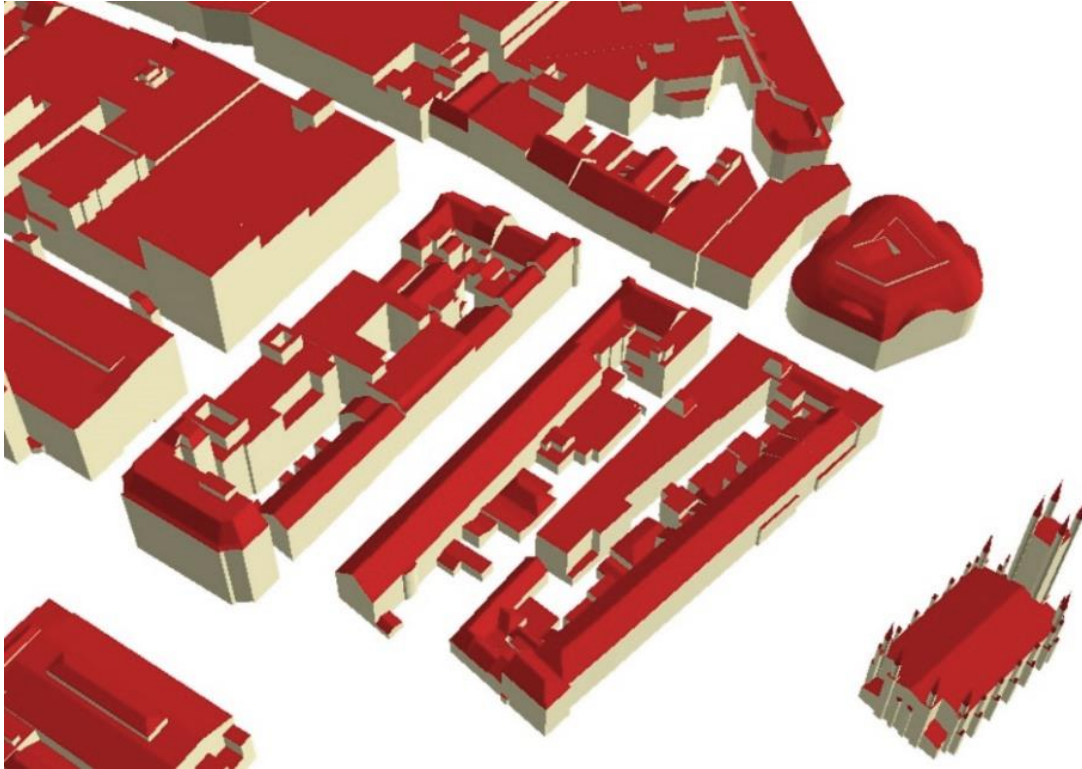


Figure 2 Close-up of LoD2 buildings, consisting of wall and roof layers

Data was translated using SafeSoftware's 'FME Data Inspector' to a PostgreSQL 9.2.0 database using the PostGIS extension. Shapefile types were converted to the equivalent PostGIS Well-Known Text (WKT) primitives (i.e. Points into WKT Point Zs, Multipatch Shapefiles into WKT PolyhedralSurfaces and TIN Zs, etc). Each table (data layer) was updated with an ID column using a Big Serial primary key allowing for auto-incrementation. This allows the 3D GIS web system to uniquely identify geometries.

4. Methodology

The systems layout was modelled on popular GISs such as ArcScene and QGIS to retain familiarity and client side technology such as HTML5, CSS, JavaScript and WebGL (through Three.js). The system is underpinned by a PostGIS database, and geometries (WKT) are brought into the scene from the database using PHP and Structured Query Language (SQL).

The WKT strings are converted into Three.js geometries in the scene. Some Three.js primitive geometries were used; for points `THREE.SphereGeometry` were used, for lines the `THREE.Line` primitive. For WKT TINZs and `PolyhedralSurfaces` custom Three.js geometries were created. The project makes use of Seidel's (1991) Polygon Near Linear (PNL) 2D triangulator implemented in JavaScript by Ahting (2014) for triangulation of arbitrary geometries. To overcome its 2D nature a micrometric epsilon value was used to distinguish between 3D points sharing X, Y values (0.0005 m).

Single selection was implemented into the system through use of raycasting; firing a ray into the scene to determine if objects exist under a mouse click (Figure 3).

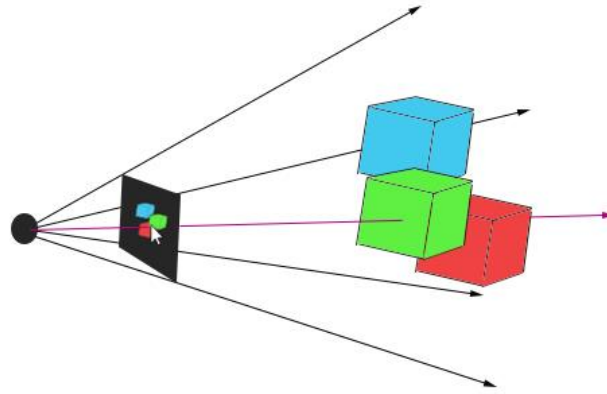


Figure 3 Raycasting (purple arrow) into the scene from the camera in Three.js

Multi-selection used a marquee selection methodology. The marquee is variable sized HTML div element controlled by the mouse. Geometries in the field of view frustum are iterated through, with vertices unprojected to 2D coordinate screen space and checked to see if they are in the defined marquee. Attribute querying was implemented by taking selected object IDs (stored in an array) and passing these to the backend PostGIS database to pull out attributes and push them into a formatted table.

Point distance measurement was implemented using a simple formula:

$$d = \sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2 + (z_2 - z_1)^2} \quad (1)$$

Where (x_1, y_1, z_1) is the first supplied coordinate, and (x_2, y_2, z_2) is the second. All geometries are constructed from triangles in WebGL, and as such surface area measurement can be determined using Heron's Formula:

$$s = \frac{a + b + c}{2}$$

$$A = \sqrt{s(s - a)(s - b)(s - c)} \quad (2)$$

Where a, b, c are the lengths of the triangles sides, s is its semi-perimeter and A is its area.

Multiple 3D buffering options were implemented through use of three of Three.js's primitives Box, Sphere and Cylinder. Transparency and dimensions are optional parameters.

Object level editing such as deletion, copying, translation, scaling and rotation were implemented by use of custom functions and built-in Three.js methods. Geometries could not be transformed in place with built-in Three.js transformation functions and needed to be brought to the system origin $(x, y, z = 0,0,0)$ by subtracting the objects center point. Edited geometries are then transformed and returned to their previous position and synced to the database using PHP/SQL.

Vertex level editing was possible through wireframing geometries, and a 'closest vertex to click'

function. This allowed for editing and updating of specific vertices. An UPDATE command is sent using PHP/SQL to update the associated geometries in the database (as WKT)

A short user evaluation was also conducted to find the strengths and weaknesses of the developed system. It consisted of a 'Think-out-loud protocol' assessment, three qualitative questions and ten quantitative, with ten participants.

5. Results

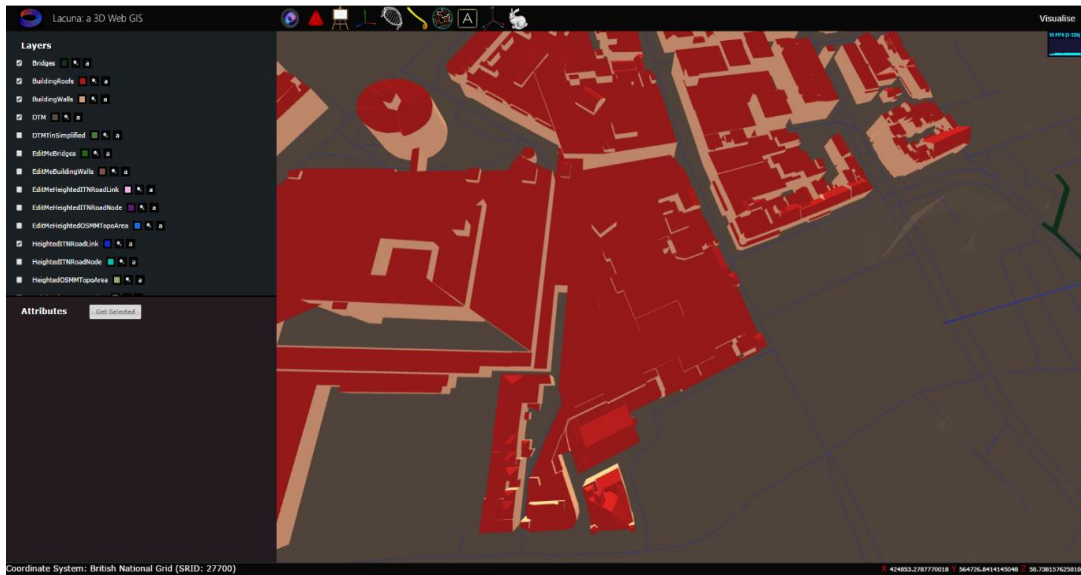


Figure 4 The system displaying various geometries

Figure 4 displays the design of the system, retaining familiarity from the user interface of popular desktop GISs (i.e. ArcScene, QGIS). It also shows the visualisation of 3D geometries into the scene.

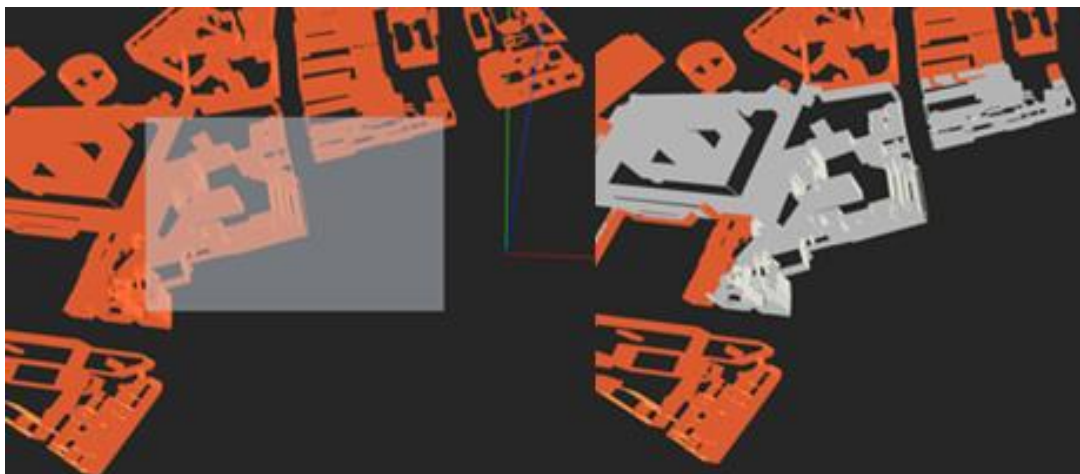


Figure 5 Marquee selection and resulting selection

Figure 5 expresses the marquee selection tool, showing how multiple geometries can be

selected.

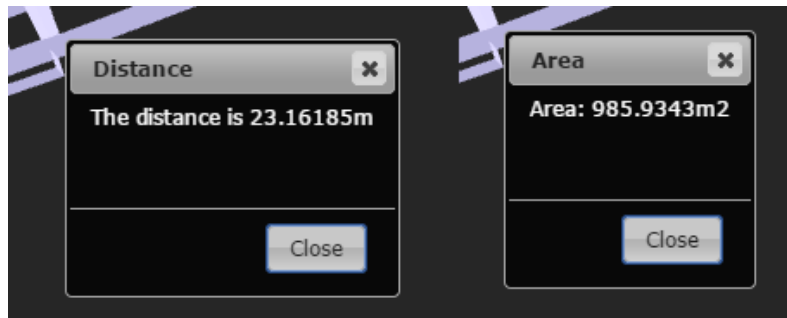


Figure 6 Distance and Area operation results

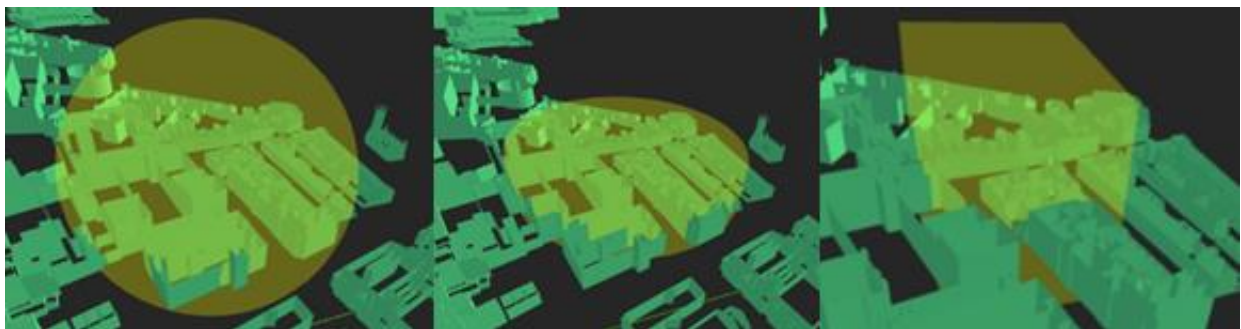


Figure 7 A spherical, cylindrical and box buffer in scenes

Outputs from the calculations from the formulas presented in distance and area function can be seen in Figure 6. Results from all three buffer operations can be seen in Figure 7. An example transformation (rotation) can be seen in Figure 8 alongside the vertex level editing interface in Figure 9.

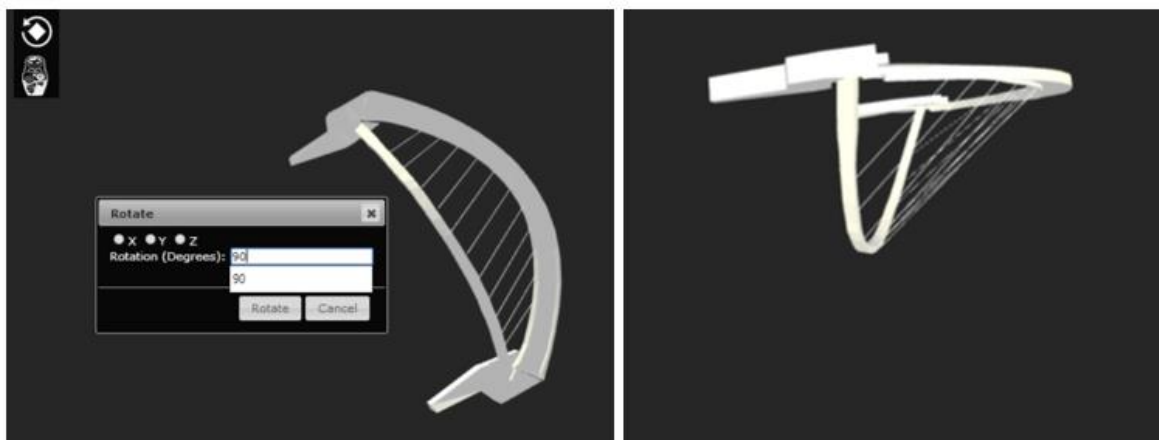


Figure 8 Geometry rotation in the scene

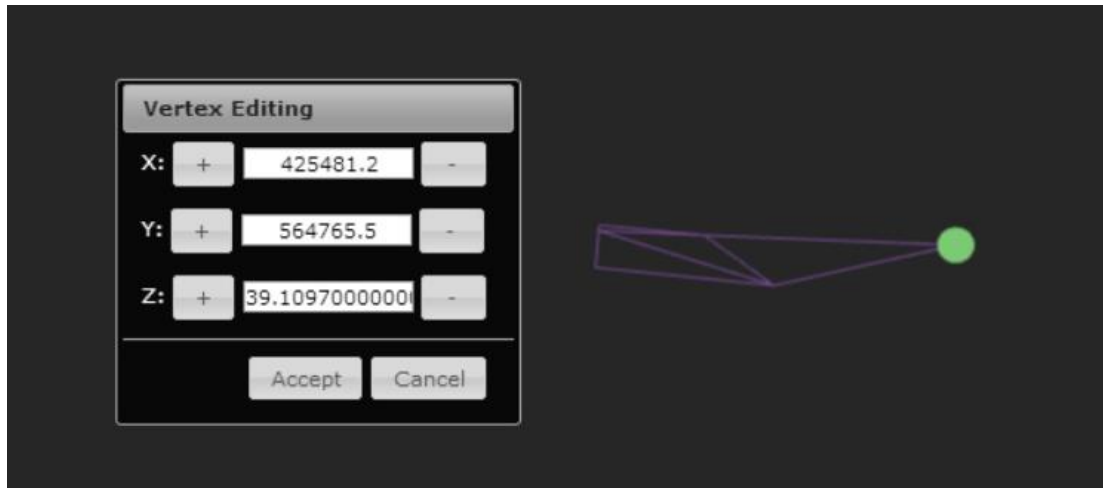


Figure 9 Vertex editing with interface

Figure 10 shows the user study results. Responsiveness and was the lowest (6.1) rated factor and editing was the highest rated (8.5).

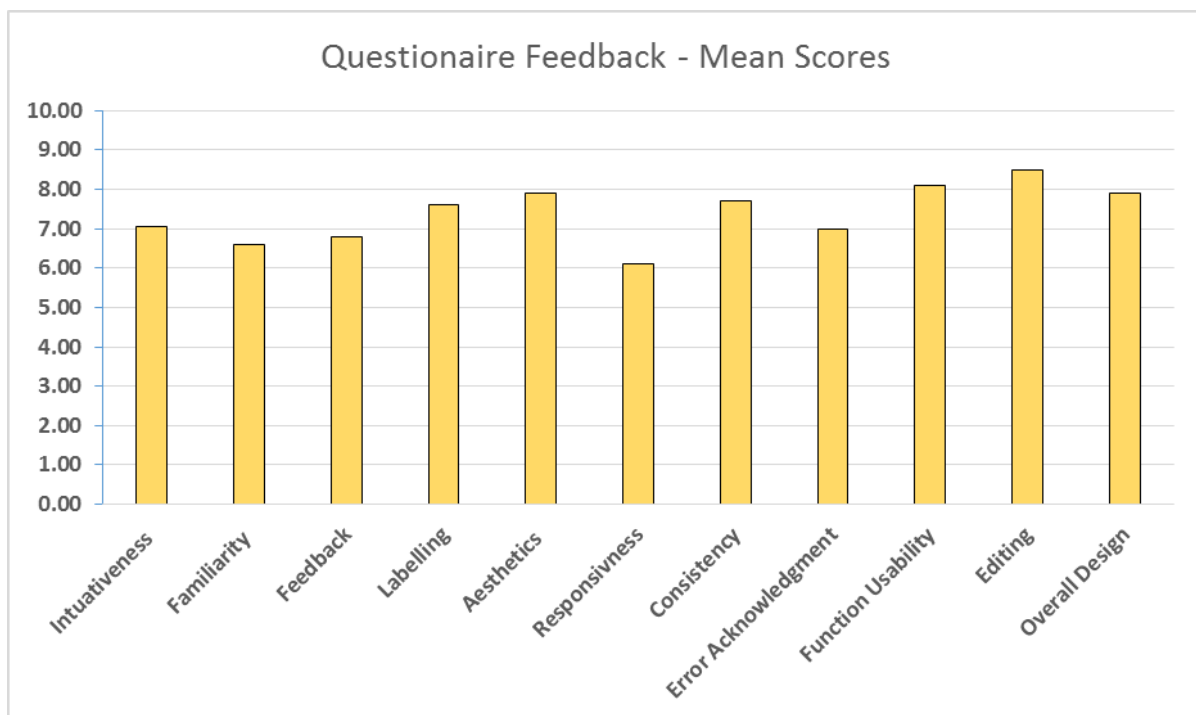


Figure 10 User study results

6. Discussion

The system developed has shown how it is possible to produce an elementary plugin-free 3D GIS, with editing tools in the web. The projects aims were achieved: implement and document visualisation, selection, attribute retrieval, measurement and 3D buffering, alongside more complex operations such as object level and vertex level editing.

The user study proved that 3D web GIS has promising potential, with favour for 3D GISs that follow similar designs to popular GIS desktop applications. Users showed an overall approval of the 3D system

implemented in both quantitative assessment (7.39/10 mean score) and think-out-loud protocol. Perhaps the most important contributions are in fields of selection and editing, although other elements of the GIS may be foundations for successive work. The project has also highlighted the applicability of WebGL/Three.js for the platform of a 3D web GIS.

The research highlights barriers for successful web GIS including a robust and efficient 3D triangulator for arbitrary 3D geometries and layer loading times for complex geometry sets (expressed in several think-out-loud protocol assessments). The latter is a critical issue on low bandwidth and low specification devices. Furthermore, the research exposes that although suitable for storage and retrieval, 3D support in PostGIS requires enhancement in order to be effective in the functionality of a 3D web GIS.

7. Conclusion and Further Work

This system shows that 3D Web GIS is possible directly in the browser using no additional plugins. The benefit of this approach is the potential for cross platform and device web GIS, built on accessible open technologies. The web GIS explorers initial steps, highlighting the potential for what could be possible with further work.

It is recommended that performance is an area of focus for future research. Use of PostgreSQL's *string_agg(expression, delimiter)* and PostGIS's *ST_AsGeoJSON* may yield improved results (as per Ellul and Altenbucher, 2014). Alternative databases with JSON support (e.g. MongoDB), client side string manipulation, and generalisation/simplification could all possibly improve transfer and rendering speeds.

Further editing capabilities such as face and edge splitting, and construction from base extrusion or primitives/constructive solid geometry might be further directions for research. The system could also benefit from integration with a topological model, allowing for topological querying and ensuring topological consistency by defined rules. Finally further spatial analysis tools such as flood analysis, 3D viewsheds and hotspot analysis would push the functionality of the 3D web GIS.

8. Acknowledgements

This project was funded and supported by the Ordnance Survey. The Ordnance Survey also made their 3D datasets available for use with this project.

9. Biography

James Milner studied a MSc. in Geographic Information Science at University College London. For his dissertation he researched the development of a 3D Web GIS built on WebGL. He currently works for Esri UK as a developer evangelist.

Kelvin Wong is an EngD research engineer at the UCL Centre for Virtual Environments, Interaction and Visualisation, Department of Computer Science, University College London. His research interests focuses on the challenges of deploying 3D geographic datasets at a national level with particular interests in usability, applications and data quality of 3D geographic information. Additional research relates to 3D visualisations and 3D requirements gathering.

Claire Ellul is a Lecturer in Geographical Information Science at University College London. Prior to starting her PhD, she spent 10 years as a GIS consultant in the UK and overseas, and now carried out research into the usability of 3D GIS and 3D GIS/BIM integration. She is the founder and current chair of the Association of Geographical Information's 3D Specialist Interest Group.

References

- Abdul-Rahman, A. and Pillouk, M., 2008. *Spatial Data Modelling for 3D GIS*. New York: Springer
- Ahting, J., 2014. Polygon Near-Linear Triangulation in JavaScript [Online]. Accessible form: <https://github.com/jahting/pnltri.js> [Accessed: 20/08/2014]
- Ellul, C. and Altenbuchner, J., 2014. Investigating approaches to improving rendering performance of 3D city models on mobile devices, *Geo-spatial Information Science*, 17(2), 73-84.
- Ellul, C. and Haklay, M., 2006. Requirements for Topology in 3D GIS. *Transactions in GIS*, 10(2), 157–175.
- Gröger, G. and Plümer L., 2012. CityGML – Interoperable semantic 3D city models. *ISPRS Journal of Photogrammetry and Remote Sensing*, 71, 12–33.
- Ming, W., 2008. A 3D Web GIS System Based on VRML and X3D. In: *Proceedings of 2nd International Conference of Genetic and Evolutionary Computing*, WGEC 2008, September 25–26, 2008, Hubei, 197–200.
- Seidel, R., 1991. A simple and fast incremental randomized algorithm for computing trapezoidal decompositions and for triangulating polygons. *Computational Geometry Theory & Applications*, 1(1), 51-64.
- Wang, G., Zhang, S., Yan, C., Song, Y., Qu, J., Zhu, Y., Li, D., 2014. 3D-GIS Analysis for Mineral Resources Exploration in Luanchuan, China. In: Pardo-Igúzquiza, E. Guardiola-Albert, C., Heredia, J., Moreno-Merino, L., Durán, J., Vargas-Guzmán J., eds. *Mathematics of Planet Earth: Proceedings of the 15th Annual Conference of the International Association for Mathematical Geosciences*. Berlin: Springer: 295-298.
- Yin, L. and Shiode, N., 2014. 3D spatial-temporal GIS modeling of urban environments to support design and planning processes. *Journal of Urbanism: International Research on Placemaking and Urban Sustainability*, 7(2), 152-169.