Error as Optimization

Using Cellular Automata Systems to Introduce Bias in Aggregation Models through Multigrids

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This paper is focusing on the idea of error as the origin of difference in form but also as the path and the necessity for optimization. It describes the use of Cellular Automata (CA) for a series of structural and formal elements, whose proliferation is guided through sets of differential grids (multigrids) and leads to the buildup of big span structures and edifices as, for example, a cathedral. Starting from the error as the main idea/tool for optimization, taxonomies of morphological errors occur and at a next step, they are informed with contextual elements to produce an architectural system. A toolbox is composed that can be implemented in different scales and environmental parameters, providing variation, optimization, complexity and detail density. Different sets of experiments were created starting from linear structural elements and continuing to space dividers and larger surface components.

Keywords: *Cellular Automata, Semi-randomness, Generative Design, Morphology Optimization*

INTRODUCTION

An error is actually a very simple process of deviation and a time based procedure. It is argued that it is not a random event, but on the contrary, a very important part of the process. In fact, it is seemingly random only for the external viewers of the system. Errors are significant for the evolution and development of form, as they constitute an origin of difference. (Adilenidou 2014) They result from the flow of information that reaches the rule-based model, which is not only different each time but also self-reorganized and self-rearranged through the same basic set of rules and inputs.

Error relates to imperfections arising from mutations of ideal bodies and geometries. It relates to symmetry breaking and repetitive variations, mutations of perfect bodies. According to Greg Lynn, commenting on Edmund Husserl's Origin of Geometry, the necessity of the mutation iterations of a perfect form is more important than the ideal geometry itself. (Lynn 1998)

The research is situated in the general framework of computation while it provides experimentation using Cellular Automata (CA) systems. CA systems have been used extensively in the area of computation. In the specific research they are used in com-

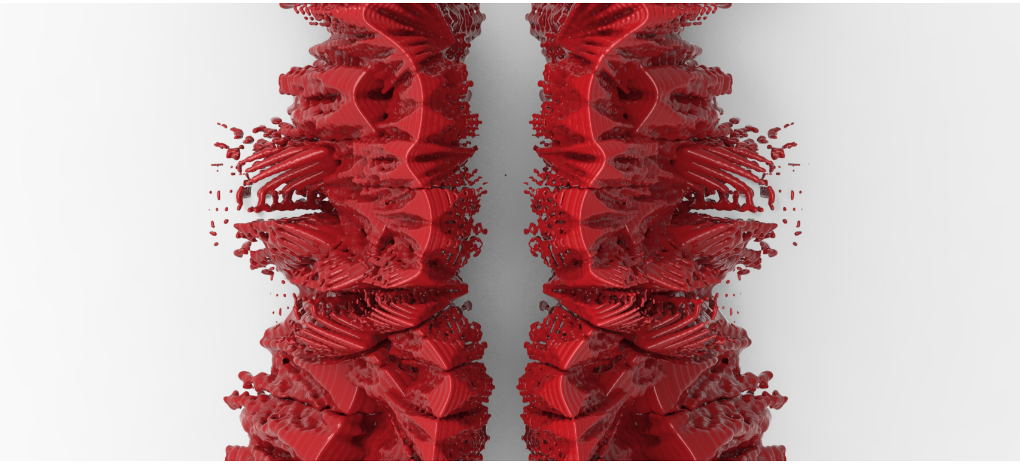


Figure 1
Mesh resulting from poin clouds

bination to differentiated multi-grids that are able to mutate before and during the process of CA proliferation through generations, leading to a different outcome and application from other CA projects, while deforming the very defined and static background of the system.

ERROR, EVOLUTION AND OPTIMIZATION

Sean Carroll explains in his book Endless Forms Most beautiful (Caroll 2005) the stages of development of an embryo to a fully developed body. The points (coordinates) of the embryo geometric ideal surface is referenced to the elements of the final body formation, the surface, pattern, layers, organs and appendages. Matter is organized with the help of the embryo "manual", the genotype. In its coordinates, the information of body structure and growth is found. Carroll talks about the geography of the embryo as a system of longitudes and latitudes evenly arranged and dividing the embryo. Longitudes are referring to the pattern of the body, the repetitive parts and the way they are varied through the body via development. Latitudes refer to the surface and the layers below, epidermis, mesoderm and other tissues. The intersections of longitudes and latitudes give the points were the appendages and organs will grow to other directions of the embryo parametric space. Carroll also mentions a region in the embryo responsible for its organization, called the "organizer" (Carroll 2005) that holds the structure of body together and maintains the order. Any change in the organizer will cause disorder and will upset the equilibrium.

The development process depends upon an automated procedure. A small set of similar genes produce a countless number of animal species. Switches turned from on to off (repressors - activators), turn on and off specific digit parts of the body on growth and act as operating instructions for the genetic toolkit, affecting the body pattern, its layering and extensions (Carroll 2005) Carroll is talking about episodes instead of instantaneous events - environmental changes or chance that affect this automated process. While the switches circuit is assembled, failures take place that produce errors in body symmetry, changes in morphology as well as in the use of appendages, creating advanced new bodies and species. In this way, errors or otherwise, deviations from the default, are leading to optimized forms and structures that are adjusted to their environment. These symmetry breaking changes are also described in Bateson's Materials on the Study of Variation. (Bateson 1894) We can trace here a very important relation between error, variation, and optimization. The body works with a repetitive structure of digits that create a pattern describing the form of each animal. The digits are proliferated in different sizes according to the rules described above. In this process we can trace an amount of randomness that is filtered with a set of defined instructions leading to seemingly random results.

RESEARCH QUESTIONS AND AIMS

The question that arises is if we can invent a process for creating an error system as a response to optimization. How an error, a deviation from the default, as an origin of evolution, is related to variation and optimization in architectural design? And how can this be implemented in structure, fabrication and formal investigation? Repetition and semi-randomness are used as a part of this mechanism. So, if we involve randomness as a partial error initiator how does this relate to the control of a designer-author over the final outcome, how does it affect the design research? And finally, how are we able to control the digital or analogue tools we are creating?

The aim of this research is to create an architectural system that is able to evolve, self- calculate its properties, and control the production of strength, robustness, spatial complexity and consistency variation. Also, to create a toolbox of elements that can lead to outcomes of different scales, leading to formal, structural and spatial explorations.

DESIGN METHODOLOGY

Cellular Automata (CA) systems are used to simulate a body development process in design. Stephen Wolfram talks about complexity arising from simplicity in his CA structures (Wolfram 2002) The role of the initial seeds arrangement in the resulting patterns is very important as described by Wolfram and Packard. Organized initial seeds can lead to symmetric patterns while the same rules with disorganized (random) seeds can lead to disorganized patterns. On the other hand, there are CA structures, where very symmetrical and organized patterns arise from disorganized initial seeds while following certain rules. (Packard and Wolfram 1985) Disorganized seeds can be considered as errors introduced to the system, while locally disorganized resulting patterns can be read as pseudo-errors of the system although they result from defined rules.

In the design research model, the proposed structure of errors consists of the cellular system and the multigrid. Like in nature, matter is distributed and is fastened together by the interaction between cells. A cellular automaton model is used to guide the formations around the differential and multi-part grid, creating point clouds, which will be meshed to provide topology and space. Instead of the Cartesian grid a more rotational, multipolar grid is introduced which is also extended in a proliferation of polar arrays and their in between Boolean operation. By subdivisions of the perfect volumes, we are found in front of a new multi-polar, multi-scale, subdivided grid. (Figure 2)

If the grid is a medium between the author of the project and the builder (Carpo, 2011) but more importantly the mean between idea and fabrication, or the network and the mass, can we introduce different types of grid, grids that result from complex systems as cellular automata, agent systems, fractal and iterative systems. It is a non-static grid, a grid that readjusts, a grid that changes, that is transformed and carries the geometry with it. A similar grid is created by Gaudi with the interaction and repetition of his ruled surfaces in Sagrada Familia.

In the experiments illustrated in this paper, the grid results from the edit points of a set of multiple polar arrays of curves that intersect creating Boolean operations in between the wireframes of different centers. The local behavior of cells is mutated via a set of errors / external conditions based on proximity, topology of the cell and cell aggregation. The outcome of this process is a number of bodies of deviated topology and structural behavior, re-establishing locally broken symmetries. The error

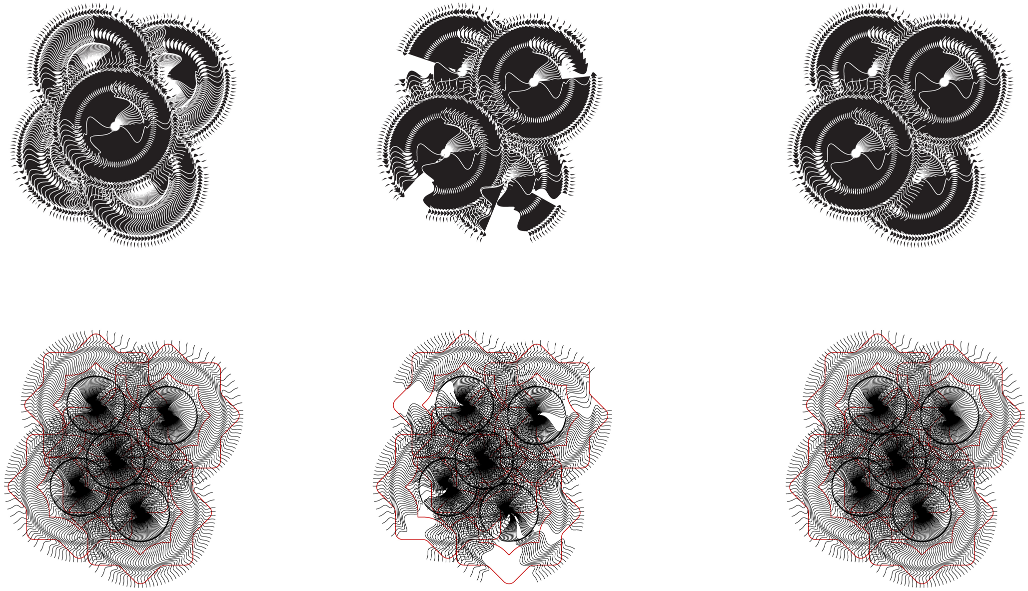


Figure 2
Multigrids

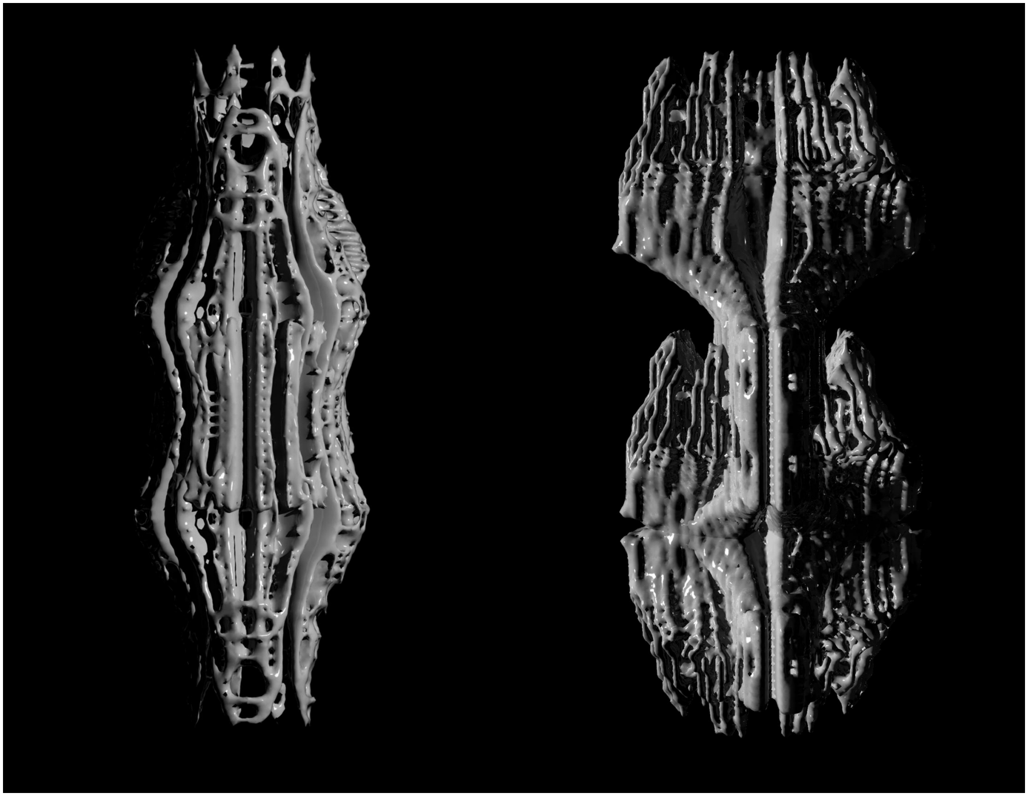
is found either on the curve- grid or on the sudden change of rules of the cellular automaton.

Gaudi's Sagrada Familia is used as an example model for investigating the complexity of form emerging through perfect polar geometries and intersections of simple ruled surfaces that become subdivisions, increasing detail and resolution. (Burry, Burry, 2012) This research attempts to revisit the connection between the use of absolute geometries, symmetries, and Boolean operations. Their distortions become "decorative elements", elements of complexity production and real-time matter distribution, displayed in a series of new prototypes, virtual and physical that examine error and randomness as a convolution primary ingredient. Boolean operation acts as an agent of complexity, sub-division, inward self-repetition, it sculpts the surfaces, it readjusts the topology of the design object.

GAUDI'S SAGRADA FAMILIA CASE STUDY

While the research has started with design tests that were linear and were consisting more of structural components than spatial distribution elements (Figure 3), the detail resolution and the sculpting qualities that the experiments revealed from the very beginning, led the discussion to the Gothic architecture and the sculpting methodologies of Gaudi in Sagrada Familia. The multigrid of polar arrays of curves, described above, found reference to the curves that were guiding the form and the detail in gothic elements, describing the geometry of ruled surfaces that were intersecting, while they were transferring load and matter. This grid that emerges from the gothic nerves, holds all the information of detail intensity, affects perforation, and light distribution. While in Gothic Architecture the ruled surface is the receiver of subcomponents of a different resolution and form, in Gaudi's Sagrada Familia, the ruled surface becomes the subcomponent. The detail and sculpting results arise from the multiplication of the

Figure 3
Initial vertical elements



ruled surface, its rotational array and its intersection with its neighboring subcomponents-ruled surfaces. The proliferation of clear geometrical forms becomes origin of complexity. These surface subdivisions were transferred in the digital interface by Mark and Jane Burry as Boolean operations in order to recreate the methodology via computation.

APPLICATION - THE CATHEDRAL

While the methodology of the research was compared and connected to the multi-grids resulting from intersecting ruled surfaces of Gothic Architecture and Gaudi's sculpting methods, the Cathedral was a perfect application model for the next set of experiments. The plan typology of the cathedral was kept intact and was used as a base for the creation of multi-grids. The aim was not to reinvent a new spatial arrangement but to rewrite the same spatial relationships through a different vocabulary aiming at a new type of spatial experience. As a first step, the parts of the cathedral were categorized and introduced defined polar grids of multiple centers. The grids created through these centers varied in scale, resolution, and density, as well as in boundary conditions according to the different spatial needs, the size of the specific cathedral part, its location to the whole system and its neighboring conditions, the context

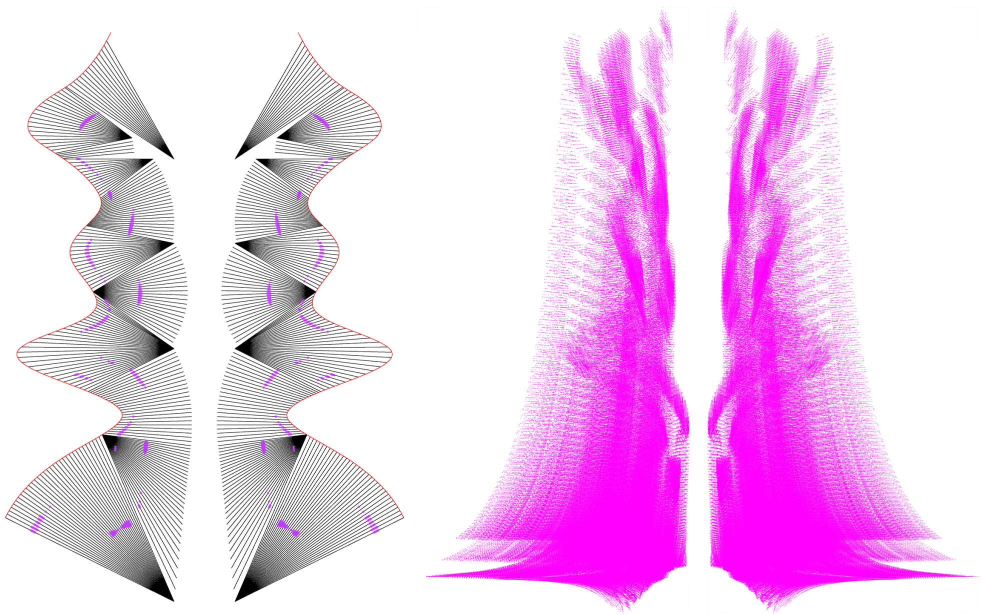


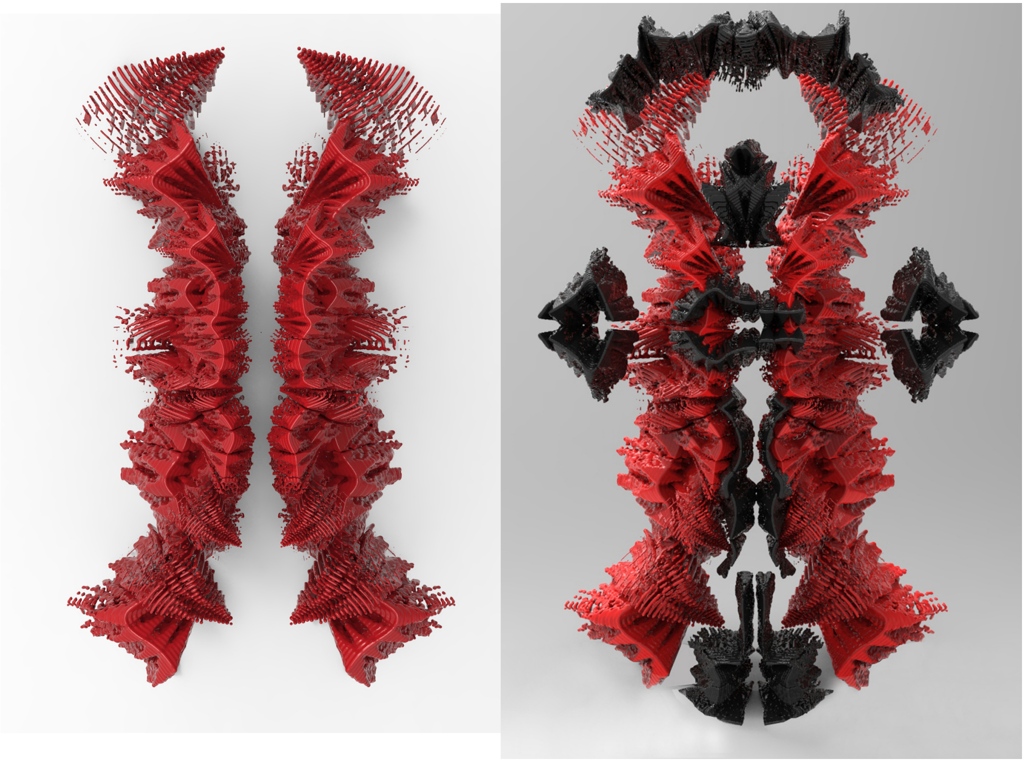
Figure 4
Multi-grids creating the central linear core of the cathedral and the resulting point cloud

conditions and the relation of the cathedral with the immediate environment of the city. This process led to taxonomies of elements, structural and spatial, but also to a pattern of directions and matter distribution. The multi-grid was used as a base for the cellular automata aggregation.

The cathedral and its parts still keep some object qualities of the initial tests but this time the object is dispersed and its boundaries are dissolved in order to make it interact with the neighborhoods. CA rules are transformed trough context geometry but also through environmental data in order to provide boundary conditions, openings, and perforation, light and shadow distribution, as well as decoration and sculpting. The symmetry of the typical cathedral plan is readjusted and mutated. The initial seeds arrangement is also mutated according to environmental factors to provide alterations in density but also changes in the local areas of the pattern, affecting the sculpting, the perforation of the surfaces as well as the volume aggregation for structural capacity. Although the linearity of the cathedral is kept, the resolution of the grid with more than 600.000 resulting editing points from polar curves of different centers and different array density, created intricate outcomes of high complexity.

The surfaces of the parts of the cathedral, the narthex, the nave, the cloister, the choir and the transept (Figure 5) are constructed through a point cloud extracted from the CA aggregation through the grids. The linear core can result to various outcomes with curves of different shapes arrayed around the same centers. (Figure 6) Mutation of the initial seeds and the CA code is reshaping and breaking the symmetry. The two mirrored parts of the cathedral typology are differentiated although they are result-

Figure 5
Central part of the cathedral – the solidification provides bearing walls and space divisions



ing from grids of the same initial center points. The same set of "genes" with different "initial switches" result to loss of information, local differentiation, and symmetry imperfection. (Figure 6)

In the surface sculpting of Gaudi, we can read the use of simple surfaces as a subcomponent for the creation of detail and complexity. The proliferation of the ruled surfaces, hyperboloids and paraboloids, and their intersection was creating carving patterns, on the larger surfaces of the Sagrada Familia cathedral. Polar arrays of intersecting surfaces in different angles, directions, densities, and repetitions was producing a result of maximum detail intensity. Inspired by this methodology, a different set of experiments was introduced. In the previous examples, the linear typology of a cathedral was simulated through different polar grids creating space distribution and structural elements. In the next experiments, Boolean operations will be used in order to create surface resolution and decoration, using the resulting elements as perforation and surface sculpting. The grids are again initiating the process but instead of space distributors they play the role of surface subdivision guides. (Figure 7)

The base used for the experiments was a set of Boolean union surfaces that were copied and rotated around a center creating a pattern. The extracted wireframe of these surfaces became the grid of curves upon which the CA would be arranged and would generate the point clouds. The first tests were

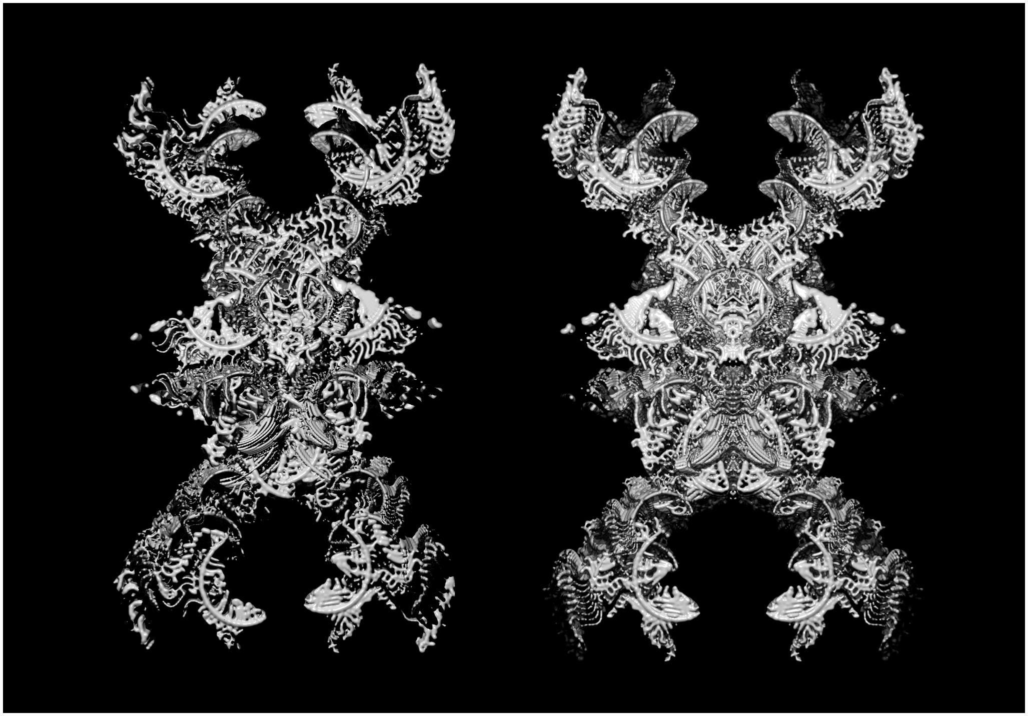


Figure 6
Different aggregations investigating the central long part of the cathedral – choir, nave and transept

examining conditions of bridging floor and ceiling through vaults while the next tests were focused into creating parts of the cathedral ceiling. The surface division resulting from Boolean geometries is reflecting the space distribution below, while it allows connectivity with the environment, through perforation that breaks the solidification of forms created by the CA aggregation. (Figure 8) The Boolean operations are breaking the rotational symmetry of surfaces as they alter the perfect ruled surface by subtracting a part from it. By mutating the code and the initial seeds we end up with many variations that are used accordingly in different parts of the ceiling.

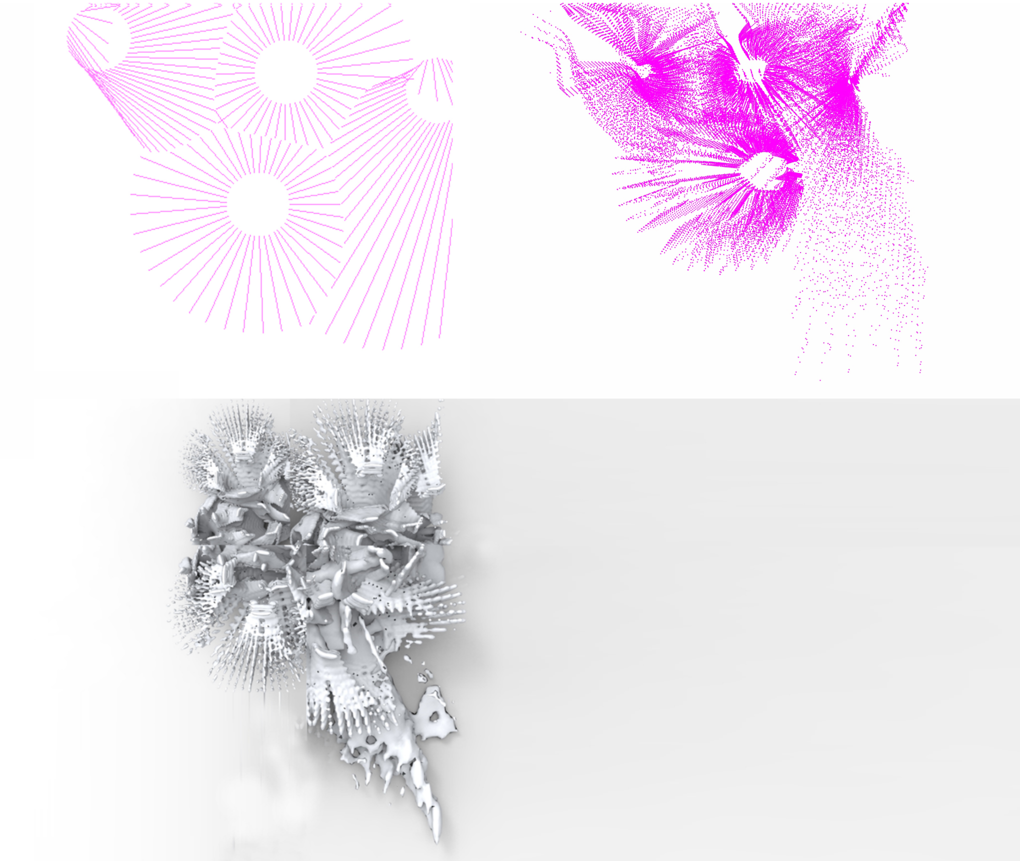
FABRICATION

In the first stage of the fabrication, Makerbot 3D printers were used. The forms were cut into 3d bricks in the size of the 3d printer plate in order to achieve a larger scale model. As a next step, UR10 robots are used for 3d printing with a custom made extruder. This process can allow for external parameters, acting at the time of fabrication, including sensorial intervention, working in parallel to the code and affecting the movement of the robot while introducing an extra level of error to the final system model.

CONCLUSIONS

In this paper a number of experiments were presented, that using the logic of cellular automata, investigate how different initial conditions filtered

Figure 7
Boolean union surfaces wireframe, resulting point cloud and mesh



through defined rules create variations, errors or else, deviations from the default condition that often relates to symmetry and to disorder of form. Complexity can actually originate from simple geometry and specific rules leading to detail concentration, disorder, intricacy and infinite variation. Sets of simple ruled surfaces were used as a base multi-grid for the CA to aggregate.

The errors introduced to the system are not random but actually have a strong connection to context parameters. There are a number questions that arise. How do you control randomness? Is it randomness, disorder or mutation what is implemented in the script? Is mutation intentional? Are the disordered initial seeds manually mutated according to parameters or they are randomly generated? This can be

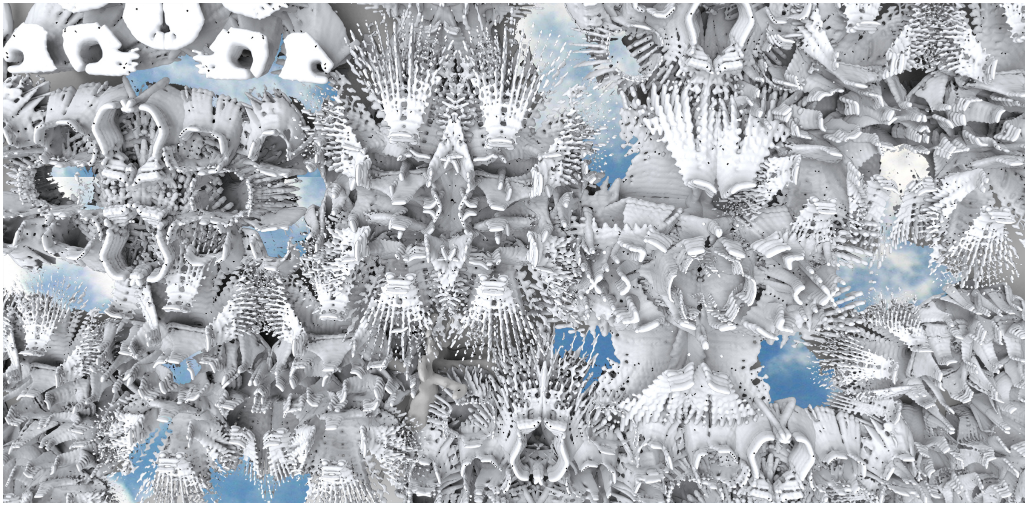


Figure 8
An assemblage as the ceiling of the cathedral

answered by accepting the fact that the location of every mutated initial seed is not as important as the analogy of mutation needed in order to feed parameters into the system. This means that the parameters in order to control the system need only a percentage of mutation in specific surface "neighborhoods" in order to provide for example perforation while the actual location of each seed is not necessarily important. The use of the error as a term, aims at dislocating it from the random to the seemingly-random area, accepting an amount of authorship over the action. This is actually very important for design research as it adjusts control over tools, evaluating how randomness is actually filtered through specific environmental, social or morphological factors aiming at formal and structural optimization.

The implication in the design research is the calibration between the amount of randomness used and the control by the author of design. This calibration extends to the tool use, either it is a program, script, or a robot. Analogy as described above is an answer to this and relates to the previous concepts of semi-randomness explained in the paper. Despite a factor of randomness, the control remains to the user.

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