DESIGN INFORMATICS

A case based investigation into parametric design, scripting and CNC based manufacturing techniques

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Abstract. The research paper exemplifies a novel information integrated design technique developed at ONL (Oosterhuis and Lenard), Netherlands, specifically appropriated for manifesting complex geometric forms. The ‘informed design technique’, apart from being highly instrumental in conceptualizing and generating the geometric component constituting architectural form in a parametric manner, is also efficiently utilized for precise computer aided manufacturing and construction of the speculated form. Geometric complexities inherent in contemporary architectural constructs and the time spent in appropriation of such topologies, fueled the ‘informed design’ approach, which caters to issues of timely construction, precision oriented design and production (visual and material) and parametric modeling attuned to budgetary fluctuations. This design-research approach has been tested and deployed by ONL, for conceiving ‘the Acoustic Barrier’ project, Utrecht Leidsche Rijn in the Netherlands and is treated as a generic case for exemplifying the ‘informed design’ technique in this research paper.

The design methodology encourages visualizing architectural substantiations from a systems perspective and envisages upon a rule based adaptive systems approach involving extrapolation of contextual dynamics/ground data in terms of logical ‘rules’. These rules/conditionailities form the basis for spawning parametric logistics to be mapped upon geometric counterparts exemplifying the conception. The simulated parametric relations bind dimensional aspects (length, width, height etc.) of the geometric construct in a
relational manner, eventually culminating in a 3D spatial envelope. This evolved envelope is subsequently intersected with a ‘parametric spatio-constructive grid’, creating specific intersecting points between the two. A pattern of points attained from this intersection: ‘the point cloud’ serves as a generic information field concerning highly specific coordinates, parameters and values for each individual point/constructive node it embodies. The relations between these points are directly linked with precise displacements of structural profiles and related scaling factors of cladding materials. Parallel to this object oriented modeling approach, a detailed database (soft/information component) is also maintained to administer the relations between the obtained points. To be able to derive constructible structural and cladding components from the point cloud configuration customized Scripts (combination of Lisp and Max scripts) process the point cloud database. The programmed script-routines, iteratively run calculations to generate steel-wire frames, steel lattice-structure and cladding panels along with their dimensions and execution drawing data. Optimization-routines are also programmed to make rectifications and small adjustments in the calculated data. This precise information is further communicated with CNC milling machines to manifest complex sectional profiles formulating the construct thus enabling timely and effective construction of the conceptualized form.

1. ONL and the Notion of Multi-disciplinarity

ONL, a multidisciplinary office directed by Prof.ir. Kas Oosterhuis and visual artist Ilona Lenard performs as a design-research body driven by contemporary Information communication technologies, focusing upon issues of collaborative design in a media (digital and electronic) augmented spatial environment. The notion of visualizing a context embedded design solution, at ONL is conceived through building a generic connectivity between geometric styled-prototypes (spawned by existent spatial scenarios) articulated with parametric relations and a corresponding data base (influencing parameters: speed of traffic etc) of their contextual settings. Such inclinations allow one to simulate emergent spatial behaviors through real time data exchange and a networked nature of the architectural grammar constituting corresponding physical prototypes. ONL, in order to manifest such an agenda, embodies a synergistic merger of the expertise offered by architects, visual artists, web designers and programmers, who work together and join forces, practicing the fusion of art, architecture and technique on a digital platform. The notion of fusing information (context driven data scapes): soft component with the physical materiality of architecture: hard component to generate a co-evolving spatiality drives the design-research ideology at ONL. The research paper describes a design strategy: the
‘informed design’ exemplifying this synergistic merger (of art and science) for the case of the ‘Acoustic Barrier’ project (Figure 1) developed at ONL.

![Figure 1. The Acoustic barrier project (with the Cockpit/Hessing showroom): ONL](image)

2. Form Finding

ONL in its attempt to decipher ‘form’ delves into diverse processes of utilizing digital to analogue means of mapping contextual dynamics onto generic geometrical compositions. The stylization process ranges from hand drawn curvilinear geometry, which is eventually digitized and parameterized, to sophisticated digital simulation based generative geometry to tactile conceptual prototypes (physical), which through a process of reverse engineering are translated into the digital realm. A relatively intuitive approximation of sets of curves, surfaces and masses is hence formulated as the conceptual root at this stage. The notion of developing a generic connectivity between the real and the virtual is employed over these conceptual prototypes by computational means. These computational means range from developing inherent connectivity of geometric conceptions with database structures, visualizing initial sketches as continuous curves and surfaces (NURBS), developing generic relations between geometric components by means of parametric design and deploying self developed scripts focusing upon extraction of digital data required for direct file to factory processes.

For the purpose of this research paper, we will specifically concentrate on the Acoustic barrier project and will subsequently elaborate upon the design development and form finding phase deployed in visualizing the projects complex curvilinear, almost reptilian form.
3. The Acoustic Barrier: Parametric Set-Up (Conceptual Resolution)

The project based in Utrecht Leidsche Rijn in the Netherlands aims to combine a 1.5 km long acoustic barrier with an industrial building (the cockpit/Hessing showroom) of 5000m2. The conceptual underpinning for the project is laid by means of articulating sets of NURBS curves, suggestive of a relation between height, width and the length of the barrier. These curves are stretched along the 1.5 km stretch of the highway and form the above-mentioned spatial guideline for the project (Figure 2)

![Figure 2. Set of related curves defining the topology of the Acoustic Barrier](image)

Subsequently, the deployment of computational logic to the abstract sets of curves is contextually derived with respect to the speed/flow of passing traffic. The swarm of cars streaming at a speed of 120 km/h along the acoustic barrier site lays the rationale for deriving parametric rules, specifically linked with developing generic geometric relations between the NURBS curves. This relational set up is specifically defined (in this case) owing to the manner in which the form of the acoustic barrier will be seen by the commuting mass. A relational rule that satisfies issues of scale, surface-continuity and smoothness (non-distracting) of the construct conditions the aspects of styling, visual perception and form generation. The barrier, a “one mile building” seen from the perspective of the highway,
(considering the above mentioned criteria) derives its curvilinear form from the basis of a context driven rule: the length of the built volume of the Cockpit emerging from the acoustic barrier will be 10 times more than its height.

This parametric relation regulates the linear form of the barrier to generate transversal sections, which are smoothly transformed from concave towards convex faceted surfaces with occasionally emerging sharp longitudinal folds. This parametric relation once set, and mapped onto the sets of curves yields a relatively smooth curvilinear surface with an equally smooth transient bulge, which houses the cockpit/Hessing showroom space (Figure 3). This ‘informed geometry’, which creates the three-dimensional skin for the acoustic barrier not only operates as a ‘form generator’ but also proves to be a ‘form regenerator’, owing to the geometrically relational (parametric) dependence of the generic curves. Any parametric alteration made to the curves, consequently leads to a regeneration/re-appropriation of form in accordance with the context based, basic rule (which induces the relation between the dimensional aspects of the 3d form) hence reflecting a new, yet controlled spatial configuration.

![Figure 3. Set of related curves with the parametric relation mapped onto them resulting in the bulging topology](image)

### 3.1 Parametric Set Up (Finer Resolution: The Point Cloud)

In order to derive a finer degree of control over the obtained (conceptual) three-dimensional form (from the network of curves), a ‘parametric structural grid’, which obtains its dimensional logic from an optimal construction, oriented perspective (e.g. dimensions of glass panels) is mapped onto the surface of the conceptual construct. This intersection results in the extraction of a distinct series of nodes/points, collectively called the ‘point cloud’ (Figure 4).
Figure 4. Point cloud generated from the conceptual 3D envelope

The point-cloud represents a parametric set-up: it describes the volume by points and establishes spatial relationships between them: by serving as a generic information field concerning highly specific coordinates, parameters and values for each individual point/constructive node it embodies. The sound barrier contains approximately 7000-point objects, whose relations are administrated in a database. These relations are directly linked with precise displacements of structural profiles and related scaling factors of cladding materials. This linkage is further extracted from the point cloud body by running specialized ‘Scripts’ developed at ONL. These will be explained in detail in the next section (1.4).

Apart from creating a precision oriented geometric configuration, working with parametric models also creates an excellent communication space for the stakeholders in the building design process and enables one to discuss varied dimensions composing the quality of the proposed space. Such an approach also releases the design process to collaborative engineering opportunities during the execution phase of the project and hence creates an open framework for generating meaningful interactions between clients and users.

4. Generative and (Re) Generative Design by Scripting

The “point-cloud” is a crucial model fostering generation and [re] generation of all point-data, parameters and the relations between the points (constructive nodes). However, in order to develop a constructive spatial structure and to manufacture the glazing and cladding material for the acoustic barrier, a novel application was programmed. (Scripting and programming refer to the process of writing a simple program in a utility language to orchestrate behavior. It consists of a set of coded instructions that enables the computer, to perform a desired sequence of operations). This application, programmed in diverse scripting languages [MAX-script, Auto Lisp] connects to a database system developed for handling all point-data and their relations.
The developed scripts operate on a simple rule: all points should look at and analyze their neighbors (in terms of co-ordinates and proximity). Such a rule-based interaction is akin to the notion of Flocks: Flocking behavior and Boids, as stated by Craig Reynolds. Boids, replicated in the case of the digital model by points/constructive nodes, are active members of a flock, calculating their position in real-time in relation to each other. Each Boid, locally, extends the principle incorporated by Flocking mechanisms of computing a limited set of simple rules, towards scripting the Point cloud behavior. This behavior of localized and limited computational performance by parts of an entire system, bring about complex reactions at a holistic level. These simple sets of rules, can be interpreted as the behavior producing genes of the nodes (junctions in the prototype) and these behaviors in-turn, are directly related with the formal articulation of the prototype: a bottom up approach directly inducing top-down performance determination.

The programmed script-routines, based on such flocking principles, when applied on the point-cloud iteratively run all the calculations to update:
- Steel-wire frames with its databases
- Steel-lattice-structure including all the execution drawings
- Dimensions and Execution drawings of glass plates.

The scripting computational component operates at three levels, each component embedding within it a series of iterative operations. Exemplification of the three scripting levels in relation with their operational performance is as follows:

4.1 SCRIPT 01

**Basic operation:** Loads the Rhino generated .DWG files containing the point clouds > Makes a single mesh out of them > Offsets this mesh by the r brace value (radius of the braces conceived by the glass manufacturer that will be used for the assembly of the glass plates) > Creates a series of spheres centered to the vertices of this mesh that represent a second point-cloud to be used exclusively for the glass plates

Script 01: Overview of Input parameters:

```plaintext
global fmin=01
global fmax=44
global rbrace=61
global threshold=250
allthepoints=#()
allcount=0
```
The script operates at two levels to perform the basic operation: Data administration phase and Mesh generation phase.

- Data administration phase: the operation involves a methodological extraction of data from the body of the point-cloud at three sub-levels namely
  o Defining ‘f min and f max values’ (the range of segments to iteratively generate the requested data) and hence subscribing a dimensional aspect for limiting the administration process to a given length.
  o Logistically naming and re-naming of the points (to be administered) in the point cloud
  o Formulating an Array wise database of the points (based on X, Y, Z co-ordinate orientation)

- Mesh generation phase: after the data administration phase, the script generates a mesh, where each face in the mesh embodies a face of a glass plate including the Scaling of the glass plate.
  o Scaling for the glass plates is defined by the ‘r brace value’ (radius of braces/scaling distance for fixing the glass plates: provided by the glass manufacturer). This value re-defines the distance parameter in the initial point-cloud configuration
  o Projection of a re-configured point-cloud version > point-cloud + alternated displaced points normal wise aligned towards the orientation of the point (with neighboring points) is initiated through a scripted iterative process.
  o A possibility for adjusting the Threshold value for searching for points can also be adjusted at this stage.

4.2 SCRIPT 02

The second Script based operation is responsible for segmentation of the entire point–cloud body into bays of 9.33 m. This generation of segments dissects the barrier into three bays with 118 points each (Figure 5, a) and derives its logic from the sequence in which the foundations for the construct have to be laid. This basic dissection of the volume apart from being appropriate for Physical construction also proves to be beneficial in terms of CPU usage and data handling and hence tends to be much more efficient in the long run. Each segment contains a group of points and its corresponding mesh. The meshes in turn describe the glass plates and the amount of displacement needed by the extracted glass plates in between adjoining segments.
4.3 SCRIPT 03

**Basic operation:** Builds the axis of the steel profiles that form the structure
> Projects the planar surfaces generated between the points, defining shape and position of the glass panels.

The third script operates at two levels > Generating steel construction (Figure 6) elements and Generating Glass plate elements (Figure 5, b)

- The script geometrically generates steel construction elements in a wire-frame mode and exports the file in a specified protocol format for the production process (to be communicated to steel cutting machines). This protocol, set up by ONL and Meijers Staalbouw (the steel manufacturing company), presents the obtained data-file in several layers, colors and named elements. The layers are set up for different purposes, for example, describing the steel-profiles in a hierarchical fashion: horizontals, tubes, diagonal profiles scaled or non scaled, highway side elements, industry side elements, etc.
- Besides the steel sections, the generation of glass plates also happens in a similar manner but these are eventually flattened down on an X, Y plane for control and visual judgment purposes and to enable one to check the script wise generation of data.
- This geometrically generated data for the glass plates is further exported, arrayed, logically named and positioned in a complex Excel data sheet, which is directly utilized by the glass manufacturer for precision based production purposes.
- This sheet is also used for further data manipulation, like optimization or correction routines.
Figure 5. a. 3d wire frame model displaying a segment of the acoustic barrier and the relations between the points in the point-cloud

Figure 5. b. 3d wire frame model displaying a segment of the acoustic barrier and the administration of all unique glass plates [generated by script]

Figure 6. 3d model displaying a construction node [= point in point cloud] of the acoustic barrier and the steel profiles, steel plates and welded joints [generated by script]
4.4 SCRIPT OPERATION OVERVIEW

The three scripts combined together present a methodological approach towards efficient translation of conceptual form to precise geometric and information rich entity. This sequential translation after offsetting the Rhino based point cloud (through script 1) through scripting can be listed in the following manner:

- Reading one after the other the .max files with the double point clouds
- Drawing 3d splines representing the axis of the steel profiles (structural) and the contours of the glass plates
- Unwrapping the glass surface and placing it on a horizontal plane as separate triangulated elements
- Naming each element with quotations
- Assigning Layer numbers to each element according to the sequence of construction
- Saving these elements (according to the specified protocol) in separate files segment after segment:
  - One .dwg file for the steel construction (to be exported to the steel company)
  - One .dwg file for the glass plate manufacturer
  - One .txt file for the glass plate manufacturer containing entries with essential data for every glass plate individually (for glass manufacturer)
  - Two separate files containing all the pairs of plates that form an angle higher than 10 degrees (for glass manufacturer)
  - One .max file containing the complete segment of 18 m length and 118 points
- Splitting of the last generated point cloud segments (script 1, generates segments of 18m length constituting 118 points) into two 9 m segments constituting 59 points (required by the steel manufacturer bearing in mind the foundation stages) and saving them as separate .max files for the steel manufacturer.

This comprehensive and precise data, processed via the Scripting and Generative design components is further communicated to the manufacturing units for computer aided manufacturing purposes (CAM).

5. CAM Techniques

CAM strategies are dealt with in a rather coherent fashion throughout the design and development stages of the acoustic barrier project. A parallel development and maintenance of a database system, which stores the script-
generated data is seen as a generic process through this project and can be easily deployed for a variety of complex spatial topologies (Figure 8).

The protocol developed for storing information in the database at subsequent stages of the design process is also directly linked with the manner in which CNC machines would process the design data. However, as a generic outcome of the computational processes mentioned above, one can extract three basic strategies deployed over architectural form to reach the production process:

- Conversion from point cloud to steel-wire frame model and administration of all its parameters in a database
- Conversion from steel-wire-frame model to steel-lattice-structure and generating execution drawings (Figure 7)
- Conversion from point cloud to glass plate manufacturing and administration of all dimensions, codes and specific values plus generating execution drawings.

![Figure 7. 3d steel lattice model and its corresponding execution drawing](image-url)

The excel database which stores the data in a numeric array corresponding with the generated execution drawings and 3d segments is bundled together and further communicated to the manufacturing units as a concise production schema. This assists in speeding up the production process and hence results in accomplishment of complex projects within the
specified timeline. The parametric design conception, filters down to the smallest detail (the point/construction node) and results in the development of two generic details to mount either glass-plates or expanded steel-plates towards the steel-structure.

Figure 8. Assembly of unique construction nodes and vertical frame at Meijers Staalbouw Factory, from parametric 3d model to mass customized production

These details, being parametric in nature, efficiently adapt to the dimensional and orientational (towards the steel structure) variation prevalent in each mounted glass-plate or steel-plate and hence proves to be a vital performative aspect, when conceiving complex spatial topologies. The database, which embeds these variations in numeric arrays is subsequently communicated to and executed by the manufacturing units to produce customized details with utmost ease and precision (Figure 8).

The efficiency and speed involved in the production process, provides both, the architect and the engineers the opportunity to erect and test/analyze 1:1 prototypes (crucial portions of the construct) for spatial and structural purposes at a relatively early stage, hence deploying corrective measures and
speeding up the realization of such complex projects. Hence the assembly phase (Figure 9) is reduced to an exercise of connecting precisely named/numbered parts (more like a kit of parts scenario) in a sequential manner to produce a holistic topological marvel.

Figure 9. (left) Perspective view of the assembled façade, (right) perspective displaying the parametrically generated steel structure and glass plate cladding.

6. Conclusion

A design-informatics hybrid, the multi-disciplinary techniques exemplified in the research paper, focuses upon a synergetic merger of technology, art and architecture to efficiently manifest much-speculated complex spatial constructs. Such ‘informed-design’ techniques, while promoting a parametric mode of operation, which enables one to communicate smoothly with three dimensional models and the project database, inherently involve a collaborative design approach, entailing derivation and appropriation of diverse tools and techniques (programming/scripting, graphic design, architecture, engineering and CAM) towards manifesting spatial constructs.

The acoustic barrier (looked at as a generic example) validates the effort needed to engage in a rather structured manner of data exchange between geometric and text based/numeric arrays (in an excel sheet) of contextual and spatial aspects and promotes the possibility of controlling and optimizing all the points/construction nodes from a datasheet. Also, the datasheet format makes it easier and faster to apply optimization and correction routines (by means of application of scripts in an iterative manner directly to the data, instead of geometrically intervening and intuitively tweaking a 3D model), which directly update geometrical data, and text-based information. Working with parametric models also creates an active
communication space for the stakeholders in the building process to discuss the qualities of the proposed environments. The parametric approach promotes setting up a relational equation between the design components, the contextual settings and subsequently the manufacturing of the construct, in the process promoting a healthy inter-linkage between the IT, design and the building construction sector. The 3d model becomes an output of a relational structure, promoting an interactive manner of re-organizing the spatial structure by means of manipulating the database underlying its formulation. This approach also helps in generating quick overviews of possible changes in form and structure of the proposed construct after decisive meetings with other stake holders (structural engineers, contractors, project managers etc), hence speeding up the decision making processes involved during the design phase. It hence opens up the design process for collaborative engineering in the phase of the execution of the project and promotes the design process as a meaningful medium of interaction with the clients and the users.

References

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