geometry was parameterised. Architectural design of space planning had been developed to high levels of detail and it was too late to share a geometric definition. If the geometry had been parametrised earlier, a shared definition would have avoided the extensive effort spent *matching geometry*. Earlier parameterisation would have also presented an opportunity to conduct a *design investigation*.

The chain of communication began with WEA who were responsible for defining the geometry, A1 were committed develop a structural design based on this. CW and the author were employed by A1 to assist the structural design process by producing a parametric definition based on WEA's geometry. Instructions from WEA to make changes to parameters were passed to the parametric modellers via A1. It is suggested that this chain may have caused the *matching geometry* procedure to become protracted.

In conclusion, the case study suggests careful consideration of the point of parametric application and the position of the parametric definition in the work flow. Benefits of a code based model definition were observed in the speed of generating results, although the higher level of control abstraction should be considered. In this case, earlier application with the parametric model positioned as a shared resource between architects and engineers may have provided a more efficient process.

7.6 Training professionals

7.6.1 Overview

Projects reviewed in this section are the result of professional training sessions conducted by the author for Ian Simpson Architects (ISA) and Whitby Bird (WB) (now known as Rambol but referred to as WB herein). Each of the projects below illustrates at least one of the tasks, sub-tasks or procedures identified in the task structure.

The training sessions were held in the offices of both companies with small groups of five to ten employees. Both practices were working with Bentley's GC. Before the training sessions each participant supplied the author with information about a current project. This information either related to a particular issue with parametric modelling of the project or described a design problem for which the author was expected to propose a parametric approach. Projects from ISA are described first and were typified by an interest in modelling and geometry methods, automating the extraction of building data, establishing work flows and control systems. Participants from WB were structural and facade engineers and their focus was on rationalisation strategies.

The projects and models described below were developed over the course of a few days, compared to the months or years of other case studies reported in this thesis. The descriptions are short and are intended to briefly describe the project and identify the salient points. Each project is numbered and given the prefix ISA or WB to indicate the office it originates from.

7.6.2 ISA Projects

Fragmented model (ISA1)

The first ISA project was for an office tower that had already been modelled parametrically. ISA required model organisation suggestions to make it more logical and easier to control. ISA's model was unstructured and mixed steps involving geometric definition, extraction of representations and design investigation. The author proposed *fragmenting* the model into four logical chunks; control, form, floors and facade. Each fragment had a series of technical problems and parameters associated with it and they could be dealt with incrementally. The complete set of control parameters were defined within a spreadsheet. The next step focused on the form of the building. This was created by defining vertex points using sets of point coordinates extracted from the spreadsheet. The vertices were then linked horizontally and vertically to define wire-frame geometry (figure 7.21 left). The next chunk involved controlling and defining a set of planes at each floor level using values in the spreadsheet. The planes intersected the wire-frame and defined the vertices for each floor. These were connected to represent the floor edges (figure 7.21 centre). The floor edges then became an input to the last fragment of the model which created a facade grid. The model operator controlled panel width and select which facade to investigate (figure 7.21 right)

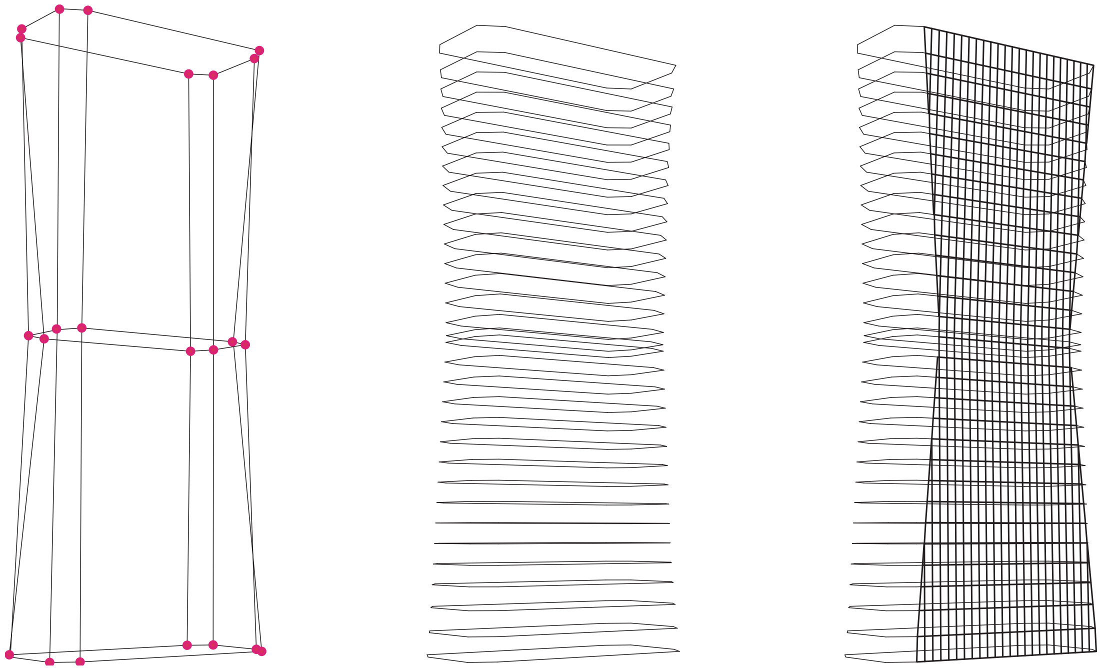


Figure 7.21: Fragmentation of model. Left: Vertices define edges of underlying geometry. Centre: floor edges. Right: facade grid.

Massing study (ISA2)

The second training project demonstrates the use of codification as an *amplifier* of design ideas to investigate a massing study. In this case the project had been developed using standard CAD and modelling techniques. The project architect was curious to see how it could be tackled parametrically. The design development process was focused on massing studies that were assessed visually (figure 7.22) and in terms of gross floor areas. An interactive control mechanism was developed to illustrate how the geometry of the proposed building type could be controlled, models and floor areas were exported. This was developed further to include a scripted loop that updated parameter values controlling building mass and automated the export of three-dimensional models and output of floor areas (figure 7.23).

Adaptive planar curves (ISA3)

The next project connects with other case studies in this thesis. This tower design method borrows the underlying geometric and control system directly from BLA, a project for ISA where the author was extensively involved. It is noted above that BLA is influenced by the

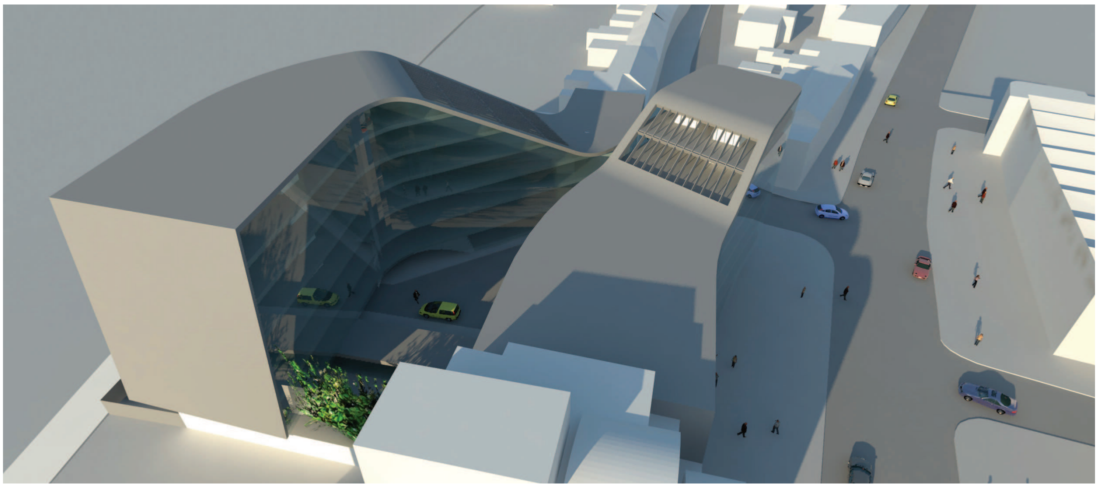


Figure 7.22: Massing study visualisation.

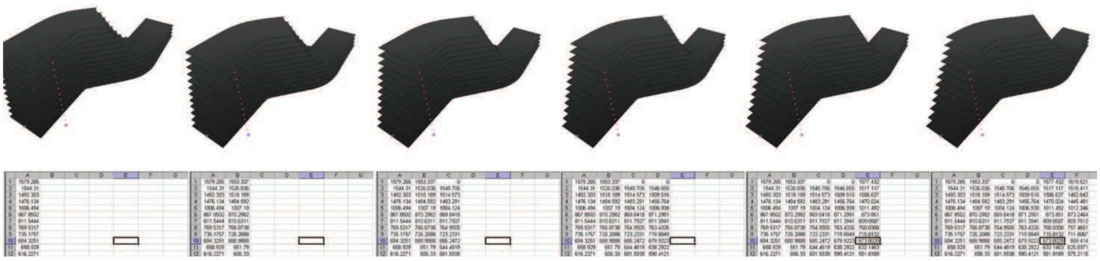


Figure 7.23: Automation of parameter change for massing study. Top: model geometry sequence. Bottom: updates to floor areas.

geometric and control systems of previous projects undertaken by the author. ISA3 was not just influenced by previous work, but actually redefines a previous model, demonstrating the procedure of *case retrieval*. The geometric method for ISA3 is illustrated in the bottom row of figure 7.24 which compares it to previous projects. The underlying principle for each of the case studies is a planar curve defined with simple rules. An array of the curves is created each represents a part of the building and each varies according to control curves. In the case of ISA3 the floor is defined in a way that constrains each edge to remain parallel at each floor level. This defines facades which are singly curved. A rational facade system consisting of four sided planar panels can be created. Control curves define the distance between the front and back of each floor plan and the dimension of the front edge varies with this distance (figure 7.24 bottom left).

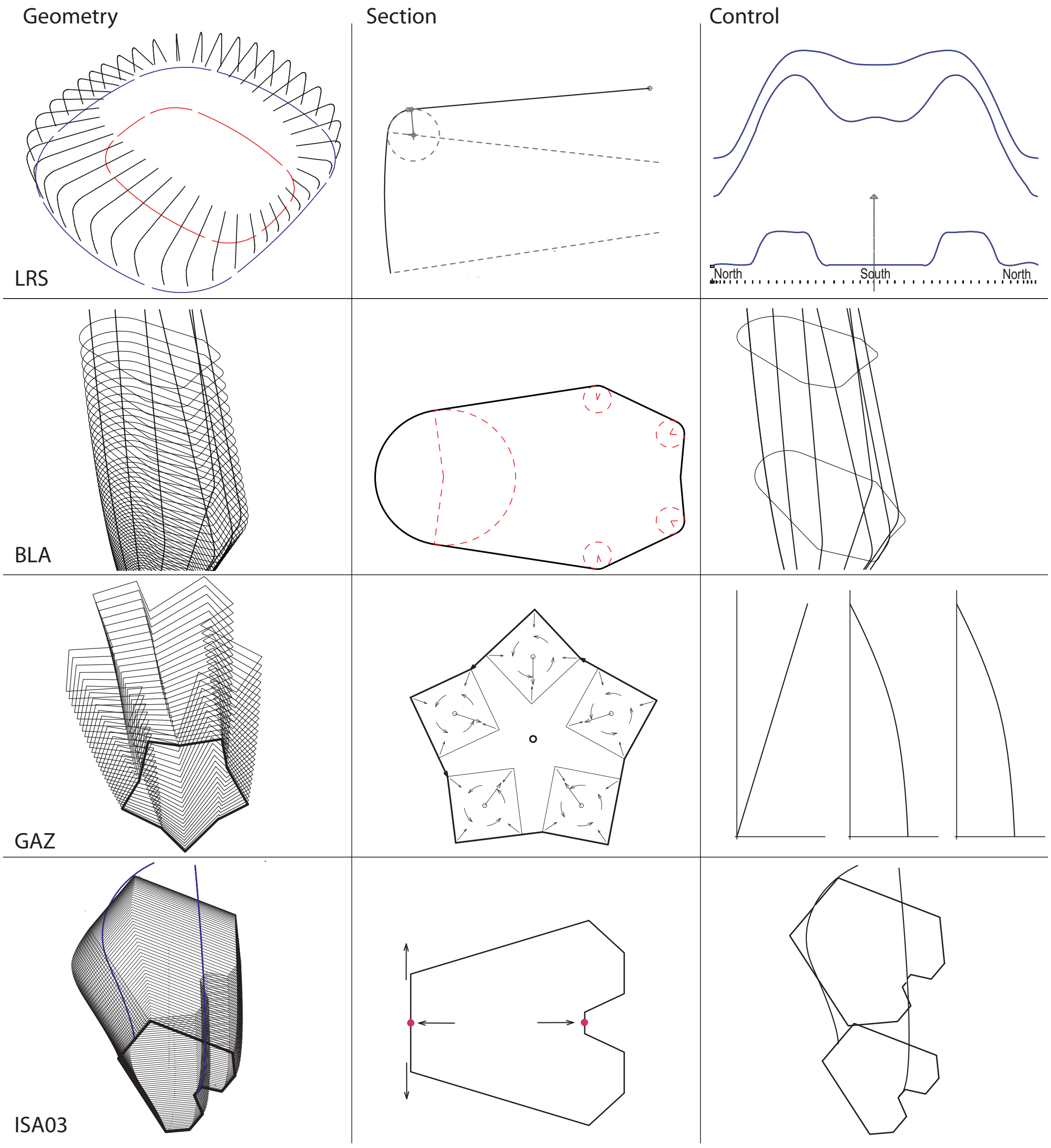


Figure 7.24: Development of the adaptive planar curve method. Top to bottom LRS, BLA, GAZ and ISA3.

Fragmented control (ISA4)

The final project developed for the ISA training session had already been through a design development process that had resulted in the definition of form as the result of massing studies. The concern for this project was how to develop a parametric model to investigate facade options using the existing models of the building mass. This illustrates a *control hierarchy* where building form is defined and controlled in a non-parametric CAD platform and imported into the parametric environment where the facade system is controlled parametrically (figure 7.25). Once the system is established, the CAD file can be edited and reloaded into the parametric model where the facade system can be applied to the new geometry. Working in this way requires the range of possible variations of the CAD model to be considered by the parametric designer and understood by the CAD modeller. ISA4 demonstrates this approach after the design development stage when significant changes to the underlying geometry are not anticipated.

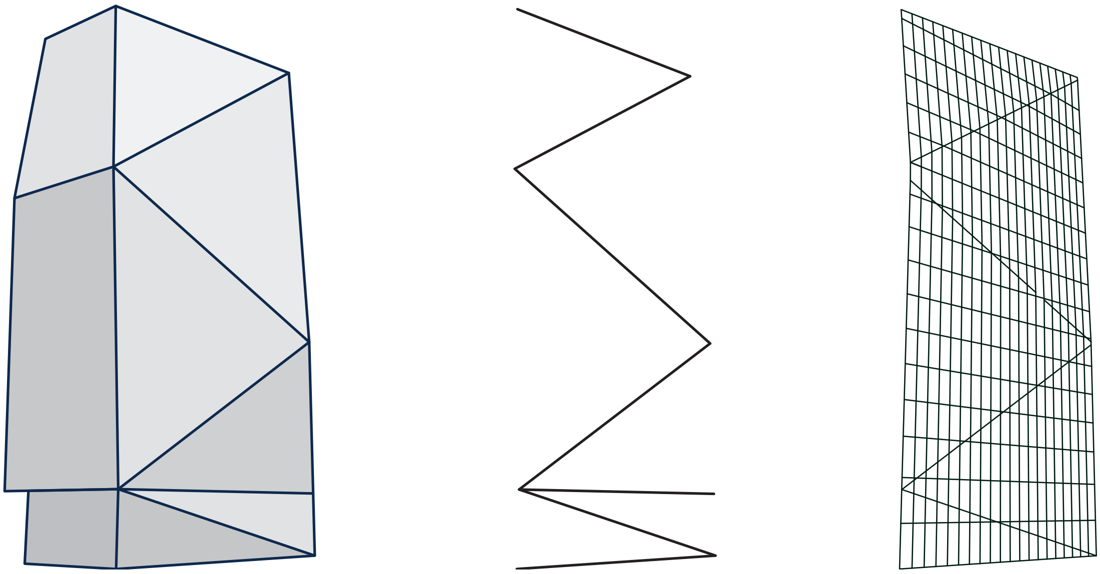


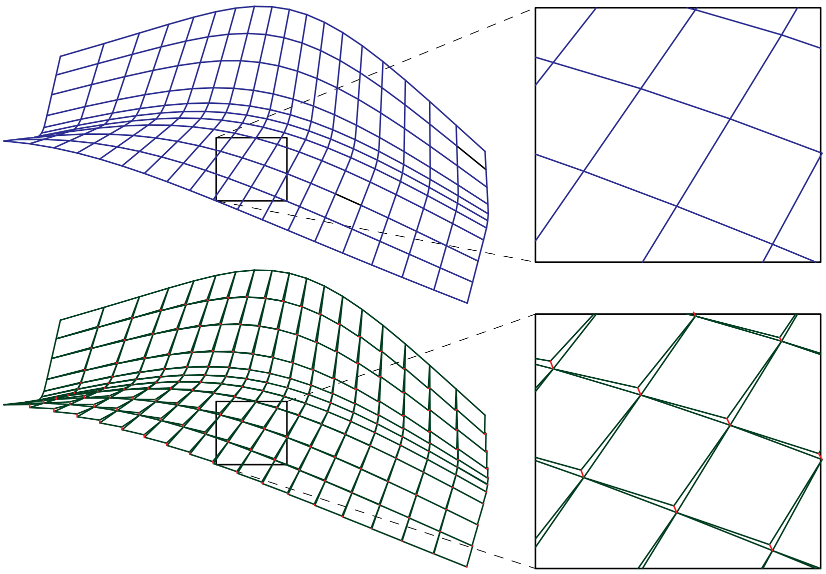
Figure 7.25: Model control hierarchy. Left: geometry by CAD modeller. Centre: facade edges extracted. Right: parametric facade grid.

7.6.3 WB Projects

The final ISA project has similarity with all but one of the WB projects. Generally the focus, for WB was on *rationalisation* of cladding systems to cover forms proposed by others. These projects all involved a *control hierarchy* whereby specific objects from CAD models were imported and formed the primary input to the parametric model. Which was then used to study rational panelisation. The projects described were developed to illustrate possible approaches and not complete solutions. It was anticipated that WB would take these proposals and use them in combination to efficiently develop rational cladding designs. The final WB project demonstrates the procedure *declare parameters rather than shape*, where the underlying control and output of a simple structural tower model is the focus of the modelling process.

Planar / twisted panel comparison (WB1)

The first WB project was an investigation into generating panels using a grid of points defined with the UV parameters of a surface. A model was constructed that defined a grid which was used to construct sets of either twisted or planar panels. For each method every panel had a value that described either its twist or deviation from the surface. To construct the twisted panels, four corresponding points in the grid were used to define the vertices, this was then repeated throughout the grid to determine a set of panels that covered the surface (figure 7.26 top). The model then wrote the out-of-plane dimension[1] of each of the twisted panels to a spreadsheet. For the planar panels the vertices were defined by taking three points, from a group of four corresponding points in the UV grid, and constructing a plane. The fourth point was then projected onto this plane (figure 7.26 bottom). The distance between the fourth point and the projected point was recorded in a spreadsheet. This system allows the grid definition to be varied and the designer can assess the opportunity for using planar panels within tolerances of the construction system as part of a *rationalisation* study.



out of plane

0.008	0.013	0.022
0.008	0.013	0.024
0.009	0.014	0.025
0.009	0.015	0.027
0.010	0.016	0.028
0.010	0.017	0.030
0.011	0.017	0.031
0.011	0.018	0.033
0.011	0.019	0.034
0.012	0.019	0.035

Distance - corner to surface

0.041	0.042	0.043
0.044	0.044	0.045
0.046	0.047	0.048
0.048	0.049	0.050
0.050	0.051	0.053
0.051	0.053	0.055
0.053	0.055	0.057
0.054	0.056	0.058
0.055	0.057	0.060
0.055	0.058	0.060

Figure 7.26: Comparison of panelling strategies. Top: twisted panels. Bottom: planar panels.

[1]In GC an out-of-plane dimension is the average dimension that each of the four vertices are from the average plane defined by four vertices (four points can define four different planes).

Projected grid to doubly curved surface (WB2)

The second WB project involved parametrising a doubly curve roof surface created by an architect to investigate the possibility of using four sided planar quads. Similar to the previous example this is a *rationalisation* procedure. A planar point grid is projected onto the surface (figure 7.27 bottom left). This defines a grid of points that is used to create panel outlines. The out of plane dimension for each panel was written onto each panel. The surface can be manipulated or the planar grid can be redefined and the effect of these changes is displayed on each panel.

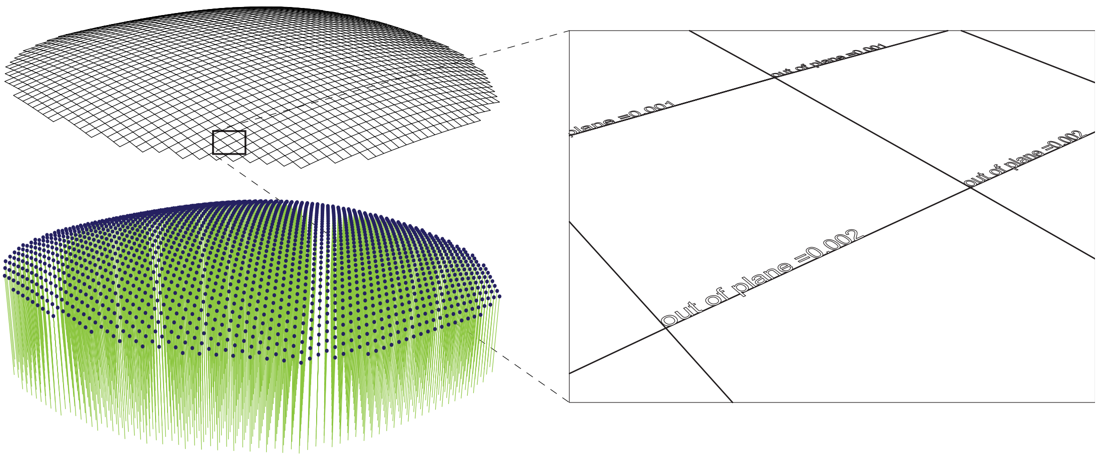


Figure 7.27: Roof panelling investigation. Bottom left: project planar grid to surface. Top left: panel outlines. Right: out-of-plane dimension written to panel.

Spherical patch (WB3)

The input geometry for the third model is a CAD file that defines a roof boundary and courtyard (figure 7.28). The architects of the roof required a radial cladding system. WB wished to investigate using a spherical patch to give *rationalised* planar cladding solution. The boundary and courtyard were extruded to create surfaces. These surfaces were intersected with parametrically controlled great circles, and arcs bounded by the extruded surfaces were extracted. The arcs were used to define a radial grid of planar panels. The parameters of the great circles could be manipulated to ensure the largest panels did not exceed construction constraints and that the curvature matched the original form proposed by the architects.

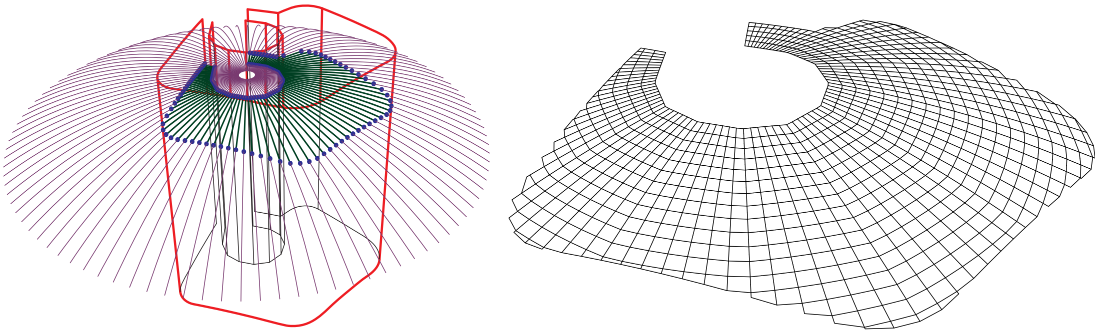


Figure 7.28: Spherical panelling. Left: imported roof outline is extruded and cuts great circles to extract radial arcs. Right: panel outlines.

Coloured panel analysis (WB4)

WB4 is the last project focused on investigation of a panelisation strategy. It is based on the import of geometry which requires *rationalisation* to determine a cladding solution. In this model, curves are imported and used to define a lofted surface. A point grid is defined using the UV surface parameters. Using this grid a scripted function creates panel outlines and the out-of-plane dimension of each outline is used to specify a panel colour. This method provides visual indication of areas of the surface where panel twist is greatest, which would inform how the grid is defined. An alternative for this system was developed where panels would be coloured if they exceeded a predefined out-of-plane maximum.

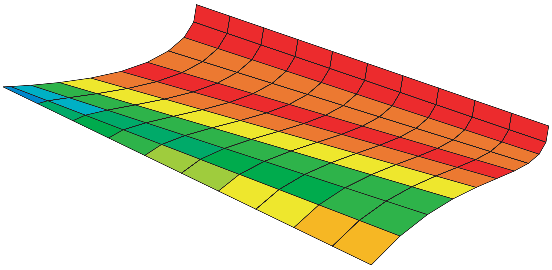
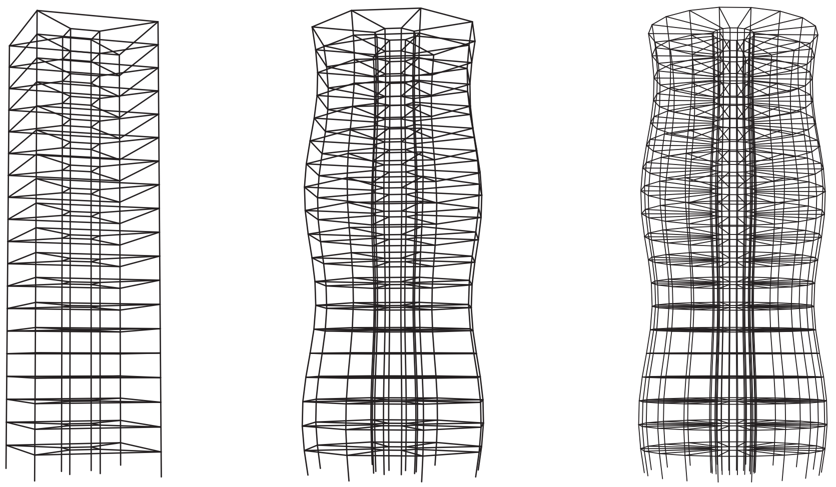


Figure 7.29: Panel colouring. Panels on doubly curved surface with function to represent out-of-plane dimension as panel colour.

Structural tower (WB5)

The final WB project illustrates *declaring parameters rather than shape*. Here, a structural system for radially organised towers was parameterised. Parameters and relationships were developed to control a tower radius, core radius, number of radial bays, number of floors and floor-to-floor dimensions. Functions could be specified to scale the radial dimensions (figure 7.30). The model automatically created a text file in a structural analysis format (figure 7.30 right). Nodes were numbered and recorded with xyz coordinates, members numbered and recorded with start and end node numbers and a member type. Later in the text file the properties of each type were defined. Developing a model in this way requires greater initial effort to declare the parameters, relationships and to set up the output routines. Once the model is set up the designer is then free to manipulate the geometry with the knowledge that the required output will be produced automatically.



node num	x	y	z
64	12.15	4	72
65	13.17	0	72
66	12.93	0.98	72
67	13.15	1.98	72
68	13.19	2.87	72
69	12.87	4	72
70	14	0	72
71	14	0.85	72
72	14	1.86	72
73	14	2.81	72
74	14	4	72
-1			

member num	start	end	type
0	6	5	1
1	6	1	2
2	6	0	3
3	7	6	1
4	7	2	2
5	7	1	3
6	8	7	1
7	8	3	2
8	8	2	3
9	9	8	1
10	9	4	2

Figure 7.30: Tower structure. Left to right: Geometry variations. Top right:node numbering and coordinates. Bottom right: member numbers start node end node and member type.

7.7 Teaching an introduction to parametric design

In addition to training sessions organised for professionals, the author has conducted several workshops in academic institutions (figure 1.1). These workshops were not part of the methodology described in the introduction, but were undertaken as part of the commitment the author made to the commercial sponsor. As this research progressed it became apparent that these could be used as an informal testing ground for the findings of the thesis. Observations on this opportunity are described in this section.