A Guide to Earthworks Measurement Utilising Digital Terrain Modelling Techniques
Sheet 1 of 6

How models are formed
A digital ground or terrain model (DGM/DTM) is created on computer from three dimensional data sets consisting of easting northing and height. The data sets are often generated from field observations and recordings to total station (EDM) or Global Positioning Systems (GPS or GNSS). This is only possible when work has been carried out. When a volume is to be computed at tender stage for example then it is necessary to extract the 3d data from the contract documents, usually the setting out drawings. The data will then be manually input to the computer. In some instances when the proposed works have been designed on a 3d computer model then this can be imported into the system.

Most software packages, including LSS which Kemp employ, use some form of Triangulated Irregular Network (TIN) process to create the model. With this, triangular planes are formed between points surveyed and the shape is controlled by break lines linking up lines of detail and topographic features such as the top and bottom of an excavation or sudden changes in gradient. The method has its limitations in that plane rather than curved surfaces are formed but practical use over many years has proved the method. Figure 1 shows a screen grab from LSS with the triangles that make up the TIN shown.

In forming a model it is important for the field surveyor or site engineer to pick up as much detail as possible particularly the break lines. When recording data prior to work commencing such as with an original ground level survey this is not a problem as the whole site is available and visible. However once work has commenced it is often, if not always, the case that the areas to be surveyed are exposed for short periods of time and in a piecemeal fashion. There is no period when, for example, the whole site is soil stripped, because as it is stripped the reduced dig is being undertaken. It is in this instance that the surveying of break lines is made more difficult. It is also the case that the soil strip survey for example is built up over a number of days or weeks from a number of different surveys.

It is worth making a special note that when it is necessary to create a ground model to define an element that is yet to be constructed it is usually necessary to rely on the setting out drawings. These drawings are often of a poor standard, typical problems are a lack of easting and northing co-ordinates or co-ordinates that have no height to define them and levels which are sporadic, only indicative of the actual position, falls that do not tie up with levels etc. To overcome this it is necessary to interpolate levels to co-ordinates and vice-versa. The use of 2d CAD drawings of the design can assist greatly in the extraction of 2d data leaving only the level to be interpolated.

Projects that have been designed in 3d such as road works that utilise MX, produce outputs that can be readily loaded to ground modelling software and hence the degree of interpolation and hence accuracy is improved.

Similarly topographic surveys undertaken by reputable land survey firms such as Kemp will be readily available in a 3d format suitable for earthworks measurement. However it is often the case with firms that if a suitable 3d output was not requested at survey tender then such data will be withheld or charged for.

Figure 1 – Triangles making up TIN that define the ground model
How Volumes are Computed

For volumes to be computed you must have two overlying surfaces that are representative of an element of the works. For example to measure topsoil you must have original ground levels (OGL) only in one model and topsoil strip levels only in the strip model. The OGL must cover the whole of the strip model, if it does not then the area of the TIN where there is no OGL will not be computed.

To compute the volume the two TIN surfaces are compared by complex vertical prisms where the node (surveyed) points of both surfaces are projected onto the other to form a difference model. The volume of each prism within the difference model is computed and summarised as cut or fill depending on whether it appears above or below the base model.

The software employed by Kemp is able to compute volumes using different methods however it is generally accepted within the profession that Complex Vertical Prisms is the ultimate and most accurate method and hence it is rare for Kemp to use any alternatives. This method takes a triangle from one model and projects it onto the triangles in the other model. Each triangle it overlaps is taken and the intersection polygon calculated. This polygon is then broken down into triangles to form vertical prisms for which the volume is individually calculated.

The results from such an exercise are highly accurate relative to the data given as the effect of every point in both surfaces is taken into consideration.

The main problem with this technique is the amount of processing required to find which triangles overlap. Without an efficient algorithm the time to compare each triangle with all the triangles in the other surface becomes prohibitive - for most computer systems employing this technique it has not been practical except for the smallest of jobs.

This method will undoubtedly give the most accurate volume between two surfaces. The algorithms incorporated into this technique ensure that LSS, which Kemp employ, can produce highly accurate volumes for large models in a very short time.

In order to deal with construction depths such as road make up etc codes may be applied to the triangles to allow the volume to be broken down by type of surface, eg road, grass, footpath, floor slab etc. This is a very simple way to define different areas and, as it is based on the triangles, requires very little extra computation. Each surface code contains the required depth to be applied to the volume.

If zones of interest do not match the points in either survey then a third model with separate codes may be utilised to define the desired ‘boundaries’. This is used primarily to break a scheme into phases of work so that the volume for each phase or section can be identified.

It should be noted that, using this technique, LSS can only produce one answer for the volume between two DTMs - there are no parameters, directions or intervals to specify. The user can concentrate on the correctness of the DTMs without worrying about the accuracy or shortcomings inherent in other types of volume calculation.
Interpolating the detailed printout
It is worth noting and remembering that computer print outs and the mathematics behind them are to the millimetre. The reality of earthworks measurement is interpolation and assumption coupled with survey and engineering judgement.

Assuming the DTM is being compiled from design drawings the features noted below are generally not included in the DTM and hence the volume. However it is possible to incorporate some of them if the client is able to give guidance. Working space would be a good example if the amount of space and the likely angle or repose are known then it can be incorporated into the DTM. Often drainage and footing are easily computed manually by a take off of length of drainage runs multiplied by average depth and trench width, footings can similarly be computed.

If the DTM is compiled from a site survey then the survey may have encompassed any localised excavations for foundations and chambers etc.

Typically the following are NOT generally allowed for and reports should by adjusted by the client accordingly:

- Excavation of footings or foundations below the underside of floor construction.
- Excavation of drainage runs or drainage tanks, chambers or soakaways.
- Excavation of services.
- Excavation for working space. This is often backfilled with imported material to items such as retaining walls.
- Bulking or compaction (ie if you dig a hole the resultant spoil may bulk say 30% when being moved in dumpers and then when placed back in the hole and compacted only say 90% will go back in.)
Interpolating the detailed printout

<table>
<thead>
<tr>
<th>Surface Description</th>
<th>Cut area (m²)</th>
<th>Cut volume (m³)</th>
<th>Fill area (m²)</th>
<th>Fill volume (m³)</th>
<th>Total area (m²)</th>
<th>Net volume (m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PH1 - Phase 1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PH1 - Main area</td>
<td>1503.120</td>
<td>-1661.806</td>
<td>707.966</td>
<td>574.031</td>
<td>1979.454</td>
<td>-1166.686</td>
</tr>
<tr>
<td>PH1 - Outer area</td>
<td>1197.840</td>
<td>-1185.177</td>
<td>438.177</td>
<td>267.059</td>
<td>705.137</td>
<td>-434.562</td>
</tr>
<tr>
<td>PH1 - Utilities</td>
<td>200.201</td>
<td>-245.559</td>
<td>31.530</td>
<td>5.296</td>
<td>231.091</td>
<td>-240.464</td>
</tr>
<tr>
<td>PH1 - Block Vehicles</td>
<td>63.254</td>
<td>-17.116</td>
<td>106.056</td>
<td>142.563</td>
<td>249.322</td>
<td>145.369</td>
</tr>
<tr>
<td>PH1 - Class in parking</td>
<td>53.932</td>
<td>-5.239</td>
<td>104.588</td>
<td>49.161</td>
<td>157.970</td>
<td>-60.587</td>
</tr>
<tr>
<td>PH1 - Block Models</td>
<td>219.418</td>
<td>-143.105</td>
<td>195.754</td>
<td>307.574</td>
<td>591.229</td>
<td>3.949</td>
</tr>
<tr>
<td>PH1 - Traffic Models</td>
<td>590.625</td>
<td>-101.650</td>
<td>777.472</td>
<td>1783.794</td>
<td>2759.324</td>
<td>1945.630</td>
</tr>
<tr>
<td>PH1 - Block Footway</td>
<td>101.164</td>
<td>-4.701</td>
<td>272.032</td>
<td>307.228</td>
<td>474.065</td>
<td>213.127</td>
</tr>
<tr>
<td>PH1 - Service play</td>
<td>54.743</td>
<td>-1.243</td>
<td>1808.762</td>
<td>3729.593</td>
<td>5638.035</td>
<td>3718.350</td>
</tr>
<tr>
<td>PH1 - Access Model</td>
<td>176.445</td>
<td>-20.979</td>
<td>197.792</td>
<td>399.989</td>
<td>597.781</td>
<td>396.382</td>
</tr>
<tr>
<td>PH1 - Soft landscap</td>
<td>223.106</td>
<td>-215.031</td>
<td>601.932</td>
<td>2132.030</td>
<td>2733.962</td>
<td>401.927</td>
</tr>
<tr>
<td>PH1 - Other</td>
<td>58.432</td>
<td>-53.045</td>
<td>193.534</td>
<td>241.373</td>
<td>295.506</td>
<td>227.960</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>2903.662</td>
<td>-1555.195</td>
<td>6306.466</td>
<td>8737.726</td>
<td>15147.102</td>
<td>5162.515</td>
</tr>
</tbody>
</table>

This first part shows the volumes within the area described as "PH1 - Phase 1". This only appears if the site is being divided into specific areas not just surfaces.

Each column shows the plan area of cut, followed by the volume of cut, the plan area of fill and the volume of fill for each surface within the phase 1 area. They are then totalled. The net volume is the difference between the cut & fill volumes and assumes that all cut will be used as fill on site. The area of a surface can often be used in other quantities such as sub-base when the area can be multiplied by the depth of sub-base required below the block paving for example.

These are the totals within phase 1, the total cut is 3595 cu m, the total fill is 8757 cu m and the balance of these two is 5162 cu m

This area described as undetermined relates to an area where the two models being measured do not overlap eg where there the original topographic survey is outside the area of the works. This area will have been identified & checked as being correct by the surveyor carrying out the volume computations.

This part shows the volumes within the area described as "PH2 - Phase 2". All the figures below relate to phase 2 only.

The name of the 2 models that are being compared. The "first survey" is design1 and the "second survey" is original

In this case the volumes are being sub divided into separate areas of the site, this is the name of the survey that controls areas that the site is divided into, not all printouts will have this.

These are the surface codes and descriptions that have been used in the volume. See the end of the printout to see if any of them have had a depth applied.

Any part of the model that has no surface applied is describe as "None" A volume is still computed however.

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- Setting Out
- GPS Surveys
- Earthworks Measurement
- Topographic Surveys
- Measured Building Surveys
- Site Engineering
- Elevations & Street Scenes
- Sections
- Non-Contact Measurement
- Initial Site Set Outs
- Utility Surveys
- Site Visits
### Interpolating the detailed printout

These are the totals within phase 2 only, the total cut is 7681 cu m, the total fill is 279 cu m and the balance of these two is -7401 cu m. Note that - is used to show cut, in this case 7401 cu m is surplus within phase 2.

This section shows the totals of phase 1 and phase 2 combined, i.e., the whole project.

The code "Void" is used by the surveyor to prevent areas from being measured. This could be for a variety of reasons such as where the model is not valid such as an "island" of the site that is surrounded by work but is itself unaltered.

These are the totals within both phase 1 & phase 2.

<table>
<thead>
<tr>
<th>Surface Description</th>
<th>Out Area (m²)</th>
<th>Cut Volume (m³)</th>
<th>Fill Area (m²)</th>
<th>Fill Volume (m³)</th>
<th>Total Area (m²)</th>
<th>Net Volume (m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soft landscape</td>
<td>242.214</td>
<td>-100.123</td>
<td>51.046</td>
<td>0.704</td>
<td>274.064</td>
<td>-193.309</td>
</tr>
<tr>
<td>Base</td>
<td>42.130</td>
<td>-41.357</td>
<td>11.130</td>
<td>4.553</td>
<td>53.440</td>
<td>-39.405</td>
</tr>
<tr>
<td><strong>Undetermined</strong></td>
<td><strong>475.349</strong></td>
<td><strong>-7401.239</strong></td>
<td><strong>566.650</strong></td>
<td><strong>279.666</strong></td>
<td><strong>1359.710</strong></td>
<td><strong>-7401.239</strong></td>
</tr>
</tbody>
</table>

**Volume between survey 1** - design model

**Volume between survey 1** - original tops

### Additional Information
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The summary confirms that fill is identified as being when the first survey (in this case the design) is above the "second survey" (in this case the original levels) this can be reversed if required.

This shows that 8.9 sq m has been coded to prevent measurement being carried out by the surveyor. That 0.001 sq m of the design model has not been measured as there is no overlap with the original levels and that there is 7479 sq m of the original topographic survey that is outside of the design.

This shows what depth has been allowed for construction make up in the design and hence not included in the volume. In this case the floor make up in the building code B has been allowed to be 465mm thick. This is worth checking as it is often necessary to make assumptions as to what depth to allow for in each element. These depths can very easily be altered.

This shows what depth has been allowed for topsoil strip in the original topographic survey and hence not included in the volume. Soil strip may not always be shown as a depth in this manner it is sometimes allowed for by transforming the levels in the original ground levels if they all relate to a single field for example. Note that the volume of soil strip could be easily computed by multiplying the area 8930 by the depth 0.3.

| Surface(s) in second survey reduced for the following depth(s) / area(s): |
|-----------------|------------------|
| 0 | 0.360 (m³) | 8930.732 (m²) |