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# Applications of 3D Modelling in Geothermal Facility Design

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**ABSTRACT**

3D design techniques have always been available to assist with the design of plant and piping facilities. For a previous generation of plants this took the form of a 1:32 scale plastic model of the piping and structures. The use of computer aided design (CAD) has introduced virtual models, however limitations in hardware and software have limited the widespread use of these until around 2005. The last 10 years has seen a rapid increase in the use of 3D modelling. New software tools and increases in computing processing power and memory have made 3D techniques more accessible for everyday design.

The non-orthogonal nature of a typical geothermal facility creates many challenges to designers. In particular many geothermal steamfields throughout Asia are characterised by rugged terrain which requires careful facility design. 3D models are now used effectively at all stages of geothermal steamfield design and give a significant advantage over previous techniques.

This paper looks at several current 3D tools and their application to steamfield design. It also examines the cost and effectiveness of 3D techniques, particularly considering the appropriateness of the modelling as it relates to the stage of the project development. Applications described include 3D modelling for concept development and environmental consenting, a single source database tool for the design of cross country piping and use of 3D modelling in both greenfields and brownfields facilities design. Also described are some of the techniques used for data acquisition to create the models.

## 1. INTRODUCTION

3D design techniques have always been available to assist with the design of plant and piping facilities. A common approach for plant design was to construct a 1:32 scale model from plastic and timber components - Figure 1 below shows such a model. Whilst this was a highly useful resource for a process plant, the technique also had limitations. Model building is a labour intensive project, and therefore building models was expensive. The models were physically large, and therefore once construction is complete, long term space for storage can be a problem. The model can only be in one place, so everyone who wishes to review it must travel to the model location.

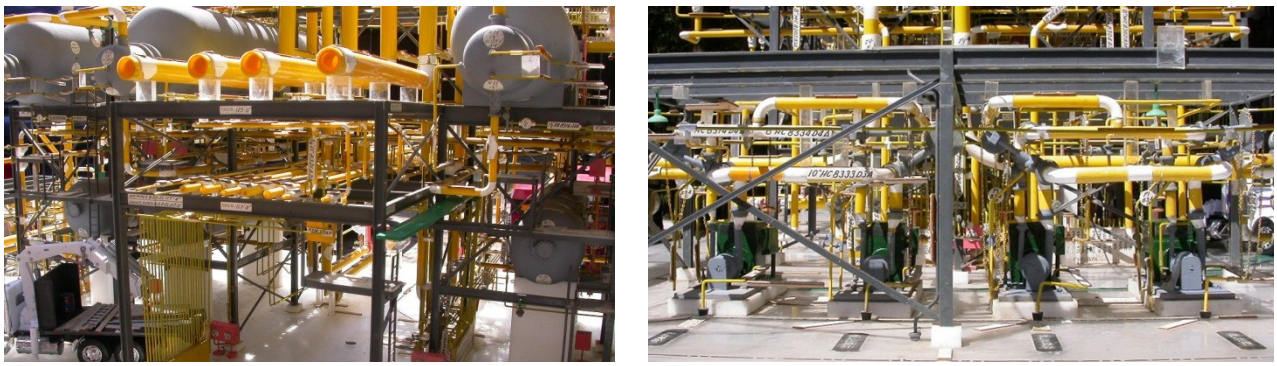

**Figure 1: Plastic Scale Model**

Whilst manageable for plant areas, this technique did not lend itself to geographically spread systems such as geothermal steamfields.

The introduction of computer aided design (CAD) in systems such as Intergraph's PDS® (PDS) and Aveva's PDMS™ (PDMS) introduced virtual models to the engineering industry. Initially produced in mainframe based systems in the 1970s, these models have moved to high powered workstation systems in the 1990s, however PC hardware performance has limited the widespread application of 3D tools until around 2005. In the last 10 years new software applications, increases in computer processing power, memory and screen sizes, and falling prices for hardware, have made 3D techniques more accessible for everyday design.

## 2. CREATION OF MODELS

### 2.1 Plant & Piping Objects

The geometry for 3D models can be created in many software packages.

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At its simplest we can use CAD software such as AutoCAD® (AutoCAD) or MicroStation® (Microstation) to draw 3D models using primitives (cubes, cylinders, tubes, spheres, cones). For small and simple models this can be highly appropriate.

When models become more extensive there are software tools which give significant productivity increases when building objects. Examples of these would be Bentley's AutoPLANT® (AutoPLANT), Autodesk's Plant 3D® (Plant 3D) and Intergraph's CADWorx® (CADWorx) for piping design. There are also companion products that efficiently draw steelwork, platforms, stairways, ladders, cable trays and other plant components.

**2.2 Existing Objects and Surfaces**

Capturing accurate terrain and object data is essential to producing meaningful models for the design of steamfield facilities, and the lack of good survey data in the past has meant modelling was not feasible.

Land surveying has historically used manual data collection methods – for example as late as the 1990s, the basic tools were a tape, level and theodolite. Acquisition of survey data was highly labour intensive. The introduction of total station devices into theodolites improved data accuracy. The addition of a Global Positioning System (GPS) to the total station device has further increased the data capture efficiency. However the technique is still highly labour intensive, and is therefore often limited to obtaining data for discrete areas such as corridors for piping or for plant and wellpad areas.

Another method that is used to obtain data for existing objects is 3D laser scanning. A rotating laser uses reflected light and time-of-flight to determine the position of objects in space. The readings returned are used to create a point cloud. Typically scans are taken from multiple locations and merged to create a complete model. This technique allows large amounts of data to be scanned quickly. The resulting model is the 3D equivalent of a raster file, and the file size can be problematic if trying to view large amounts of data. It is therefore often necessary to go through expensive conversion processes to change the point cloud to 3D solids. The benefits of laser scanning are the accuracy and completeness of the model – which is particularly important for brownfields work (modifications or additions to existing plant). Models such as that shown in Figure 2 below can be easily interrogated for dimensional information such as sizes of objects or absolute location.

**Figure 2: 3D laser scan image**

To capture terrain data for many square kilometers of a geothermal steamfield a technique called LiDAR can be used. An airborne high frequency laser is used to image the ground and measures time for the reflected signal to be received at the aircraft. The aircraft is fitted with a GPS to coordinate the data into a full digital terrain model (DTM).

Figure 3 below shows a digital terrain model obtained using LiDAR survey techniques. Vertical accuracy below 50mm can be achieved but requires low flying with narrower scans and therefore more passes. A vertical accuracy of 150mm is more readily achieved on clear land and some 300mm when vegetated (Reutebuch, S. et. al. (2003)). Where land is heavily vegetated it is important to correctly compensate for the forest canopy height.

When using contours produced from DTMs as backgrounds for steamfield development drawings, the management of file sizes becomes important. For example the AutoCAD® *.dwg contour file sizes for the steamfield in Figure 3 below are 14 MB for 5m contours and 83 MB for 1m contours. The 5m contours are appropriate for development and concept planning work and the file size is manageable. For detailed design the 1m contours were necessary, and consequently the background file was cut into many smaller files to make the drawing size manageable.

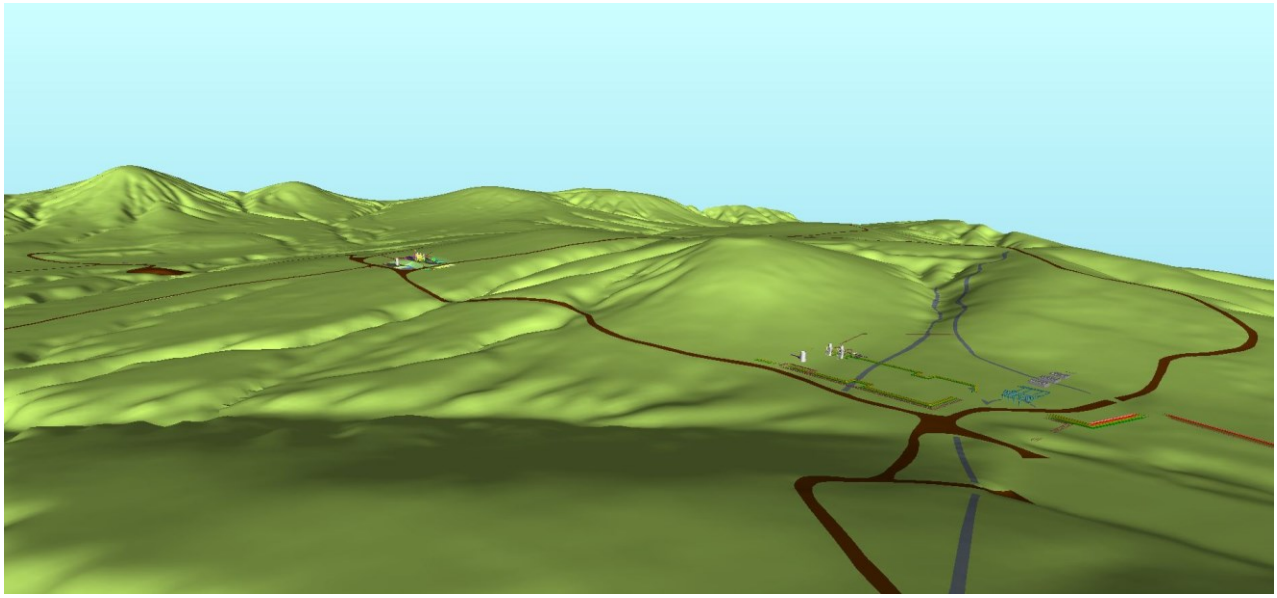

**Figure 3: Steamfield concept design using terrain obtained from LiDAR survey**

## 3. WHY DO WE PRODUCE 3D MODELS?

3D models are being used primarily for visualization. Many end users do not read or interpret drawings easily. Our human brains relate better to 3D models than we do to 2D representations in drawings. 3D models give us the ability to add meaningful colour to views – which further improves understanding.

So the 3D models become a major communications tool. For the design of steamfield facilities 3D models are being used for:

a) Concept design and layout
b) Detailed design
c) Constructability reviews
d) Access and operability reviews
e) Safety in design reviews
f) As a visual aide during Hazard and Operability Studies (HAZOPs)

Clients are now recognizing the value in 3D visualization and are prepared to invest in it to get full models of their sites.

## 4. VIEWING MODELS

Models for engineering use are produced in CAD packages such as AutoCAD® or MicroStation®. When CAD packages were initially developed they were used for 2D drafting. This means that typically they have not had good 3D viewing features. Figure 4 below shows a 3D plant area model view as seen in AutoCAD®. 3D objects in this view are transparent, and so we see a wireframe view of the system – which is difficult to interpret. For ready viewing we need the capability to shade or render objects at high speed and to have navigation tools which allow ready access to any part of the model.

Two software packages which do this are Autodesk's Navisworks® (Navisworks) and Bentley's Navigator (Navigator). Figure 5 below shows the same plant area model viewed in Navisworks®. The AutoCAD® model is simply opened in the Navisworks® model, and can be used immediately. Enhancements to the view can be added such as particular colour schemes, preset views, background styles, animations, and review comments.

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**Figure 4: AutoCAD plant area model**

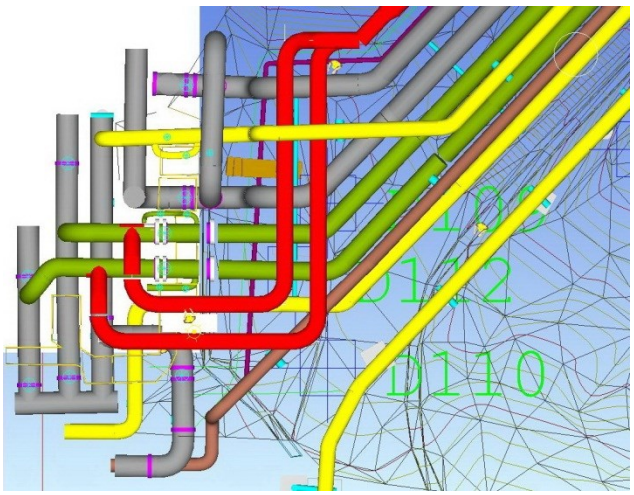

**Figure 5: Same plant area model viewed in Navisworks**

One of the benefits of the Navisworks viewing software is the ability to overlay models from a variety of sources. For example GIS contour data can be loaded along with AutoCAD® drawing file information. In Figure 6 below, a structural model produced using Autodesk Revit® (Revit) software has been overlaid with a plant piping model from AutoCAD® and AutoPLANT®.

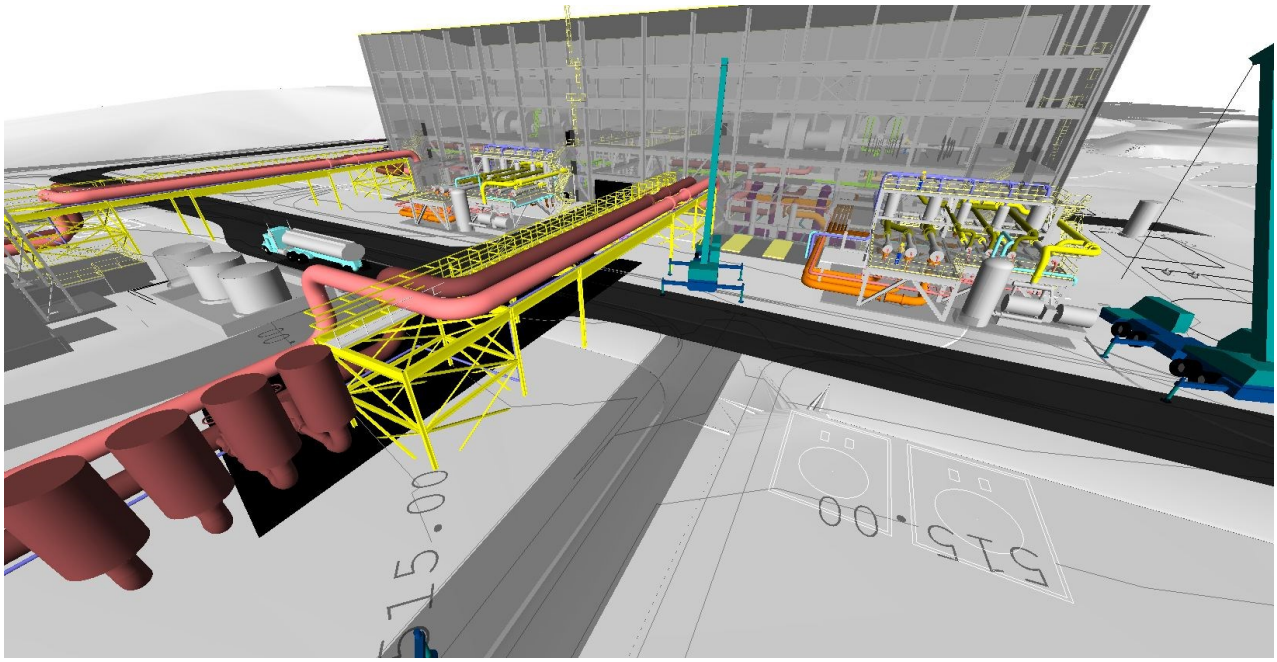

**Figure 6: Combined Revit® and AutoCAD® model viewed in Navisworks®**

## 5. 3D MODELLING FOR CONCEPT DEVELOPMENT & ENVIRONMENTAL CONSENTING

During the concept development and environmental consenting for a geothermal steamfield, there are many different types of data used:

- Aerial or satellite photographs
- Elevation models
- Land use and cadastral maps
- Information on existing roads and other infrastructure
- Volcanic or lahar risk maps
- Geological features
- Scientific assessment maps
- Locations of key social/cultural features
- Concession boundaries
- Resource boundaries

The best tool for managing this collection of data is a Geographic Information System (GIS). GIS systems enable users to capture, store, manage and analyse spatially referenced data. Figure 7 is a map produced from a GIS system which shows terrain overlaid with the concession boundary and other physical features such as wells, springs etc.

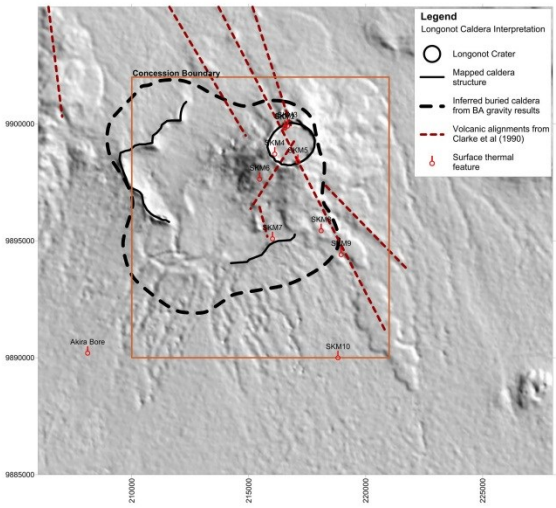


**Figure 7: Map Output from GIS System (Alexander, K. et. al. (2011))**

### 5.1 Constraint Analysis for Route Selection

Geothermal site development is often a delicate balance between keeping costs under control and simultaneously managing risks to an acceptable level. Selection of routes for site access roads and pipeline corridors is a key part of the development.

GIS is an ideal platform to perform complex constraint analysis processes that are both visually meaningful and clearly auditable. Different aspects that govern the suitability of a particular route, such as land-use, slope, vegetation, geology, proximity to infrastructure, ecologically or socially sensitive areas, distance, etc. can be overlaid with each other, and ranked with agreed weightings to produce an overall constraints map. This constraints map (refer Figure 8) can be easily updated to reflect differing weighting scenarios, and is then used to develop the corridors and paths of least resistance between two points (refer Figure 9).

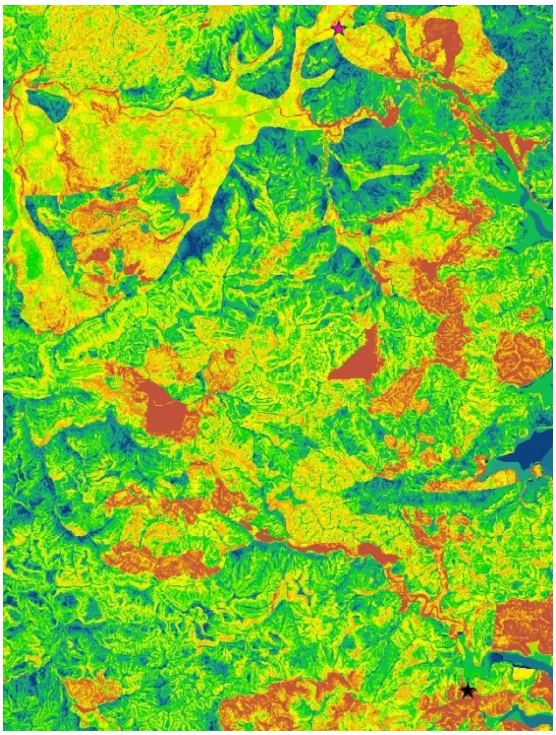

**Figure 8: Total Constraints Map**

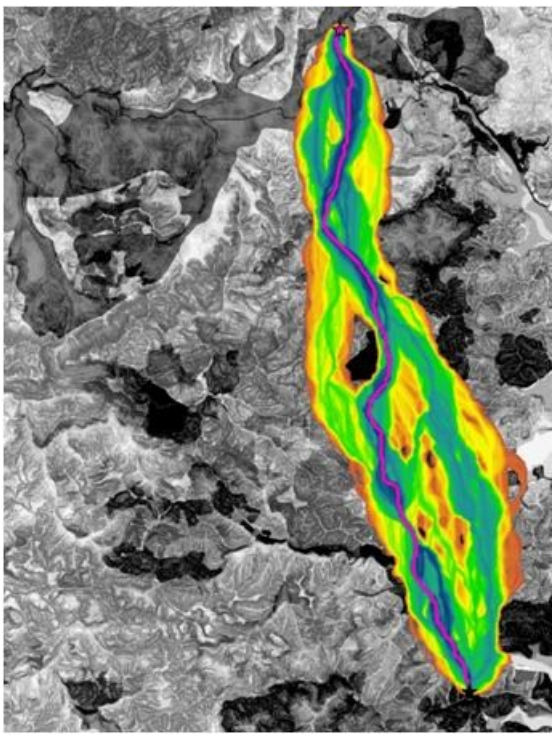

**Figure 9: Corridors and "Best Path"**

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## 6. PROVIDING CONTEXT FOR VISUALISATION

### 6.1 Visualisation of site roading

When developing site roading, one of the criteria that has a large impact on installed costs is the maximum gradient. In the case below, two options for road gradient were being considered – the steeper one shown in blue, and the flatter one shown in red. The steeper route results in a shorter overall roading length and is generally cheaper than a flatter system, but it comes with increased risks for construction, and for maintenance and operation during its lifetime.

The model was deliberately kept simple because it was being used to make high level decisions on the site roading; the digital terrain model (DTM) is very coarse and the roads are shown as single lines only. The single line view of the roads (Figure 10) makes it very difficult to assess scale. It is therefore important to include objects in a model which give the viewer a frame of reference. These need to be recognizable objects such as vehicles, buildings, pipes, landmarks etc. In the case below, a number of full size container trucks were added in to give context to the model (see Figure 11), and this assisted the end-user with interpretation of the options.

**Figure 10: Terrain model with roading options**

**Figure 11: Same view with trucks added to give context**

### 6.1 Local Context

For visualization of a local region it is highly beneficial to have recognizable landmarks – particularly when dealing with the public on issues such as environmental consents. Figure 12 below shows a 3D model produced for the Te Ahi O Maui geothermal project near Kawerau, Bay of Plenty, New Zealand. Kawerau is an industrial town which has very characteristic features such as the local mountains, the Tarawera River and the pulp & paper and timber mills. The 3D model has been overlaid with an aerial photograph of the local area, providing immediate recognition for anyone familiar with the area.

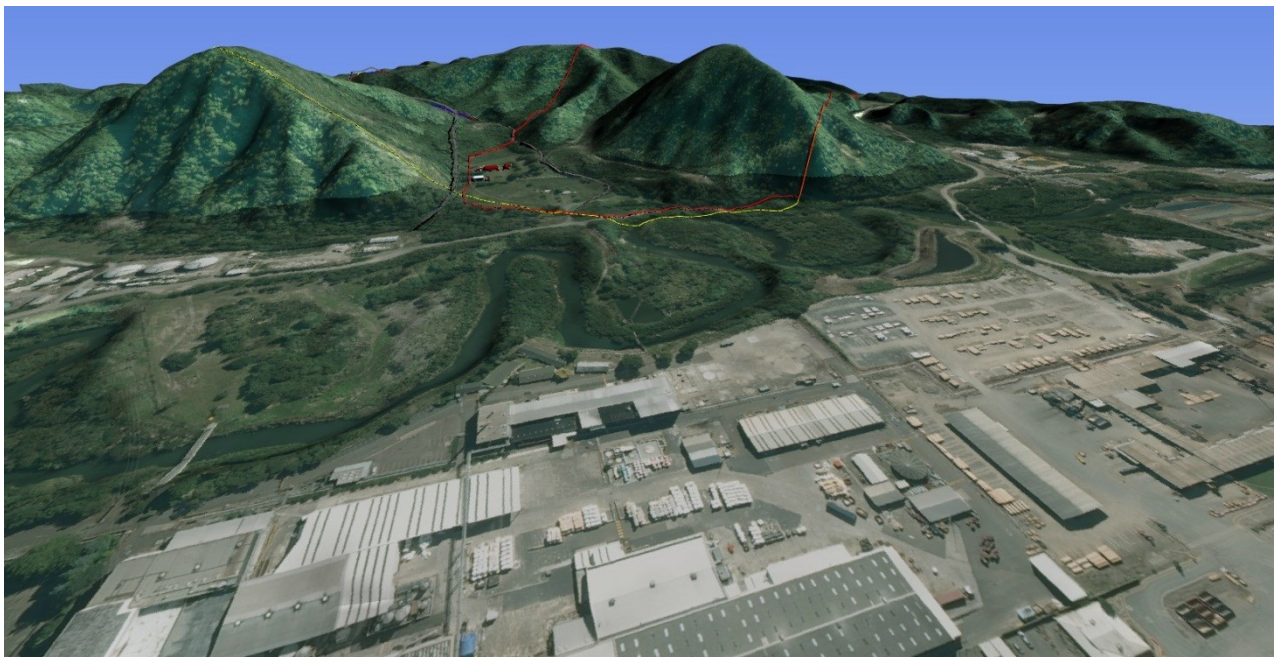

**Figure 12: View of proposed TAOM development, Kawerau, NZ – using aerial photo overlay**

## 7. SINGLE SOURCE DATABASE SYSTEM FOR CROSS-COUNTRY PIPING DESIGN

The design of cross-country piping is quite different to plant piping. Plant piping is typically built on an orthogonal grid. The pipe runs along pipe racks or in buildings. In contrast, for most geothermal sites, there is very little that is orthogonal in the steamfield piping, other than the expansion loops. This creates challenges when creating models for pipe stress analysis and in producing drawings of the piping system.

To streamline the design process, Jacobs has developed an automated system called RouteDESIGN which generates both the engineering pipe stress model and the design drawing files from a single source database. Early versions of RouteDESIGN produced a single line representation of the pipe in the drawing files. This was ideal for presentation in engineering drawings, however as more use was made of 3D modelling, the single line representation proved to be limiting. A single line in a 3D model is difficult to see when overlaid on terrain (see Figure 13), and the lack of volume means that it is not easy for viewers to assess or visualize the pipeline size.

To get more useful output from RouteDESIGN, a section of code was added which simultaneously draws a 3D representation of the pipe and supports at the same time as the single line version. This is immediately viewable in the virtual model – see Figure 14.

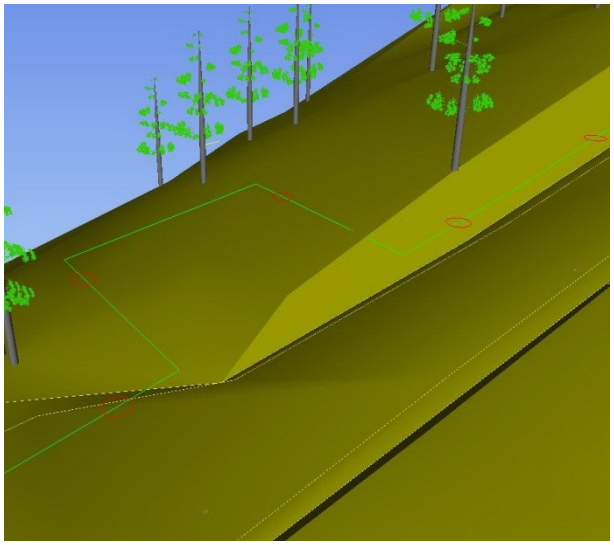

**Figure 13: Single Line Cross Country Piping**

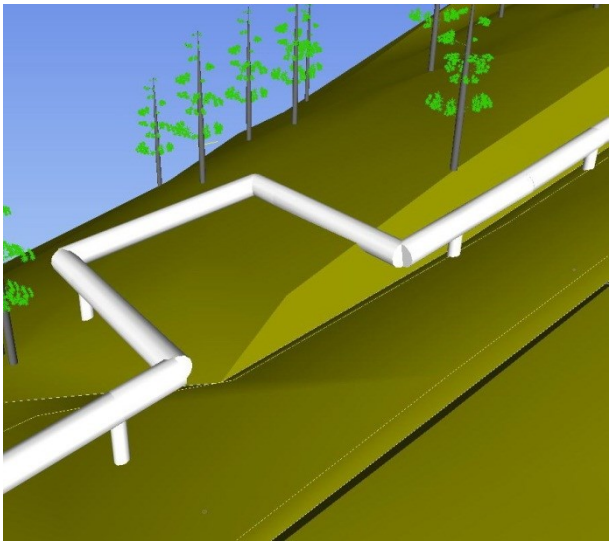

**Figure 14: Solid Model of Cross Country Piping**

The 3D model was deliberately kept simple: changes in direction are simple butt joints (elbows are not drawn), pipe supports are drawn as half line size, fixed points such as anchors and linestops are three-quarters line size and coloured red to make them readily identifiable (see Figure 15). Irrespective of height, pipe support stanchions are modelled as 6m long cylinders that penetrate the

ground surface and consequently any additional length is hidden from view (see Figure 16). This means that it isn't necessary to know final details such as pile size and exact support heights to create a model for review.

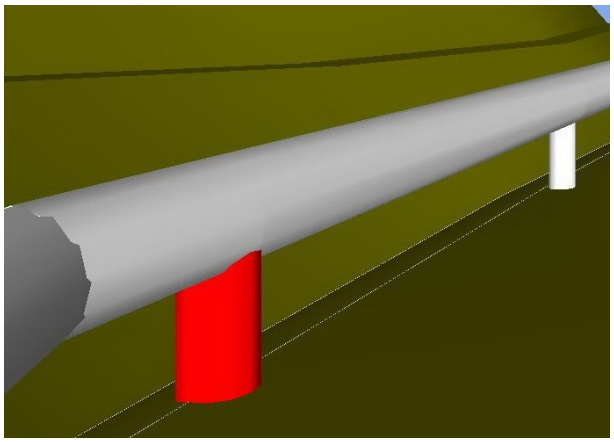

**Figure 15: Fixed point shown in red**

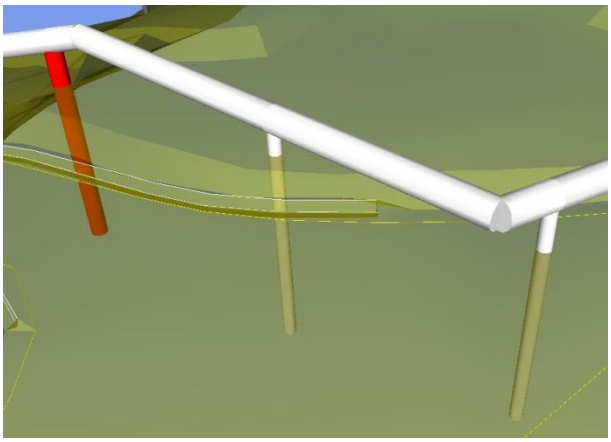

**Figure 16: Pipe Support Stanchions**

Anchors and linestops are high load supports for pipelines, being essential for restraint in a seismic event. It is therefore essential that they be carefully sited to avoid locations of poor soil stability or other features which could affect their integrity. Having them clearly identified in the 3D model allows for ready assessment during concept design reviews.

No additional input is required to create the 3D model, so the addition of a small section of code to the RouteDESIGN software has provided great benefits to the cross country piping design workflow. This enables a more comprehensive review to be carried out in a shorter time than was previously possible.

## 8. BROWNFIELDS DEVELOPMENTS

Carrying out project work within existing facilities is commonly called brownfields development. For steamfield facilities this work is the addition of make-up wells and their associated cross-country pipelines to connect them to an existing steamfield network.

Fitting new pipes within a network of existing piping and support structures is a difficult task, and if not done accurately, will lead to significant delays and costs at the construction stage due to the re-work required.

Figure 17 below shows an example where the most efficient piping layout required the piping to be threaded between a number of existing pipes in a tight space. A survey was used to produce an accurate model of the existing piping and allowed a number of concepts to be tested and reviewed with the client. The model allowed the detailed piping design to proceed with confidence that the pipe could be fitted into the space available.

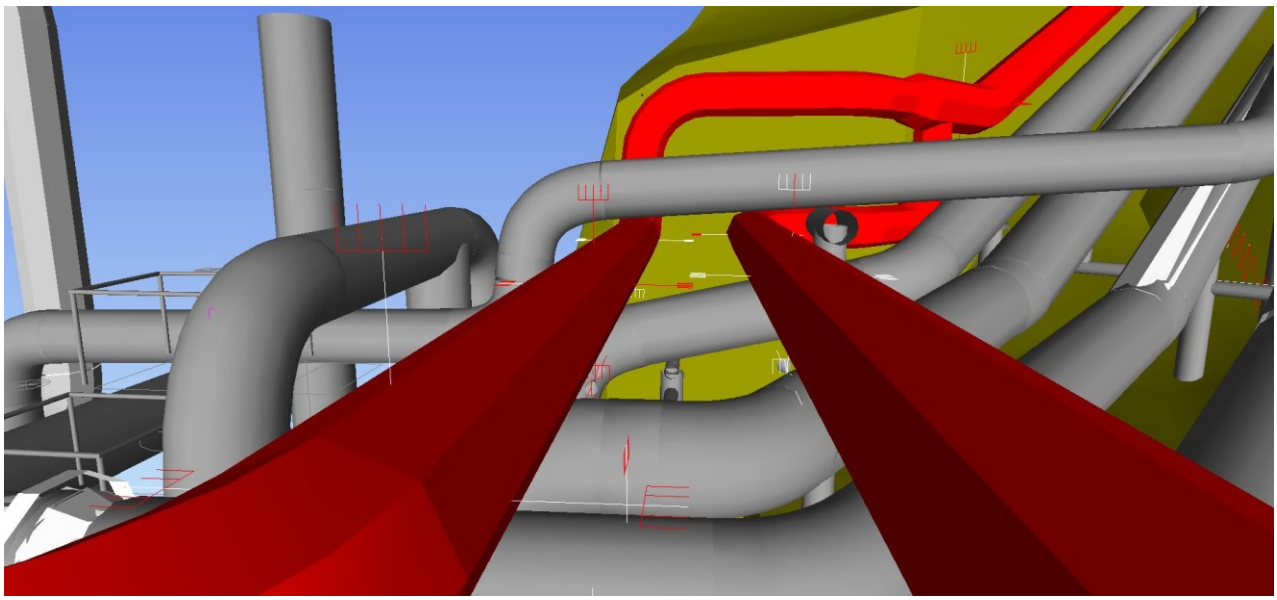

**Figure 17: New piping with minimal clearances to existing**

## 9. CONTROLLING MODEL COSTS

The level of detail in a model must be appropriate to the end use. The best practice is always to keep the model as simple as is possible for the intended audience and usage. Every facet, surface, and face in the model has to be stored, loaded and processed by the computer graphics system, and any unnecessary detail reduces performance. It is also likely that extra detail means more manhours and therefore greater cost.

A common example of the different approaches to modelling detail would be a piece of process pipe. A pipe can be modelled as an annular shape (i.e. a cylinder minus a slightly smaller cylinder). Typically for plant models we are not concerned about the inside of the pipe, hence a simple cylinder shape will suffice for the model (i.e. just model the outside diameter of the pipe).

Junctions between pipe support stanchions and pipe support heads do not need to be built as a trimmed intersection as they would when fabricated. They can simply be modelled as full centerline intersections. Externally both appear the same – which is all that is important for a steamfield model. In Figure 18 and Figure 19 below the horizontal member has been made partially transparent to illustrate the differences between these modelling approaches.

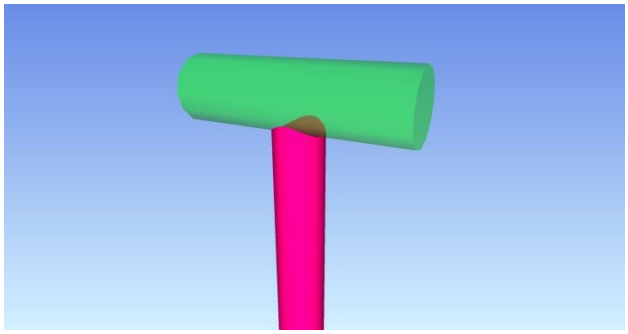

**Figure 18: trimmed intersection**

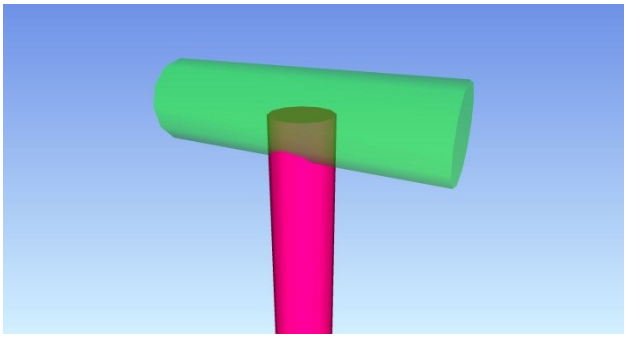

**Figure 19: Centreline intersection**

Using models received from third-parties can also add unnecessary detail to a 3D model. Taking the example of a centrifugal pump: a manufacturer producing a model of a pump has an entirely different need from a plant designer. The manufacturer is interested in every detail of the pump – the shaft, casing, impeller, bearings, seals, bolt holes, base plate etc. – see the example in Figure 20. A plant designer is only interested in a subset of this information: the overall size and shape, the nozzle locations and sizes. So a simple pump model can be constructed from a small number of primitive shapes such as cylinders and boxes – see Figure 21.

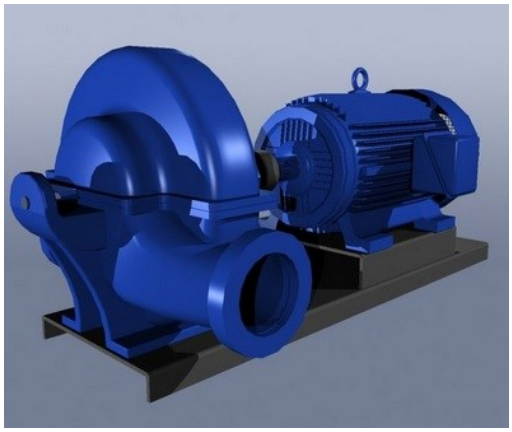

**Figure 20: Complex pump model**

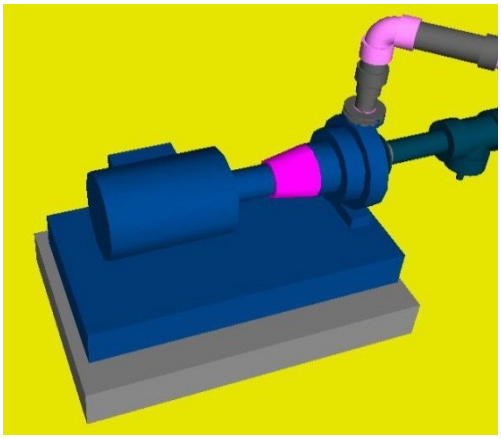

**Figure 21: Simple pump model**

## 10. CONCLUSION

Current tools available to us mean that 3D modelling is readily accessible for steamfield design and facility owners are recognizing the benefits that models bring to their projects. Nevertheless the cost of models is highly dependent on the level of detail used and this must be managed to an appropriate level for its end use. It is further recognized that the level of detail required will change through the life of a facility, with coarse data being required at the concept stage and finer data during detailed engineering design.

GIS tools are beneficial for the visualization of complex datasets, whilst CAD tools are more suitable for engineering applications. The gathering of terrain data for either GIS or CAD must be appropriate for its intended end-use and file sizes need to be managed.

For visualization to be effective the scale within a model must be readily understood. So when producing simple models it is essential to include objects that give viewers the correct sense of size.

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## 11. ACKNOWLEDGEMENTS

Thanks to Carl Avis for use of his industrial piping scale model photographs.

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CADWorx: http://www.coade.com/products/cadworx-plant

Microstation: http://www.bentley.com/en-US/Products/MicroStation/

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