Model Setup IDM - "How to Setup Geo-referencing in a Building or Linear Infrastructure Model"
Appendix B: Geo-referencing BIM

Gateway to Melbourne, Australia. Source: Fender Katsalidis, Architects

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buildingSMART
AUSTRALASIA

Geo-referencing BIM

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Version History

Version	Date	Scope	By
0.1	7 July 2016	First draft	JMi
0.2	2 Aug 2016	Coordinating Data from Sites with Differing Scales section added, Use Cases section draft added	LGr, PPa, NBr, JMi
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2.0	Dec 2019 Jan 2020	Document edited as a User Guide and technical report for bSI publication	JMi & JP

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1   Introduction

This document is aimed at all building or infrastructure (generically built asset) modellers, to robustly establish the guiding model set-out parameters - map location and site configuration - for their particular asset model.

This IDM defines a standardised way for setting up a multi-disciplinary project model using the IFC open standard format data.

Often a collaborative model project has work commenced without definition of shared model setup. The result is that when commencing design coordination, clash detection etc the discipline models are not in the same location and/or have different storey names and settings, incomplete project information etc.

This document additionally defines a standard way of incorporating Cadastral data as a starting point of accessing explicit land zoning and planning data.

Information to be defined in the model setup template includes:

- defining the cadastre, urban context, terrain, site elements
- setting the project reference location & design grids
- defining paper North for documentation & model location for export
- defining storey and/or vertical/horizontal zoning
- specifying the spatial organisation structure (ifcProject, ifcSite, ifcBuilding, ifcStorey) & their GUIDs for collaboration synchronisation

Having established a model template based on the above, a procedure is defined to inform all project members and adopt a testing methodology to ensure compliance.

- exporting & testing of the project Master Template
- using a test object to ensure geometry, location, and object semantics
- checking IFC settings in authoring tools
- creating a native discipline model by each team member
- coordinating IFC Entity mapping with project team members
- performing iterations and validation of a team model

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2   Coordinating Data from Sites of Differing Size[1]

A small Site is one which fits into a 1 Km square.

A large Site may extend over tens, or even hundreds, of kilometres.

In such a large site, there is at least one common feature that covers the whole site but usually there are also many distinct smaller sites that are worked on separately but still have to be totally coordinated within the overall site.

For example, a road over tens of kilometres would be the large site but within that site could be many bridges and/or small structures such as buildings that are part of the whole project.

2.1   The Objective

We want to work with a large site (for example a long road) but also be able to bring data in from many smaller sites (Site 1, Site 2 etc.) where:

- Site 1 knows nothing about Site 2 and Site 2 knows nothing about Site 1.
- Site 1 has its own local coordinate reference system with its own local origin.
- Site 2 has its own local coordinate reference system with its own local origin.
- We want the procedures to be applicable to anywhere in the world.

For simplicity we assume that all sites use the same unit of measurement for coordinates and heights. For example, metres.

2.2   A World Coordinate Reference System

How do you define a unique coordinate reference system that is applicable anywhere in the world when the world is not flat?

Because the world is very close to an ellipsoid (a sphere that is squashed in a bit at the top and the bottom) it is possible to fit an ellipsoid to the average shape of the Earth and use longitude, latitude and distance from the surface of the ellipsoid (ellipsoid heights).

So, we'll look at how longitude and latitude are actually defined, and what we mean by height. But first we need to set up the terminology that we will use because as we will see, without precise definitions, significant error can be made when bringing data together.

2.3   Datums and Coordinate Reference Systems

Because of the difficulties in accurately mapping the Earth, and with additional complexities such as continental drift, it is important to define the major terms being used so that everyone is working with the same vocabulary and understands why certain things are always needed in specifications.

The word datum is regularly used in mapping.

A datum is a definition of space, using the minimum set of independent parameters so there is no ambiguity.

A datum maybe:

(a) Geodetic

A geodetic datum describes the relationship of a 2D or 3D coordinate reference system to the Earth. For example, Longitude, Latitude and Ellipsoid height.

(b) Engineering (flat earth)

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[1] Peter Parslow, UK Ordnance Survey, Neil Brown, Listech and Lee Gregory, 12d Solutions (editor) are the authors of this section.

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(c) Vertical (height or depth)

For example, the Great Britain Ordnance Datum Newlyn, Dutch Ordnance Datum, or the Australian Height Datum.

A coordinate system is a mathematical model for describing a coordinate. For example, (longitude, latitude, ellipsoid height) or (Easting, Northing).

There are basically three coordinate systems of interest to Surveyors

(a) Cartesian. These may be

- Earth-Centred, Earth Fixed (ECEF) XYZ

This is an important coordinate system.

The origin (0,0,0) is at the centre of mass of the earth, the Z-axis a line from the geocentre through the internationally defined pole (International Reference Pole IRP), the X-axis is a line from the geocentre through its intersection with the International Reference Meridian (IRM) and the Y-axis is extended from the geocentre along a line perpendicular from the x-axis in the same mean equatorial plane towards 90 degrees East Longitude.
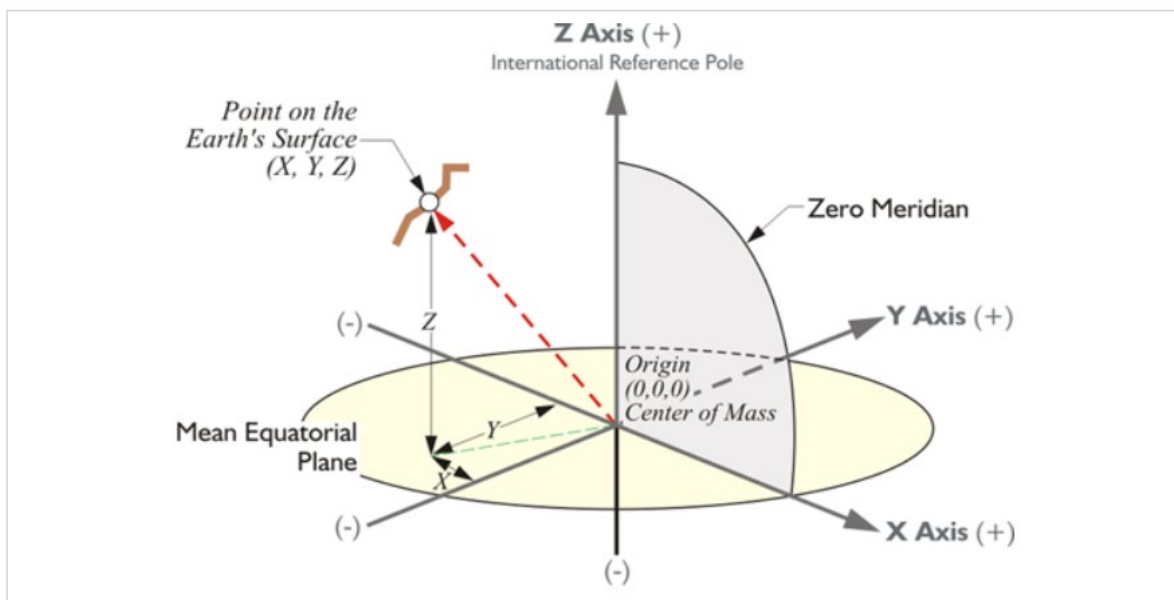
Figure 1:   Three Dimensional Cartesian Coordinate (ECEF)[2].

Any position on Earth can be given an XYZ coordinate. Although these coordinates are useful for geodetic calculations they are not useful for everyday work.

- Projected (onto a plane) as Easting and Northing

Projections will be discussed later.

- Engineering grids (flat earth).

(b) Ellipsoidal - longitude, latitude and ellipsoid heights

(c) Height: nominally orthometric heights/depths

Each of (b) and (c) are explained in more detail below.

A Coordinate Reference System (CRS) has two parts:

(a) Datum

(b) Coordinate System

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[2] Source: GPS for Surveyors

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A coordinate reference system may be 3D (three axes), 2D or 1D (height).

A Compound CRS (CCRS) includes two, or more, CRSs, but it is common practice to describe CCRS simply as a CRS.

2.3.1   Ellipsoids and GPS

Today, it is widely accepted that the Earth's shape is best approximated by an ellipsoid that has been revolved around the Earth's polar axis. Put another way, the shape is a sphere that has been squashed at the north and south poles. The non-spherical shape is due to the earth spinning.

The most common way of defining an ellipsoid is by describing the semi-major axis value and an inverse flattening value (this parameter describes the "squashing" of the ellipse).
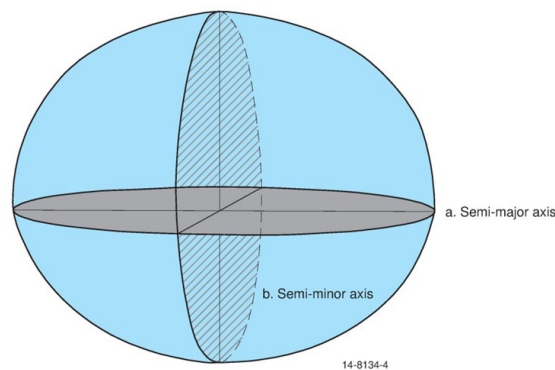
Figure 2:   Ellipsoid Axes.

Over the years a number of ellipsoids have been used to best approximate the Earth's shape,

The "best fit" is usually concerned with matching a locally definition of zero height (the Earth's equipotential gravity field) to a geometric ellipsoid shape.

As such, there is a wide number of definitions for such an ellipsoid and it depends if you were after a best fit for a region (e.g. a country) or the whole world.
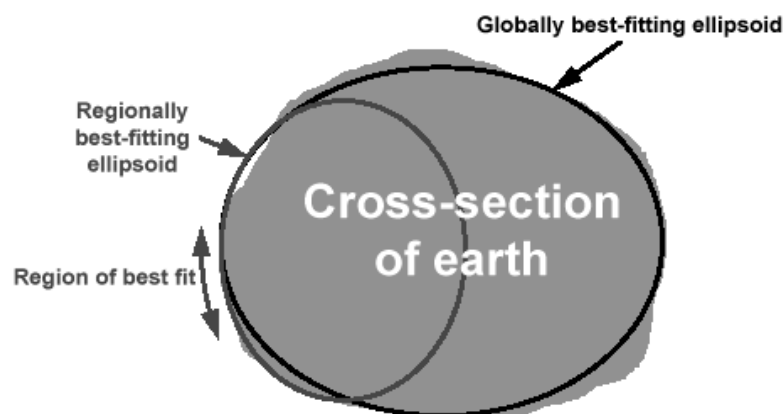
Figure 3:   Earth Ellipsoid Cross-section

But with the advent of the US Department of Defence's Global Positioning System (GPS) which uses satellites, things changed.

All satellites orbit around the centre of mass of the earth so using an ellipsoid with its centre at the centre of mass of the earth is best for working with GPS. That is, use an Earth centred (geocentric) ellipsoid. With the centre fixed, the semi-major axis and flattening that best matches the earth as a whole can then be chosen.

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The 1980 Geodetic Reference System (GRS80) posited such an Earth centred ellipsoid with semi-major axis 6,378,137.0 and inverse flattening (1/f) of 298.257222101.

This GRS80 ellipsoid was adopted at the XVII Generally Assembly of the International Union of Geodesy and Geophysics (IUGG). GRS80 is now used by many mapping systems around the world.

Some commonly used ellipsoids, now and in the past, are:

Table 1:   Commonly Used Ellipsoids

Example	Ellipsoid	Semi-major axis/ Inverse Flattening (m)	Notes
Maupertuis 1738	Maupertuis	6,397,300 191	This ellipsoid was used in France.
Airy 1830	Airy 1830	6,377,563.396 298.3249646	This ellipsoid is used in Britain for the Ordnance Survey National Grid OSGB36 coordinate reference system.
Australian National	ANS	6,378,160 298.25	This was the ellipsoid used in 1966 to define the Australian Geodetic datum (AGD 84) used for AMG (Australian Map Grid) calculations and ISG (Integrated Survey Grid) coordinates
NZ Geodetic 49	NZ Geodetic 49	6,378,399.065 297.0	This was the ellipsoid used to define the NZ 1949 Geodetic datum. The semi-major axis given here has been adjusted to compensate for errors in units conversion from links to meters.
Geodetic Reference System 1980	GRS80	6,378,137.0 298.257222101	As previously mentioned this was the ellipsoid adopted by IUGG in 1979. It is used in the North American Datum of 1983, in the European Terrestrial Reference System 89 ETRS89, in Australia's Geocentric Datum of Australia GDA 94 (used for MGA-Map Grid of Australia calculations), the New Zealand's NZGD2000 datum as well as most other geocentric Earth model datums around the world.
World Geodetic System 1984	WGS84	6,378,137.0 m 298.257223563	This ellipsoid is currently used by Global Positioning Systems. It is used by the US Department of Defence and for the London Survey Grid for the Crossrail project. The ellipsoid GRS80 was originally used in the World Geodetic Systems 1984 (WGS84) but this ellipsoid was later changed to WGS84. The small difference in the flattening results in a tiny difference of 0.105 millimetres in the semi polar axis.

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2.3.2 Longitude, Latitude and Ellipsoid Height

Once the coordinate reference system (including the ellipsoid) is defined, a position on the Earth's surface can be uniquely described in terms of Longitude, Latitude and Ellipsoid height and these are commonly known as Geodetic coordinates.

Longitude is an angular quantity measured from the Greenwich meridian in London. It is most commonly described in terms of degrees, minutes, seconds (or a decimal number), East or West of the Greenwich meridian.

| Longitude | Latitude | Earth System |
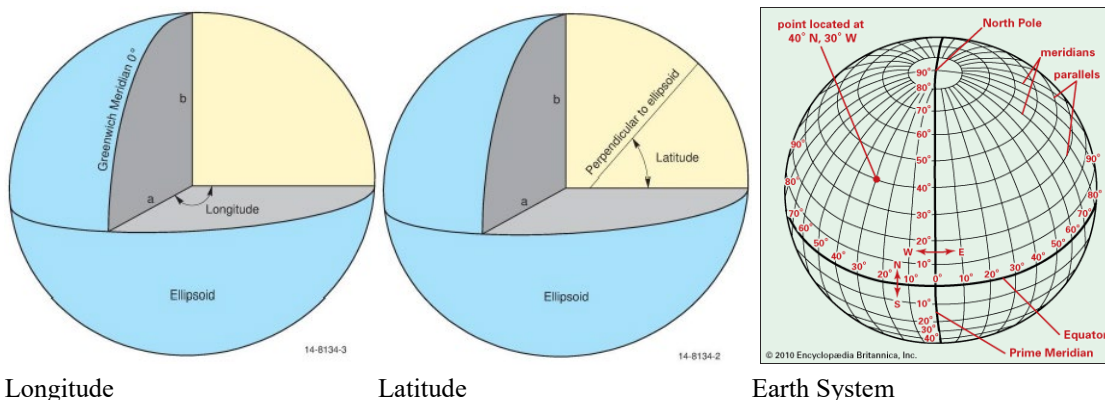
Figure 4:   (a) Longitude, (b) Latitude, (c) Earth System.

Latitude is an angular quantity measured from the equatorial plane, to the plane defined by the point position and the perpendicular line to the ellipsoid surface. It is most commonly described in terms of degrees, minutes, seconds South or North to the equator.

Examples are 50°40'46,461"N 95°48'26,533"W or -35.89421911 139.94637467[3]

The ellipsoid height, h, of a point is the height of the point above the reference ellipsoid. With such an ellipsoid a GPS can be used to find the latitude, longitude and ellipsoid height without needing to refer to anything else on the ground.

2.3.3 Heights

Heights as most people think of them, are usually defined by the equipotential gravity field.

Or more simply, two heights are the same if water will not flow between them. One height is greater than another if water flows from one to the other. Gravity is what determines how water flows so the definition of equal heights is defined by gravity.

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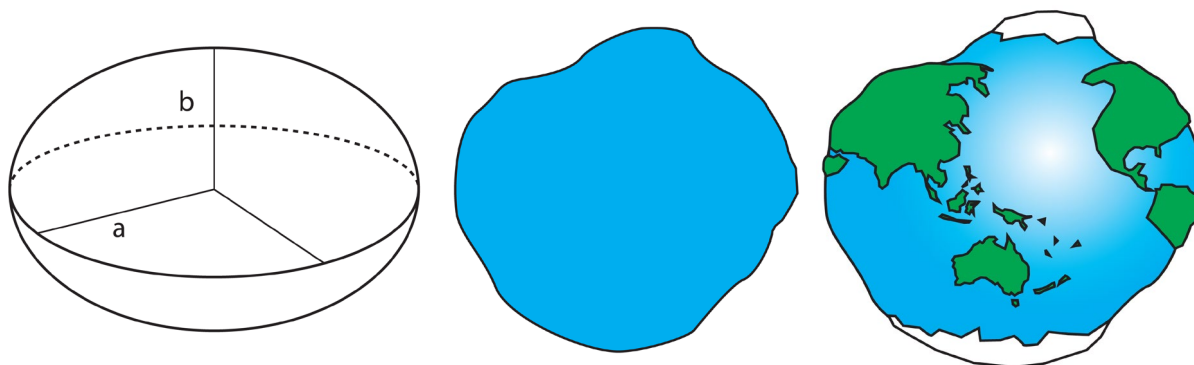
[3] see ISO_6709 for details of the formats,

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Earth as an Ellipsoid   Earth as a Geoid   Earth's True Shape & its Terrain

Figure 5:   Theoretical & actual representations of the Earth

To date there is not one height system for the whole world and most countries or regions define what is called a geoid which is a surface that corresponds closely to mean sea level and its imagined extensions under (or over) the land area.

The geoid is height zero and heights measured from a geoid are known as geoid or orthometric heights.

Most height datums are not based on ellipsoid height but are based on the geoid e.g. OSN in Great Britain and AHD in Australia.

As gravity does not come into the ellipsoidal definition, orthometric heights and ellipsoid heights are two different things.

So ellipsoid heights from GPS observations need to be corrected to a geoidal (orthometric) height. To do this, we require the separation or gap between the two different surfaces at any point. This separation is known as the N value.

The N value is generally non-zero and varies with latitude, topography and geology.
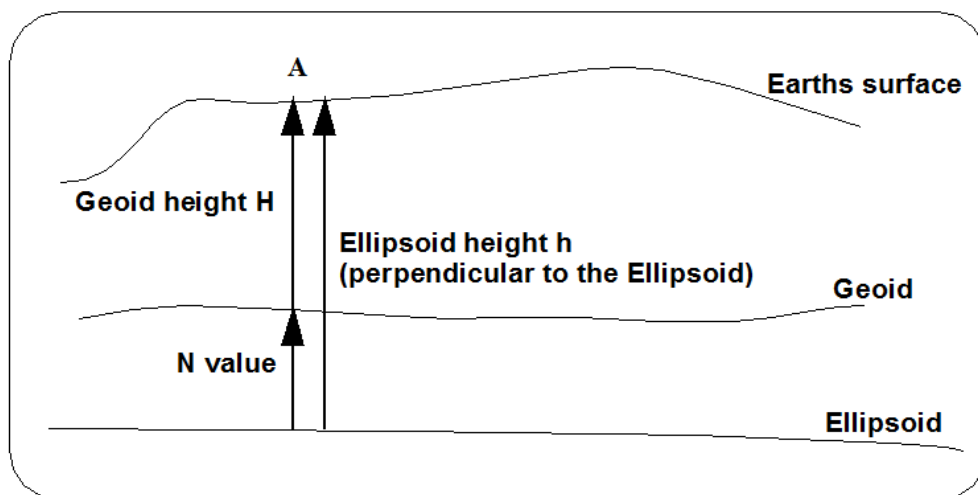
Figure 6:   Ellipsoid Height

The Ellipsoid height = Geoid height + N value

 or

   h=H+N

N values can be defined in a geoidal model such as Geo-referencing BIM [4] which represents grids of N values over all of Australia.

For a given Geodetic coordinate, an N value can be interpolated from the model and applied to the ellipsoid height to give a geoidal height.

Similarly, the N value can be used to convert a geoidal height to an ellipsoid height.

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[4] see http://www.ga.gov.au/ausgeoid

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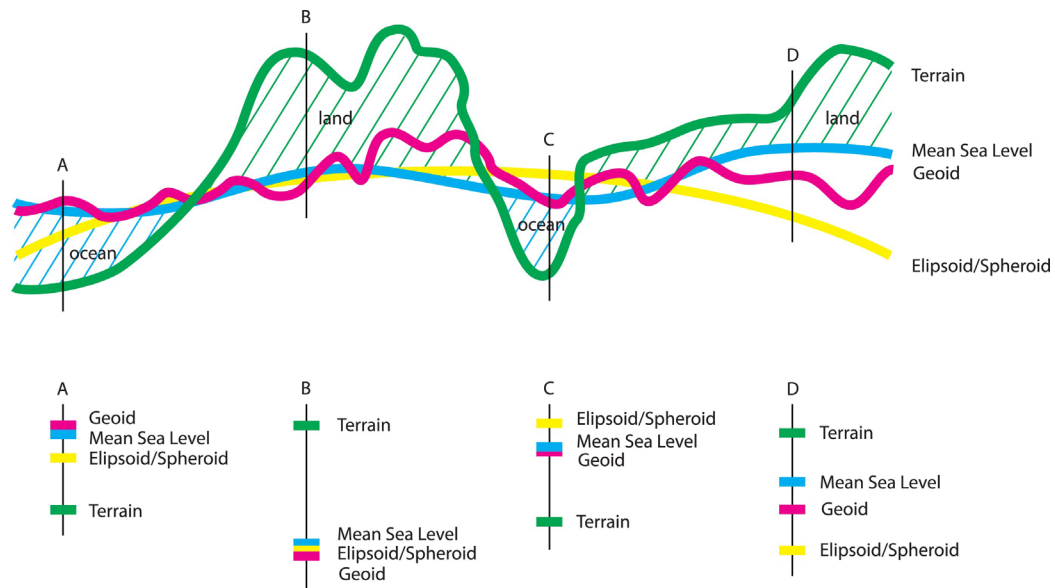
Figure 7:   Four examples to describe how ellipsoid height relationships may change[5].

A and C show the Earths' terrain as being below Mean Sea Level - this is equivalent to an area of ocean. Note how the Geoid and Mean Seal Level are very close to the same value, but their relationship to the Ellipsoid/Spheroid varies. B and D show the Earths' terrain as being above Mean Sea Level - this is equivalent to an area of land. It is worth noting that the differences between the Geoid and Mean Seal Level is much greater than in the ocean examples. And, similarly, their relationship to the Ellipsoid/Spheroid varies.

2.3.4 Plate Tectonics - Continental Drift

We now have a coordinate reference system that gives us a unique coordinate for anywhere on the earth but there is one small hitch - continental drift. For example, Europe and the United States are drifting apart at approximately 2.5cm per year

The definition for zero longitude was the meridian of Greenwich but due to continental drift, over time the land masses move around with respect to each other and with respect to the meridian of Greenwich.

This leads to the use of either a static or a dynamic datum:

(a)   a static datum is fixed to a continental land mass and the coordinate of a point is fixed in time. Hence positions need to be referred to where things were at a given instant in time (an epoch). Due to continental drift, this means that the datum slowly distorts.

The horrors of working with coordinates that change over time has meant that most datums to date have been fixed datums. For Australia, the GDA 94 coordinate reference system is a fixed datum and uses the ellipsoid GRS80 with a reference epoch 1994.0.

So the Eastings and Northings and longitude and latitude for a point must be adjusted back to where that point was at that epoch.

(b)   a dynamic datum is fixed to the stars (quasars). A dynamic datum is independent of continental drift and the tectonic motion is described by a velocity field. The coordinate of a point changes over time so the epoch of the observation must also be recorded. That is, they are 4D coordinates.

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[5] Note that for this diagram the relationship between these four has been exaggerated to understand better the nature of this 'wobbling'. **Source:** ANZLIC Intergovernmental Committee on Surveying & Mapping

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An example of a dynamic datum is the one used for GPS which is referred to as WGS84. Unfortunately this is the same name as the name given to the ellipsoid the datum uses so one has to be careful what is being referred to when just WGS84 is mentioned.

GPS uses the ellipsoid called WGS84 but the WGS84 coordinates of tracking stations used to computer the GPS broadcast orbit are adjusted annually for tectonic motion to an epoch at the half year mark.

Hence the WGS84 (GPS) position of a point must also have an epoch attached to it. For example WGS84(G1150) where 1150 is the number of weeks since January 1980.

Most people are not aware that GPS uses a dynamic datum

In January 1994, GDA94 and WGS84 (the datum) were coincident (apart from the slight difference in the chosen ellipsoid which is insignificant for most practical applications) but as the Australian tectonic plate is moving at about 7 cm per year in a north easterly direction, there is an increasing difference in positions in terms of the two systems. This will amount to about a 1.8 metres difference between the two systems by 2020.

So the coordinates from the dynamic datum that GPS uses need to be transformed to the static datum GDA94 and this transformation changes over time.

For Australia there is a 14 parameter transformation published to use for going from GPS to GDA ECEF XYZ coordinates where seven parameters are the normal 3D Helmert parameters between coordinate systems and the other seven are for time.

2.3.5 How We Draw Things and Map Projections

Although every position on the earth has a unique Geodetic Coordinate (longitude, latitude, height) in a given coordinate reference system and you could design things in a grid of longitudes and latitudes, working in such a system would be very difficult. Just calculating the actual ground distance between two points given in latitude and longitude would be a nightmare.

So to represent ellipsoid data on a flat surface for mapping, it is necessary to use a map projection.

Map projection enables points on the ellipsoid surface to be mathematically projected onto an imaginary developable surface. That is, onto a surface that can be "rolled out flat".

So for a plane
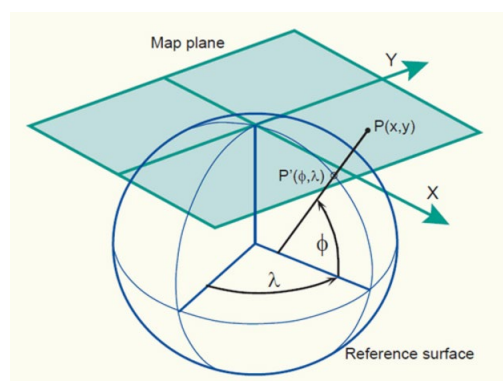
Figure 8: Map Plane Projection.

However typically, this surface is a cylinder or a cone.
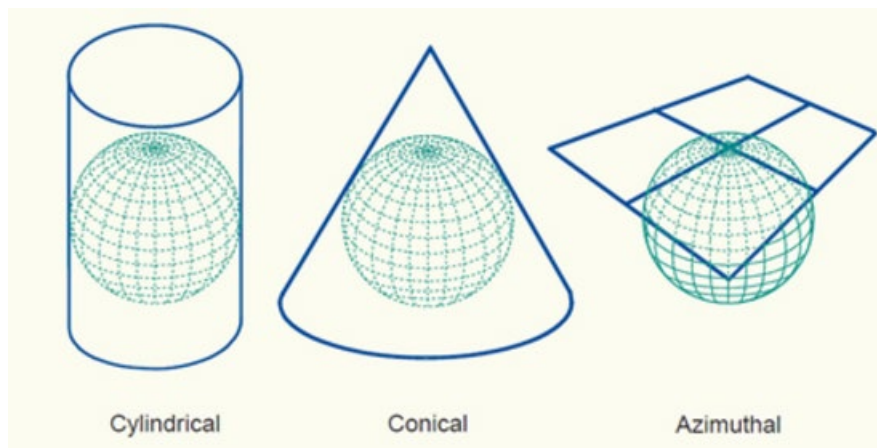
Figure 9:   Map Projection Types.

It is impossible to wrap a flat piece of paper over the entire globe without it wrinkling so the one map projection can't cover the entire globe. But it is rare to have a project that scans the whole globe so a map projection can usually be chosen to best suit the project.

The important thing about a map projection, is that in the region you are working in, you can go from a longitude and latitude to a unique map coordinate, and also from a map coordinate back to a unique longitude and latitude.

So once a map projection has been defined, you can use the map coordinates or longitude and latitude to uniquely define a point.

The x and y coordinates in the map projection are often called Eastings and Northings.

It is important to note that the distance between two points over the surface of the ellipsoid is different to the square root distance between the projection of the two points onto the grid on the flat piece of paper. And what that difference in distance is depends on the map projection being used.

So the standard square root distance using the coordinates given in Eastings and Northings is NOT the distance on the ground between those two points.

It is also important to note that even though different map projections may be used for a region, as long as they are based on the same coordinate reference system (and hence the ellipsoids used must be the same), then for a given point it is always possible to take the coordinates in one map projection and calculate the unique longitude and latitude for that point, and then calculate the unique coordinate for that same point in the other map projection.

So you can go between two map projections that are based on the same ellipsoid without anything. But beware, the calculations may be complex[6].

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[6] and should be undertaken by a professional Land Surveyor!

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2.3.6 Transverse Mercator Projection

A commonly used map projection is the Transverse MercatorTM projection.

The Transverse Mercator system projects coordinates onto a cylinder that rather than being upright, is tangent to a point on the equator and the entire length of a Meridian of Longitude (called the Central meridian).

Equator

Meridian of Longitude
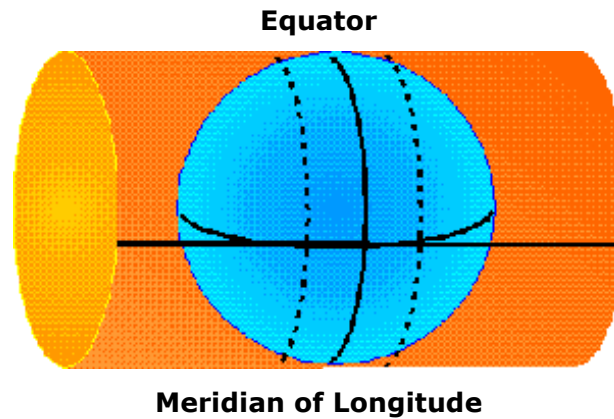
Figure 10: Transverse Mercator Projection tangential to a meridian of Longitude

The Transverse Mercator projection also has a secant form where the size of the cylinder is reduced by a given factor called the scale factor of the Transverse Mercator projection.

When the scale factor is less that one, the cylinder slices through the ellipsoid along two lines - one on either side of the Central meridian.
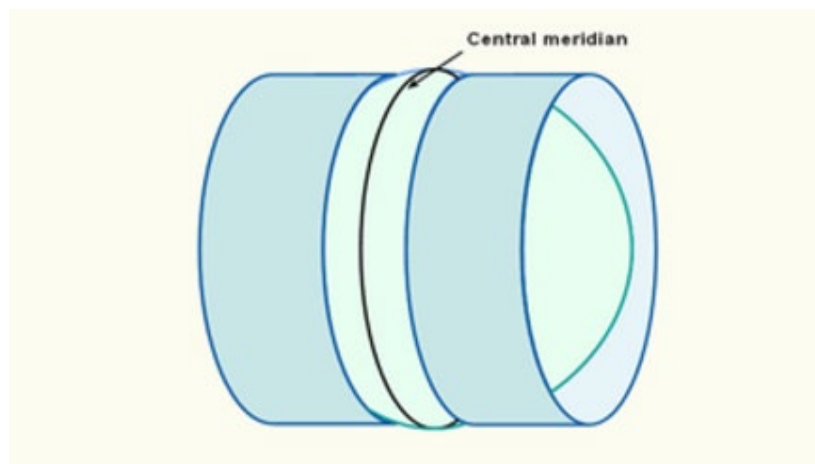
Figure 11: Secant Transverse Mercator Projection form, reduced by a scale factor.

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So looking at a slice through the equator, for the Transverse Mercator and the Secant Transverse Mercator we have:
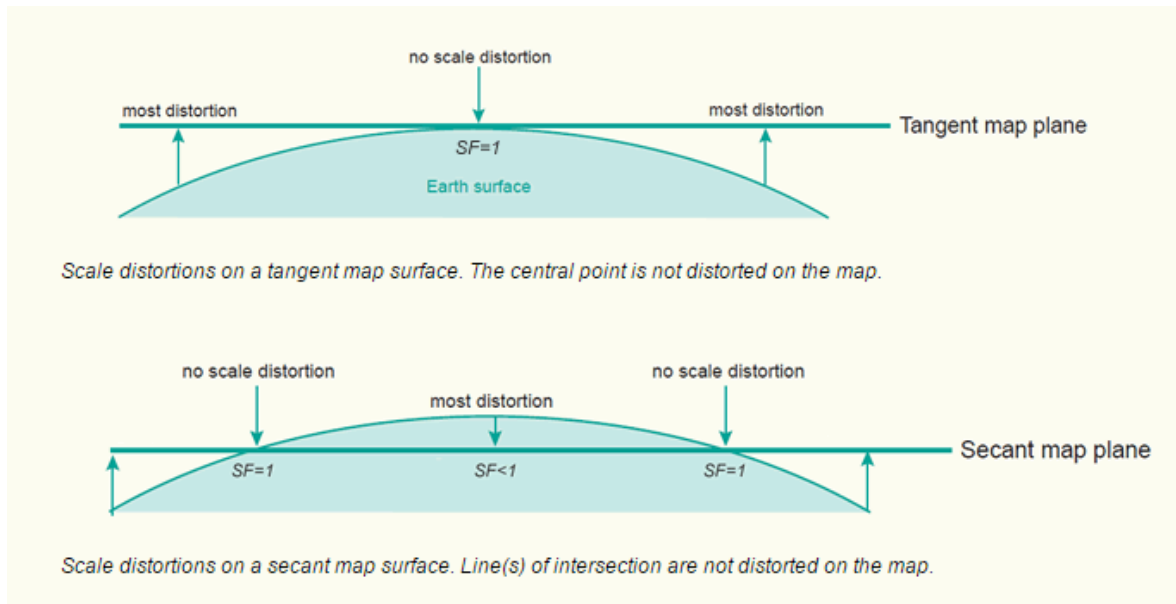
Figure 12: Transverse and Secant Transverse Mercator distortions compared.

In the diagrams it is easy to see that the distance between two points on the slice through the sphere will not be the same as on the grid on the unrolled cylinder and the distortion varies depending on the point's position in relation to the central meridian.

This distortion of scale is called the scale factor and for any map projection it varies from point to point.
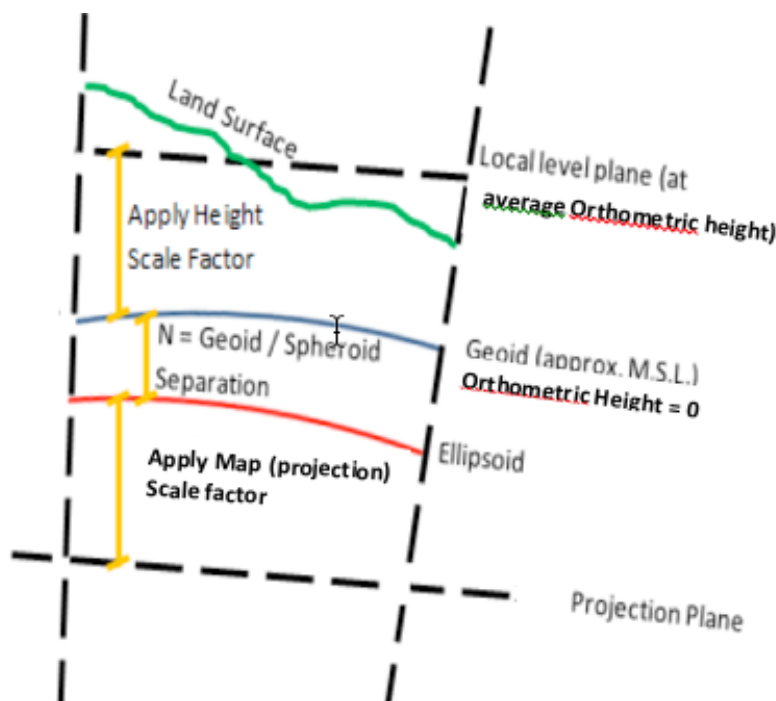
Figure 13: The relationship of the combined factors in determining heights.

Figure 13 shows the relationship of the combined (Height Scale factor x Map Scale factor) and the change from Local Ground distance to the Grid (projection) distance.

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The Secant Transverse Mercator projection is probably the most widely used around the world, especially as it is the basis of UTM described in the next section, although the Lambert Conformal Conical Projection (which is base on a cone instead of a cylinder) is sometimes used when the area is much wider east-west than north-south (e.g. some East-West States such as Tennessee in the USA).

See here ESRI resources: Tables 1 and 7 in "Geographic_coordinate_systems.pdf" provide a list of geodetic and vertical datums used in various areas of the world, respectively. Table 2 in "Projected_coordinate_systems.pdf" provides a list of projected spatial reference systems with their area of use.

http://resources.arcgis.com/en/help/main/10.1/018z/pdf/geographic_coordinate_systems.pdf
http://resources.arcgis.com/en/help/main/10.1/018z/pdf/projected_coordinate_systems.pdf

See the Crossrail project in the Case Studies for an example of UTM used for setting out a large linear infrastructure project Transverse Mercator for London Survey Grid for Crossrail.

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2.3.7   UTMs and Zones

The Universal Transverse Mercator (UTM) projection splits the world into 60 zones of 6 degrees of longitude. The zone numbering starts at longitude 180 degrees West.

Each of the 60 zones uses a Secant Transverse Mercator projection with a Transverse Mercator scale factor of 0.9996 and the longitude at the centre of each zone is the central meridian of the (secant) Transverse Mercator projection for that zone. As such, by supplying a zone number, a number of parameters about a projection can be deduced.

Figure 14:   UTM Grid Zones of the World.

 As smaller example, Australia is covered by the UTM zones 49 to 56.

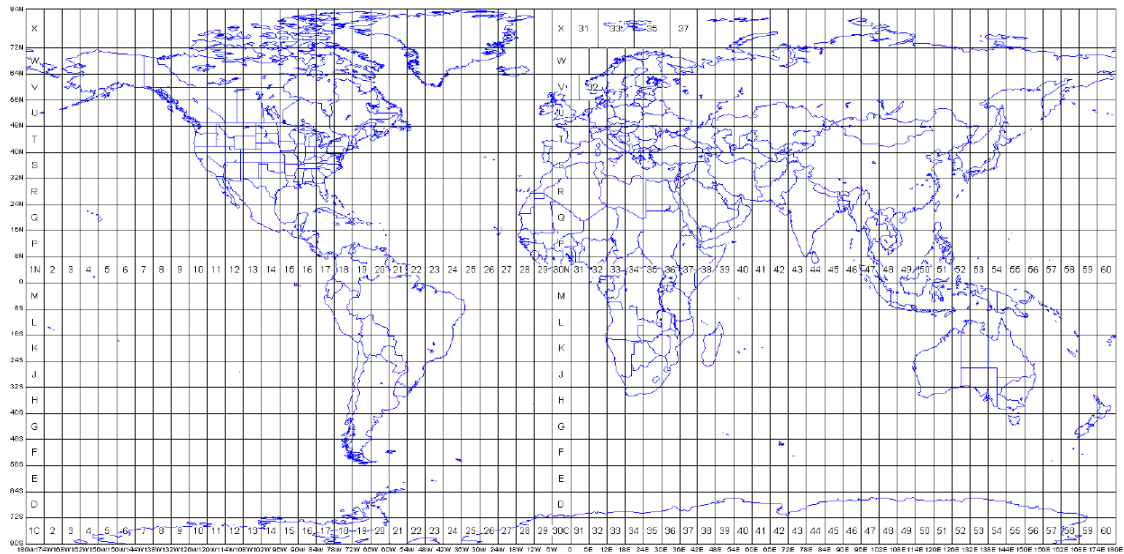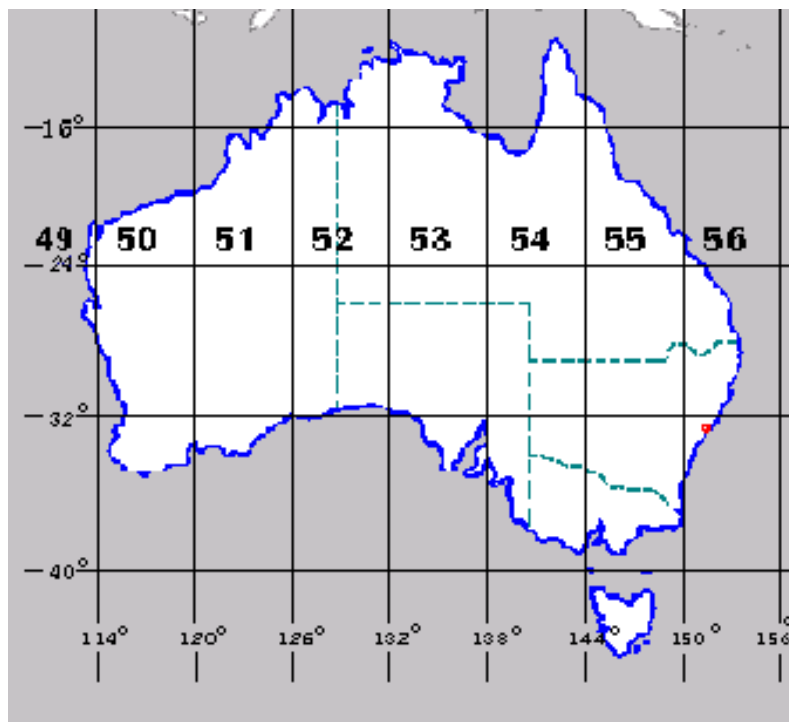**Figure 15:**   UTM Grid Zones for the Australian Continent

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The UTM projection is designed to cover the world, excluding the Arctic and Antarctic regions.

To avoid negative coordinates for positions located west of the central meridian, the central meridian has been given a (false) Easting value of 500,000m. The equator has been given a Northing value of 0m for positions north of the equator, and a (false) Northing value of 10,000,000m is allocated to the equator for positions south of the equator.

This is why UTM coordinates are so large.

The Map Grid of Australia (MGA) is a UTM defined on the ellipsoid GRS80.

A Warning on Using Different Ellipsoids

> *In Australia for example, AMG (Australian Map Grid) is also a UTM but it is based on a different coordinate reference system that uses a different ellipsoid to GRS80 used for MGA and so the latitudes and longitudes of the same point on the earth are different and the MGA and AMG coordinates are also different.*

> *Because the ellipsoids are different, going between MGA and AMG is mathematically very complex. And even worse, straight lines in one system do not go to straight lines in the other system and arcs do not go to arcs. So a road or railway defined by arcs and straights in AMG does not map to straights and curves in MGA.*

2.3.8 Height Scale Factor, Combined Scale Factor and Ground Distances

The ground distance between two points not on an ellipse will of course be different to the ellipsoid distance between the projection of the two points onto the ellipse.

For small distances around a given point, the orthometric height is constant and the ratio of the straight line 3D distance between the given point and a nearby point (using orthometric heights) and the ellipsoid distance for the two points is called the Height Scale Factor or the Elevation factor for that point

The Combined Scale Factor (or Ground factor) is defined to be:

Combined Scale Factor = Height Scale factor x Grid Scale factor.

Hence for a small area around a given point (including it's orthometric height), the Combined Scale Factor for that point is a multiplier to convert the 3D straight line distance between the given point and another close point to the map grid distance between the two points.

Conversely, if you have two close map grid points and their orthometric heights, and know the Combined scale factor for one of them, then dividing the 2D map grid distance between the two points by the combined scale factor will give you the ground distance between the two points.

So for close points on a grid (map projection), it you have the orthometric heights for the points and the combined scale factor for that point at that orthometric height, then the 2D grid distance between two close points can be turned into a 3D ground distance.

For maps in State Plane Coordinates in the USA, the Combined Scale factor is also provided for the map. In Australian, Control Marks are given in longitude and latitude, MGA coordinates (grid coordinates – Eastings and Northings), an AHD height and the Combined Scale Factor for that point at that AHD height.

Note: the Height Scale Factor is actually defined to the Mean Sea Level rather than the ellipsoid surface and the calculation of the Combined scale factor will take the N-values into consideration.

2.3.9 Azimuths (Angles) and Norths

Geo-referencing BIM

One final point is that most maps require a North direction and angles to be shown. However just as we have a number of different distances, we also have different Azimuths and Norths.

- Magnetic North – north as given by a compass.
- Geodetic Azimuth – derived from the inverse between two points of known latitude and longitude.
- "True" Azimuth – this is derived from astronomic observations and can usually be considered the same as a geodetic azimuth.
- Geodetic North – direction to the Polaris
- Grid Azimuth – derived from the inverse between two points defined in Northing and Easting. That is the standard calculation for an angle between the coordinates for two points.
- Grid North is the north on the map grid. That is, straight up the page.
- Project/Plan North – the Grid north model can be adapted to a very localised limited area. The typical example is "plant grid" where an assumed north is used, with all with all directions and coordinates rotated to that basis

The important thing is that these are all different and it is imperative that for the overall project it is define what is to be used otherwise errors will occur when bringing Sites together.

In particular if a local project north is used, the relationship (angle) to the overall project system is required. For example, if the Overall project is in a Map Projection, then the angle between the local Project north and Grid north is required.

Geo-referencing BIM

2.4   The Objective Resolved

Our objective was that we wanted to work with a large site such as for a long road but also need to be able to bring data in from smaller sites Site 1 and Site 2 in such a way that:

- Site 1 knows nothing about Site 2 and Site 2 knows nothing about Site 1.
- Site 1 has its own local coordinate reference system with its own local origin.
- Site 2 has its own local coordinate reference system with its own local origin.
- We want the procedures to be applicable to anywhere in the World.

For this to happen for the overall project, all we need is to define a suitable coordinate reference system (a datum and a coordinate system) which usually has a map projection so that Easting and Northings (longitude and latitude) and heights can be used anywhere over the entire site.

The large scale structures for the project (the road or railway, or the layout of a whole town) are designed in that selected project map projection.

The distances on the map grid are not the same as ground distances but for such a large scale project there will be people with sufficient surveying knowledge to position things correctly from the map coordinates.

But what about the designer of say a building on Site 1 somewhere inside the large overall site?

Or the people constructing the building who are wanting to use plans and drawings where the relationship to the distance on the ground is not distorted so they can use their standard tape measures to set things out?

These people need to use a local coordinate system, with an origin somewhere conveniently located in the building site Site 1, with an x-axis that lines up with something easy to use on the ground (for example the side of the building) and the units of measurement are identical to the units on the ground. That is, the units of measurement are not distorted and you can use them to set things out using tape measures etc. Also heights on Site 1 may only be measured relative to a particular height on the site (and for simplicity we'll assume they have the same units of measurement as the units on the ground).

Luckily the answer is straightforward.

As long as Site 1 is small (under one kilometre) then such a local coordinate system can be set up and used just as it has been done for the past one thousand years.

But what you must then be able to do is for that Site 1, define how to uniquely go from those local (x,y) coordinates for Site 1 to the overall map projection coordinates (Eastings and Northings) being used for the overall project. And also how to uniquely go from the local heights to the Height datum of the overall site.

The secret to success is that because the site is small, the scale factor which varies at every point over the site, is very close to one constant value over the small site. So one fixed value for the scale factor can be used for the small Site. Note that although this value is constant it would rarely be one.

So over that small Site, the square root distance between two points in map coordinates (Eastings and Northings) is simply the ground distance multiplied by the same fixed scale factor.

Hence over that small Site, you can have the local coordinates and the map projections coordinates on the one sheet of paper and straight lines and arcs will remain straight lines and arcs in both coordinate systems and the distances are related by the one fixed scale factor.

Geo-referencing BIM

For two such 2D coordinates systems, you can uniquely define the following transformation to go between the two sets of coordinates for the points:

- The x and y translations required to take the local origin in one coordinate system to the coordinates of the same point in the other coordinate system
- A Rotation about the local origin
- A scale factor

This combination is also known as a (2D) Helmert transformation and it is being regularly used throughout the world on building sites to go from the local coordinates for one building to the local coordinates of a building on a site nearby.

Although the 2D Helmert parameters are used to transform between the two coordinate systems, the four parameter (x translation, y translation, the rotation and the scale) are rarely directly measured. Instead the four parameters can be uniquely calculated from having the coordinates of the same two points (A and B), in both coordinates systems.
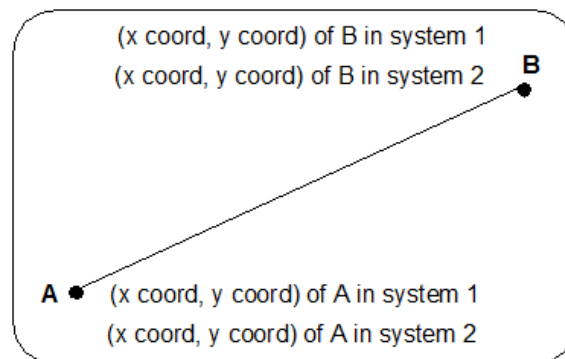
Figure 16: 2D Helmert transformation parameters

(x coord, y coord) of B in system 1 (x coord, y coord) of B in system 2

A (x coord, y coord) of A in system 1 (x coord, y coord) of A in system 2

So for Site 1, you only need the find out the map coordinates (Eastings and Northings or longitude and latitude) for two of the points you already know the local coordinates for.

From these known coordinates the four 2D Helmert parameters x translation, y translation, rotation and scale, can be uniquely calculated and then used to transform the local coordinates to the map projection coordinates.

The inverse transformation can then be used in that small site to transform map projection coordinates to the local coordinates for that small site.

For site heights, you only need the have both the overall project height and the site height known at one point on the site and the difference of those two heights (a Z shift) give you the Height adjustment that can be used to calculate the project height for any other local height.

Special Notes

1. *Because for the map projection there is a unique mapping between the map coordinates and a longitude and latitude, the coordinates for A and B can be given in longitude and latitude instead of in map coordinates. But then you must be capable of calculating the map coordinates from the longitudes and latitudes before being able to use them to calculate the parameters of the 2D Helmert transformation.*

2. *The rotation (angle) is NOT the angle to magnetic north (the direction in which a compass needle points), or true north (the direction of the North Pole). It involves grid north which is the direction northwards along the grid lines of the map projection.*

Geo-referencing BIM

> *Maps issued by the Ordnance Survey in the UK contain a diagram showing the differences between true north, grid north and magnetic north at a point on the sheet.*

3. *Knowing that the calculation of the 2D Helmert transformation requires that the scale factor be virtually constant over the site gives a measure of how large a Site can be for using only local coordinates over the entire site.*

4. *Thinking of the future where dynamic datums may be more commonly used, adding a time stamp (epoch) to the reference coordinates (and hence the transformation) might be worth consideration[7].*

2.5   Best Practice Recommendations

The size of the overall site determines whether a local coordinate system can be safely used for the entire project. If that overall site is too large (typically over 1 Km) then Geodetic Coordinates need to be used and to make design for the overall site more intelligible, an appropriate map projection selected for the overall site.

Once it is declared to be a large project and the map projection defined for the project, then all design work that goes over the entire site must be done in the (Easting, Northing) coordinates for that map projection.

For any work being done on a small Site within the overall site, local coordinates can be used on that particular small Site BUT two points must be uniquely identified on that small site and the local coordinates and the Eastings and Northings (or the longitude and latitudes) of those same two points must be recorded and published.

The parameters of the 2D Helmert transformation are then calculated for the small Site from these two points and they should also be recorded and published. This transformation MUST be used for converting between local coordinates and the map projection coordinates used for the entire project. The inverse 2D Helmert transformation can also be used for converting between map projection coordinates in the small site to the local coordinates for the small site.

The height in the local height coordinates and in the Geodetic Height coordinates must also be known at one point and the differences in those two heights (Z shift) can be used as the height adjustment for all other local heights.

By following the above simple procedures, full coordination can be maintained on even the largest projects but people can still safely work with their local coordinates on small sites within the overall project.

Important Notes

1. *For every small site within a large project, a Land Surveyor should be used to establish the two sets of coordinates and calculate the 2D Helmert transformation parameters. But after that, normal local procedures can be used.*

2. *If the overall site is small, then the same principles apply when there are a number of local coordinate systems within that same small site.*

    To apply the principles there should be the one major (local) coordinate system defined for the overall site but instead of needing the map projection coordinates of the two points for a smaller site, you only need the coordinates of the two points in both the overall local coordinates (the major coordinate system) and the local coordinate system of the smaller sub-site.

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[7] See final Recommended Practices

Geo-referencing BIM

3.   *Having the two points identified rather than just giving the 2D Helmert transformation parameters is very important because you can always double check on the site that the coordinates were correct.*

4.   *The two points should not be too close together. Ideally they should be at opposite sides of the site.*

5.   *When setting up the local coordinate system the average scale factor must be taken into consideration. It is not sufficient to simply apply an offset and rotation to the map projection coordinates to create the local coordinate system. It is recommended that a surveyor perform a survey of the site to establish control points and link them to the appropriate geodetic datum. If no survey is available then the scale factor can be computed by dividing the square root distance by the ellipsoidal distance between two points near to the average height of the site. The ellipsoidal distance can be computed using appropriate geodetic software.*

5.   *In practice, for the small site most surveyors would determine the coordinates of more than just two points in both coordinate systems and would probably use least squares to determine the 2D Helmert transformation from all points. Using more than two points may be redundant but it allows for cross checks to be made to help eliminate errors.*

3   Case Studies

3.1   Crossrail, London UK

The Crossrail project in the UK is a project that spans 118 Km.

For the project the London Survey Grid was used and this is defined as using the WGS84 ellipsoid and a special Transverse Mercator projection. This was spelt out in the project brief.

In preparation for the project, a network of primary survey stations with London Survey Grid coordinates were established across London and the rest of the project.

If there was any data in the UK Ordnance Survey British National Grid (OSGB36), the brief noted that OSGB36 is actually based on a different ellipsoid to the London City Grid. Consequently, the brief provided the transformation (formulae) to be used to bring OSGB36 based data into the London City Grid.

But it was noted that the OSGB36 data is only +/- 400 mm anyway so the brief stated that to obtain more precise conversions, "a local best fit formula shall be derived from the nearest primary or other common survey control stations"

That is, a 2D Helmert transformation is to be used to calculate Helmert parameters using survey control points precisely known in the London Survey Grid as well as in local coordinates.

And in case you thought that once you were inside your building you could forget about such things:

3.3.7.4   For Building Surveys:

a)   The maximum error between permanent survey control stations shall not exceed ± 5mm or 1 part in 10,000 for distances exceeding 50 metres;

b)   The height difference between any two points used as permanent bench marks shall not be in error by more than ± 3mm on any floor or by more than ± 1.5mm per metre of height between floors;

c)   In fully-controlled surveys the absolute plan position of well defined detail shall be accurate to ± 15mm at 1:50 scale or ± 30mm at 1:100 scale, when checked from the nearest survey control station on that floor;

d)   Directly measured figured dimensions shall be quoted to the nearest 0.01 metre;

e)   The quoted level of any feature relative to the nearest bench mark on that floor shall be to ± 5mm.

Some other pertinent extracts from the Topographical Surveys and Mapping brief for the London Crossrail project are included in the Case Studies below.

Geo-referencing BIM

3.1 London Survey Grid and datum

3.1.1 London Survey Grid (LSG) definition

3.1.1.1 All topographical survey and mapping work shall be reported on the London Survey Grid.

Note:	The London Survey Grid is a Transverse Mercator Projection with parameters chosen to minimise grid distortion caused by the Earth's curvature over the LU area. The distortion is such that for large portions of the area projection corrections can be ignored. The Grid was formerly known as the LU Grid, the LUL Grid or the Crossrail Grid

A network of primary survey stations with London Survey Grid co-ordinates has been established across London.

3.1.1.2 LSG height datum shall be used. The LSG height datum level is set at approximately 100m below OS Datum at Newlyn.

Note:	The LSG height datum is an orthometric height datum chosen to provide positive values for areas of interest to LU. This datum is realised by the network of OS benchmarks that have been connected by spirit levelling to LU survey control points. . In areas that will interface with Crossrail projects the Crossrail First Order benchmarks should be used. Trials in 2009 indicated that GPS survey heights can be transformed using the Ordnance Survey Geoid Model 2002 (OSGM02), plus the 100m shift, to produce acceptable LSG Height Datum values

The London Survey Grid is defined by the following parameters:

Parameter	Value
Spheroid	WGS 84
Semi major axis	6,378,137.000m
Semi minor axis	6,356,752.3142m
1/f (f = earth's flattening)	298.25722356300
e″	0.00669437999013
Datum	Xrail84 *
Projection	Transverse Mercator
Central meridian	W000°-09'-30"
Latitude of true origin	N051°-10'-00"
Easting of true origin/ central meridian	78,250.000m
Northing of true origin	-2,800.000m
Central meridian scale factor	0.9999999
• Xrail84 * = Datum as derived by the Crossrail project in 1984.	

Geo-referencing BIM

3.1.2 Grid computation

3.1.2.1 Distances shall be reduced to the WGS 84 spheroid.

3.1.2.2 The London Survey Grid scale factors given in Attachment 7.1 shall be used.

3.1.3 Relationships between London Survey Grid and other grids

3.1.3.1 *Ordnance Survey grid* (also known as the British National Grid or OSGB36)

3.1.3.1.1 The formulae in Tables 1 and 2 in Attachment 7.3 shall be used for conversion of OS mapping to and from London Survey Grid within the areas shown in Attachment 7.2. These formulae are accurate to a commensurate standard as the OS mapping ie +/- 400mm.

3.1.3.1.2 To obtain more precise conversions of existing survey information held on the OS grid a local best fit formula shall be derived from the nearest primary or other common survey control stations.

London Survey Grid Scale Factors

London Survey Grid eastings	London Survey Grid scale factor	Correction mm per km	London Survey Grid eastings	London Survey Grid scale factor	Correction mm per km
48,000	1.0000111	11	78,000	0.9999999	0
49,000	1.0000104	10	79,000	0.9999999	0
50,000	1.0000097	10	80,000	0.9999999	0
51,000	1.0000090	9	81,000	1.0000000	0
52,000	1.0000084	8	82,000	1.0000001	0
53,000	1.0000077	8	83,000	1.0000002	0
54,000	1.0000071	7	84,000	1.0000003	0
55,000	1.0000065	7	85,000	1.0000005	0
56,000	1.0000060	6	86,000	1.0000006	1
57,000	1.0000055	5	87,000	1.0000008	1
58,000	1.0000049	5	88,000	1.0000011	1
59,000	1.0000045	4	89,000	1.0000013	1
60,000	1.0000040	4	90,000	1.0000016	2
61,000	1.0000036	4	91,000	1.0000019	2
62,000	1.0000031	3	92,000	1.0000022	2
63,000	1.0000028	3	93,000	1.0000026	3
64,000	1.0000024	2	94,000	1.0000029	3
65,000	1.0000021	2	95,000	1.0000033	3
66,000	1.0000017	2	96,000	1.0000038	4
67,000	1.0000015	1	97,000	1.0000042	4
68,000	1.0000012	1	98,000	1.0000047	5
69,000	1.0000010	1	99,000	1.0000052	5
70,000	1.0000007	1	100,000	1.0000057	6
71,000	1.0000005	1	101,000	1.0000063	6
72,000	1.0000004	0	102,000	1.0000068	7
73,000	1.0000002	0	103,000	1.0000074	7
74,000	1.0000001	0	104,000	1.0000080	8
75,000	1.0000000	0	105,000	1.0000087	9
76,000	1.0000000	0	106,000	1.0000094	9
77,000	0.9999999	0	107,000	1.0000101	10

Geo-referencing BIM

Factors for conversion between London Survey Grid and British National Grid

	North West area	South West area	Central area	East area	South area	South East area
Rotation (Rot)	358°.55579884	358°.55810730	358°.55752333	358°.55728250	358°.56006098	358°.55962194
Scale factor (SF)	1.000254411	1.000243743	1.000192479	1.000146053	1.000217914	1.000152383
Shift Eastings	-454195.142	-454182.581	-454157.420	-454133.105	-454163.487	-454129.735
Shift Northings	-131867.340	-131886.233	-131872.044	-131861.837	-131899.767	-131885.180
P=SFxCos(Rot)	0.999936674	0.999927024	0.999875520	0.999829003	0.999902061	0.9999836358
Q=SFxSin(Rot)	-0.025209808	-0.025169252	-0.025178154	-0.025181187	-0.025134508	-0.025140520
Note: Rotation is a conventional anticlockwise angle						
For converting British National Grid to London Survey Grid the conversion equations are:						

$E_{.London\ Survey\ Grid} = (E_{.British\ National\ Grid} \times P) - (N_{.British\ National\ Grid} \times Q) + shift\ Eastings$

$N_{.London\ Survey\ Grid} = (N_{.British\ National\ Grid} \times P) + (E_{.British\ National\ Grid} \times Q) + shift\ Northings$

Table 1 Factors for conversion of British National Grid to London Survey Grid

	North West area	South West area	Central area	East area	South area	South East area
Rotation (Rot)	01°.44420116	01°.44189270	01°.44247667	01°.44271751	01°.439938901	01°.44037806
Scale factor (SF)	0.9997745653	0.999756316	0.999807558	0.999853968	0.999782133	0.99984764
Shift Eastings	450612.718	450610.266	450607.111	450603.379	450607.363	450602.420
Shift Northings	143236.271	143238.209	143235.329	143233.058	143239.590	143236.998
P=SFxCos(Rot)	0.999428078	0.999439752	0.999490721	0.999537011	0.999466418	0.999531712
Q=SFxSin(Rot)	0.025196986	0.025156987	0.025168464	0.025173833	0.025123557	0.025132860
Note: Rotation is a conventional anticlockwise angle						
For converting London Survey Grid to British National Grid the equations are:						

$E_{.British\ National\ Grid} = (E_{.London\ Survey\ Grid} \times P) - (N_{.London\ Survey\ Grid} \times Q) + shift\ Eastings$

$N_{.British\ National\ Grid} = (N_{.London\ Survey\ Grid} \times P) + (E_{.London\ Survey\ Grid} \times Q) + shift\ Northings$

Table 2 Factors for conversion from London Survey Grid to British National Grid

Note:	Transformation blocks given in tables 1 and 2 have been created such that the differences along the boundary edges when using adjacent sets of conversion parameters is within the 1:1,250 mapping accuracy of ± 400mm, equivalent to 0.3mm at map scale.

Geo-referencing BIM

3.2   NSW Cadastre, Suburban Sydney AU

In the New South Wales Torrens Title, land is registered in a central database. Each parcel of land is given a folio number which identifies the land in accordance with a registered plan.

The registered plans only contain relative positions to identified marks on the ground. That is, only distances and bearings are shown between points on the plan and to the known marks - no coordinates are shown.

This system works over time (and continental drift) because everything is relative to the known marks and as long as those known marks are not disturbed, the distances and bearings between the other points will still hold.

What this system does not easily allow for is the production of a coordinated cadastre. That is, of an overall plan where each point has coordinates - a digital cadastral data base (DCDB).

However, what has been required on all plans now registered is that they must now have two marks on the plan (that are connected to other points on the plan) that have known MGA coordinates for them. That is, coordinates in the Australian Geodetic datum GDA94.

Although the plans do not contain coordinates, if a point on a plan is given the coordinate (0,0) then the bearings and distances can be used to give local coordinates to all the points on the plan.

So, for registered plans covering small areas, we are in the same position as having a number of small sites with their own local coordinates and with each of the sites having two known points in an overall Geodetic Coordinate system.
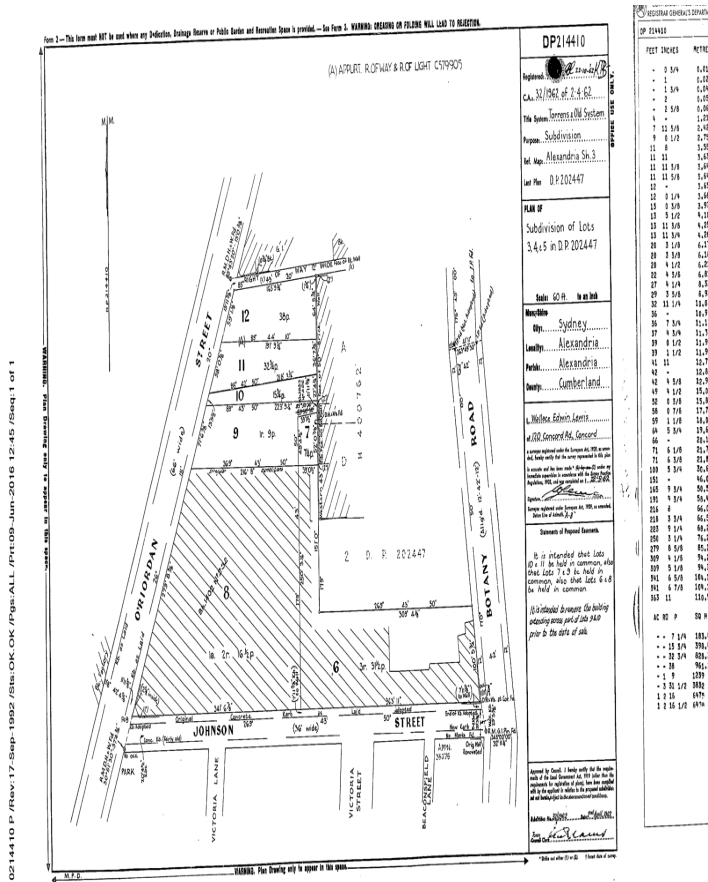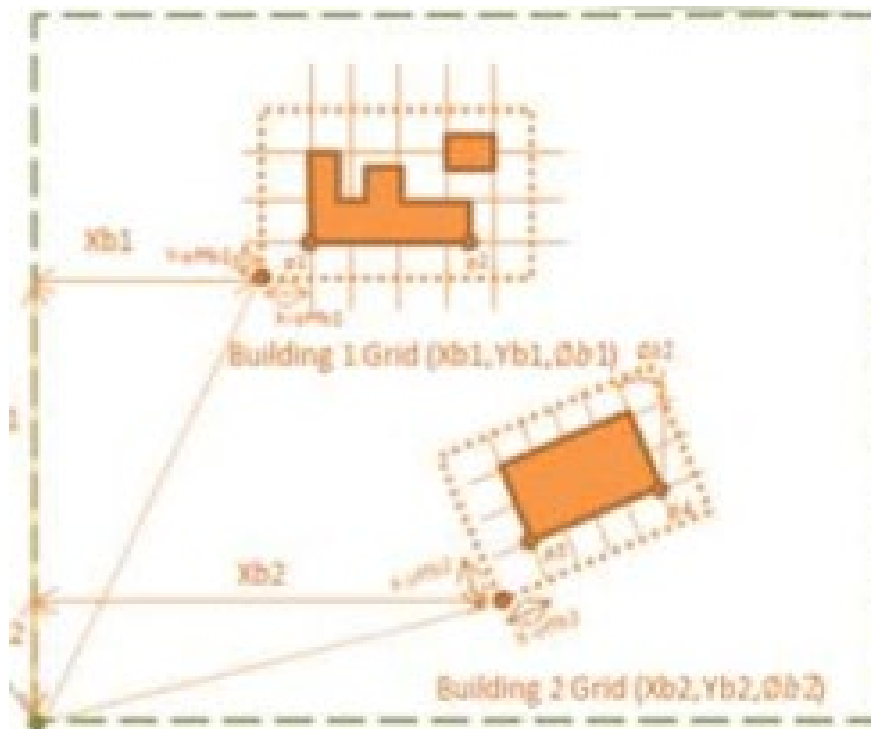

Figure 17:   NSW Title, cadastre details

Geo-referencing BIM

So, following the procedures previously outlined, cadastral plans can be brought into a larger project.

Figure 18:   Project Model set-out example.

3.3   Issues with Current Modelling

The 2D Helmert transformation provides a way to transform between the local grid system (x, y) to the national grid system (E, N) accounting for the average point scale factor arising from the map projection. The IfcMapConversion object defines what is essentially a 2D Helmert transformation that can be used to convert between grid systems.

However, if consumers of the local grid coordinates are to assume that computed distances are ground distances then care must be taken in the computation of the 2D Helmert transformation. In some cases BIM users start with E, N coordinates which they simply subtract some amount from to get x, y coordinates that are small enough to be compatible with their design software and (perhaps) apply a rotation to make the local system fit better on paper plans. In that case the local grid system would not provide approximate ground distances (a scale factor is needed).

Consider the following example in MGA Zone 55 coordinates (metres):

    Point A: E 329,787.879 N 5,827,330.591

    Point B: E 330,787.879 N 5,827,330.591   -> 1km west of Point B

If both points have an ellipsoidal height of 0.0, then the grid distance is 1,000.000 and the ground distance is 1,000.045.

If both points have an ellipsoidal height of 500.0, then the grid distance is 1,000.000 and the ground distance is 1,000.123.

The difference between the grid and ground distances is already significant at 0 height above the ellipsoids and gets significantly larger as the height increases. Many cities around the world have much higher elevations (e.g. Mexico City at about 2,250). So, depending on how the local coordinate system is derived, it may or may not approximate ground distances.

Geo-referencing BIM

The important thing is to have a link to the national grid.

Thinking of the future where dynamic datums may be more commonly used, adding a time stamp (epoch) to the reference coordinates (and hence the transformation) might be worth consideration.

4. Model Setup Use Cases

Figure 19 below sets out the context of establishing a model at a specific location, with its spatial subdivision and related attributes.
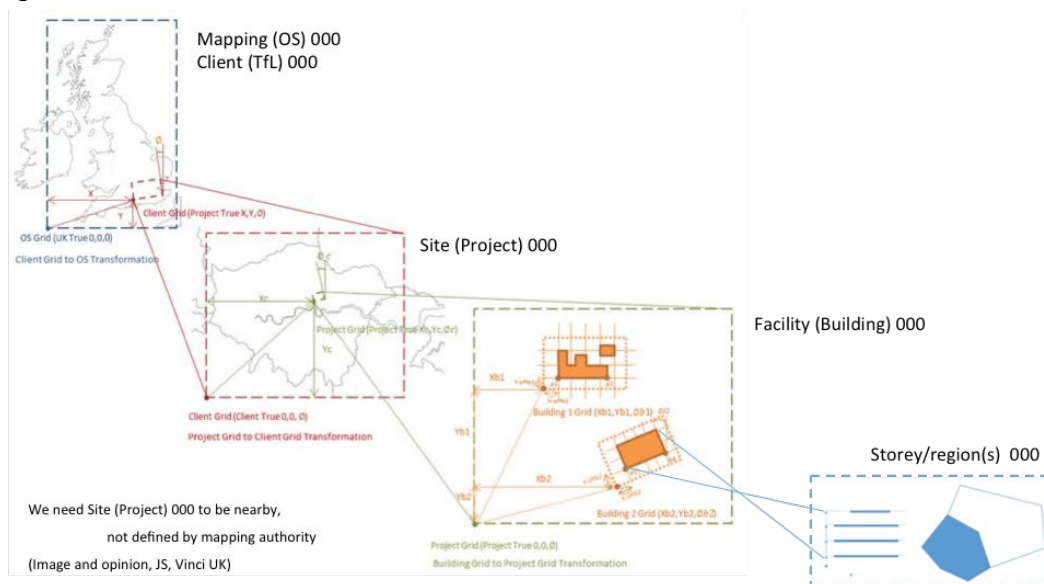
Figure 19:   Model Setup Overview

4.1   UC0: Project initiation: existing setup context

by Client or Facility Manager

•   Integrated information from existing built facility setup for new or modified facility on an existing site

4.2   UC1: Project initiation: non geometric info

by Lead Designer and/or Client or Facility Manager

•   Project, Site and Built Asset[8]
•   Name, Description, Guid, Long Name,
•   Object Type and/or Classification and/or Phase
•   Any additional project psets?
•   Pset_ProjectCommon

4.3   UC2: Site location: geolocation

by Surveyor and/or Mapping Authority and/or Land Title registrar (or Client/Advisor)

•   Site 0/0/0: Lat, long, elevation, north (WGS84) or IFC4 full geolocation of site
•   Should be within site or SW of site but nearby, and an authorised benchmark
•   Optional Site boundaries, features, terrain (tin etc),
•   Optional marking of 0/0/0 with point, pyramid or grid lines
•   Optional set-out dimensions and angles of 0/0/0 from site features
•   Built Asset Address (deprecate?)
•   LandTitleNumber: cadastre reference

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[8] *Built Asset* is used generically to refer to IfcBuilding and its forthcoming infrastructure siblings in IFC5

Geo-referencing BIM

- Any additional site psets?
- Pset_SiteCommon
- weather detail,
- map reference (see BS1192 part 4, section 7.7.2 Table 8)

4.4 UC3: Facility location: cartesian

by Lead Designer

- Locate facility 0/0/0
- Should be within facility or SW of facility but nearby
- Optional marking of 0/0/0 with point, pyramid or grid lines
- Optional set-out dimensions and angles of facility 0/0/0 from site 0/0/0 or from site features
- BuildingAddress
- ElevationOfRefHeight (deprecate?)
- ElevationOfTerrain (deprecate?)
- Additional Built Asset psets?
- Pset_BuildingCommon: for all types of building
- Pset_BuildingWaterStorage: to capture the water supply requirements
- Pset_BuildingUse: to capture the current and anticipated real estate context.
- Pset_BuildingUseAdjacent: to capture the adjacent buildings use.

4.5 UC4: Model set-up

By Lead Consultant

- Include UC1, UC2, UC3
- Optional Storey datum(s) or region 0/0/0(s)
- Optional dimensioning of these datums or 0/0/0(s)
  - from Facility 000
- Optional marking of datum(s) or region 0/0/0(s)
  - with point, pyramid or grid lines
- Elevation (deprecate?)
- Additional psets?
- Pset_BuildingStoreyCommon

Notes:

- Point, pyramid and grid lines are just component occurrences.
- Model set-up does not indicate where 0/0/0 is using component occurrences!
- Model set-up may have component occurrences at the 0/0/0 location!
- Applications or online services must be able to generate 'model set-up'. Is IFC4 geolocation in coordination view?
- Authoring applications must be able to read 'model set-up'
  - ◦ as a design transfer coordination view and/or
  - ◦ as a reference coordination view.

Geo-referencing BIM

4.6   The Geo-Referencing Process

The site model that defines the cadastre or terrain, locates built assets and geographic features etc, represented in IFC2x3 and IFC4 by the *ifcSite* entity, is generally in a local cartesian grid coordinate system in order to simplify calculations. The process of relating the local site model to a more general map grid coordinate system based on a map projection (such as that used by the State or National Mapping Authority) is called geo-referencing.

The local coordinate system has a local origin and may be aligned arbitrarily according to shape of the site. It is commonly assumed that distances computed from coordinates on a plane (grid distances) in the local coordinate system represent distances on the ground on the curved surface of the Earth (ground distances). That is, earth curvature is assumed to be negligible.

In a map grid coordinate system, which is designed for use over a wide area, this assumption is not valid. As a result, there will in general be translations, rotation and scale differences between the local coordinate system and the map grid system. Together these components form a transformation which can be used to geo-reference the local grid coordinates.

A **2D Helmert transformation** is defined on this basis and its parameters stored in *ifcMapConversion (*attributes *SourceCRS, TargetCRS, Eastings, Northings, OrthogonalHeight, XAxisAbscissa, XAxisOrdinate* and *Scale)*.

Table 2:   **IfcMapConversion Attributes**

Attribute	Definition
MapConversion Properties	Properties that specify the transformation between the local grid coordinate system and a map grid coordinate system.
Eastings	The shift in X between the two coordinate systems
Northings	The shift in Y between the two coordinate systems
OrthogonalHeight	The shift in Z between the two coordinate systems
XAxisAbscissa	The X component of the rotation between the two coordinate systems
XAxisOrdinate	The Y component of the rotation between the two coordinate systems
Scale	The scale in X, Y between the two coordinate systems

A 2D Helmert transformation can be computed using two or more survey marks with coordinates in both the local and the map grid coordinate systems (see 2.4 The Objective Resolved**,** p17-18).

4.6.1   Small Sites

If the extents of the site are small (up to approximately 1km square) then a single transformation should be sufficient to relate the local and map grid coordinate systems.

4.6.2   Large Sites

For large projects, using a local cartesian coordinate system that does not consider earth curvature will result in significant errors between measured and computed distances.

If the project involves discrete infrastructure dispersed over a wide area, it may be sufficient to establish a transformation for each site. For example, a railway project might have bridges, tunnels and stations and each of these built assets will require a local coordinate system and a transformation to relate it to the map grid system. Note that this may require several contiguous sub-models of the built asset, e.g. for a tunnel 3km long.

If it is not possible to subdivide the project into a number of small sites, then the project should be based on a map grid coordinate system and use rigorous geodetic computation.

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4.6.3 Example 2D Helmert Transformation

In this example two reference points (Ref1 and Ref2) have been defined at opposite ends of the site. The points have been connected to local survey control by a Land Surveyor.

The resulting coordinates of the reference points in the national map grid coordinate system (Map Grid of Australia Zone 56) are:

```
Ref1   E = 333,780.622      N = 6,246,775.891      H = 97.457
Ref2   E = 333,906.644      N = 6,246,834.938      H = 98.291
```

where E is Easting, N is Northing and H is orthometric height (AHD).

All values in metres.
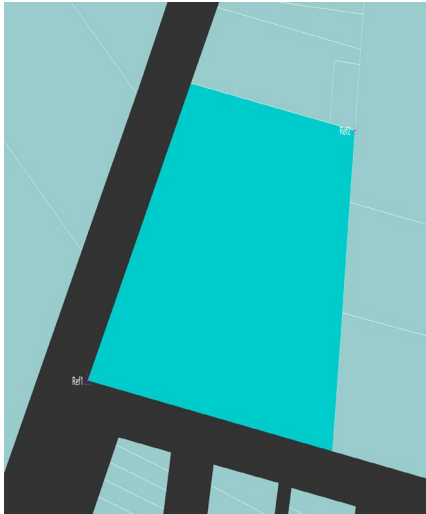
Figure 22:   Site in the map grid coordinate system (grid north is up the page)

A local grid coordinate system has been made for the site to reduce the size of the coordinates and to align the site to better fit on paper plans. The resulting coordinates (in metres) of the reference points in the local grid coordinate system are:

```
Ref1   X = 0.000        Y = 0.000        Z = 0.000
Ref2   X = 116.611      Y = 75.960       Z = 0.834
```

where X, Y, Z represent a right handed Cartesian coordinate system with Z equivalent to up.

All values are in metres.
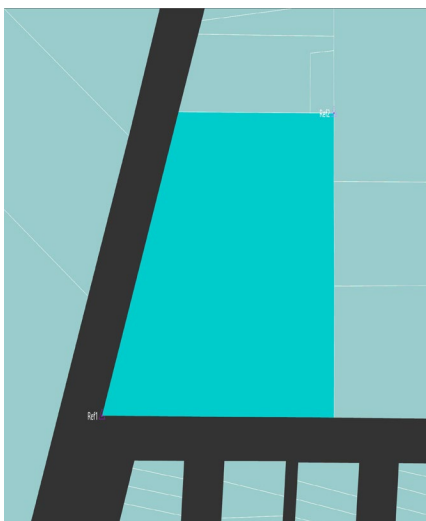
Figure 23:   Site in the local grid coordinate system (Y is up the page)

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A 2D Helmert transformation can be computed from the coordinates of the two reference points. The parameters of such a transformation are:

```
X Shift = 333,780.622
Y Shift = 6,246,775.891
Z Rotation = -7°58'28"
Scale = 0.999998₉
```

The corresponding IFC parameters are:

```
Eastings = 333,780.622
Northings = 6,246,775.891
OrthogonalHeight = 97.457
XAxisAbscissa = 0.990330045
XAxisOrdinate = -0.138731399
Scale = 0.999998
```

The transformation is applied as follows to convert coordinates from local to map grid:

```
E = (A * X) - (B * Y) + Eastings
N = (B * X) + (A * Y) + Northings
H = Z + OrthogonalHeight
```

where

```
A = Scale * cos(Rotation),
B = Scale * sin(Rotation), and
Rotation = atan2(XAxisAbscissa, XAxisOrdinate)
```

4.6.4 North in Model setup

I hope I can clarify this a bit for you. As an architect you probably use 'North' mainly for orienting a plan and its exact meaning is not very important in that sense. With small projects North (be it true, grid or magnetic) is essentially in the same direction no matter where you are on the site. In the context of surveying and map projections North has a very specific meaning.

First some theory....

Map projections are generally defined with a particular relationship to geodetic north (which is defined using an internationally accepted definition of the spin axis of the Earth - the Conventional International Origin or CIO). You can think of this as True North. However, the Northing axis of map grid coordinates do not generally point towards geodetic north. Rather they point towards grid north. The difference between grid north and true north depends on where you are within the projection. That is because map projections represent the earth as a flat plane and must necessarily introduce distortion - both in terms of distances (which we have been discussing previously) and in terms of directions.

These distortions are why large projects must be done on a map projection and not an engineering grid if high accuracy is needed. If you recall, for a small region within a map projection the distortion in distances can be approximated using a "scale factor" which is treated as constant over the area. The equivalent for directions is a "local rotation".

There are different types of map projections with different mathematical properties. To keep things simple lets talk about Transverse Mercator (TM) which is used in Australia and many other countries. Note that Universal Transverse Mercator (UTM) is just TM with a defined set of parameters - mathematically they are the same. One of the parameters of TM is the "central meridian" which is a line of longitude that defines the centre of the projection. Only along the central meridian does grid north and true north coincide. In all other places there is a difference between the two known as the "grid convergence".

----

[9] The scale of 0.99998 is only in the X and Y (not Z).

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The difference between magnetic north and true north changes over time. Generally in a surveying and engineering sense magnetic north is not very important. It is important for navigation, orienteering etc. but not for mapping. I don't think we need to consider it at all, except to recognise that it exists and if you use a compass you are not getting true north.

Astronomical north can be safely ignored in the context of IFC. It is important for astronomical measurements and space geodesy which are used in defining national map systems like GDA. From a user centric point of view, such as with IFC, we need not concern ourselves with it.

Now for IFC...

For the *IfcProjectedCRS* the definition of North comes from the map projection it is based upon. If geodetically rigorous calculations are used the differences between grid north and true north will be taken care of (just as for grid and ground distances). However, most engineering or architectural software packages do not work with projected coordinate systems.

The *IfcGeometricRepresentationContext* defines the 'WorldCoordinateSystem' (i.e. the local engineering coordinate system) used by the project and, optionally, 'TrueNorth'. The Y axis of the 'WorldCoordinateSystem' may be aligned with a local landmark (e.g. road) or to make the plans fit better on paper. If the Y axis of the 'WorldCoordinateSystem' is not aligned to true north, then the 'TrueNorth' attribute should be included to record the difference between Y axis and the (average) direction of true north.

The *IfcMapConversion* transforms betweens the 'WorldCoordinateSystem' and the *IfcProjectedCRS*. The *IfcMapConversion* effectively includes the 'TrueNorth' rotation as well as a scale factor for the distances and offsets for the origin.

Note that for large projects both the 'TrueNorth' rotation and the *IfcMapConversion* are not perfect as they just remove an average distortion between the 'WorldCoordinateSystem' and the projected CRS. So once again, for critical large scale infrastructure projects the calculations should be done using the projected CRS and not a local engineering system.

[Source: Neil Brown - email on 31st August 2017]

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5.   References

Wikipedia articles!

ISO 19111:2007 describes Coordinate Reference Systems in general; it is currently under revision.

Wikipedia, Helmert transformation

ISO 19161-1 is currently under preparation. It will describe the International Terrestrial Reference Framework, and how to establish national terrestrial reference frameworks. The ITRF is managed by the International Earth Rotation and Reference Systems Service; the UN would like it to be more formally recognised.

ISO 19127:2005 describes how to manage a register of Coordinate Reference Systems. ISO TC211 and the International Association of Geodesy have established a "Control Body for the ISO Geodetic registry network" to manage the ISO "register of registers". ISO 19127 is currently under revision to better describe this.

A guide to coordinate systems in Great Britain, Ordnance Survey UK, D00659 v3.0 Aug 2016 see here