DIGITAL ENGINEERING IN IDENTIFYING POTENTIALLY SETTLEMENT AFFECTED STRUCTURES FROM ADJACENT TUNNELING AND EXCAVATION

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1. ABSTRACT

Potential settlement of structures from tunnelling and excavations have typically been manually identified through comparison of structures' footprints against settlement modelling. This time-consuming exercise requires manual re-processing after every alteration in the settlement model and is prone to human error. As a part of large scale tunnel and excavation works, Golder Associates and PSM developed a digital engineering solution to automatically identify structures that are predicted to be affected by settlement, and its magnitude. The tunnels stretch for fifteen and a half kilometres through inner Sydney with six box cut excavations, the settlement model of which can now be re-analysed in less than half an hour.

Vertical displacement from initial state settlement was modelled, and Surfer used to output contours of the modelled settlement. These contours were intersected with the footprint of the structures along the route and the value of the greatest intersecting contour attached to the footprint. As a part of the settlement analysis, adjacent basements were also classified into proximity zones using horizontal and vertical distance of basements to box cut excavations and the tunnel walls. The 3D CAD models of the box cut excavations and the centreline of the tunnel were brought in and the angle and distances to the basements along the alignment calculated.

The scripts were created with the Extract, Transform and Load software FME, and the python package ArcPy. This solution is highly flexible and able to be adapted to other settlement effect analyses.

2. INTRODUCTION

2.1 PROJECT OUTLINE

The project involves the construction of a twin tunnel and a series of box cut excavations in inner Sydney, including some of the most densely populated and developed parts of Australia (Australian Bureau of Statistics, 2017). The project is designed to help link Sydney's transport infrastructure and is a multibillion-dollar project.

PSM were contracted to undertake modelling of the settlement effects of the tunnelling and box cut excavations. The vertical displacement from the initial state and output contours of the modelled settlement from Surfer, and derived algorithms to classify adjacent basements into proximity zones based on the distance to box cut excavations and tunnel centrelines. After manually comparing structures and predicted settlement and algorithms, it was realised that there was potential for the use of digital engineering to automate the process. PSM contacted Golder to explore the possibility of collaborating with their GIS and digital engineering team.

Settlement was modelled by integrating two scripting languages (FME and python) to automatically pull in the digital models of the planned tunnels and stations, basements, building outlines, and infrastructure such as roads and railways. It compared these geometrically to the settlement contours and algorithmically to the box cut excavations and tunnel walls for the proximity zoning.

2.2 PREVIOUS PRACTICE AND AUTOMATION OF IDENTIFYING STRUCTURES POTENTIALLY AFFECTED BY SETTLEMENT

Historically manual methods have been used to identify structures that are predicted to be affected by settlement and allocate magnitude, visually overlaying modelled settlement contours with aerial photography or plans of structures and calculating distance and angle to excavations by hand. While this is a simple method and not technically complex, it is a time-consuming process requiring significant resources to repeat the process each time a new settlement model is produced. By automating the process of identifying structures, this process can be done in less than an hour, and re-run using updated or alternative models. It also eliminates the risk of human error.

Due to the large variety of formats being used as inputs and to maximize the flexibility of the script and its outputs it was decided to base the automation around FME, and to integrate the geospatial Python package, ArcPy. FME is an Extract, Transform and Load software, and originally designed to convert between geospatial formats. It is a visual scripting language with large capabilities in geospatial analysis and manipulation. Data is read into the script, manipulated using transformers that are linked in the order the manipulations are to occur, then output in the desired format or formats. Python is a general purpose scripting language that is extended by the addition of specialist packages, such as the ArcPy package created by ESRI to complement their ArcGIS suite of programmes.

The settlement had three aspect that needed to be analysed, the vertical settlement from the initial state that was represented by contours, the proximity zones for the tunnelling, and the proximity zones for the box cut excavations. FME scripts were created to analyse these three aspects, integrating ArcPy in as a shutdown script for the latter two. A shut-down script will execute once the FME script has completed, allowing the newly created files to be manipulated by python.

3. SCRIPT WRITING

3.1 VERTICAL INITIAL STATE SETTLEMENT SCRIPT

The CAD file output by Surfer used colour to symbolize the settlement values of that contour, and was georeferenced to the project co-ordinate system, Geocentric Datum of Australia 1994 Map Grid of Australia Zone 56. When FME reads a file the data is stored as a temporary FME feature store file, an FFS. This is the data manipulated by the script, meaning the original files are left untouched. After analysis and manipulation the FFS is converted to the defined format and saved.

The FME script removed any elevations from the data which may have been created during exporting from Surfer, in order to ensure that all features being analysed were on the same plane. This is important for a later step where features are analysed using their intersections. Extraneous features, such as title blocks, legends, were removed by a filter using the CAD layer name and line type. Using a conditional statement the colour attribute of the contours was used to attribute the numeric value of the modelled deformation, giving the FFS an extra attribute. A conditional statement uses an if-else-then structure to filter data points through a series of yes-no tests to deduce how the data point should be interpreted. The data required cleaning up, as the contours were made of multiple lines that had tiny discontinuities and sections where they overlapped. This came from them being exported from Surfer with labels still turned on. Transformers were used to manipulate the data to create a single feature from lines with equal settlement values that overlapped, and then drew a line between the end points of lines of the same deformation value that were within 5 metres of each other. All lines of the same settlement value that had touching end points were then combined into a single feature.

This data was passed along to downstream parts of the script, as well as output into a ShapeFile. This was used to give the option of visually inspecting the results in a GIS system. The features were sorted in descending order of deformation, causing the largest values to be passed along first and the smallest vales last. This was used as during the geometric intersection as the first value that intersects with the structure is the value assigned to it.

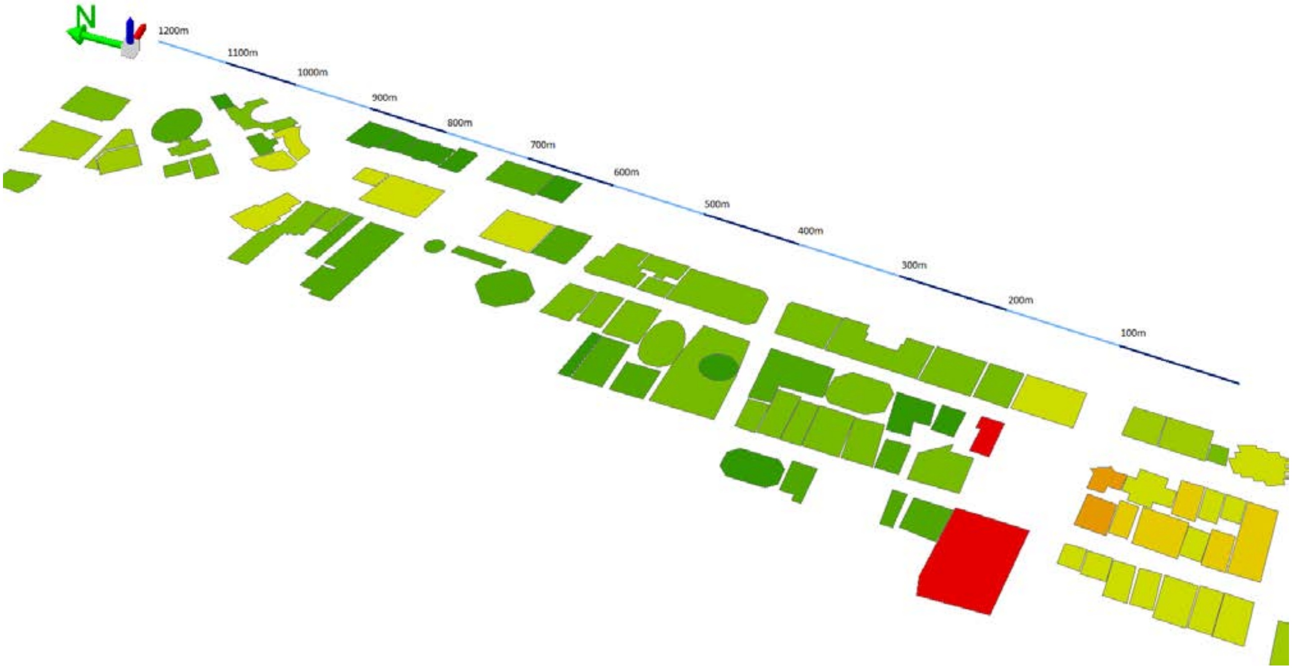

Figure 2: A graphical representation of the maximum predicted settlement effects on buildings along the alignment, with red indicating greater settlement effects.

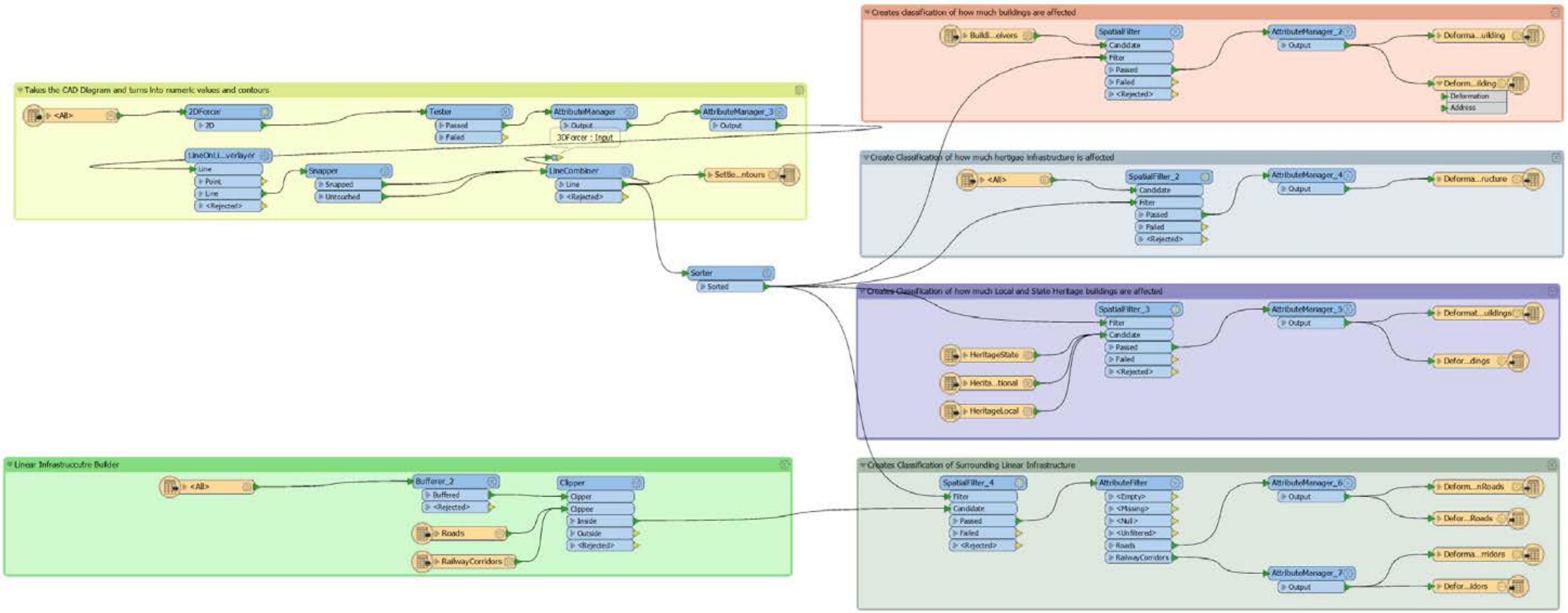

Figure 1: The FME script used to perform the analysis of the vertical displacement of the initial state and its effects on surrounding buildings

Classification was done separately on surrounding buildings, heritage infrastructure listed under Section 170 of the NSW Heritage Act 1977, other structures on the local, State, and National heritage registers, and surrounding surface linear infrastructure from the NSW Digital Terrestrial Database. Data on structures was held in an ESRI geodatabase and CAD formats, with the data on surrounding surface linear infrastructure extracted from an ESRI geodatabase during the analysis. A 200m buffer was placed around the centreline and this used to clip out the roads and railway corridors within the zone of interest.

Each type of feature was connected to a spatial filter transformer as the candidate, with the contours as the filter. This was programmed to tests whether the filter has certain interaction with the candidate. For this work we tested to see if the filter touched or intersected the candidate. If the structures have one or both of these interactions the attribute values of the highest deformation contour interacting are attached to the attribute table of the structure. If there are no interactions the feature is considered to have failed, in other words it isn't within the zone of predicted settlement and not considered further. The extraneous attributes are removed, such as the name of the CAD file layer and colour of the contour from the CAD file. Results were extracted as excel spreadsheets of the attributes, for example the address and predicted settlement of the buildings, or the road name, cadastral details, and predicted settlement of the roads. They were also output as shapefile to allow easy display and symbolizing based on predicted settlement in GIS.

3.2 PROXIMITY ZONE CLASSIFICATION

For Proximity Zone classification, ArcPy was integrated into FME as a shut down script. A shutdown script is executed once the FME script has finished executing, allowing manipulation of data that cannot be done by FME, such as attaching files to features in geodatabases, or commencing processes such as exporting maps from GIS software. We calculated two proximity zones, one for distance from box cut excavations and another for the tunnelling centreline.

3.2.1 Proximity Zone Classification of Basements to Excavations

To calculate the proximity zones for basements to excavations, a 3D CAD model of known basements along the alignment was bought into FME. The maximum and minimum Z values of this were extracted using an FME transformer and attached to the data, which was output as a mulitpatch ShapeFile. A multipatch is a geometry type used for storing and representing the shells of 3D data.

The box cut excavation designs were brought in as well, and also had their minimum and maximum Z values extracted. Unlike the basement designs, which were rectangular prisms with additional prisms below them to represent pits, the basement designs were irregular prisms, some with slightly varying Z minimum values, in the order or centimetres, over the excavation base. The minimum and maximum X, Y, and Z values were extracted and added to each feature as attributes, and all the box cut excavation designs put into a single multipatch file to allow proximity classification. X, Y, and Z values were included to allow manual verification of the results. An ArcPy script was then executed by FME which defined the projection systems used in the multipatches of the basements and box cut excavation designs, specifically Geodetic Datum of Australia 1994 Map Grid of Australia Zone 56 and Australian Height Datum. This is required to define the units used in the subsequent calculations. A Near3D ArcPy function was then executed, comparing the output box cut excavations against the basements, and calculating the total distance and the vertical and horizontal angles to from the point on the basement closest to the nearest box cut excavation, as well as the distances along the X, Y, and Z axes.

These values are added to the multipatch as attributes. The attribute tables can be extracted to excel files and used to classify the buildings into proximity zones, as well as be displayed in GIS using symbology indicating the distance to an excavation.

3.2.2 Proximity Zone Classification of Basements to Centrelines

A process similar to that above was used for classifying basements into proximity zones in relation to the centrelines of tunnelling. Again, a CAD file was bought in, the X, Y, and Z limits extracted to allow manual verification, a exported as a multipatch. The centrelines were already stored in an ESRI geodatabase format, so were not required to be translated.

The steps from above were repeated, the basements had their projection systems defined, then the distances and angles were calculated. The distance and angles in this case were to the closest point on the nearest centreline, there being two centrelines for the twin tunnels.

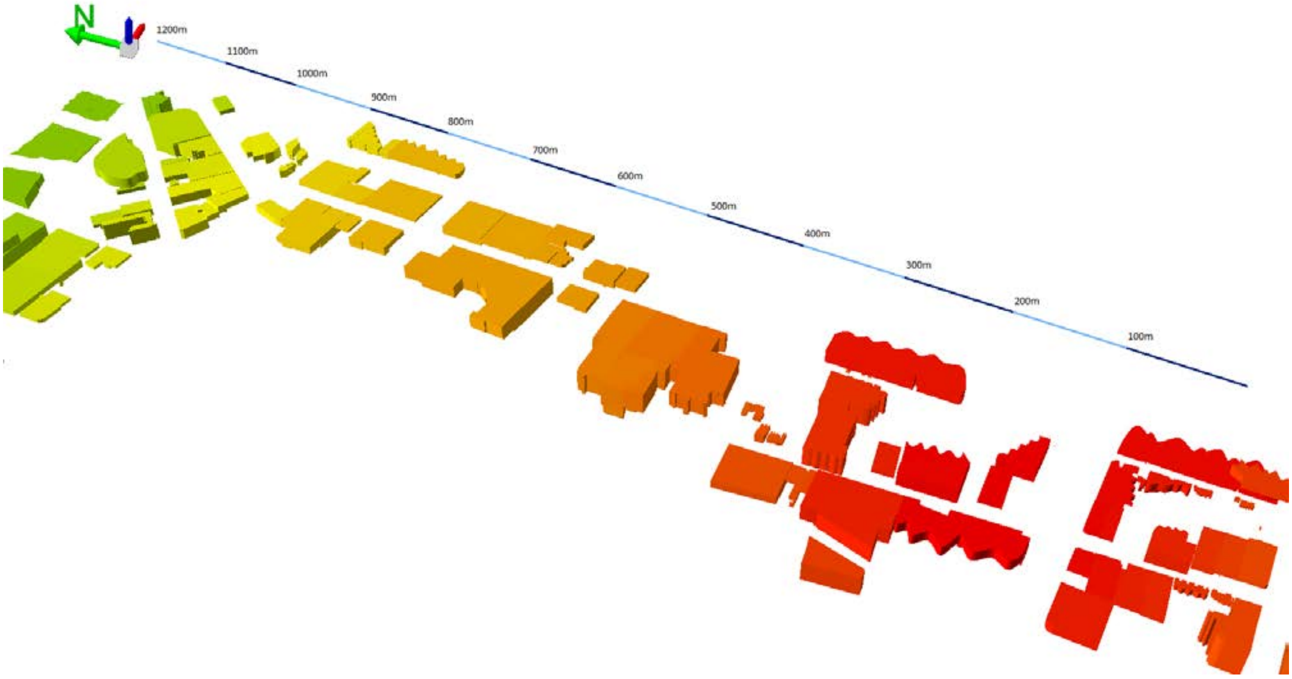

Figure 3: A graphic representation of the 3D distances of basements to excavation. Red saturation indicates closeness to the excavation, becoming greener as it becomes further away.

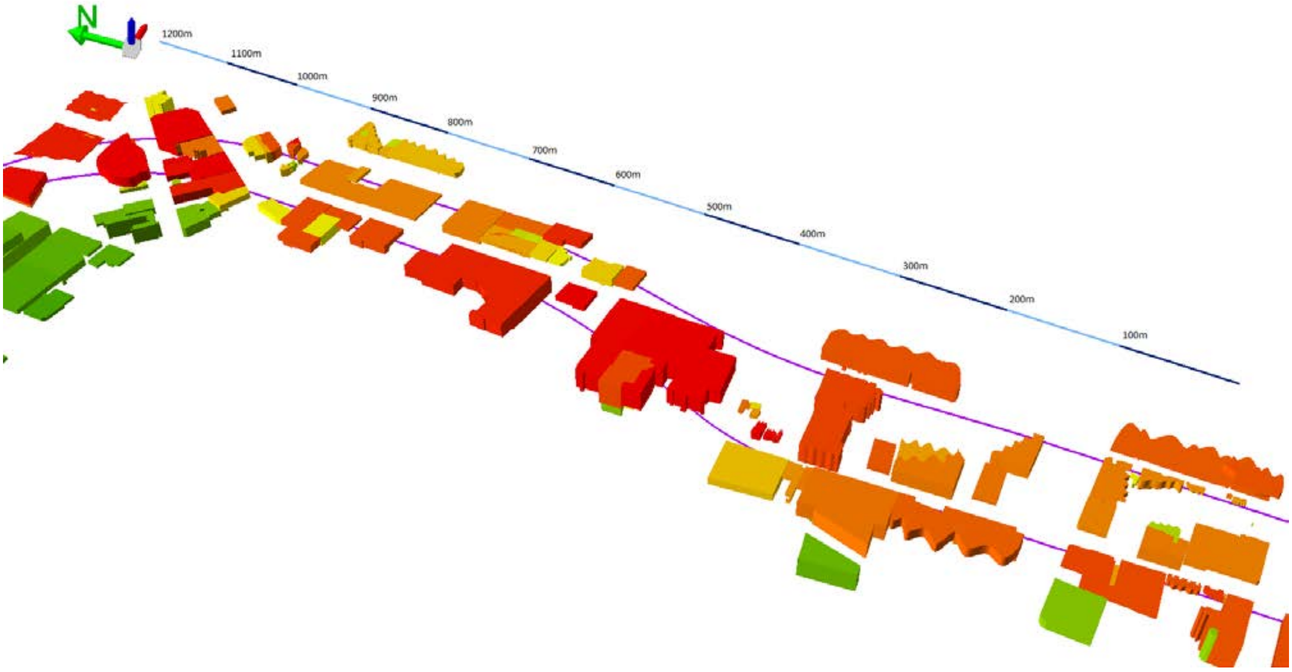

Figure 4: The same scene from Figure 3, representing the 3D distances of basements to centreline. Red saturation indicates closeness to the excavation, becoming greener as it becomes further away

4. EXECUTION OF THE SCRIPTS

The vertical initial state settlement script is able to run with data that is available from a server on the same network in less than fifteen minutes. Speed tests have put it at 11 minutes, while the proximity zone classifications for the basement to excavations and basements to centrelines have been speed tested to be 1 and a half minutes and 43 minutes respectively under the same conditions, which analysed 2154 separate basements in each script. During the running of scripts, no input is required from the user, allowing it to be run in the background while they undertake other work. In the case of new data being used or updated data, it only requires the user to redirect the data paths or to update the scripts, which is a relatively trivial task.

Unlike human calculations, these scripts are able to be repeatedly run and have the same results, which are also extremely accurate. The inclusion on bounding box information allows the results to be manually verified by the user.

5. DISCUSSION AND FUTURE USE

The ability of this script to quickly reprocess data with new settlement models, as well as the incorporate new data around basements and structures as they become available and output data in a variety of formats for different uses, shows the time and cost saving benefits using digital engineering. The script is able to be easily adapted to other situations where the effect of predicted or actual changes in ground conditions on pre-existing structures needs to be identified, or distances need to be calculated for large amounts of entities. The results of this analysis are able to be leveraged once they are in digital format, such as excel table being put into reports, multipatches being placed into 3D PDFs, or placed into web maps.

This project shows the importance of ensuring that projects are geospatially and digitally enabled, as it is able to deliver more accurate results for clients, and save time and cost for consultants. Digital engineering methods and automation such as this project will become increasingly common and achievable as clients and collaborating firms work in the 3D space and are producing and consuming more digital data.

6. Terminology

- Z Value: The value in a three dimensional Cartesian co-ordinate system denoting height
- Multipatch: a geospatial data type used for storing and representing the shells of 3D data
- ShapeFile: A geospatial file format that stores vector data, such as points, line, planes, or multipatches
- ArcPy: a python package that is used for geospatial analysis and manipulation, created by ESRI
- Python: a programming language, which can have packages added on to extend its capability
- FME: An Extract, Transform, and Load programming language specializing in geospatial data manipulation.

An acronym for Feature Manipulation Engine

7. References

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