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Designskolen Kolding



Generating a scalar logic: producing the "it's a SMALL world" exhibition

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Abstract

This paper presents the design project "it's a SMALL world", an exhibition design developed for the Danish Design Centre in 2009. The project investigates the making of a generative design environment by which multiple design parameters as from program, site or the subsequent digital fabrication and assembly process can be negotiated. In this paper we discuss methods for understanding the emergent interrelationships between encoded parameters, how to manage these and their impact on design. The implementation of the design necessitated a novel design method that allowed to blend the qualities of a generative design approach, that can adapt through recursion gradually to local requirements, with explicit definitions. The project showcases with its new developed manufacturing system for non-standard element how customized digital design and production tools allow for a novel nearness to material and new ways of production and collaboration of architects, engineers and the crafts.

1. INTRODUCTION

Parametric design strategies allow architectural design to move from the space of the absolute to the space of the variable. By incorporating parameters defined by events exterior to the design space reflecting environmental, programmatic or structural concerns, these flexible models create a new potential for design to be inherently responsive and adjustable. During the last 20 year a new design practice has emerged in which architects become the developer of bespoke design environments that allow dynamic interfacing between design intention and contextual information [1, 2, 3]. This design practice has allowed for projects of high degrees of complexity that directly engage defined contexts such as day light [4], spatial envelope [5] or structure [6].

However, as this new practice matures a new set of designs problems are being identified. A key problem is accounting for the complexity of design solutions that arise when multiple parameters are incorporated. Parametric design does not inherently resolve the ways by which parameters with different optima can be interfaced and negotiated. Instead differing design criteria can impose contradicting solution spaces that lead to local maxima and therefore challenge an ideal of optimisation [7]. An emerging research question asks how to develop models to control the complexity of this new design space. What are the tools by which the variable and the responsive can be negotiated, how are these evaluated and what are the design consequences of this negotiation?



Figure 1: The "it's a SMALL world" exhibition at the Danish Design Centre Copenhagen.

This paper presents the design project "it's a SMALL world", an exhibition design developed for the Danish Design Centre in 2009. The project investigates the making of a generative design environment by which multiple design parameters can be negotiated. Informed by the questions above, the project

investigates methods for understanding the emergent interrelationships between different parameters, how to manage these and their impact on design. A second interest in the development of "it's a SMALL world" lies with fabrication. The exhibition design explores how non-standard design practices can make new use of old materials. By developing bespoke interfaces negotiating design and fabrication tecniques the project investigates how these can allow us to rethink crafting as that which is informed by code increasing the complexity and detail of design solutions.



Figure 2: Speculative testing of the merging of the design parameters.

In the following we will describe the development of a flexible model informed by a generative logics resulting in complex and emergent design properties. Describing the process from initial concept design through to production, the paper examines how the inherent flexibility of parametric design can be used firstly to allow for iterative and responsive design process and secondly to allow for the continual adjusting and amendment of the design in response to the material properties, detailing and fabrication data. The metric system is to be used throughout and if it is necessary to quote other units then these should be added in parentheses. The use of unnecessarily complicated notation and formulae should be avoided and the material should be presented in the simplest possible manner. Avoid using footnotes.

The manuscript is expected to be written in correct and easily readable English. An author who is not proficient in English is advised to seek help in editing the manuscript before typing. Both English and American spellings are acceptable, but each paper is expected to follow one style consistently. Please avoid the use of contractions such as can't and aren't; spell out full words such as cannot, are not.

2. RECURSIVE LOGICS: DESIGNING FOR DIFFERENT SCALES

The "it's a SMALL world" exhibition brings together the different scales of architecture (landscape, city, building) with the scales of objects (furniture, garment, jewellery). Presenting 18 high profile designers, architects and craftsmen working with sustainability, new materials and technology, the curatorial concept was to develop an exhibition design that could incorporate Non-standard Practice and New Craftsmanship while simultaneously developing sustainable and environmentally conscious strategies for material use and transport. The exhibition was organised in 6 scenarios each holding a distinct identity and while together establishing the exhibitions design intent.



Figure 3 All three scalar levels were used for the design. Each of the three levels double the size of the hexagonals. In the final design the sizes of the hexagonals were detemined with respect to the sheet size of the material and the cutting bed of the CNC miller.

Our key objective was to create ways by which the intimacy of object with its focus on craftsmanship and detail as well as its direct relationship to the body could be presented alongside the abstracted scales of architectural models and urban design while maintaining audience focus and attention. To allow for this we developed a scalar approach based on the fractal subdivision of a hexagonal matrix. The hexagonal matrix exists as an underlying substructure organising the 6 exhibition scenarios. By subdividing the matrix locally we found ways of engaging the scale of the exhibited objects while maintaining design continuity and integration.



Figure 4: The logic of the subdivision is both geometrically and mathematically defined.

The matrix uses a recursive logic. Each hexagonal can be subdivided into three diamonds, chamfered and devised a second set of smaller scale hexagonals that again can be further divided. At each scale the matrix is identical creating inherent self-similarity and classifying it as fractal system [8]. In difference to pure fractal systems the hexagonal packing system is not complete. Each time the hexagonal is subdivided into diamonds the chamfered triangles become fragmentary parts of the pattern. To add to this inherent fragmentation the design recursion is treated non-linearly and locally creating a dynamic neighbouring where the very large can be situated directly adjacent to the very small. In this way the organisation system breaks the fractal ordering creating a new more irregular patterning which adds to the complexity of the substructure.



Figure 5: The "it's a SMALL world" exhibition at the Danish Design Centre Copenhagen.

2.1. New use of old materials: folded plate structure

The exhibition uses the commonplace building material DiBond. Our aim for the project is to explore how new digital fabrication techniques can lead to innovative uses of standard materials. A composite of aluminium and plastic, DiBond is an interesting material as it, in difference to most other building materials, can be scored and folded allowing for the construction of structural surfaces. Dibond is furthermore lightweight easing transportation and fully recyclable. Finally, DiBond is pre-coated eliminate the need for a final surfacing or painting.

Using CNC milling the material is scored defining the crease lines, folded into boxes – or cassettes - which in turn are plastic welded together. The thickness of the material as well as its stiffness allows each of the cassettes to act as independent structural units that in turn can be bolted together for added strength. The logics of unfolding allow us to address sheet allowing for ease of fabrication.



Figure 6: The generative design systems script is made of several subsequent steps which build up the final design of a scenario.

3. CREATING THE DESIGN SYSTEM

"it's a SMALL world" is developed as a multi-parameter flexible design system. The aim for the design system was to enable non standardised designs solutions while managing complexity and detail. Using a generative logic intention was to find ways to use the merging of different design parameters creatively to find new emergent complexities. Furthermore the flexible design system enabled an iterative design process enabling continual redesign and negotiation with the curatorial team. The design system spans from design to production allowing for the continual redesign to take place right up to production. The design environment is developed in the parametric CAD package Generative Components by Bentley Systems [9]. The design system was based on the programming of the hexagonal substructure. To be able to programme the fractal logic of the hexagonal matrix a base grid was defined by setting out the centre points of the large scale hexagons. This grid is subjected to local recursive subdivision by dividing them into three defining diamondshapes, chamfering the diamonds and define the next order of 3 smaller scale diamonds. To be able to identify the pattern as a singular extension rather than an overlay of several nesting patterns is was important to define ways in which the subdivided surfaces could delete the base grid. To do this we devised a sense of neighbourship allowing each cell to be aware of its neighbouring cells and define itself in relation to these.



Figure 7: The design system was developed within the parametric modelling tool Generative Components and used its graphic interface for user interaction.

To control the scaling of the hexagonal grid we introduced attractor points by which areas of intensity at which subdivision is most concentrated could be defined. To ease the visual feedback we interconnected the attractor points into a nurbs surface. The nurbs surfaces allowed an intuitive understanding of the interpolation between the attractors. By manipulating the topology of this surface we could increase or decrease the effect of the parameters on the exhibition design. Finally a crop line was to developed by which the outline of the individual scenarios could be defined.



Figure 8: Articulating the complexity of the surface

3.1. Developing the parameters

The exhibition surfaces exist as complex extrusions of the hexagonal matrix. The extrusion of the surface is

defined by multiple variables allowing the surface to be expressed.

- Pop: creates a offset in height allowing the individual cassettes to interpolate in steps
- Slide: generates a general sloping of the elements
- Inversion: turns elements inside out making them closed surfaces or open caveties
- Height: defines the upper surface of an element
- Bottom: defines the lower surface of an element

The parameters affect the system's overall topology by defining the particular geometry of the single element. While maintaining its position within the overall topology a single cassette can change in the edge geometry as well as height, angle between the flanges and the cassettes top. Merging the different parameters allows the design of surface that "pop-slide" or "slide-invert" combining the parameters into new emergent qualities.

These operations were codified as different layers of geometrical transformation. Each set of parameters is given its own controlling nurbs surface by which the intensity of its effect can be altered. The resulting 6 nurbs surfaces, including that of the hexagonal matrix, account for the full parametric design space. During the design process each of these parameters would be tweaked and further adjusted, looking for the emergent properties that result from the overlay of the different parameters.

Within the design process it turned out that even simple overlays of a small amount of operations created great difference in the designs that were not foreseen. The emergence of these new properties was crucial for the design development and indicates that the behaviour of our responsive environments is of a complex system.

Working in an exploratory and sketching manner, the transformation of elements and the overlay of different parameters allowed development of a series of design experiments with a broad variety of geometrical expressions. Working iteratively, these experiments were continually evaluated and adjusted in respect to the design criteria of the exhibition design.



Figure 9: Merging the different parameters allows combining the qualities into new design – as here "popslide"

3.2. The process

The system is constructed as an integrated information model consisting of two layers: a generative 3d representation and a derived two dimensional layer containing the 2d manufacturing information. All basic geometrical values and relations for the further fabrication are derived from the 3d model which in turn form the basic information for the generation of the 2d manufacturing data.

The code was structured as an open series of transactions allowing for the insertion of further layers. This open-ended design of the code sequence allowed us to continually adapt to the many structural and material constraints uncovered during the design process. As the structural principles of the cassette system were

unknown accounting for material thickness, joints and tolerance were discovered during the design process through physical models and full scale prototypes.

3.3. The models:

In order to investigate and test the the cassettes and the automated creation of their unfolded patterns we used laser cut cardboard models quick prototyping. The precision of the cardboards models allowed us to test the designs, take decisions for further developments and communicate the design to the curators and fabricators.



Figure 10: The differing tests in paper, full scale prototypes and FE Analysis.

A key purpose for the models was to check system code. This was crucial as the irregularity of the hexagonal matrix and the many deformations achieved through the merging of the different design parameters, created a high degree of complexity. The manifold appearances and orientations of the cassettes caused further challenges in the process of writing the unfolding of the cassettes from a 3d representation into 2d production drawings. To place the connecting joints we encoded each single cassette to contain information about the position and scale of its neighbours. Before unfolding the 3d geometry into the 2d patterns each element queries the position and size of its neighbours allowing the element to adopt the number and position of its joints. In the quick protyping this inherent interconnectivity was tested and adjusted.

Finally, the models gave crucial information on the requirements of detailing and assembly of the final design. Especially the numbering of the elements, crucial for the identification and assembly required novel solutions. The non linearity and inherent recursion of the system prohibits a sequential indexing, as used in normal grid based systems. Instead jumps and gaps in the numbering appear. Our test with different

numbering systems showed that producers actually didn't require a coherent numbering of the elements. It was sufficient if every element is numbered with a unique digit and indicates the assembly process by having its neighbours numbers engraved at the according sides. Equipped with a printed 2d overview of the scenario, users could assemble even complex systems with ease.

3.4. The prototypes

During the design three sets of full scale prototypes were developed. The prototypes were crucial as they established the relationship to the manufacturers. Building the prototypes became a collective learning that created a shared sense of the process as well as trust supporting the further collaboration. Through the prototypes we gained essential knowledge on the systems material behaviour and its processing which was incorporated within the generative system.

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Figure 11: Initial tests of the unfolding system

The insights gathered were directly related to the production process of the cassettes. A first insight was learning to account for material thickness and how thisadds to the overall size of the individual cassettes. This thickness had to be incorporated as a scaling of the unfolded patterns. A second insight lay with the direct tooling of the material.Multiple milling heads of varying size for scoring and cutting and of two angles for folds of more or less than 90 degreessufficient had to be included in the code. The final folding process was executed manually as well as the subsequent plastic-welding of the cassettes seems.

A final insight was learning to work with tolerances. Each step of the manufacture of the cassettes inherit imprecision that sum up in the joining of multiple elements. This effect is usually countered by the introduction of tolerances in design. This is especially important in fractal systems where the pattern scales differently across the system. The measurement of the prototypes allowed us to get an indication of the tolerances and understand their causal relation to the manufacturing process.



Figure 12: The final production process consisted of four subsequent step cutting, folding, gluing and the assembly.

3.5. FE Analysis

Finite Element Analysis models were used to generate further understanding of the restraints of counter levering, balance and weight. The generated 3d models were imported into the FE software while the material and structural parameters for the FE analysis were developed empirically using the prototypes as examples. This was necessary due to the system's novelty in relation to the ordering of elements, the structural properties of the cassettes and the lack of technical data on the properties of glued DiBond panels. The results of the analysis were imprecise but sufficient to learn about the principal tectonic behaviour of the scenarios.

The resulting parameters for the maximum counter levering and balance were integrated into the design giving an awareness of the physical limits of the designs.

3.6. Producing the final design

The final design consisted of almost 400 unique elements which created the 6 scenarios. The cassettes ranged in edge length from 35 cm to 150cm – the maximum size scaled in respect to a full size sheet of DiBond.

The experience gathered within the prototyping phase enabled a smooth production process. The interface to the machine was mature, the manufacturing of the elements were conducted in the estimated time whereas the assembly process was even faster. Every scenario was completely built on the production site before it was shipped to the exhibition space. Equipped with 2d drawings, renderings and a model of every scenario the assembly process was taught to the teams. For conducting this instruction it was sufficient that designers and builders constructed two assemblies conjointly. Due to the precision, the self instructing numbering system and the perfect fit of the elements all further construction could be executed by the team alone.

4. PROBLEMS: OVER DEFINITION OF SPATIAL PROGRAMME

During the design process an inherent conflict between the design's generative logics and the curatorial ambitions became apparent. Where the generative model was excellent at incorporating the emergent properties of the multiple design parameters, it was quickly understood that the population sizes, meaning the amount of cassettes included in each of the scenarios, would need to be radically increased if the system should seamlessly engage the design criteria of the exhibition design. In designing the system we had predicted the need for imposing particular heights for pedestal or table surfaces but we found that the amount of objects placed on the individual surfaces left little opportunity for interpolation between these. As each scenario was programmed to encompass the different objects, models and videos, the surfaces became highly specified creating demands for height and size so as to give the audience access to the exhibited objects. This process of programming the exhibition surfaces created strict design criteria which in the end contradicted the variable design space of the generative model.



Figure 13: The exhibition design

The solution became a process of manual tweaking and hard coding the geometry. During the design process we developed strategies for creating a general layout and spatial intention of the scenarios as pure generative models after which they were further amended and modified in hard code. Where this part of the design phase broke the flexibility and therefore reversability of the parametric model and was highly unintuitive as each modification would necessitate a process assessing the numerical value of a particular point position, it retained the encoded logics of the model and allowed us to proceed the design into digital production drawings.

This problem allowed us to understand the ability to respond to given design criteria. If the design solution should be fully generative and parametrically defined we would need population sizes 6 fold the amount we had. In average each scenario consisted of between 40 and 80 individual cassettes and increasing the number was unfeasible dues to the restrictions in cost and space.

As a means of investigating the relationship between design criteria and population size we developed set of speculative models which were exhibited in the final show. These 3D printed models explored population sizes of several hundreds and allowed us to explore the range of emergent qualities that the generative model suggests. Here, we investigated the means of the system interpolate and merge the different qualities of popping, sliding, and inverting the geometry as well as defining its height. These speculative models are in a sense scaleless. As abstract models the design criteria were defined particular spatial qualities. They are simultaneously fully scaled as well as pointing to a variety of images of the very small; the crystal or the snowflake, and the very large; the grotto, the landscape or the city.

5. PROBLEMS: ARCHITECT AS PRODUCTION DESIGNER

A second lesson to be gained from "*it*'s a SMALL world" lies with the process of going from design to production. The design and production of the "*it*'s a SMALL world" exhibition demonstrates that knowledge from all parts of an architectural design and realisation process can be included into a generative system. This knowledge can be activated and provides an expanded design space that allows for a quicker and more direct engagement with design as big parts of the generally iterative process of design and communication with specialists can be bypassed.



Figure 14: Speculative testing of the emergent properties within the system

On the other hand side the direct outputting to fabrication meant that the design team becomes responsible for the precision of the production tools. In this way architects gain a new role as they become responsible for the execution of the design. In Branco Kolarevic's terms the architect regains a gothic ideal – now in the form of an "information-masterbuilder "[10]. As this term suggests a positive influence in a new design practice on all phases of the process it is accompanied by a massive rise of liability. In "*it's a SMALL world*" the generative system works across the present legal borders. The codification of process and knowledge in a model as presented in this paper and other work [11] makes it impossible to place the process in today's legal framework. The quality and precision of our design could solely be assured by intense testing and prototyping. This shift has consequences for the setup of building consortia and the distribution of budgets as those involved in the production have to share their part with the authors of the generative system.

These needs for changes in legal frameworks are widely discussed in the last years [12]. Yet as a new collaborative model this inherent problem of the file to factory process can also become an opportunity for a new level of material awareness in architectural design culture.

In "*it's a SMALL world*" the inherent complexity and non-linearity questions digital fabrication processes that are based on the extraction of preferably simple geometric rules to generate complex geometries for fabrication. A well established method of this kind, wherein fabricators remodel the structure according to provided rules, allows Foster and Partners in their Geometry Method Statement approach to have a well defined division of liability, while assuring the perfect execution of the building design [13]. But what happens when the complexity of the code increases and design and production become tightly interwoven, as in the "*it's a SMALL world*" design system? In his lecture at the 2009 Design Modelling Symposium in Berlin Kai Strehlke, leader of the CAD-CAM group at Herzog&DeMeuron, proposed a process of backwards engineering the design from the production data as a means of testing the design. Whereas this process is labour some and complex, it could be used as a means of assuring the quality and precision of a generative production system (Gengnagel 2009).

This is a new problem for a building practice of high complexity working with non-standard practice. As a research problem it gains relevance with the introduction of performative design strategies. The implementation of environment data and material behaviour pushes the complexity further as coded responsiveness on local level is the core of these systems. As the complexity of the project increases it becomes unlikely that the designer can remain separate from the production process.

6. CONCLUSION

In conclusion "*it's a SMALL world*" develops strategies by which the multiple parameters defining the design space can be negotiated and merged. The defined nurb surfaces allow us to interactively define an interpolated surface by which the influence of a particular parameter can be designed. Through visual feedback the effect and the intersections between the parameters can be assessed and adjusted. The key opportunity of this design process is incorporation of the emergent properties that these intersections bring forth. Designing "*it's a SMALL world*" is as such a process of discovery. Learning to design within the generative design space, is learning how to take advantage of the qualities that the parametric design suggests and to tweak and adjust this into a usable design.

In developing the design we found that the population sizes of the system needs to reflect the amount of design criteria imposed upon the surface. In *"it's a SMALL world*" the limited scale of the individual scenario posed a negative limitation for working with generative design strategies. But as a practice architecture often designs for large quantities of repeated elements. In this way the generative design process points to the scale of the repeated element, the unit or the brick, and its relationship to the whole. However, it is a recognisable part of the architectural design process that the design criteria become increasingly defined as a project is matured. It is therefore likely that the process of needing to break the generative logic of a system so as to finally tweak and modify the design would be part of most generative design practice far removed from the architectural process of drawing. It is therefore important to develop better strategies for integrating this final stage of design amendment while retaining the encoded logics of the system.

The second aim for "*it*'s a SMALL world" is to develop solid strategies for digital fabrication. The second level of the design environment generates production drawing directly used as instruction for CNC milling. In developing the system we found ways to incorporate material thickness, tolerances, the variable tool sizes and detailing for screw holes. The system was proved to be flexible and therefore able incorporate the continual changes that learning to work with the DiBond material and the CNC miller involved. This second level was developed as an integral part of the design environment. This is practical as it allows design control of this final tweaking. However, as the making of production drawings become part of the system the responsibility for their precision shifts from that of the producer to that of the architect. In the

scale of *"it's a SMALL world"* this problem is limited. But it is clear that as generative and parametric design strategies become part of architectural design practice we need to address this shift in responsibility between design and fabrication.

Acknowledgments

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