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Summary

This paper reports on research undertaken during preparation of a competition entry for a new roof structure at Zurich International Airport.

Using MicroStation Generative Components and Maya dynamic scripting (MEL), the structure attempts to address traditional modernist concepts of openness, lightness and legibility of the flow of forces, whilst utilising parametric design to generate a randomised space frame structure. The resulting roof is presented as an architectural proposal in its physical context.

Furthermore, the paper suggests the introduction of threshold levels and selective form finding routines within the script, which, if combined with rapid prototyping techniques for instant evaluation and mutation purposes, explore the possibility of a widened conceptual approach towards structural design.

Keywords: space grids; tensegrity; generative components; maya dynamics; form finding; membrane construction; rapid prototyping; architecture of non-simultaneous events

1. Introduction

The process described on the following pages is essentially architectural, but of a kind which regards structural and other specialist input as integral part of early decision making and development of architectural concept. This approach is truly collaborative, but still maintains its focus on responding to a set of architectural, rather than structural, criteria in the first instance. In that, the description of the project is straightforward, setting out a list of client criteria, their respective translations into design parameters, and a synthesised design response to them.

Of particular interest, in the given context, is the tooling, the application of parametric design tools within mainstream architectural and modelling software, as well as the ability to visually evaluate design by using rapid prototyping technology.

However, in order to leave the field of reflective description and arrive at progressive research, a clear distinction needs to be drawn between the merely parametric and the generative. Basis for the latter are the introduction of some level of testing and feedback, whereby the original parameters are progressively adjusted in line with some form of ideally automated evaluation.

In that respect, this paper is taken at the half-way stage of and ongoing process of research, and describes mainly the parametric properties of a static design whilst suggesting possible interjection points for automated feedback, adaptation and form generation.

2. Project Description

In November 2006, the operator of the Zurich regional trainline Glattalbahn launched a competition to design a new roof structure for a proposed tram stop outside Zurich International Airport building.
2.1 Context
Located between the existing forecourt, which is dominated by the roof to the existing bus station, and a motorway flyover providing the main access to the terminal, the new structure was asked to perform a number of functions in more or less direct physical relation to the pure provision of a tram shelter. Questions of economy and representation, minimum impact and recognisability, passenger safety and comfort of access combined to pose problems of a level of considerable intricacy not foreseen by the designers when the project and its site were first approached.

2.2 Design Parameters

![Fig. 1 View of Zurich International Airport Bus station and site for new roof structure](image)

2.2.1 Signal Character
Zurich Flughafen is one of the terminal stops on the Glattalbahn train line, a sort of regional tramline, which links Zurich station with the airport above ground. Due to the importance of the airport in the regional context, the roof assumes the requirement to act as a marker.

2.2.2 Ensemble
The new structure has to work within the context of a series of structures and complete an interesting sequence of spaces which guide airport customers from the point of arrival, via an underpass under the main access road, towards a main bus terminal, airport entrance and check-in hall. Maintaining a certain language and volumetric presence is of particular importance: in other words, the task is to re-interpret the parochial subtext of a tram stop in an environment of air travel bigness.

2.2.3 Lightness
The structure had to negotiate a high concentration of infrastructure and circulation zones, thereby limiting the points for vertical support. This suggested a light and stable roof construction.

2.2.4 Recognisability
The line has recently undergone a re-design including all stops and line infrastructure, to achieve a unified Glattalbahn brand. In particular for the airport terminal, recognisability is paramount in order to guide customers emanating from the
terminal building and lead them through a potentially confusing environment of a bustling airport entrance and major bus terminal without getting lost. The proposed roof therefore suggests a generous cover detached from station infrastructure which, in its design, paraphrases the Glattalbahn corporate identity visible elsewhere along the line.

2.2.5 Transparency

Particular focus was directed towards transparency in the horizontal direction, in order not to obstruct views from the motorway access road towards large scale signage and advertising on the façade of the terminal building, as well as vertically, in order to maintain the feeling of being in the open and to not cover over the remaining space in front of the terminal building, between an existing tunnel under the motorway and the bus station roof.

2.2.6 Cost

The cost parameters set by the client body were tight and permissive only of a basic cover to the minimum area necessary, i.e. the two platforms and a link to the airport building. The presented design looks to minimise material and achieve a level of standardisation which allows covering over the entire site available, shadowing the volume of the existing bus stop roof.

3. Parametric Design

The resulting proposal was for a roof structure which mirrored the existing bus stop roof in size and volume, provided high amount of transparency from the road, minimised the amount of material used, paraphrased the architectural language of the airport entrance in general, whilst allowing the structure to recede and act as shelter rather than container, in line with the open walk-on nature of the function it is accommodating.

The idea was one of a hovering forest, expressed by a random arrangement of vertical members in a space grid system, developed using parametric modelling techniques.

3.1 Experiments using MicroStation Generative Components

Initial experiments were conducted using Bentley’s Generative Components (Beta) through MicroStation. Starting from a guiding surface enveloping the available space and providing necessary volumes and clearances, an initial algorithm was written to arrange random length members on pre-specified grid points.

![Fig. 2 Guiding surface and random length surface normals in MicroStation Generative Components](image-url)
3.2 Experiments using Maya dynamic modelling

Using Maya’s scripting language MEL in conjunction with its own dynamics tools, a different tack was taken in order to achieve a randomised arrangement of vertical members.

3.2.1 Tools

Fig. 3 Maya hair tool

Fig. 4 Random length and angle sticks using Maya hair dynamics

Readily written algorithms for animating hair growth were edited and adapted for the particular purpose. In this instance, parts of the original script were maintained to generate progressive growth of straight members from a number of fixed points on surface, with individually rather than collectively randomised lengths and angles.

3.2.2 First Application

The routine was applied to a number of points on the same guiding surface, arranged along ribs at regular intervals, and animated over time.

Fig. 6 Hair system emanating from guiding surface along ribs at regular intervals
3.2.3 Grid development

With a view toward structural stability, starting points for hair growth were now arranged at grid points on the guiding surface, and amount of directional variety of the growing verticals limited to a small margin around the surface perpendicular. This system was eventually adopted to develop the space frame structure.

![Frame 1](frame1.png) ![Frame 20](frame20.png) ![Frame 40](frame40.png)

Fig. 7 Random length hair growth on gridded guiding surface, surface normals

3.2.4 Parametric interdependencies

The relationship between member length and section diameter was incorporated in the algorithm, and real-time evaluated during the animation process.

![Image](image.png)

Fig. 8 Length analysis and resulting extrusion diameters

In addition, a grid was algorithmically defined through the halfway points along a line connecting vertical members' centers, at first, and third points for the final roof design. Node points of the resultant surface are defined as end points of tension cables connected to the vertical member end points (see Fig 9 below).

![Image](image.png)

Fig. 8 Scripted interdependencies between extrusions
3.2.5 Roof design

![Diagram showing roof design components: sticks, sticks and cables, sticks, cables, raft, sticks, cables, raft, membrane.]

Fig. 9 Roof make-up

Compression members: tubular steel sections
Tension members: Macalloy solid steel bars
Raft from tubular steel sections
Membrane: textile netting

3.3 Optimisation

By incorporating maximum and minimum values for angles between tension cables, structural overall stability is controlled. Optimisation is required and offers itself to be incorporated in the algorithm. The below structure of in excess of 500 vertical members is, as was shown, grown simultaneously with its supporting cable net and raft. While the range of lengths is controlled by the maximum angle between verticals and cables, derived from structural requirements within a space grid system, parameters concerning weight distribution, cost, discharge of surface water, just to name a few, can be incorporated and made to feed back into the overall roof design.

![Diagram showing roof generation at various stages.]

Fig. 9 Real-time roof generation

4. Prototyping

Traditionally more problematic is aesthetic evaluation, and imaging and prototyping techniques are employed in parallel with design development and made to impact on parametric decisions directly. Below figure shows stereolithographic output at various stages of the design process: the development of the structural components; testing of various outputs for stability with identical cable thicknesses; final display model of the roof structure in context.
The brittleness of the stereolithographic model, as opposed to Selective Laser Sintering, inadvertedly provided structural testing in its most basic, but for the given purpose perfectly adequate form. However, limitations to the minimum thickness led to a very heavy appearance to the final model, belying the original intention of a tensile structure.

Communication of the structure’s lightness, transparency and unimposing nature had to be re-assigned to the world of computer visualisation and more traditional ways of drawing. Plotted models appear to pose a similar problem to the way design is communicated as did the emergence of computer visualisation, i.e. the suggestion of accuracy and truth through its apparent exactness which can distract from the actual character of a design proposal and actively mislead in the wrong direction.

5. Discussion, Conclusion

The presented project hopes to show a quick, elegant and relatively sophisticated way of tackling a design task incorporating a large number of interdependent physical components, within a short period of time and the peculiar and quite unique context of architectural competition. It does so by first algorithmically describing parametric interdependencies using Bentley Generative Components within the MicroStation environment, later by adapting and adjusting scripted algorithms for dynamic behaviour within the Maya animation package.

By doing so, the design process is transformed from one of static dependency to one of progressive generativeness. At the core of both lies the conceptually informed design decision of a level of physical randomisation as response to the posed design task.

In extension to the techniques and methods performed so far, this paper suggests the introduction of a testing and
automated feedback process in order to achieve a level of automated optimisation and self-organisation within the structure. This optimisation is seen in two ways: on the one hand, in traditional material form, i.e. minimisation of material used, cost, standardisation of components, which can be performed by a relatively simple process of feeding back numerical evaluation of the generated structure and incorporating it into the algorithm; on the other hand, the more complex and interesting issue of aesthetic evaluation and concept of quality in a more holistic, non-descript and by extension non-linear way.

This kind of optimisation, it is suggested, is best performed in the context of selection from a large number of outputs, introduction of mutation within the dependencies; in other words, elevation of randomness from physical output to conceptual basis of structural design.

Whilst this research is ongoing and not physically manifest within this written paper, it is believed to be implied in the general approach towards design as shown in the development of the structure. It hints at a holistic approach in the tradition of Buckminster Fuller, whom we employ to have the final word:

"We find in the mechanical structuring of the universe, that compressive organisation is limited to the dimensional confines of heavenly spheres themselves, and that vaster structural integrity of the universe is maintained within the infinite limits of tensile stress principles only, which we identify as gravitational attraction."[...] R Buckminster Fuller

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