Geotechnical Design with Rhino and Grasshopper: Reinforcing First Principles in Hong Kong Practice

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ABSTRACT

This paper demonstrates how accessible parametric tools can strengthen first-principles geotechnical design without relying on computationally intensive software. By focusing on core concepts such as stress distribution, soil consolidation, and volume assessment, the approach uses modern digital platforms to enhance visualisation, support sensitivity studies, and enable iterative, data-driven design. Rhinoceros 3D (Rhino) and its visual scripting environment, Grasshopper, are employed for efficient Excel data import, dynamic 3D surface generation, geometric manipulation, and real-time model updates, maintaining transparency to underlying calculations rather than relying on black-box software packages. Three Hong Kong–based case studies illustrate these capabilities. In Pile Design and Rockhead Projection, borehole-derived contours are converted into parametric soil and rockhead surfaces, allowing pile layouts to be projected to determine founding levels and rock-socket lengths that automatically update during predrilling. In ELS Visualisation, settlement calculations including elastic, drawdown, and creep components, are imported from Excel to generate live settlement contours for rapid sensitivity testing and serviceability assessment. In Reclamation Quantification, multiple stratigraphic surfaces are used to compute dredging volumes and ground-treatment extents, supporting efficient and environmentally informed optimisation. These examples show how parametric modelling enhances understanding, streamlines processes, and supports geotechnical decision-making.

1 INTRODUCTION

Over the past several decades, rapid advances in the availability of digital tools, computational power, and data connectivity have transformed everyday engineering practice. Modern workflows now routinely incorporate finite element analysis (FEA), extensive numerical modelling, and more recently, emerging artificial intelligence (AI) applications. While these tools provide unprecedented analytical capability, they often operate as opaque "black boxes," distancing the designer from the underlying soil mechanics principles that ultimately govern ground behaviour. In contrast, the fundamental theories that shape geotechnical engineering; such as Terzaghi's effective stress principle (1936), Boussinesq's elastic stress distribution (1885), and the empirical frameworks used to describe soil stiffness, strength, and consolidation; have remained consistent for decades. These principles are rooted in observation, laboratory testing, and incremental scientific refinement. Despite their empirical origins and inherent uncertainties, they continue to underpin modern design codes and remain the foundation of engineering judgement. As computational tools grow more sophisticated, it is important to be aware of the disparity between the natural uncertainty of their empirical origins and today's computational precision.

This paper proposes that parametric modelling platforms—particularly Rhinoceros 3D (Rhino) and its visual programming environment Grasshopper—offer a practical means of reconnecting modern calculation workflows to core geotechnical fundamentals, without requiring specialist numerical modelling expertise or significant software investment. Rather than replacing first-principles thinking, these tools make it more visible: calculations remain transparent in Excel, while Rhino and Grasshopper handle the geometry, visualisation, and iterative updates that would otherwise consume significant manual effort. Their capacity for real-time feedback, dynamic geometry manipulation, and direct interoperability with Excel makes them well suited for procedures grounded in first-principles analysis, and their outputs can be readily converted into the standard deliverables required for formal engineering submissions.

To illustrate this, three Hong Kong–based case studies are presented. Each demonstrates how parametric tools can be integrated into geotechnical practice to enhance interpretation of subsurface conditions, improve visibility of calculations, and streamline iterative design. The examples cover:

1. Pile design and rockhead projection using contour-derived surfaces;

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2. Excavation and Lateral Support (ELS) settlement visualisation directly linked to calculations; and
3. Reclamation volume estimation and ground-improvement quantification using parametric surface interactions.

These case studies highlight how parametric modelling can strengthen engineering understanding, reduce design risk, and improve design efficiency while reinforcing, rather than replacing, the fundamental concepts at the core of geotechnical design.

1 METHODOLOGY – THE USE OF RHINO3D & GRASSHOPPER FOR GEOTECHNICAL APPLICATIONS

This study employs Rhinoceros 3D (Rhino3D) together with its visual programming environment Grasshopper to develop straightforward parametric design and analyses for geotechnical engineering purposes. The methodology is structured around three core functions of the software: data import, data visualisation, and data manipulation. These functions enable the creation of dynamic, interpretable ground models and the integration of engineering calculations directly from Excel.

1.1 *Software Environment*

Rhino3D is a CAD platform built on the non-uniform rational B-spline (NURBS) modelling framework, enabling accurate representation of geometric entities such as curves, surfaces, solids, and point sets. Its lightweight architecture, affordability, and wide interoperability make it well suited to geotechnical processes, where engineers must integrate multiple data formats including contour grids, digitized borehole logs, and databases of instrumentation records.

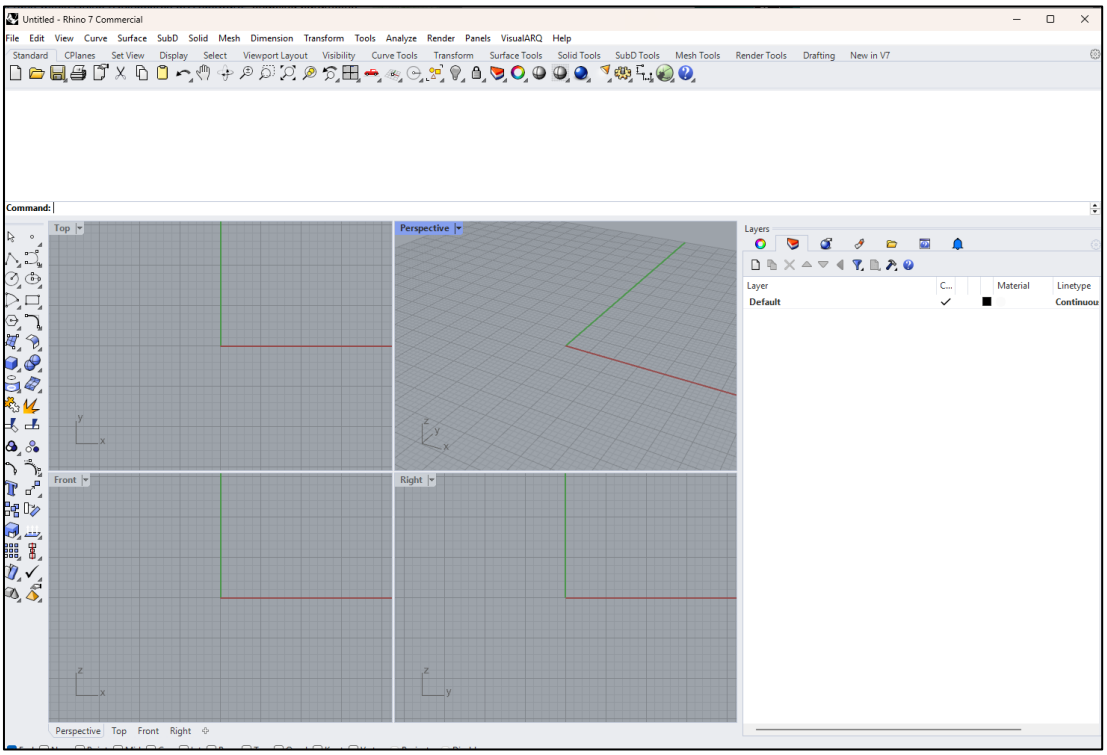


Figure 1 - The Rhino3D Interface (Rhino 7)

Grasshopper, a plugin native to Rhino, provides a visual programming interface in which users connect components representing operations, parameters, or data structures. Complex procedures can be built by linking these components into logic-based sequences. Unlike black-box numerical tools, Grasshopper exposes all intermediate steps, ensuring a clear line to the underlying calculations that inform geotechnical design.

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Figures 1 and 2 depict the Rhino interface and the Grasshopper canvas respectively, providing context for the modelling environment applied throughout the methodology. The Rhino interface shows a 4-viewport setup with toolbars and layer manager open. Note that the command bar enables interoperability with traditional text based coding scripts. The grasshopper interface shows various components linked together, typically inputs and parameters on the left, execution components in the middle and output components on the right.

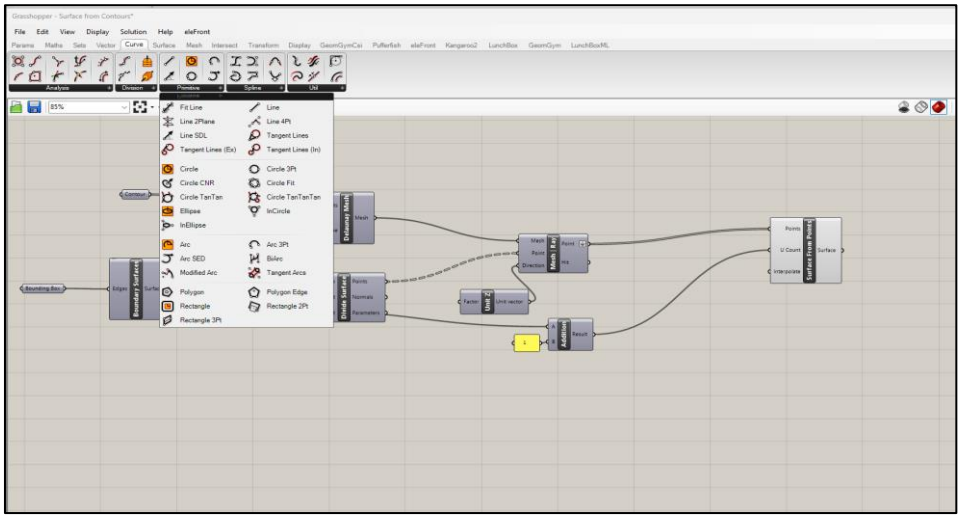


Figure 2 - Grasshopper Interface with Components on Canvas. The Component Dropdown Menu is open on the Toolbar

1.2 *Data Import and Visualisation*

Throughout its compilation and interpretation, ground investigation data in Hong Kong are usually consolidated into digital workbooks (eg. MS Excel), where borehole locations, levels, and stratigraphic boundaries are stored for design use. To import these datasets into Grasshopper, community-developed plugins such as LunchBox and TT Toolbox are used. Their Excel Reader components allow Grasshopper to link directly to workbook files with minimal setup, extracting XYZ coordinates and descriptive soil parameters, refreshing whenever the spreadsheet is updated, and structuring the data as points, lists, or hierarchical trees. The imported coordinates can then be visualised in Rhino as point clouds or used to generate curves, surfaces, or meshes, within the Grasshopper environment, based directly on the data being read. Figure 3 demonstrates this, where columns from Excel are translated into 3D points within Grasshopper. Should any of the data points be updated, the Grasshopper procedure can be set up to automatically reflect the change visually in the Rhino viewport.

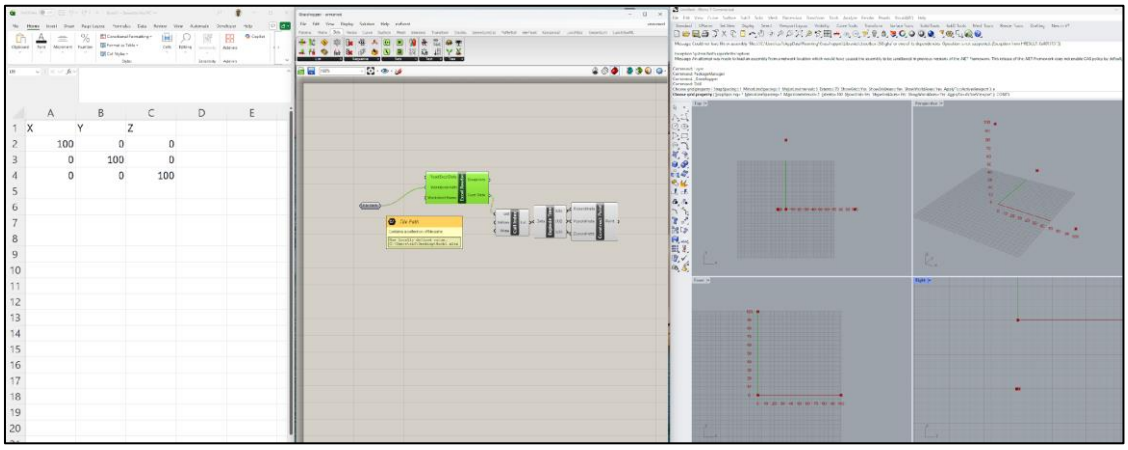


Figure 3 - Grasshopper Canvas: Live Data Import from Excel Using LunchBox Excel Reader Component

Grasshopper's data structure is based on hierarchical data trees. Each branch represents an array of items which can be organised in lists or joined together. This multi-layered system of data organisation allows the software to manage the type of complex datasets that are common in geotechnical practice (e.g. settlements data for multiple cofferdams of varying shapes, inferred levels of various strata from multiple boreholes, or in-situ test results for various soil types). This ensures that geometric and numerical data can be processed in parallel while maintaining full traceability.

1.3 *Data Processing and Geometric Transformation*

After import, the data can be manipulated using Grasshopper's broad range of geometric transformation tools. Geometry may be shifted, rotated, scaled, or reoriented, allowing ground models or structural elements to be adjusted interactively while remaining tied to underlying design parameters and calculations.

These transformations can be linked directly to parameters stored in Excel such as pile diameter, rockhead levels, or setting out points, enabling easier updates to pile toe levels, surface elevations, or excavation geometries. Grasshopper also provides tools for working with point-based data, allowing engineers to deconstruct and reconstruct points, project locations onto surfaces, and extract elevation information from terrain or geological models. These capabilities make it straightforward to interrogate and refine geotechnical geometry as design assumptions evolve. These tools are particularly useful when, for example, projecting pile footprints onto rockhead surfaces or when generating cross-sections through geological strata, both of which rely on accurate point and surface interrogation.

Once the underlying geometry is established, geotechnical contour data imported from software packages such as Surfer or from other CAD sources can be transformed into continuous 3D terrain surfaces. Instead of relying on a series of discrete contour lines, Grasshopper's meshing and surface-fitting components allow these curves to be blended into a coherent ground model. By using Grasshopper components such as Mesh From Contours, Delaunay Mesh, or NURBS Surface Fit, the contours are converted into a fully connected surface that updates automatically whenever the source data or borehole interpretations change.

Grasshopper generates geometry in a live, parametric state, but completed elements should be "baked" into Rhino to create static objects in a layer for export. These fixed outputs can then be incorporated into drawings, exported to BIM platforms, used for additional analysis, documented, or passed on to drafting teams.

2 CASE STUDIES

The following case studies illustrate how Rhino and Grasshopper can be used to visualise, interpret, and manipulate geotechnical data to address practical engineering challenges.

2.1 Pile Design and Rockhead Projection

The first case study focuses on the challenge of accurately determining pile founding levels in a Hong Kong design process setting, where a defined engineering rockhead (typically Category 1 (c) or equivalent) can vary significantly due to fractures, weathering, topographical undulation, and the typically sparse distribution of boreholes in early design stages. Even small changes in interpreted rockhead can alter pile lengths, socket depths, and construction quantities. Traditionally, these levels are derived by reviewing boreholes, studying contour maps, and carrying out manual interpolation. This approach becomes slow, labour intensive, and prone to error when applied to large pile groups or frequently revised designs.

To streamline this process, a parametric procedure was developed using Surfer, Rhino3D, and Grasshopper. Borehole-derived rockhead levels are first interpreted and gridded in Surfer to generate a contour model of the Category I(c) rock surface. These contours are then imported into Rhino, where Grasshopper converts them into a continuous three-dimensional rockhead surface, a simple procedure for this is illustrated in Figure 4. The project's pile layout is subsequently loaded into the file as geometry and Grasshopper projects them through this surface to determine individual founding levels and socket lengths.

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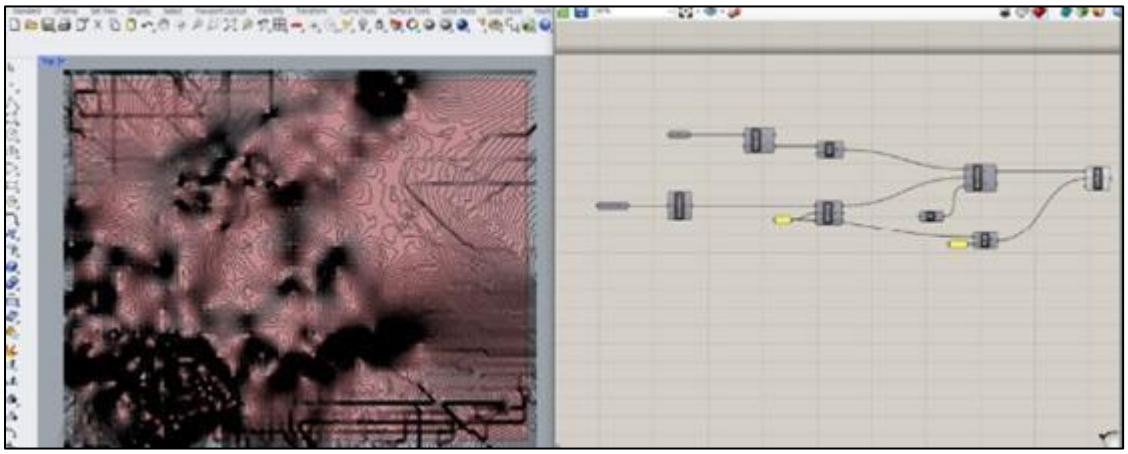


Figure 4 - Plan Rhino Viewport of Contours are Converted to a Surface by a Grasshopper Script Live

The Grasshopper protocol follows a clear sequence that links the interpreted ground model directly to the pile layout. Surfer-generated rockhead contours are first brought into Rhino and referenced in Grasshopper as curve geometry. These curves are then converted into a continuous three-dimensional surface using tools such as Mesh From Contours or Delaunay Mesh, providing a live representation of the interpreted rockhead. With the surface established, the project's pile data are imported, enabling their geometries to be modelled as curves and projected downward until they intersect the rockhead surface; these intersection points define the starting point for calculation of founding levels for each pile and form the basis of the updated pile schedule. Figure 5 shows the execution of the Grasshopper script to read from the pile schedule and project the visual image of the data onto the underlying rockhead surface, including pile lengths, rock sockets, and any bellouts.

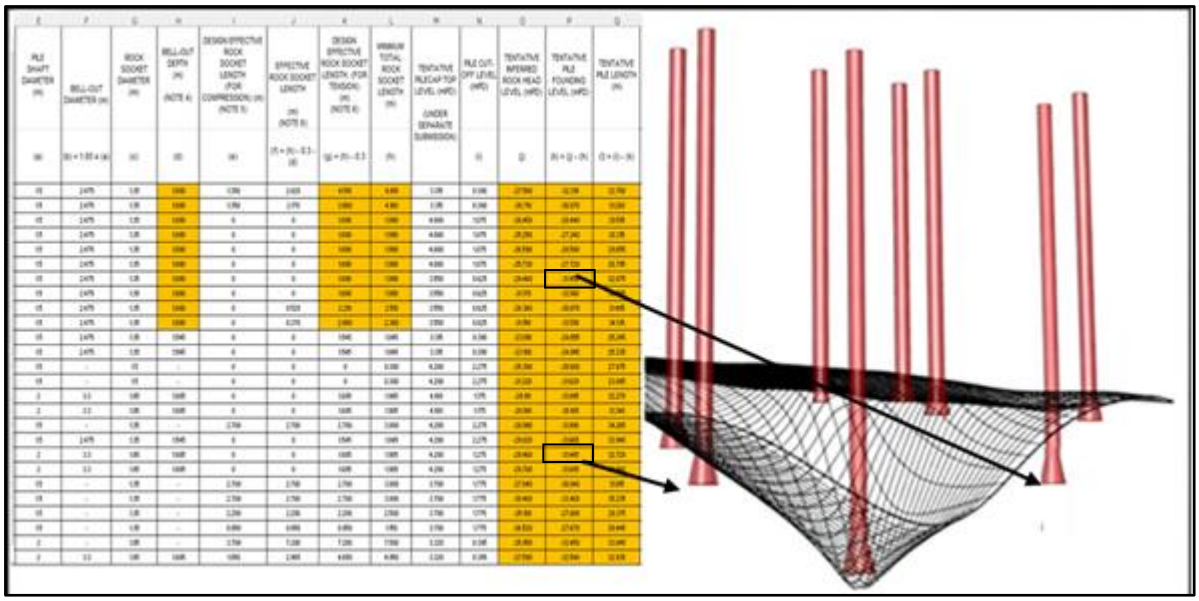


Figure 5 – Pile Schedule Updates can be Automated through Grasshopper's "Write to Excel" feature as Rockhead Surface Changes

To complete the process, calculated founding levels are written back into the relevant Excel schedule using the Write to Excel component, ensuring that any revision to the contour model or pile layout is reflected automatically across the design documentation. The pile schedule in Excel is set up to calculate the resulting

final founding level accounting for minimum socket length and other relevant factors. This creates a fully parametric environment in which updates to borehole interpretation or structural layouts instantly propagate through the model.

The resulting engineering outcome is a model which provides a live, databased representation of rockhead and its interaction with the pile arrangement. Founding levels update instantaneously when boreholes are reinterpreted, when new investigation data becomes available, or when structural engineers adjust pile positions. The process also allows the designer to inspect pile-to-rock interaction visually, verify assumptions, and quickly identify anomalous or unexpected founding depths.

This approach provides several practical advantages for foundation design. By replacing manual interpolation with a fully parametric process, significant time is saved; particularly on projects involving large pile groups or frequent layout revisions. Accuracy is improved because founding levels are derived from a continuous contoured surface rather than isolated spot checks and the full pile geometry is being considered. In addition, any updates to the ground model or pile arrangement feed automatically through to the schedule. The procedure also enhances transparency, allowing engineers to visually verify how each pile interacts with the rockhead surface and to identify anomalies quickly. In addition, multiple stratigraphic surfaces can be stacked within the Rhino–Grasshopper environment, enabling the creation of geological profiles along the pile alignment and supporting more informed decisions regarding socket depths, founding criteria, and layer transitions. The direct links to Excel facilitate clearer coordination with structural teams and reduce drafting workload.

2.2 Excavation and Lateral Support (ELS) Visualisation

The second case example addresses a common challenge that arises once the engineer has completed the initial settlement calculations and must present the results clearly in drawings or design figures so that potential impacts on nearby utilities or sensitive receivers can be assessed. Evaluating ground movements around deep excavations is a critical aspect of ELS design, particularly in dense urban environments where foundations, utilities, roads, and other assets lie close to the cofferdam. Although the settlement calculations themselves are typically grounded in first-principles soil mechanics such as elastic compression, groundwater drawdown, and long-term creep, their spatial interpretation is not as straightforward. Conventional workflows often require engineers to manually transfer the calculated settlement values into CAD or GIS platforms to generate contour plots, a process that is slow, prone to repetitive effort, and difficult to adapt when multiple cofferdam layouts, strut configurations, or pile toe levels must be compared, parameters which all have implication on the final settlement contours.

To address these limitations, a parametric Grasshopper script was created to link directly to the Excel-based settlement calculations prepared by the design team. Rather than treating calculation and visualisation as separate steps, Grasshopper reads the settlement values in real time and generates spatial contour plots within Rhino. As a result, settlement patterns update swiftly whenever input parameters change, enabling rapid sensitivity studies during ELS optimisation.

During the optimisation stage, design iterations are carried out by adjusting key stiffness and boundary-control parameters. These include strut elevation and preloading, strut and pile axial/bending stiffness, and, where relevant, excavation sequence. Then the finite-element (FE) model is run to obtain updated wall deflections and free-field ground movements. In parallel, seepage analyses are also run to quantify changes in hydraulic head during dewatering and excavation stages, and the extent of groundwater drawdown associated with the updated arrangement is exported. The FE outputs and the seepage results are brought through into Excel, where the settlement calculations are set up to convert these inputs into settlement values, with corresponding offsets to the ELS wall. On this basis, elastic compression, drawdown-induced settlement, and time-dependent consolidation are being computed at control points or along user-defined sections as desired. Grasshopper reads these computed values directly from Excel and generates the settlement contours in Rhino, providing an rapid parametric visualisation of the combined settlement response shortly after the analysis stage has been completed.

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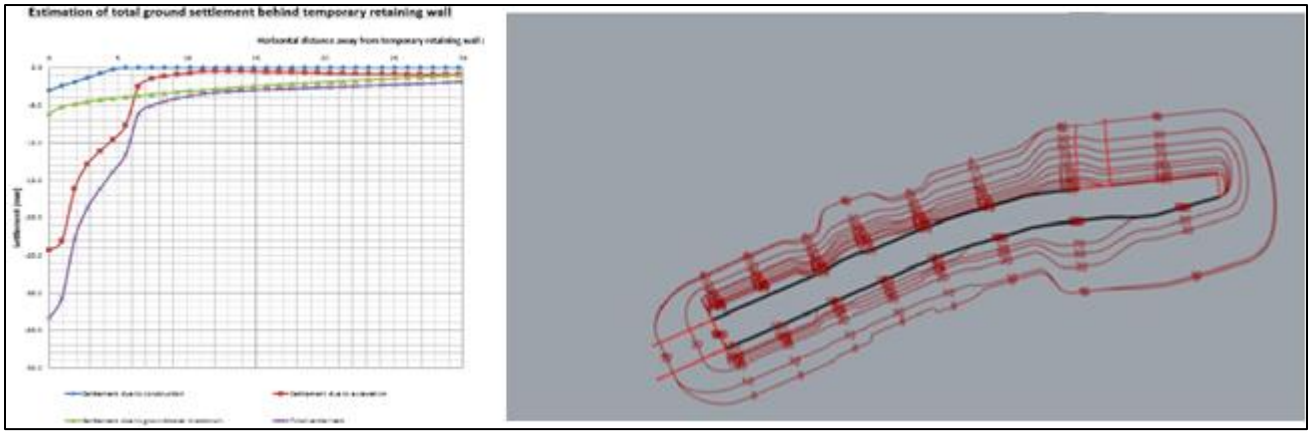


Figure 6 – Settlement Contours Generated in Rhino as Grasshopper Reads Directly from Excel

Figure 6 shows on the left an example of a set of settlement curves (including elastic settlement, drawdown, and consolidation) for a given section of a planned ELS, to the right - the Grasshopper projection of dozens of such curve sets as offset contours surrounding a proposed cofferdam. The resulting model provides a clear, intuitive view of settlement behaviour around the excavation. Since the visualisation is live-linked to the Excel-based calculations, engineers can vary key parameters such as strut levels, toe depths, or cofferdam geometry and see the impact shortly after updating the excel file, without redrawing contours by hand. This accelerates decision-making and improves transparency, as the connection between input assumptions and predicted ground movements is visible in a short space of time.

This approach delivers clear benefits for ELS design. It removes the repetitive drafting usually needed to generate settlement contours for multiple options, and its parametric setup provides rapid feedback when strut positions, pile toe depths, or other input parameters are adjusted. This makes it easier to converge on arrangements that minimise ground movements. Since the live contours sit in the same Rhino CAD environment as utility surveys and structural layouts, coordination improves and potential clashes can be identified at an earlier stage. All outputs remain tied to calculations in Excel, strengthening auditability and engineering confidence. These advantages reduce risk by flagging potential impacts on surrounding assets early in the design process.

3.3 Reclamation and Ground Improvement Quantification

The third and final case example builds on the methods and processes introduced in Section 3.1. In the first case example, contour data was used to generate surfaces. This third case study extends that approach by demonstrating how multiple surfaces that define stratigraphic soil boundaries can be combined to tackle a common challenge encountered during the planning phases of a reclamation and seawall design project. Early-stage reclamation design requires quick yet defensible quantity take-offs to guide option selection, logistics, and pricing. For example, it is important to understand how much marine deposit must be dredged, or where ground improvement zones (ie. beneath seawalls or slopes) are required and to what extent. Contractors must also estimate fill volumes for different target platform levels and formation elevations, all at an early stage to inform their financial and logistical decisions going forward.

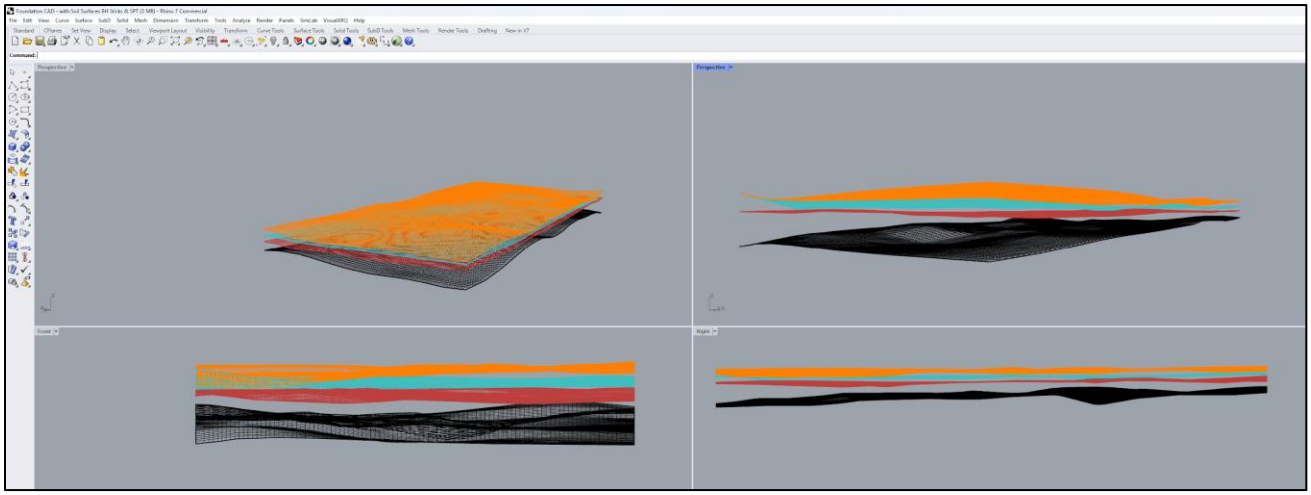


Figure 7 – Multiple Soil Surfaces Created in Grasshopper and Baked into Rhino Viewport

The solution involves developing a parametric environment in Rhino + Grasshopper that engages internal site boundaries and setting out points with stratigraphic surfaces all as initial inputs. The objective is to produce live volumes and quantity tables that will aid planning and decision making. Lines and curves representing the site boundary, seawall alignment, berthing areas, and zones designated for heavily loaded structures are imported into Rhino and used as volumetric boundaries. These boundaries are then extruded through a set of stratigraphic surfaces such as proposed ground level, existing seabed, marine deposit top and base, alluvium horizons, decomposed granite, and engineering rockhead, which have been generated using the same method described in Section 3.1.

Grasshopper then evaluates the interactions between these boundaries and the underlying surfaces to compute, by subtraction, dredging volumes, ground-treatment extents, and fill quantities at locations such as seawalls, slopes, and platform areas. Because the script is fully parametric, any adjustment to alignment, formation level, or treatment depth automatically updates the calculated volumes, allowing planning-stage design changes to be reflected in the associated logistical and financial implications.

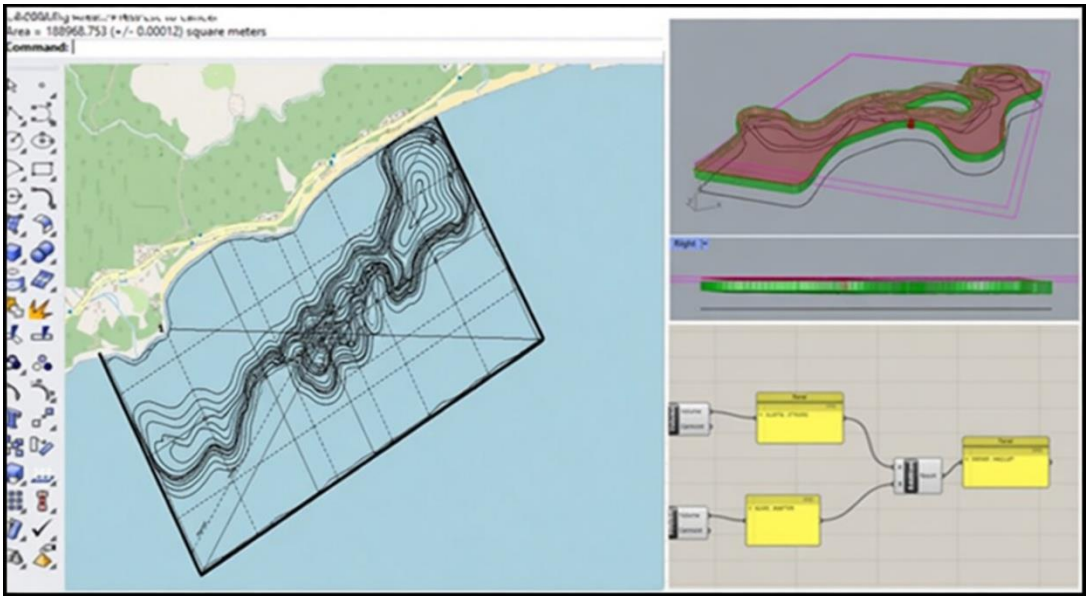


Figure 8 – Surfaces can be projected through soil layers to get volumes

The solution provides rapid updates to dredge, treatment, and fill quantities as seawall centrelines, formation levels, or treatment depths evolve during planning and tendering. Areas where soft materials thicken, such as

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beneath seawall corners, are quickly highlighted, allowing designers to trial minor alignment or level adjustments to reduce treatment or excavation demands. Because these volumes are computed directly from the stratigraphic model, section cuts and spot checks confirm that the results remain geologically consistent without introducing the risk of error through manual handling of CAD operations.

4 FROM PARAMETRIC MODEL TO FORMAL SUBMISSION

A practical concern for Hong Kong practitioners is how parametric model outputs translate into the standard deliverables expected by regulatory bodies such as the Geotechnical Engineering Office (GEO) and the Buildings Department (BD). The Rhino + Grasshopper workflow is designed to complement, rather than replace, conventional submission formats, and the conversion from live parametric model to formal drawing or calculation report follows a straightforward sequence.

Once a parametric geometry is finalised, Grasshopper's "Bake" function deposits static geometry into named Rhino layers. These baked objects—surfaces, curves, pile lines, settlement contours—can be exported directly as DWG or DXF files, which are then opened in AutoCAD or MicroStation for annotation, dimensioning, and title block addition in the conventional manner. The resulting drawings are indistinguishable from those produced through a traditional workflow and are fully compatible with GEO submission requirements, including the preparation of foundation layout plans, pile schedule drawings, and ELS general arrangement drawings.

On the calculation side, the Excel workbooks that drive the Grasshopper scripts already constitute the formal calculation record. Since all geotechnical assumptions, input parameters, and computed results reside in the spreadsheet, these files can be directly formatted and submitted as calculation appendices without any transcription step. This preserves auditability and satisfies the traceability requirements that checking engineers and regulatory reviewers typically expect. The parametric model therefore acts as a quality assurance layer over the conventional submission package, not a replacement for it.

5 INTEGRATION WITH NUMERICAL ANALYSIS

The geometry developed within Rhino + Grasshopper is compatible with a range of downstream analysis environments, and the ecosystem of available plugins continues to grow. For structural analysis, well-established Grasshopper plugins such as Karamba3D provide parametric finite element analysis of beam, frame, and shell elements directly within the Grasshopper canvas, while the GeometryGym suite enables direct model export to industry-standard platforms including SAP2000, ETABS, Oasys GSA, and Robot Structural Analysis. These workflows are particularly relevant where geotechnical geometry intersects with structural design; for example, transferring pile cap layouts, retaining wall geometries, or seawall cross-sections into a structural model without rebuilding from scratch.

For geotechnical finite element software such as PLAXIS, direct interoperability with Grasshopper is achievable through the PLAXIS Python API, which allows model geometry, soil zones, and construction stages to be defined and run programmatically. Published examples of this approach include work by Arup on the Euston Station redevelopment (Major Projects Association, 2023), where Grasshopper was used to extract cross-section geometry from a BIM model, which was then passed to PLAXIS via Python scripting to automate the setup and execution of multiple FE analyses. While this level of integration goes beyond the visual, accessible workflow described in this paper, it illustrates the direction of travel for parametric geotechnical practice. In the near term, the more common workflow, and the one applied in the case studies here, is for PLAXIS outputs to be exported as CSV or pasted into Excel, from which Grasshopper reads the results for visualisation and sensitivity review.

6 CONCLUSIONS

This paper demonstrates that technological advancements in parametric modelling can be used to emphasise first-principles geotechnics rather than replace or supersede them. By keeping calculations visible in Excel and using Rhino + Grasshopper for live geometry and visualisation, engineers can interrogate assumptions, iterate parameters, and see the consequences of design changes quickly. The three Hong Kong applications—pile founding to rockhead, ELS settlement visualisation, and reclamation quantity modelling—showed similar results: faster, auditable procedures that reduce drafting effort, minimise data handling errors, and improve coordination with colleagues and stakeholders. Although the approach does not eliminate the inherent

uncertainty in GI or enhance the accuracy of the analysis, it makes that uncertainty visible and easier to test through structured sensitivity studies. The workflow also sits naturally within Hong Kong's formal submission environment: parametric outputs are readily converted into the standard 2D drawings and calculation reports expected by regulatory bodies, and the same geometry can be exported to analysis platforms for further numerical investigation. In everyday practice, this turns parametric modelling into a practical advantage, with better decisions reached sooner and a clear line back to the underlying fundamentals of soil mechanics.

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