DESIGN EXPLORATION WITH CIRCULAR DEPENDENCIES

A chair design experiment

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Abstract. The paper demonstrates the need for advanced models of representation for circular dependency networks common in design problems that deal with multiple constraints. Constraints in a design problem are generally perceived as limitations to design exploration. The careful construction of constraint relationships can help to turn constraints into design drivers for the problem instead. Closely related to the notion that new goals may emerge from creating designs is the idea that one goal of planning may be the design activity itself (Simon 1981). The interplay of many constraints can lead to circular dependencies that make design exploration a challenge as any change causes ripples throughout the entire design construct. D'Arcy Thompson (1942) describes form as a diagram of forces. The construction of design representations that reflect such dependency networks pose a challenge and are far from exact matches of the task environment (Simon 1981). The paper proceeds in mapping these abstract observations of the circular dependencies in the design process to a chair experiment from design to fabrication giving detailed descriptions of the interdependencies of material, fabrication and aesthetic constraints. The experiment shows how those constraints were instrumental in achieving the aesthetics of the full scale prototype.

1 Introduction

The focus on geometry at the core of today's digital design representation poses a set of challenges when dealing with the circular dependencies between the different constraints in the design process. Parametric models expand the possibilities of tying additional representations into the geometric representation, and digital fabrication allows for prototyping cycles to test the design iteratively. But geometry does not capture the additional design aspects, such as material resistance and assembly sequences. The lack of feedback from physical prototypes to the geometric representation of the design, is a major shortcoming of today's digital design environments. To integrate feedback into the generative process is a big challenge. Norbert Wiener (1948) lays out the importance of feedback in his influential book "Cybernetics" and in how a system can work toward a goal through feedback and adapt to a changing environment.

The example exposes on the one hand, the limits of complexity that can be dealt with in today's digital design environments, and on the other hand the lack of adequate computational models for linking the different aspects of design conceptually, even in the relatively simple case of the chair project. In conclusion, the paper lays out possible extensions to the current geometry centered digital design paradigm based on the findings of the chair design experiment and gives some suggestions for models that could help to link the gaps in the digital design environments of today.

2 Chair Experiment – Circular Exploration between Surface and Material Constraints

Example of a design experiment that integrates several constraints in pursuit of an aesthetic design goal formulated through a geometric sketch.

The chair experiment was conducted as a test application of a puzzle connection detail (Kilian 2003) on a designed object scale such as a roof or a piece of furniture. In this case due to time and cost constraints a chair was chosen as the test case as both material amounts and fabrication tools stay at a manageable stay for an initial first run.

2.1 PROCESS

The chair experiment was conducted over a period of three months starting with a design idea in form of a geometric sketch model. The aim was to produce a prototype using thin plywood and explore the aesthetic and structural potential of single curvature based assemblies.

Chronological the first step following the geometric sketch in Rhino was a paper based, 1:2 scale, paper mockup. The literal translation proved to be structurally insufficient. The findings of the paper mockup though were valuable in identifying the weak spots in the assembly for a second round of geometric modeling. For the second digital representation a parametric model was chosen and implemented in different of parametric environments, namely CATIA© and Generative Components (GC)©. The parametric model was at the center of the iterative modeling cycles. The topological structure of the control geometry allows for adjustment for both the models proportions and the number of parts (in the case of GC). The main role of the parametric model is to collect and unify the findings from the range of prototypes and aesthetic evaluation conducted in the process. The dependencies are circular; meaning any change in one parameter affects all the other parameter. These cross dependencies are a challenge and usually the goal is to eliminate such effects in a design process. In the chair example these cross dependencies were intentionally allowed and studied for their potential in driving the aesthetics of the chair design further. The core parameters were:

- thickness of material
- maximal allowable curvature
- tolerance for friction fit joints
- tolerance for assembly critical joints
- scaling of structural components
- aesthetic parameters for proportion
- aesthetic parameters for distribution of parts
- aesthetic parameters for number of parts

Some of the parameters, for instance the assembly tolerance parameter, were added during the process due to experiences with the full-scale partial prototypes. Others were there from the beginning as for instance the proportional parameters.

Some of the parametric descriptions have topological flexibility meaning they can adjust fluidly to the adjustment of the number of parts through proximity triggered point selectors and topology independent representation of parts.

2.2 GEOMETRIC SKETCH

The geometric sketch captured and established the aesthetic intention of the design as a stylized constraint free, spatial composition carrying the idea over into geometric form. This design was produced in a matter of hours directly within the three dimensional modeling environment. It is not measured to be to scale or even functionally tested but is purely a geometric response to a design idea that formed the basis and evaluation base for all further exploration as more and more constraints were integrated into the design up to the full scale prototype.

Figure 1. The geometric model sketch.

The guiding principle was the interest of the author to design a chair from thin curved surface pieces with a light-weight, feature-rich appearance. The geometric sketch establishes a testing platform to measure later design variations against. It was not directly used for the following design representations except for the first paper mockup. Later models were developed from scratch, guided by the findings of the earlier prototypes. This was done to avoid post rationalizing the initial geometry and instead let the design idea and its geometric manifestations evolve and mature without the direct transfer of the initial geometry.

2.3 PAPER MOCKUP

The mockup is a direct mapping of the geometry sketch into a paper model at a scale of 1:2 in order to verify the spatial validity of the design. The paper model helped to validate the developable surface condition for all the parts of the geometric model sketch. But it also showed substantial structural flaws with the open meshed curved surface assembly. Through several iterations adjustments were made in the physical prototype to test possible changes. These findings were passed on into the next design presentation, the parametric model of the next iteration.

2.4 PARAMETRIC PLATFORM FOR GATHERING REVISIONS AND EXPLORATION

The parametric model numerically links the parameters in a simultaneous representation of the design. By gathering and connecting different design aspects it plays a central role. However, in the overall design process it is only one of several design drivers. There are other factors in the interaction between the different design representations that are not captured by the parametric model, for instance the aesthetic of the design or the assembly sequences. Therefore the design is not completely externalized but still many of the circular dependencies become apparent even in this partial representation of the design.

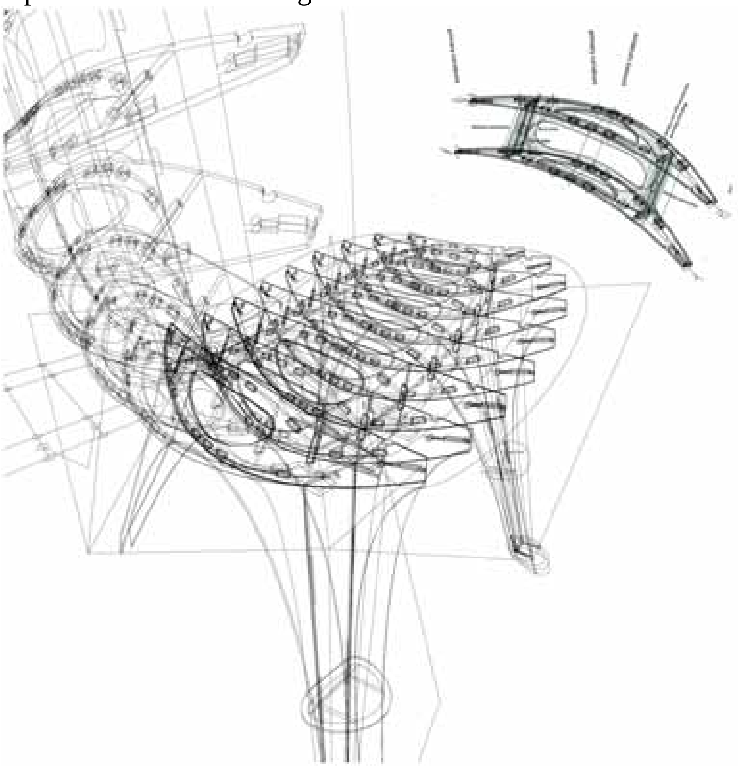

Figure 2. The parametric controlled geometry with full assembly details.

2.5 DEVELOPMENT PROTOTYPE

With the parametric model it is possible to create partial prototypes to integrate the detailing strategy into the geometric information. Several iterations were necessary for this step to find the right parametric environment to support the integration of material thickness and parametric adaptive detailing. The challenge is to formulate the approach in a way that captures the essence of the design sketch while adding structural and assembly logic. The initial approach taken proved insufficient both in aesthetic terms and in terms of assembly. The transformation created too many details in an otherwise solid appearance while loosing the rib like aesthetic.

Key points regarding exploration: The establishment of a material strategy is a key design decision in the process and carries equal importance to the early design geometries.

2.6 DETAIL PROTOTYPE SERIES

This is an instance of iterative prototyping of a selected portion of the overall design in order to test the assembly, fabrication, and aesthetic function of the design. Adjustments are integrated into the parametric model. The parametric model acts as the vehicle for the integration.

2.7 CALIBRATION OF THE PARAMETRIC MODEL

The process of calibrating the parametric model involves the iteration between producing a prototype, analyzing its shortcoming and translating the results into the parametric representation either through changes in the topology or in changes of the dimensional parameters. All parameters affect each other; any change in the geometry has potential influence on the remainder of the model.

2.8 FABRICATION PREPARATION

The final prototype is mainly tested for assembly tolerances and grain alignment and preparation of the layout of parts within the material constraints of the sheets available.

2.9 GENERATION OF CONNECTOR DETAIL

Structural integration of the parts relies on two principles combined. One is the friction fit jointing of tangent surface assemblies and second the spatial assembly of parts in an interlocking way that blocks the friction joints from coming undone. This principle propagates through the entire assembly effectively locking all parts in place.

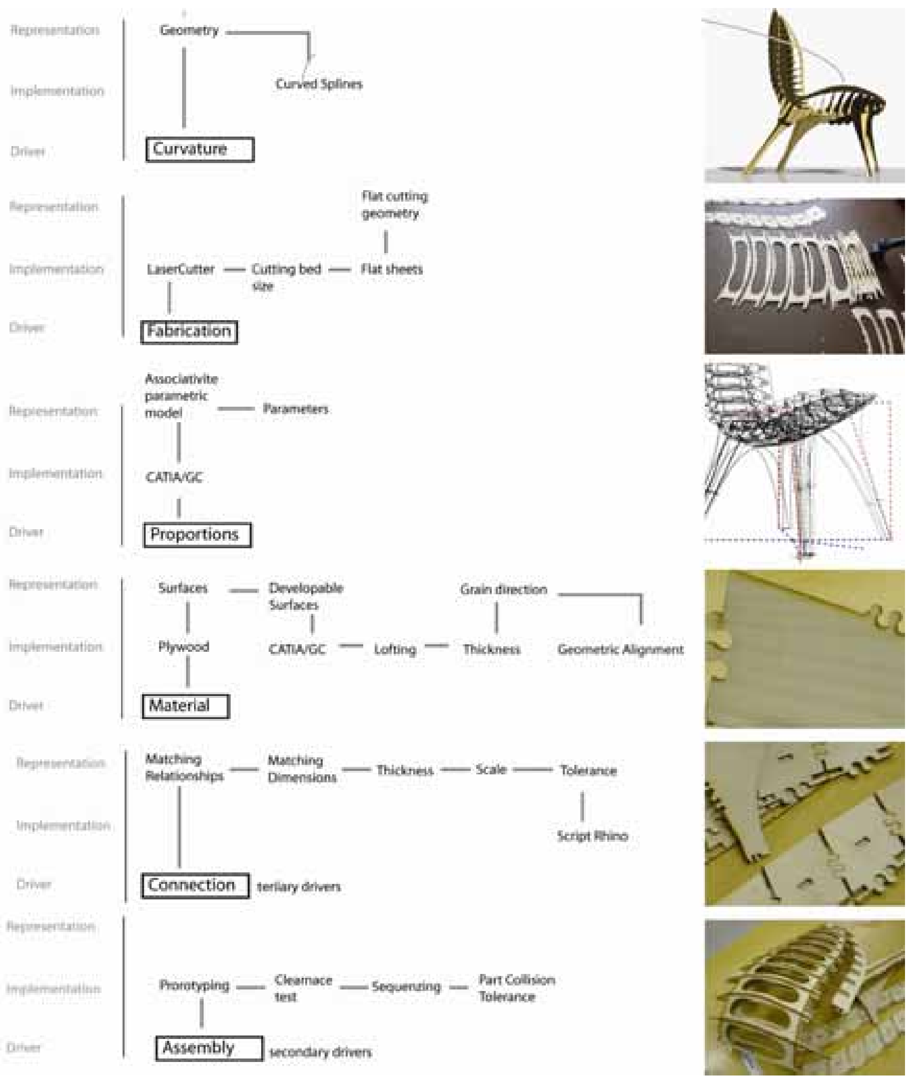

Figure 3. The different design drivers, their representations and implementations.

2.10 ASSEMBLY

The material properties for the wood chosen mandated the alignment of the grain perpendicular to the direction of curvature to avoid cracks and breakage. The perpendicular alignment meant also that bending the wood required a far greater force and was not possible in many of the tighter locations where many curved parts need to be assembled simultaneously. For those parts light steaming was applied to protect the wood during excessive stress and partially pre-bend the parts in the desired shape. The assembly worked relatively smoothly and took several hours. A proper assembly sequence needed to be developed from the geometric constraints. One person could assemble the over 140 parts following this strategy. The biggest challenge were the final edge strips since they required the connection of all parts at the same time. The legs were only partially successful because of inaccuracies. They were not fully modeled parametrically. In further iterations they would be fully integrated into the parametric representation.

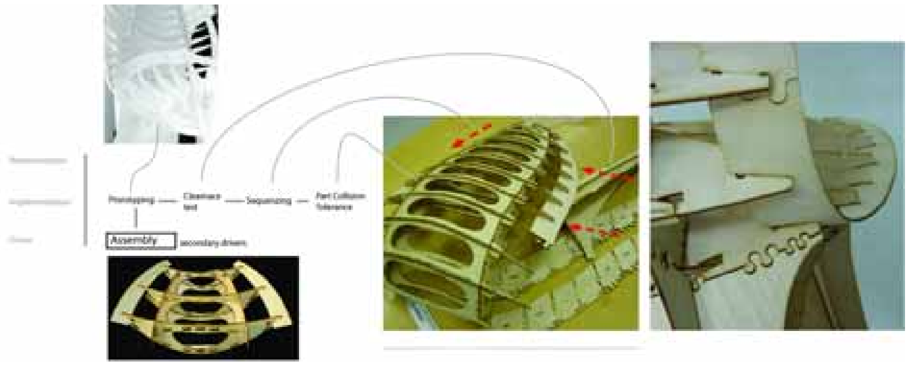

Figure 4. The assembly factors playing into the design.

3 Analysis of the Projects

Surfaces play an increasingly important role in design representation and also led to the increased reliance of architectural representation on geometry overall. This has led to many of the frustration and misunderstandings in design in the digital context. At the core of the geometric representation stands the surface. Despite the importance of solid based modeling in engineering and architecture the surface is still at the core of design representation as even solids are composed of surfaces and a considerable percentage of design software does not implement full solid modeling function but rather relies on surface representations The surface condition has many facets and only few of them are captured in digital surface representation.

The separation of sculptural expression and translation into a buildable system led to some of the most stunning buildings such as Bilbao or Walt

Disney Concert Hall. However, at the same time it demonstrated the lack of domain integration into the initial design process. The author argues for embedding a structural and material sensitivity into the design process through the use of digital design representations.

4 Conclusion

The chair experiment was successful in developing a partially functioning prototype of a chair exploiting the possibilities of curved wood surfaces in a structural assembly. The parametric model as the repository for the prototyping revisions proved successful. The parametric model's functionality to support the circular properties of the project is limited, as the model can only receive information fed to it through the input parameters. It is difficult to argue for a general model for instance for material simulation. This specific case did not simulate material for material realism but rather used an abstract representation as a design rational to develop the aesthetic of the design.

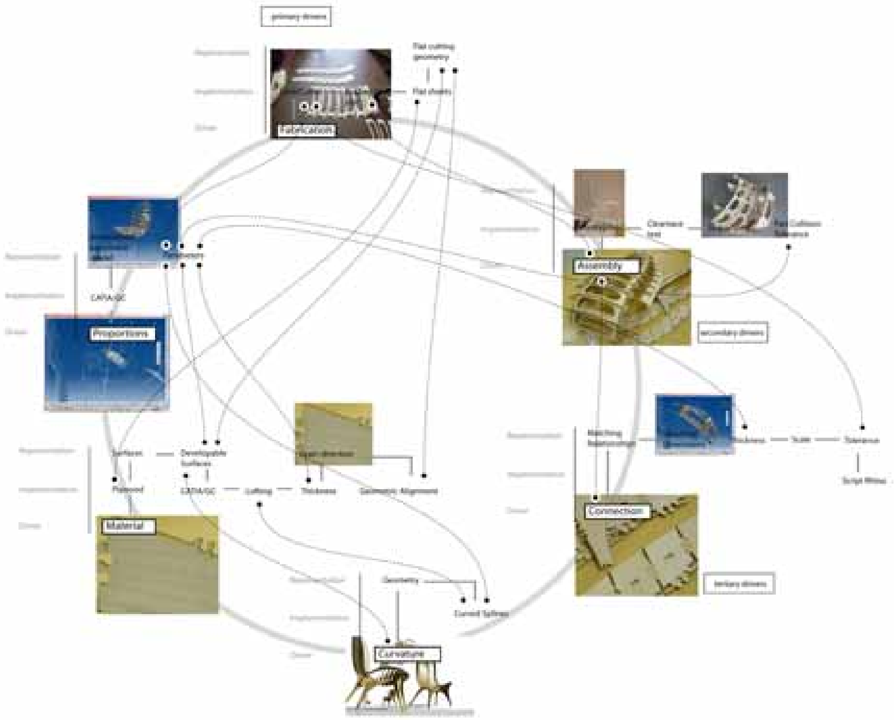

Figure 5. The full dependency diagram of the design experiment.

The experiment was part of the author's dissertation. Circular dependencies were observed in most projects independent of scale or domain and managing them properly can make the difference between success and failure of a project. Beyond the management of a project the circulars main research interest is the potential for triggering aesthetic potential and synergies between the different domains adjacent in the design.

5 Acknowledgements

The chair experiment is part of a chapter on circular exploration in the Ph.D. thesis of the author titled "Design Exploration through the Bidirectional Modeling of Constraints". The paper in parts uses the material and has some additional sections. I would like to thank my dissertation committee Prof. Takehiko Nagakura, Prof. William J. Mitchell and Una-May O'Reilly for their comments and support.

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