3-15-2019

Fractal Dimension as Objective Function in a Genetic Algorithm for Application in Architectural Design

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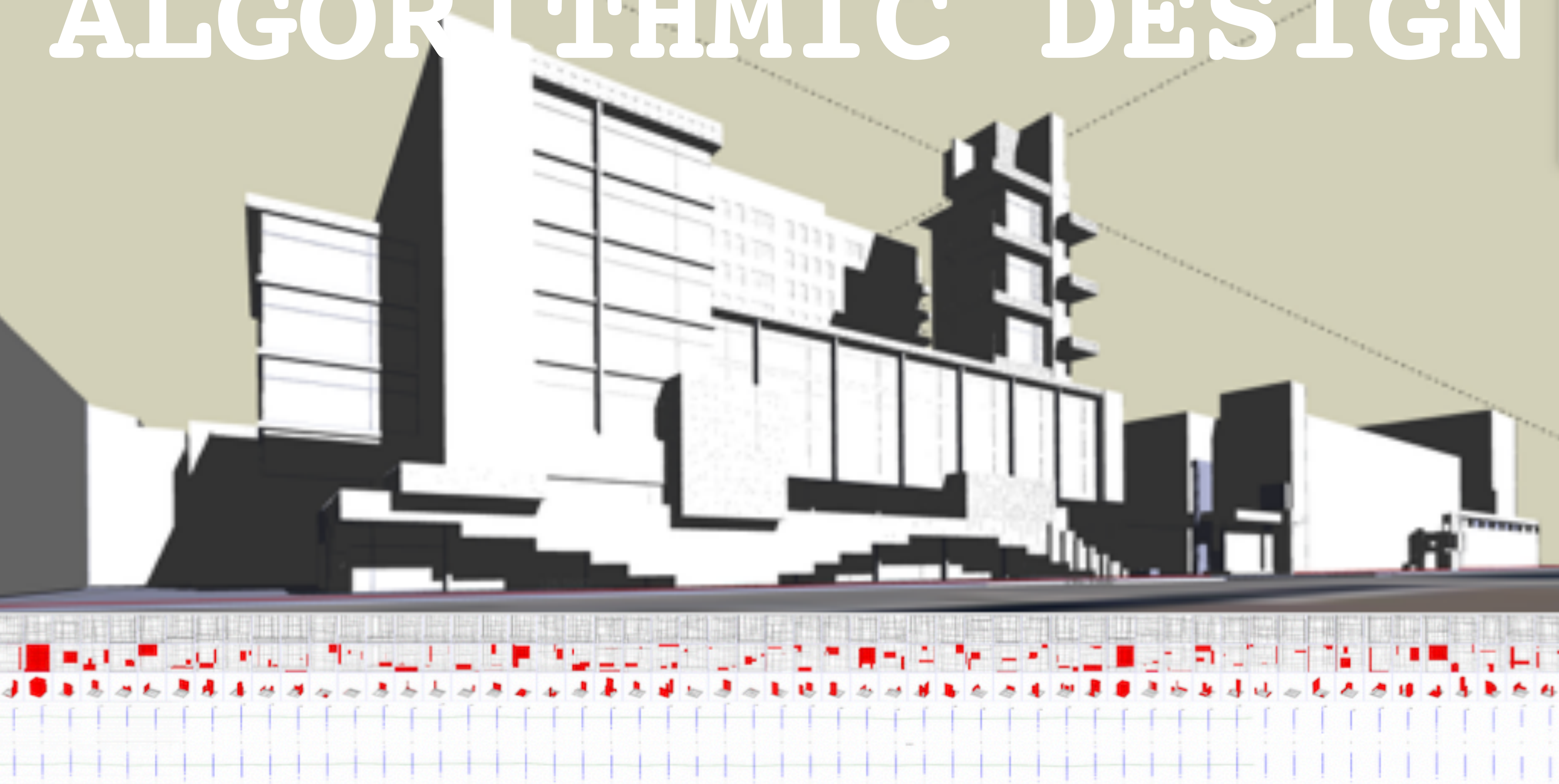

Pin-Up # 2: Fractal dimension as objective function in a genetic algorithm for application in architecture and design 3.6.19

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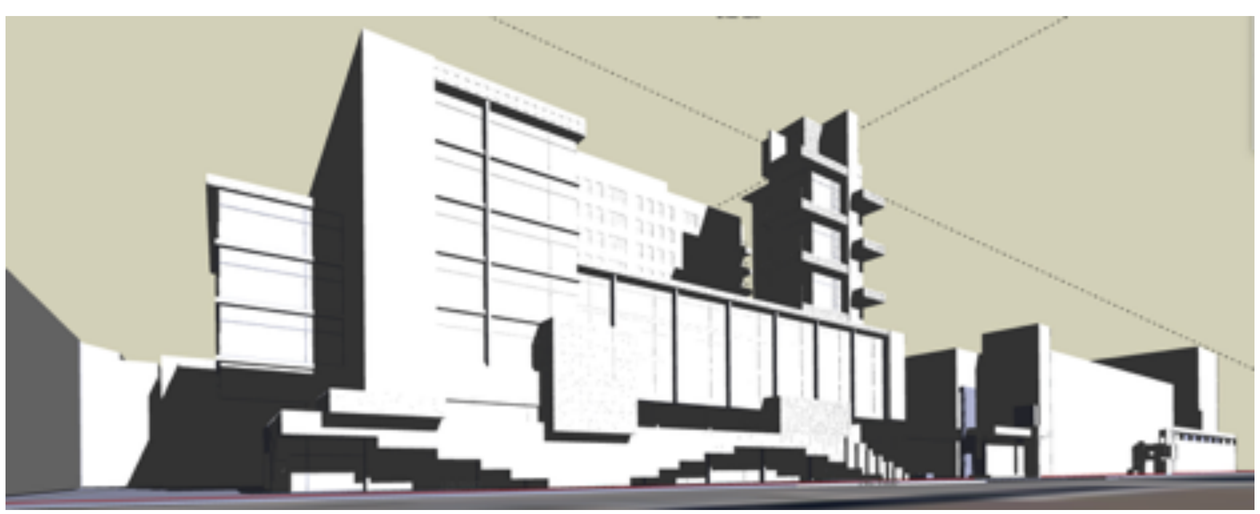
Pin-Up # 2: Fractal dimension as objective function in a genetic algorithm for application in architectural design 3.6.19

This is a mid-project review heading into the final review. The following pages will explain and demo how fractal dimension (FD) is being incorporated as a tool for the 3D modeling software *SketchUp* and show how this tool was used as a design aid with myself as ‘designer’ to create a building proposal for a current mixed-use project in downtown Ithaca, NY. Although the building is hypothetical, the project is a real project that myself and a team competed for professionally but were not awarded. The full program and specifics of the project are available on Dropbox.

Thank you very much for continuing to participate as a juror. Please respond to this email with any informal feedback you may have as per a typical design critique. There are 6 or so licensed architects acting as jurors including yourself and we have modeled this project as a scientific study with the jurors acting as human subjects in dialogue with myself. The reason for this was so that the feedback collected from jurors could be incorporated in the final dissertation document to establish how the idea of using FD as a design aid was considered by professionals in the field of architecture.



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Fractal Dimension:

Fractal geometry has been a part of architecture since time immemorial. It was not until the 80's, however, that Benoit Mandelbrot coined the term 'fractal' and developed quantitative methods for assessing them such as fractal dimension (FD). Fractal dimension is a simple graphic method for assessing the space filling attributes of an object. The intuition is that a convoluted line begins to fill the picture plane in a way that a straight line does not. For planar spatial data, it is as if the line is between 1 dimension and 2 dimensions. This fractional dimension or *fractal* dimension will be higher if the line is convoluted (has detail) at multiple scales. The detail does not necessarily have to be the same repeating shape although for standard fractals it is. An object with scale invariance has self-similarity over multiple scales or detail everywhere. The more you zoom in or out the more detail there is.

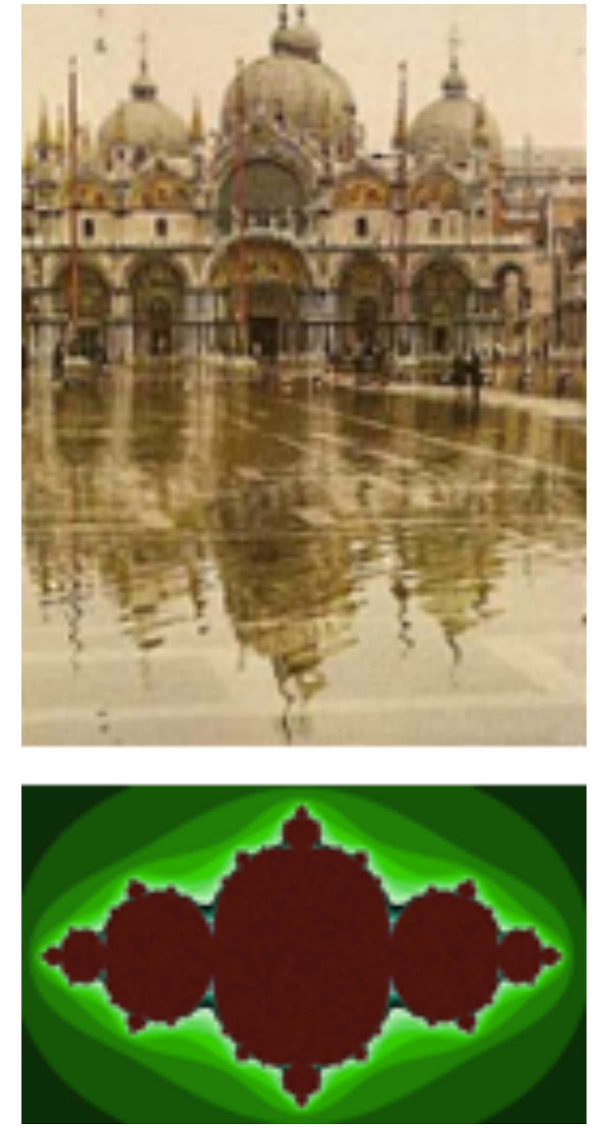

Fig 1. Above: San Marcos Church in Venice reflected. Below: San Marcos Julia fractal, J(-3/4, 0).

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Fractal dimension for regular shapes:

Fractal dimension for a geometric fractal like the Koch Curve (shown below) is the ratio of the initiator (r) to the generator (N). The initiator is a straight line that is divided into an equal number of segments (3 for Koch Curve). The generator is the number of line segments in the repeating geometric shape superimposed on the initial segmented line (4 for the Koch curve). Fractal dimension = log N/ log r. So in this sense, the Koch curve has a fractal dimension of log4/log3 or 1.26186…

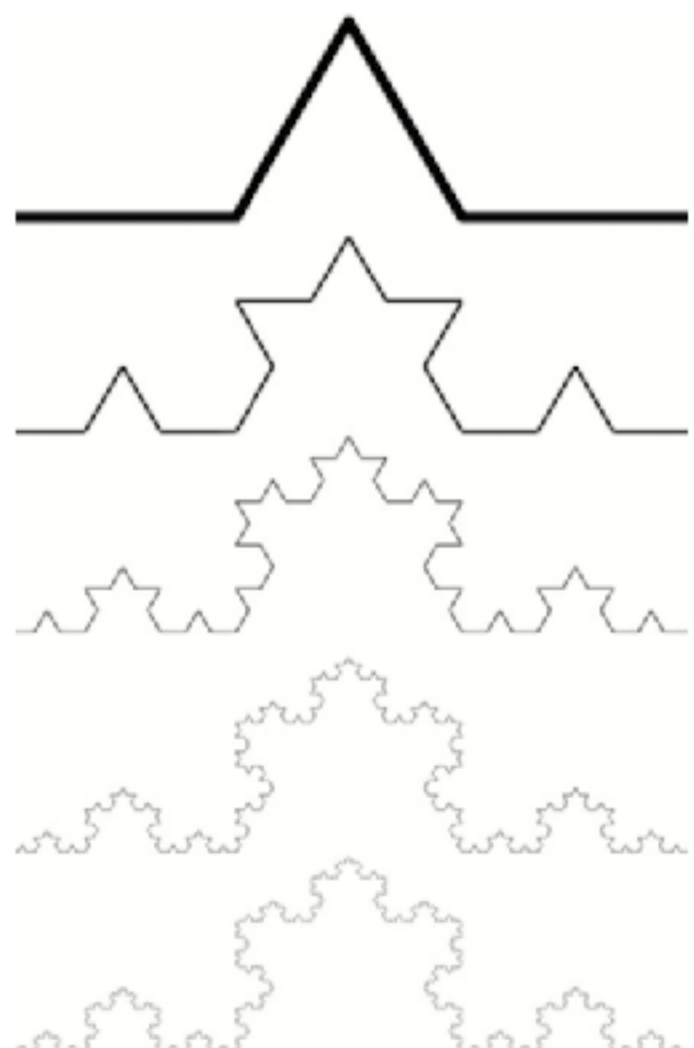

Fig 2. Koch Curve

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Box-counting dimension:

Fractal dimension can also be determined using box-counting dimension. BCD is useful for irregular objects such as rivers and trees or in this thesis for not strictly repeating orthogonal compositions. BCD is determined by covering the object with different size boxes and counting how many cells contain the object compared to the overall number of cells in the grid. In the drawing below you can see that a smaller grid requires less area to cover the shape. Comparing all the numbers of boxes will yield 1.26186…

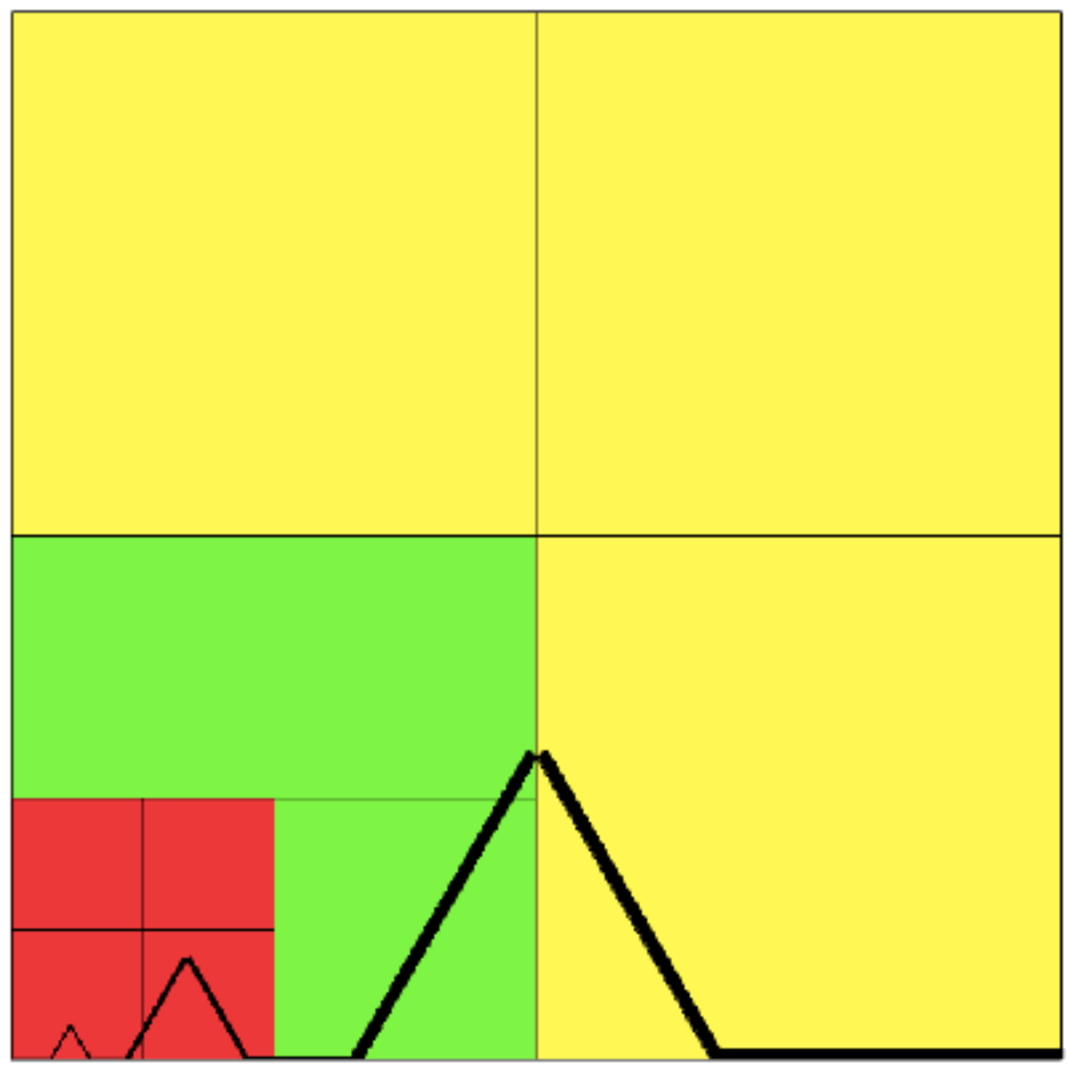

Fig 3. Koch Curve measured with BCD, notice how smaller iterations of the shape require fewer boxes to cover them, for instance, the red grid can cover the shape with 1 cell..

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Fractal dimension

Fractal dimension has been used discriminatively to analyze the self-similarity of buildings and landscapes. In addition to this analytic approach, we investigate using fractal dimension as a *generative tool* to aid the designer in creating scale invariant self-similar form.

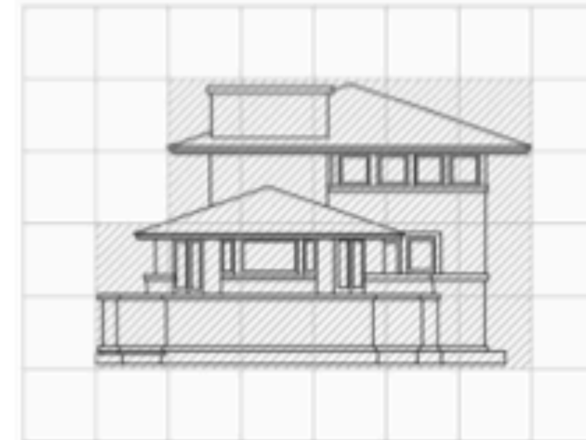


Fig. 1. Starting grid placed over the east elevation of the Tomek house showing box-counting

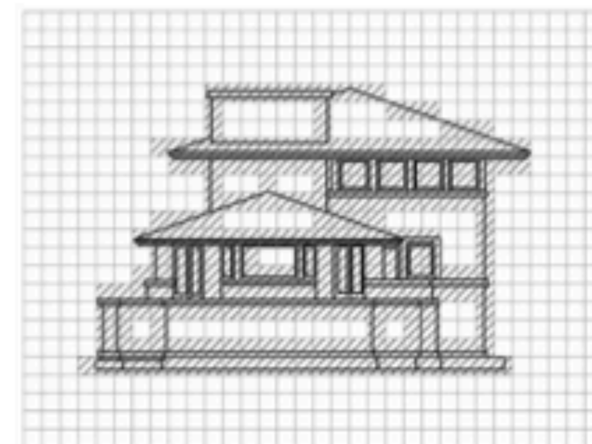


Fig. 2. Third stage grid placed over the east elevation of the Tomek house showing box-counting

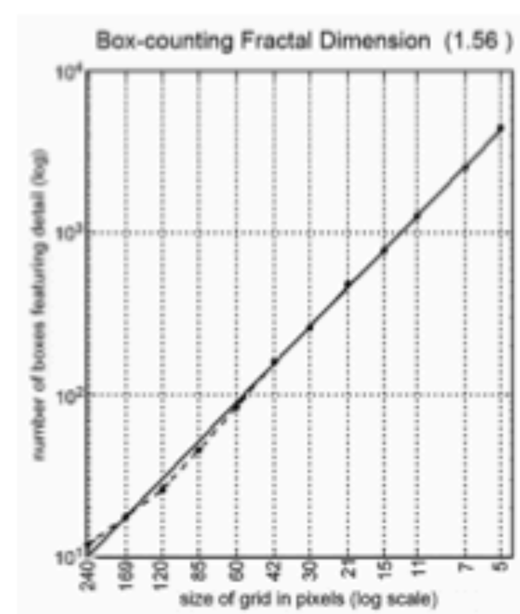


Fig. 3. Log-log diagram of the comparison between the number of boxes counted in a grid

FIG 4.1. Fractal analysis of FLLW's Tomek House (Otswald, Vaughn, 2008). **FD = 1.56**

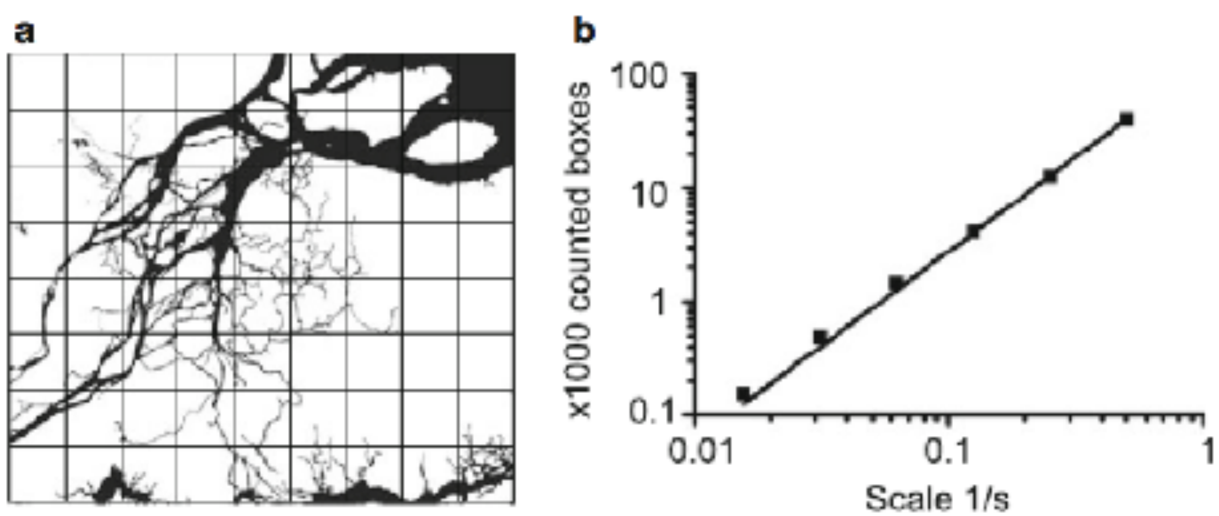


FIG 4. Dougherty, Geoff & A. Haidekker, Mark. (2011). Medical imaging in the diagnosis of osteoporosis and estimation of the individual bone fracture risk.

Algorithmic Design Background

FIG 4.2 Michael Hansmeyer. 'Genuinely procedural shapes. Neo-baroque.

fig 1.2.4 fibrous assemblage - Fibrous House

FIG 4.3 Roland Snooks, Multi-agent algorithmic design strategies (Snooks, 2014).

Algorithmic Design Background

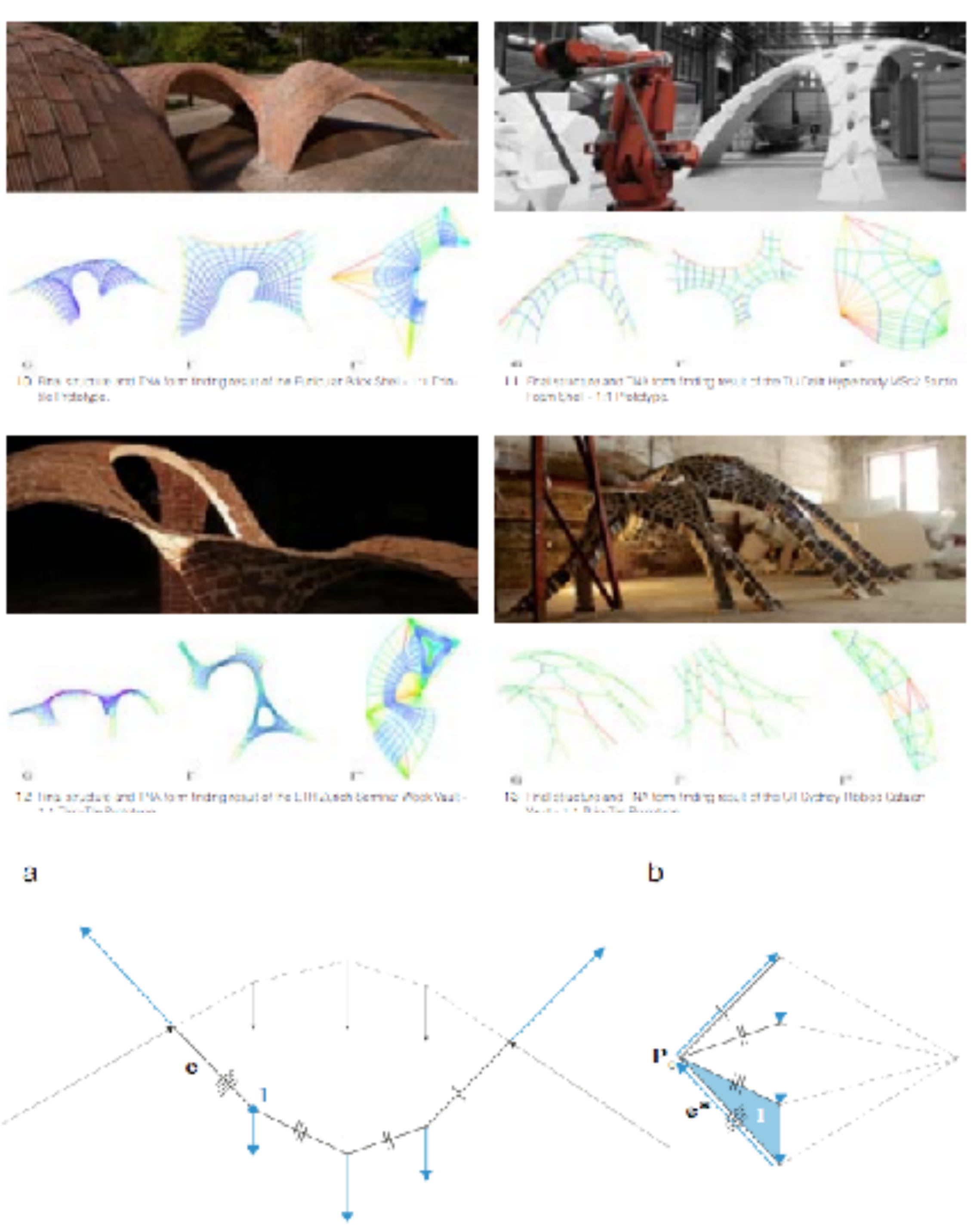


FIG 4.4 Funicular Shell Design Exploration, (Matthias Rippmann, Philippe Block, 2013).

FIG 4.5 Rafael Guastivino, Catalan Architect.

Algorithmic Design Background

FIG 4.6 Antonio Guadi. "Hanging Model" (1889).

FIG 4.7 Rafael Guastivino, Bridge under construction.

Algorithmic Design Background

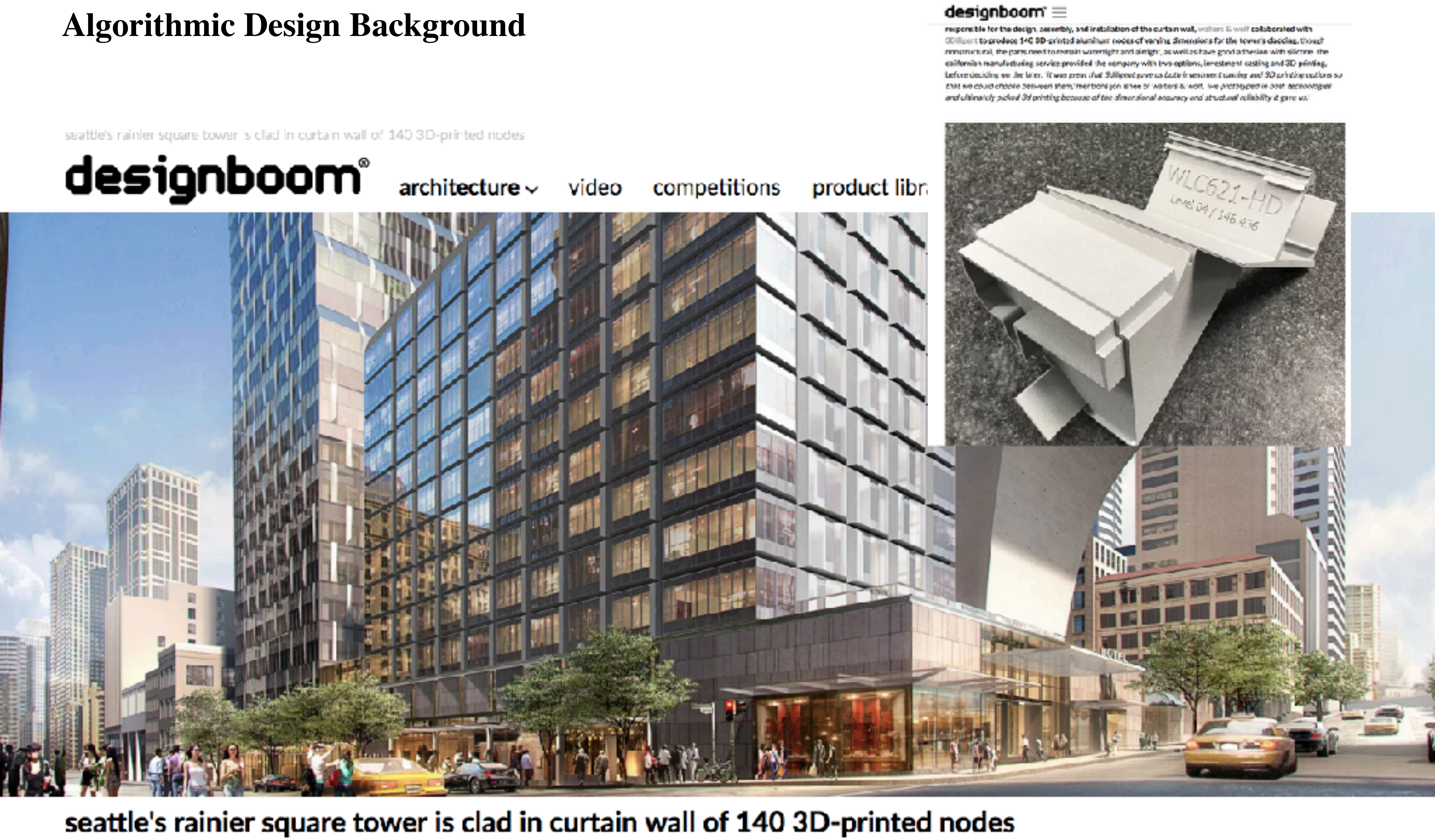


FIG 4.8 Rainier Square Tower (NBBJ Architects, 2019).

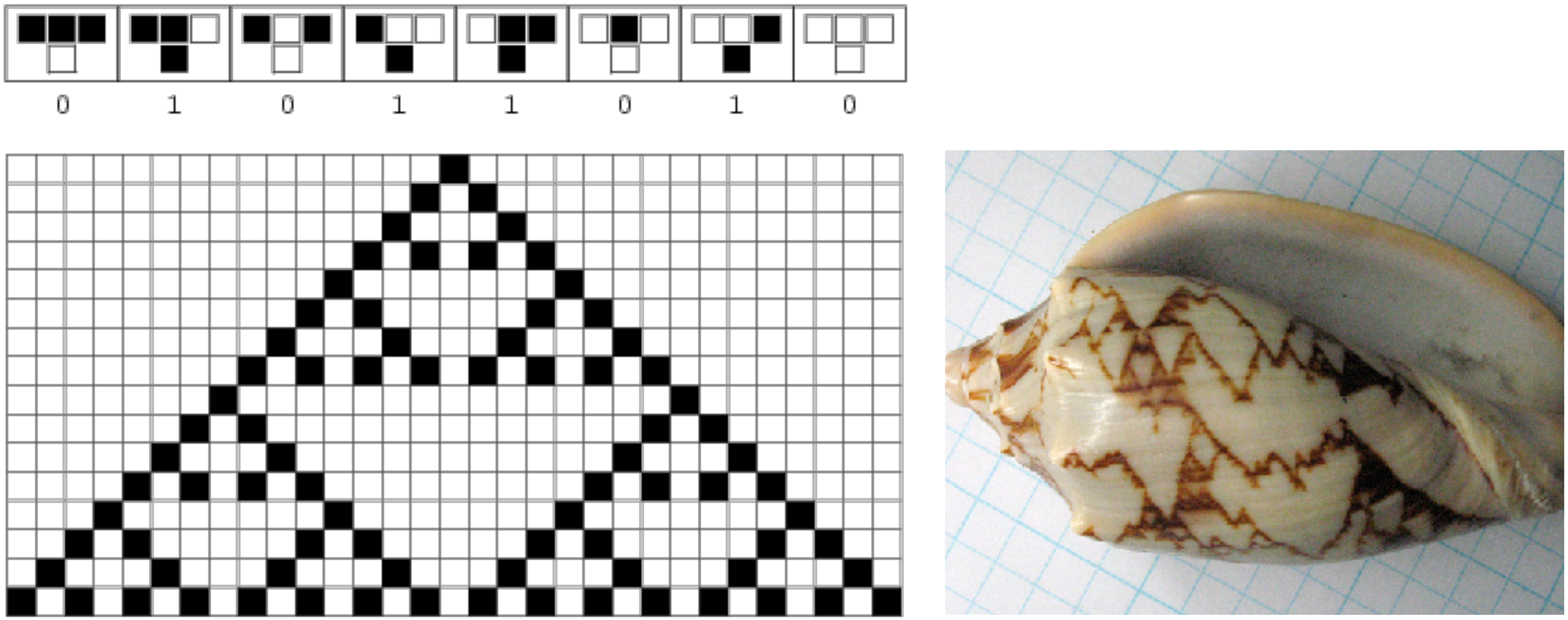


FIG 4.9 Elementary Cellular automata and shell.

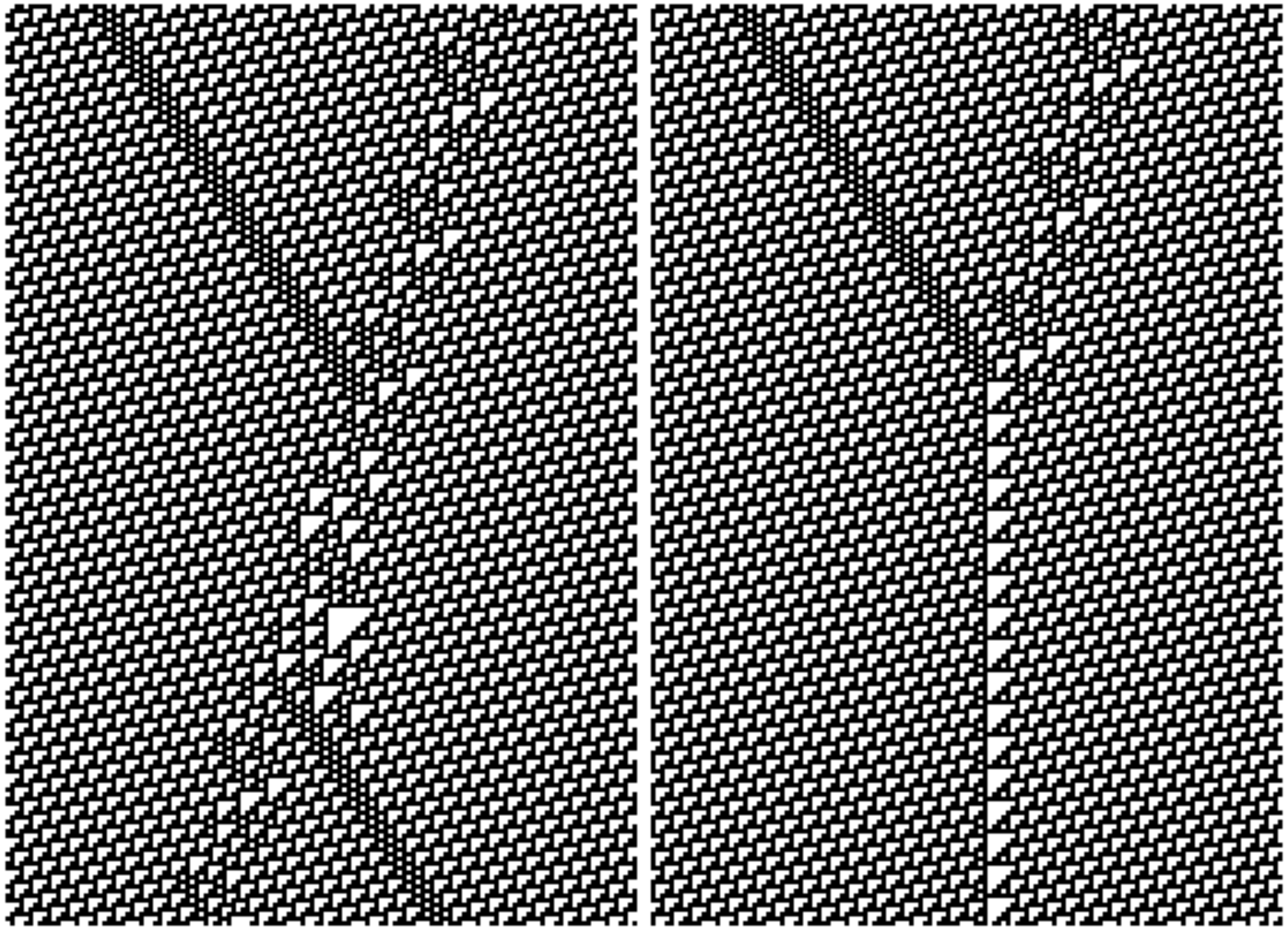


FIG 4.0.0 Rule 110. Turing Complete.

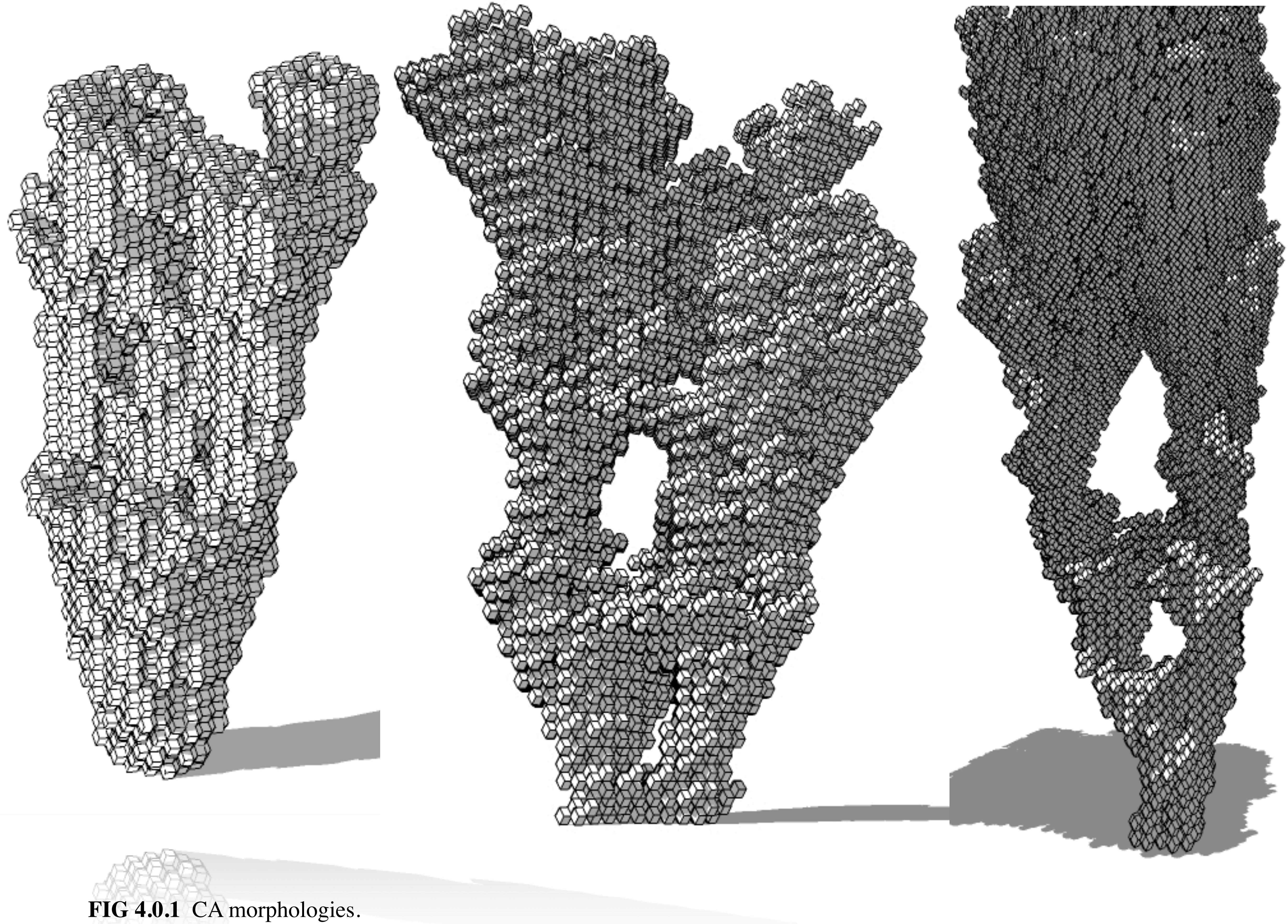


FIG 4.0.1 CA morphologies.

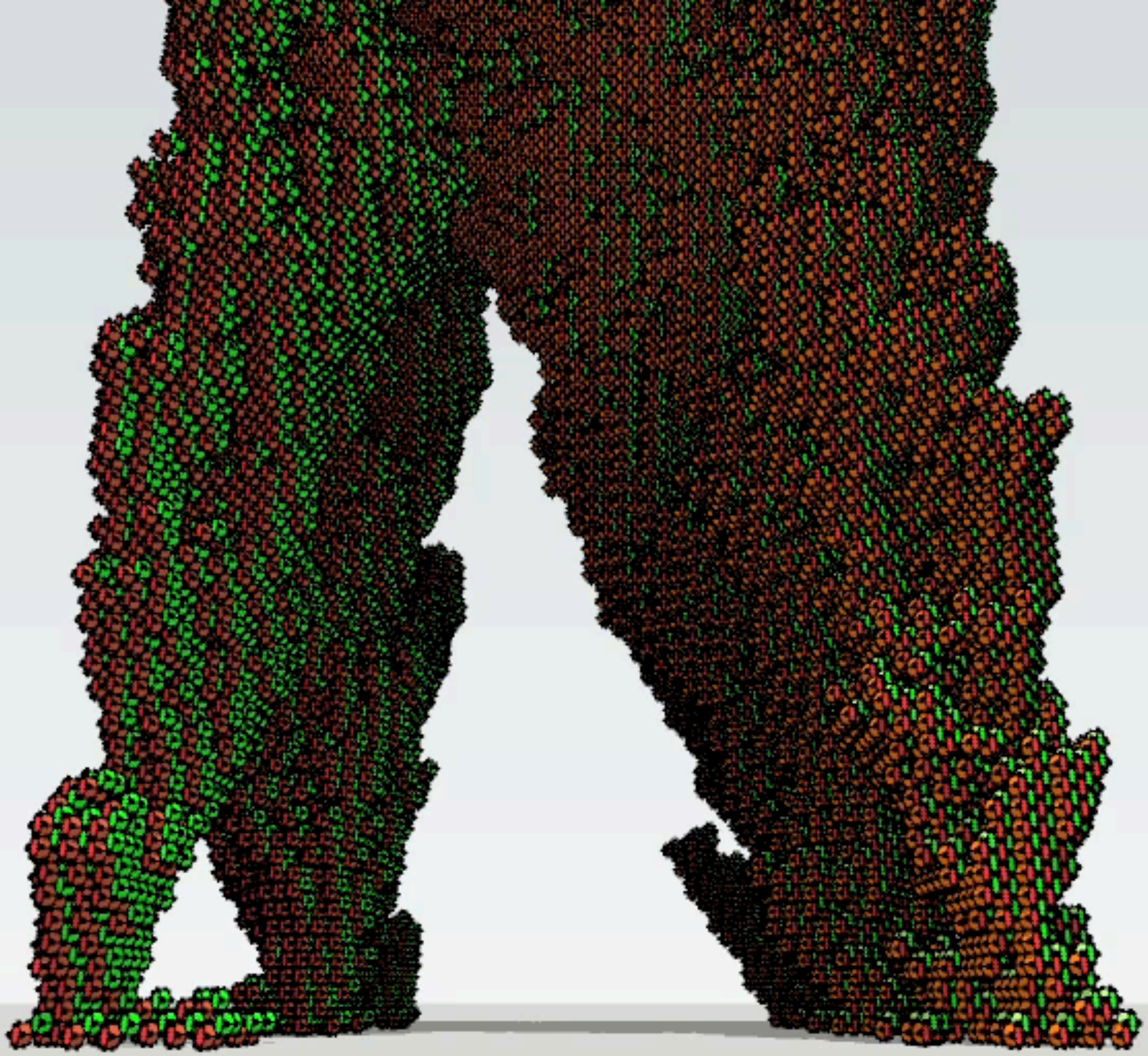


FIG 4.0.2 Cellular automata models developed by author 2012.

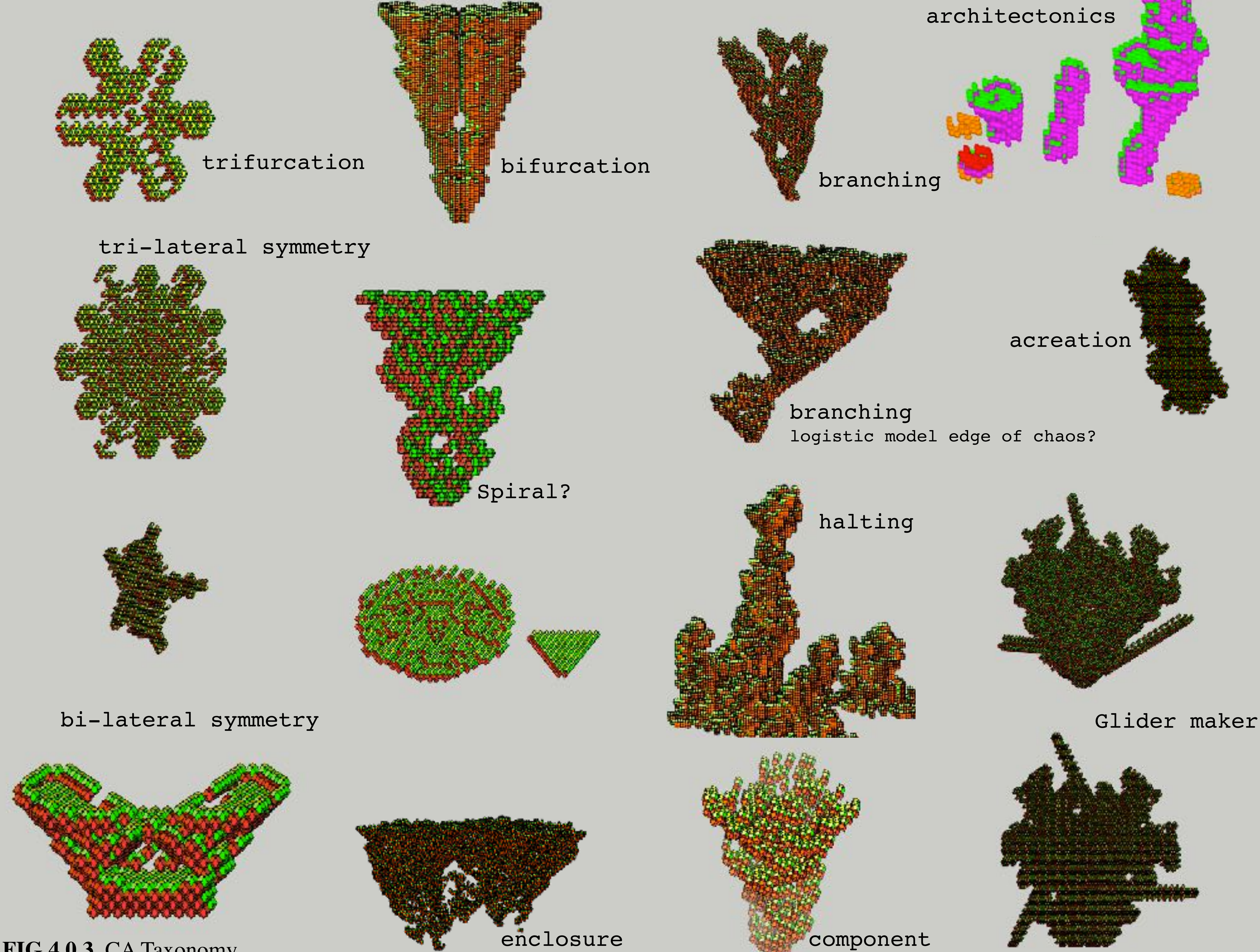


FIG 4.0.3 CA Taxonomy.

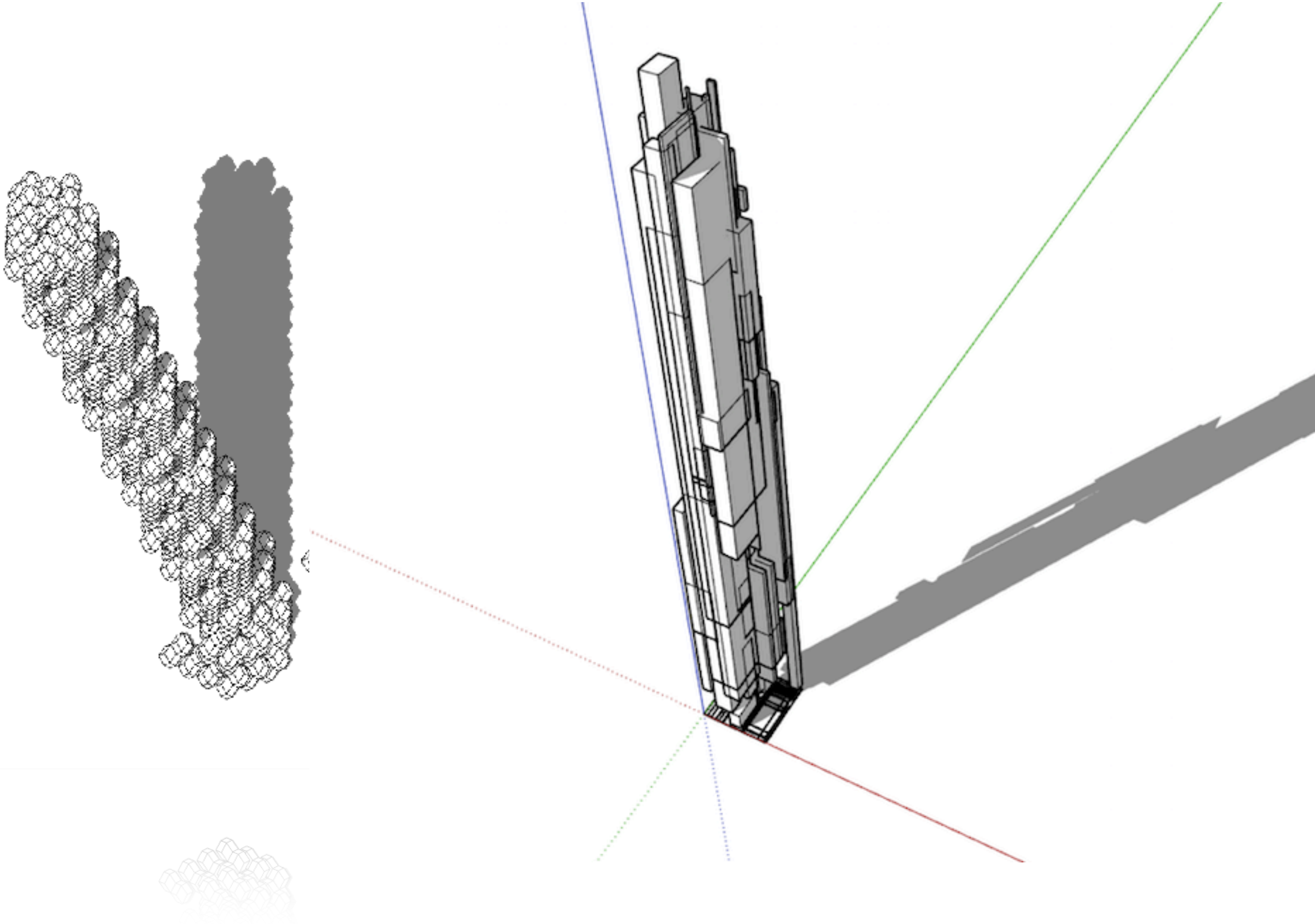


FIG 4.0.4 CA on left and FD model on right.

Quick Review Pin-Up #1

Previously for Pin-up #1, an algorithm was designed and implemented in Python which created random 2D compositions given a set of rules such as orthogonally and overlap and then selected for those with higher fractal dimension using a genetic algorithm. Masses were extruded from 2D elements randomly given certain parameters. Runs were outputted as a timeline and the final exemplar outputted as a .ctl file to be imported into SketchUp for ‘designer’ modification.

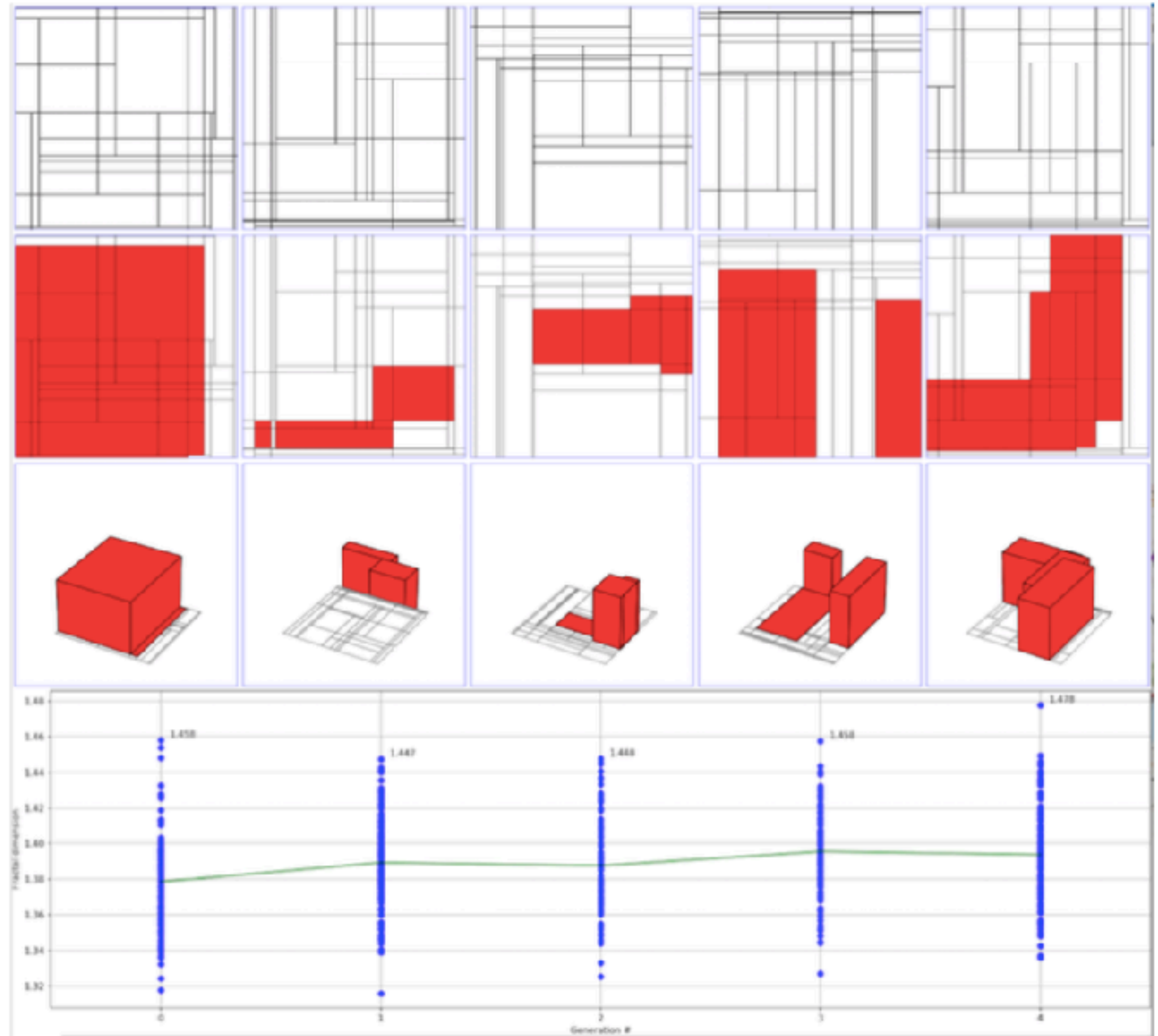
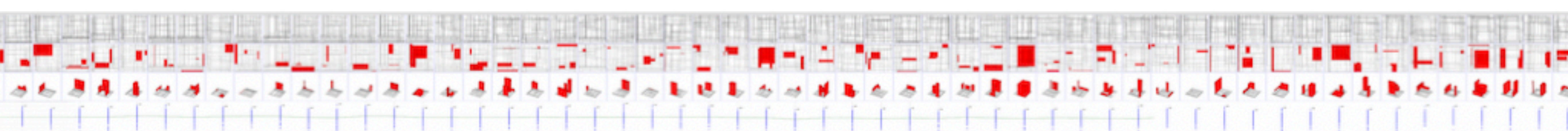


FIG 4.1. Output from algorithm for Pin-up #1.



Pin-Up # 2

For Pin-up #2, a fractal dimension (FD) tool using box-counting dimension was implemented in SketchUp. The plugin incorporated a genetic algorithm which selected for a target FD and outputted 2D and 3D models. Models could be manipulated by hand and fed back into the algorithm for further evolution. The loop was closed.

Models were assessed for compositional elements such as point, line and plane as well as focal point, secondary focal point, counter point, rectilinear motion, diagonal motion, curved motion, rhythm, terminal, texture and visual delight. Models were implemented as design solutions and inspirations for an architectural problem. 3 levels of investigation were focused on: micro, mezzo and macro levels. In addition to these 3 levels, a contextual analysis was performed after the schematic design phase.

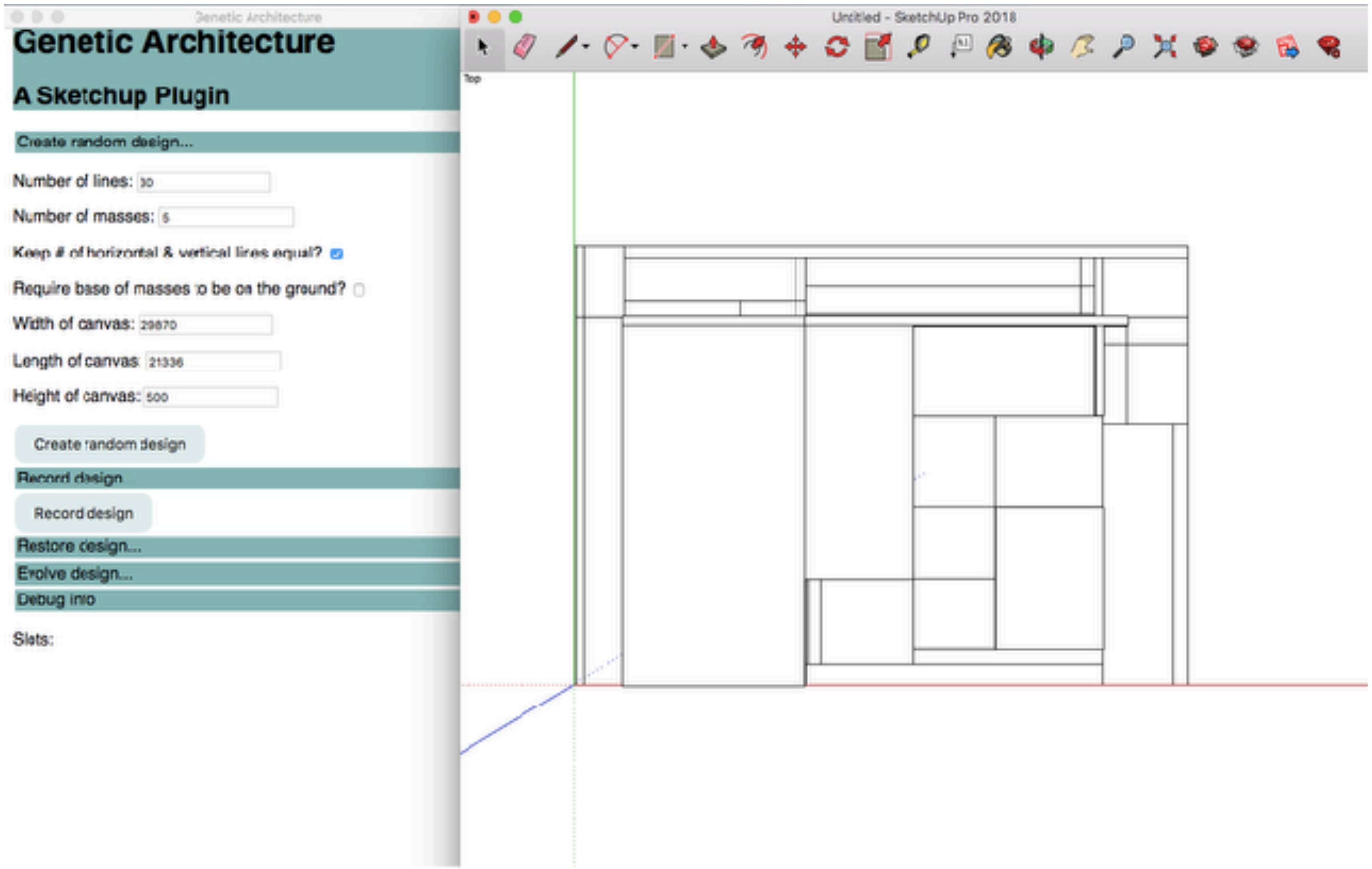


FIG 4.2.

Theme, development and variation

(3 primary levels of self-similarity)

Micro, Unit block: This could be a masonry unit. Potentially each block could be different.

Mezzo, architectonic level: This is the level where architectural systems happen such as: fenestration, stairs, structural systems, acoustic systems, envelope.
Combination of elements create
space, rooms. outdoor gathering loci, etc.

Macro, block plan (parti): An intention of the design was to see the self-similar element as *theme* run through the building from the smallest component to the largest. The fractal attribute should be more than surface treatment and integrated into the space plan and general layout.

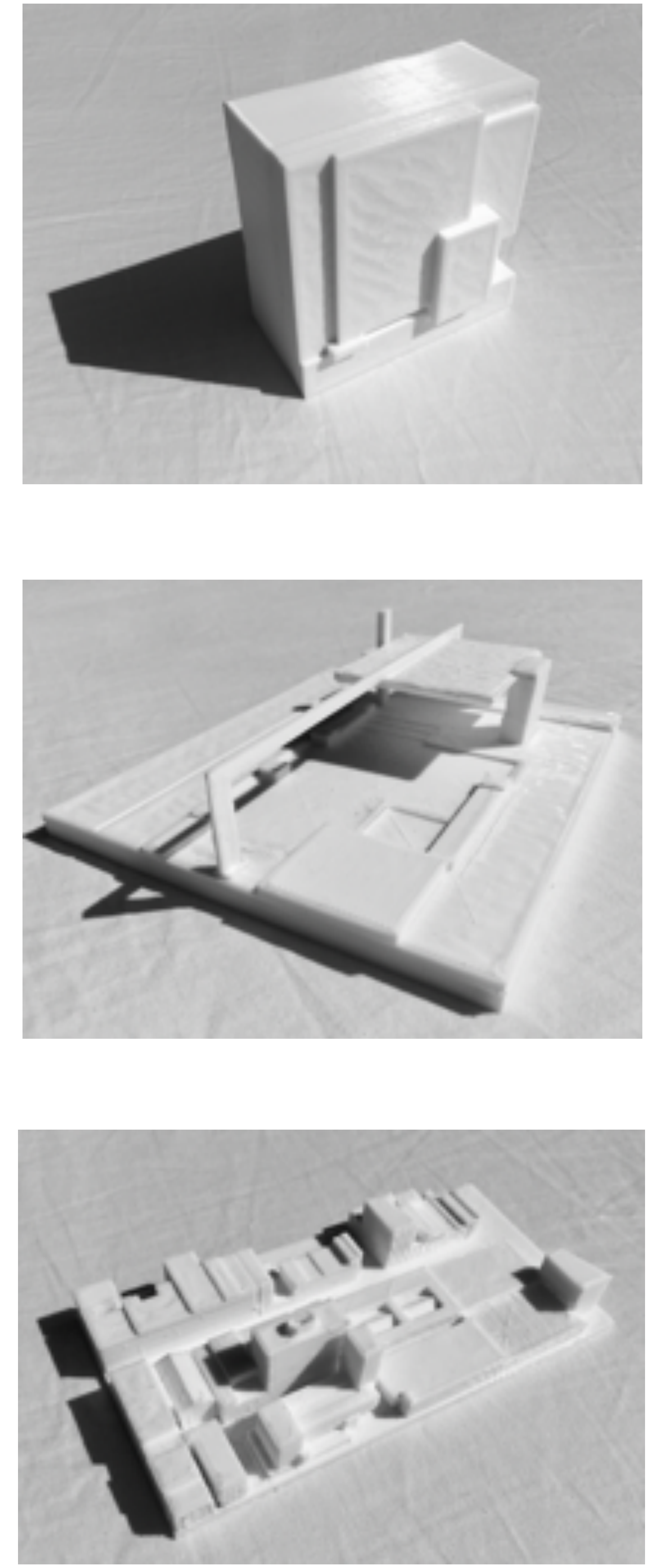


FIG 5. 3D prints of models representing 3 levels of scale.

MICRO

After thinking about the project in the back of my mind for several months and sketching massing studies for the building volumes, I began experimenting with the FD tool in SketchUp to create orthogonal compositions with 30 lines perpendicular to each other. Although constraining the design to straight perpendicular lines is kind of like designing in black and white, this constraint simplifies the process for now with the idea that more variety may be added later. Initially I evolved random compositions to have a higher FD and modified them manually as well, extruding more masses and using the Push/Pull tool to enhance relationships I liked and resolve odd things that didn't feel good.

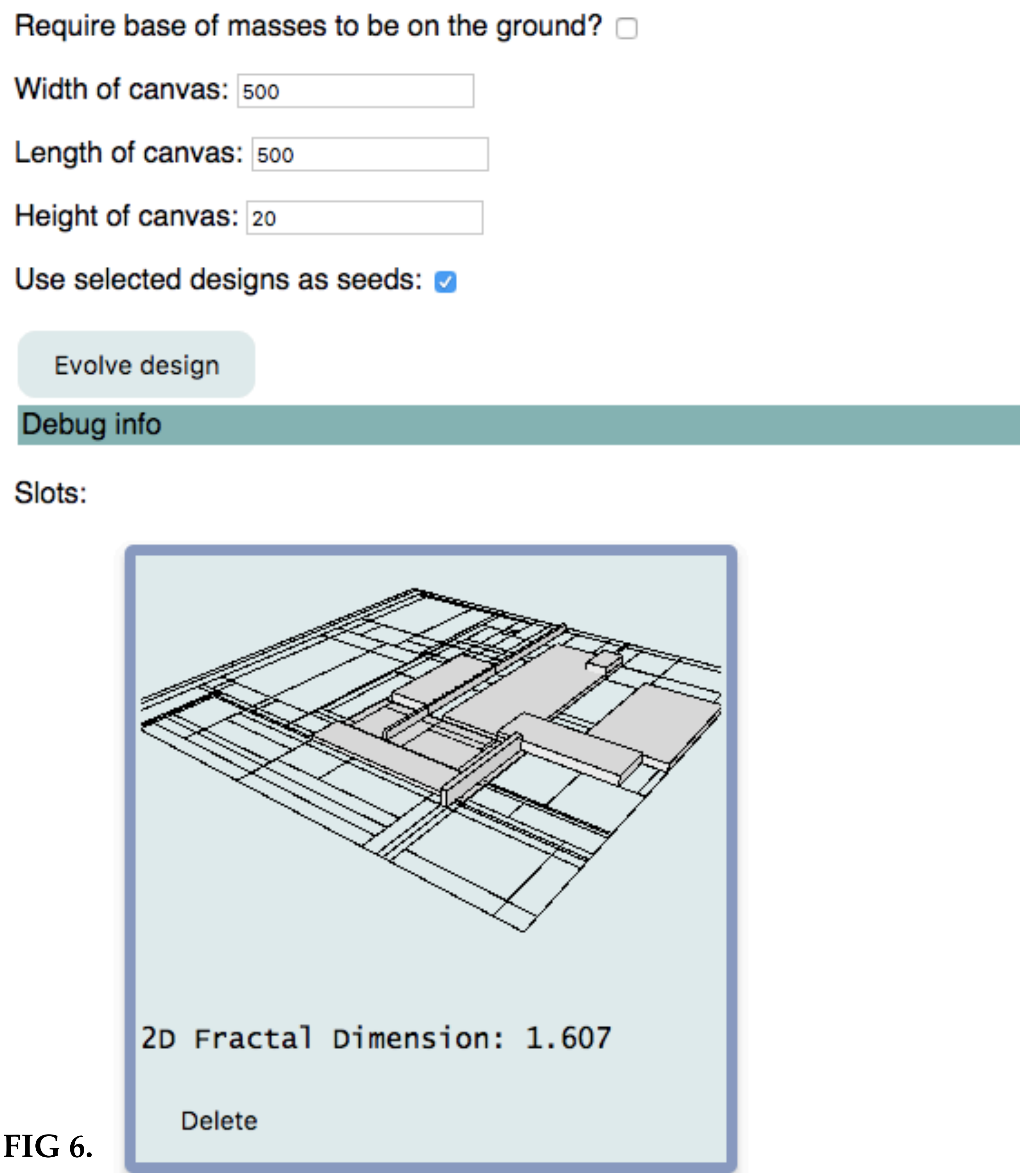


FIG 6.

M I C R O

The rules for generating composition were explained previously so they will not be reiterated here. It is important, however, to emphasize that orthogonal compositions are focused on because of their constructibility and relative simplicity in terms of modeling and coding. It should be noted that orthogonal abstractions are still able to capture a variety of geometric form such as diagonals and curves, for instance the Barcelona Pavilion is in some ways a composition of triangles. For this study, rectilinear motion was sought.

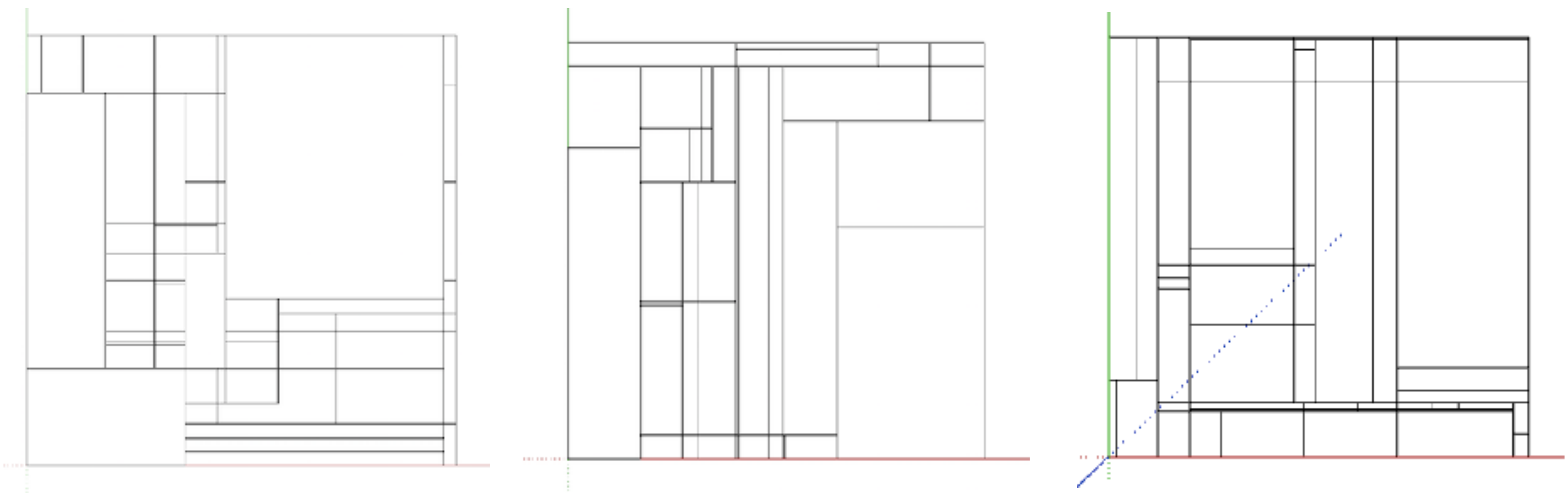


FIG 6. Examples of 2D outputs

MICRO

Later in the analysis phase the fractal dimension of surrounding buildings, especially the Herald Square building adjacent to the site to the immediate north was analyzed in terms of fractal dimension which then could inform the detail for the compositions used in the design. The fractal dimension of the landscape and the surrounding environment could also be used as well as other complimentary metrics used to assess fractal geometry such as multi-fractal analysis and Lacunarity[1].

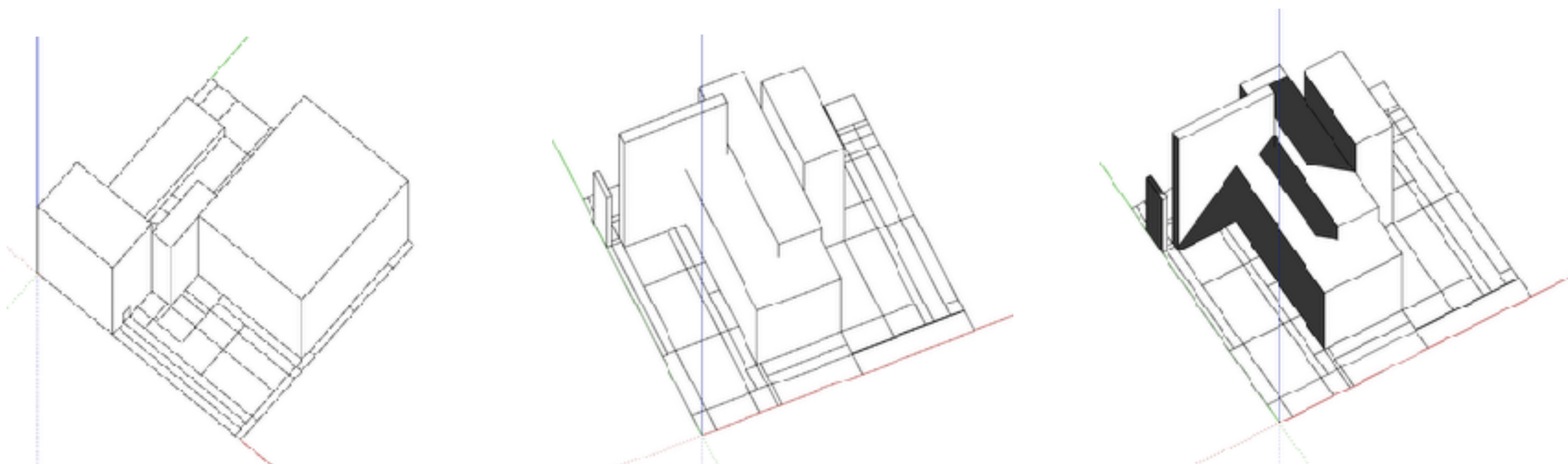


FIG 7. Examples of 3D outputs

1. *Lacunarity is a counterpart to the fractal dimension that describes the texture of a fractal. It has to do with the size distribution of the holes. Roughly speaking, if a fractal has large gaps or holes, it has high lacunarity; on the other hand, if a fractal is almost translationally invariant, it has low lacunarity. Different fractals can be constructed that have the same dimension but that look widely different because they have different lacunarity. There are applications of lacunarity in image processing, ecology, medicine, and other fields. http://groups.csail.mit.edu/mac/users/rauch/lacunarity/lacunarity.html*

MICRO

At this stage, the fractal dimension algorithm was used without much of a relationship to site or context but the thesis is that quantifiable tools such as these could relate to such attributes. Generally more complex composition were developed using many iterations and selecting for higher FD.

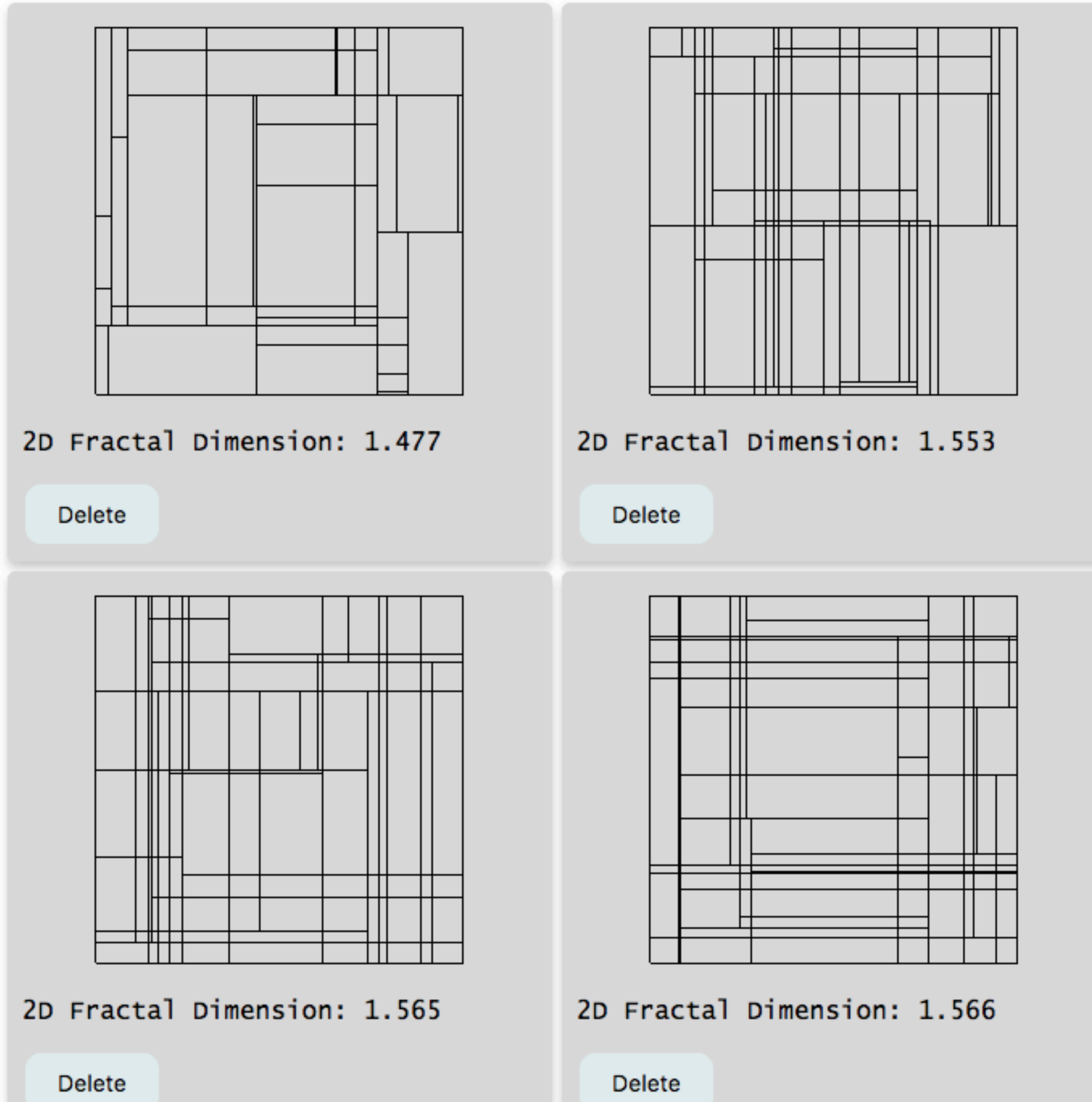


FIG 8. Mixing and matching seeds to create new designs, i.e., designer as genetic algorithm ‘matchmaker’.

M I C R O (discovering masonry module)

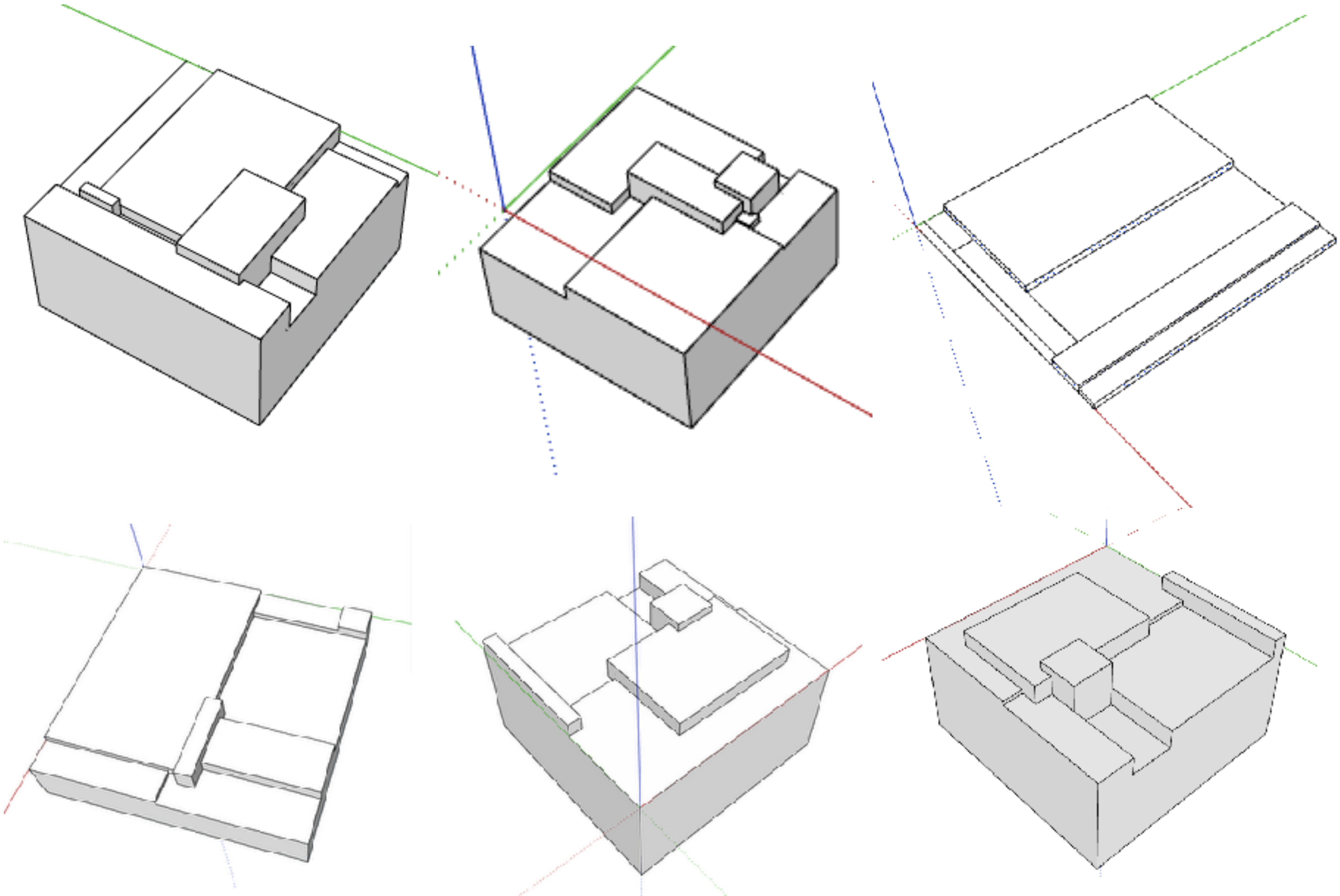


FIG 9.

M I C R O

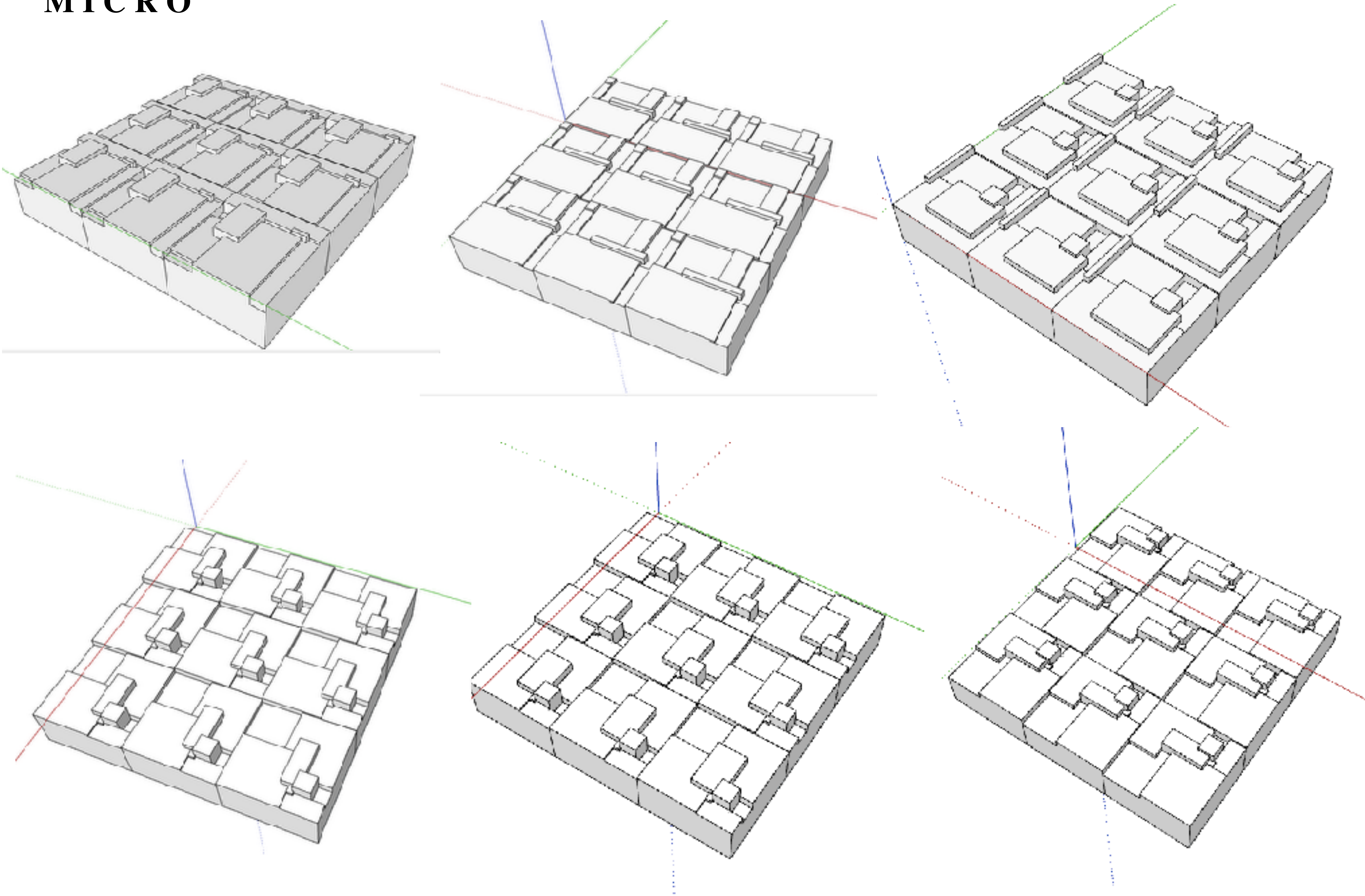


FIG 10.

M I C R O

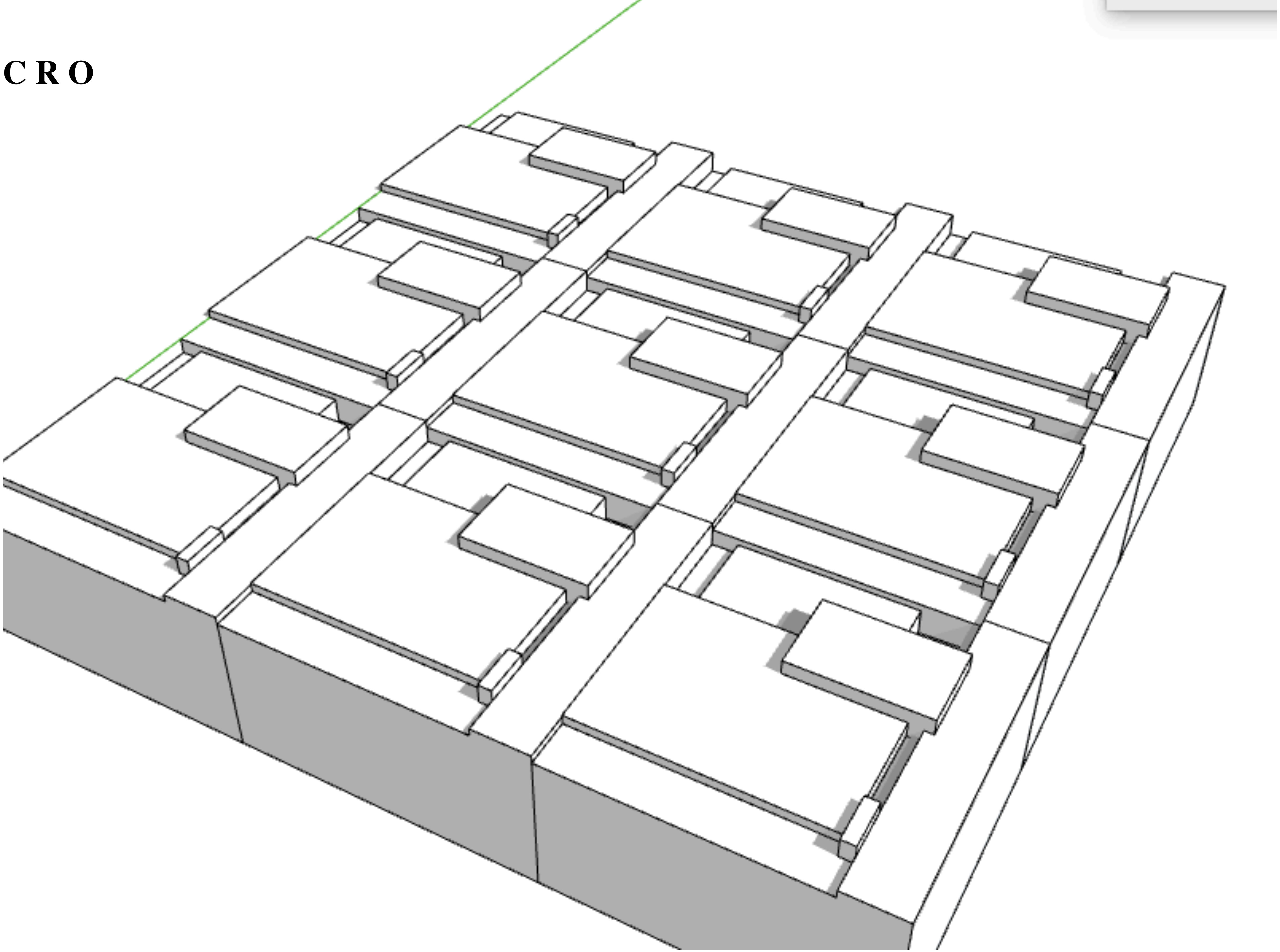


FIG 11.

M E Z Z O

Another level of applying the fractal dimension tool was at the mid-level. This was considered to be more at the human scale and at the scale of architectonic systems such as fenestration systems and envelope systems etc. The exercise on the next couple of sheets shows the evolution of 2D compositions with parametric inputs related to a specific area of the building. The composition was then overlapped on the building like a mask and various masses extruded by eye and incorporated into the overall building design (Fig. 14).

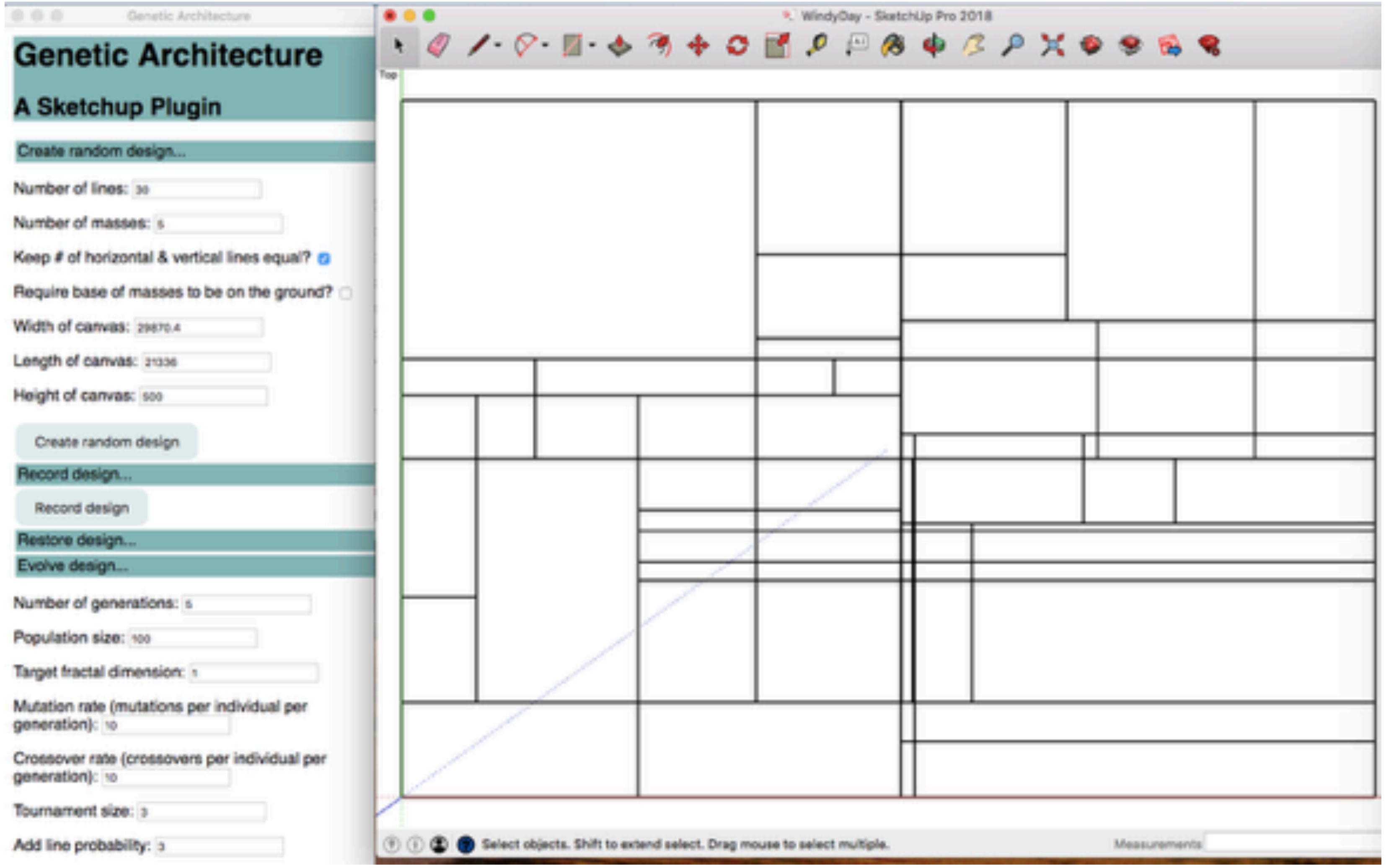


FIG 12.

MEZZO

These images show how the exemplar 2D composition was applied to the building mass and incorporated into the overall building design. The bottom image shows the 3 levels of detail as an ensemble 3D composition. The idea for this building is that the complexity of the detail would increase downward so that the building would begin to pixilate as it approached the street.

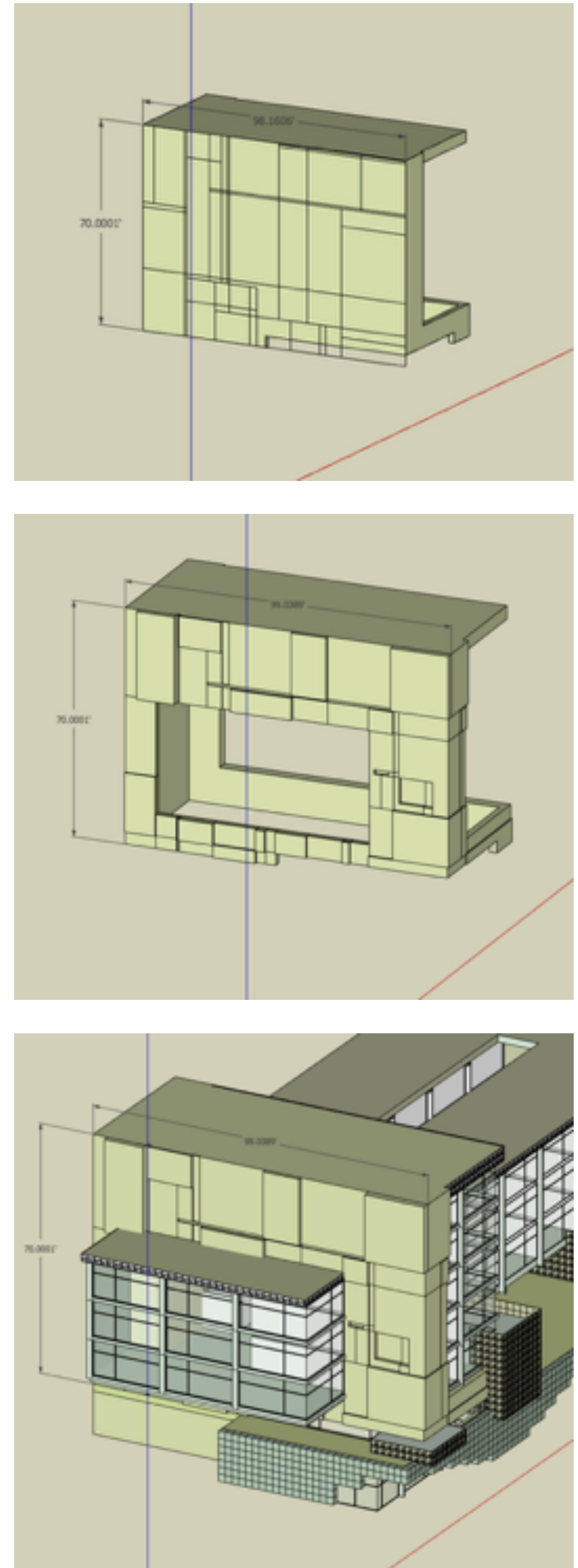


FIG 14.

M A C R O (massing)

Keeping the center mass of the building low to five stories enabled the views to be preserved as well as offering a potential for deciduous trees to shade the building from the summer sun and helped to transition from the neighborhood scale to the tall Herald Square building. The site experiences high levels of traffic on Green Street as well as high levels of pedestrian traffic making it an obvious option for the new transit station that the city requires. Retail is located at ground level around the entire building with a mix of affordable and workforce housing on the floors above for a total of between 70 to 100 units depending on how the flexible space is divided into one bedroom, two bedroom, or three-bedroom units.

The site along Green Street sits between regional vehicular traffic and the pedestrian-centric historic downtown. This site is one of the six original blocks laid out as the original plan of Ithaca by Simeon Dewitt in 1806, yet has never had a strong sense of place. The site is an edge, making it ideal for a transit hub as well as a mixed use retail and much needed affordable residential. As a complicated edge between different regimes, the project also lends itself to a formal solution using fractal geometry.

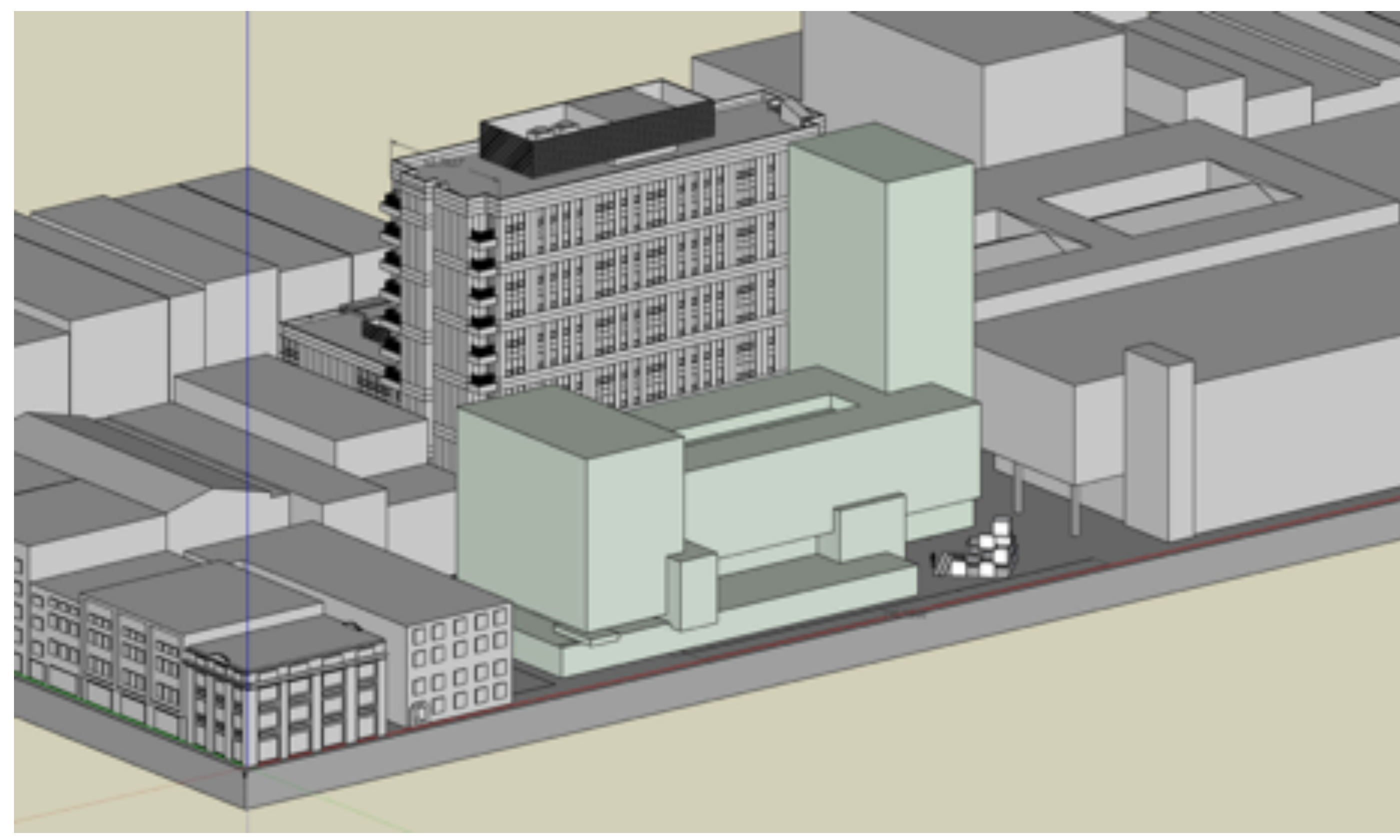


FIG 16. Massing study.

MACRO

The site faces south and has beautiful views of the Ithaca's southern valley. It was important to open up the building to the south as well as preserve the southern exposure of the existing Herald Square building to the north by locating the more vertical masses to the the northeast and northwest corners of the site. This move allowed for the the building to be a good neighbor and also to locate utility and service corridors to the north. By keeping the center mass of the building comparatively low (to five stories) the views from Herald Square are preserved as well as offering a potential for deciduous trees to shade the building from the summer sun.

FIG 18.

MACRO

The site experiences high levels of vehicular traffic being on Green Street as well as high levels of pedestrian traffic making it a wonderful option for the new transit station that the city requires. Retail was located at ground level around the entire building with a mix of affordable and workforce housing on the floors above for a total of between 70 to 100 units. The flexible space can be divided into one bedroom, two bedroom, or three-bedroom units.

FIG 19.

MACRO

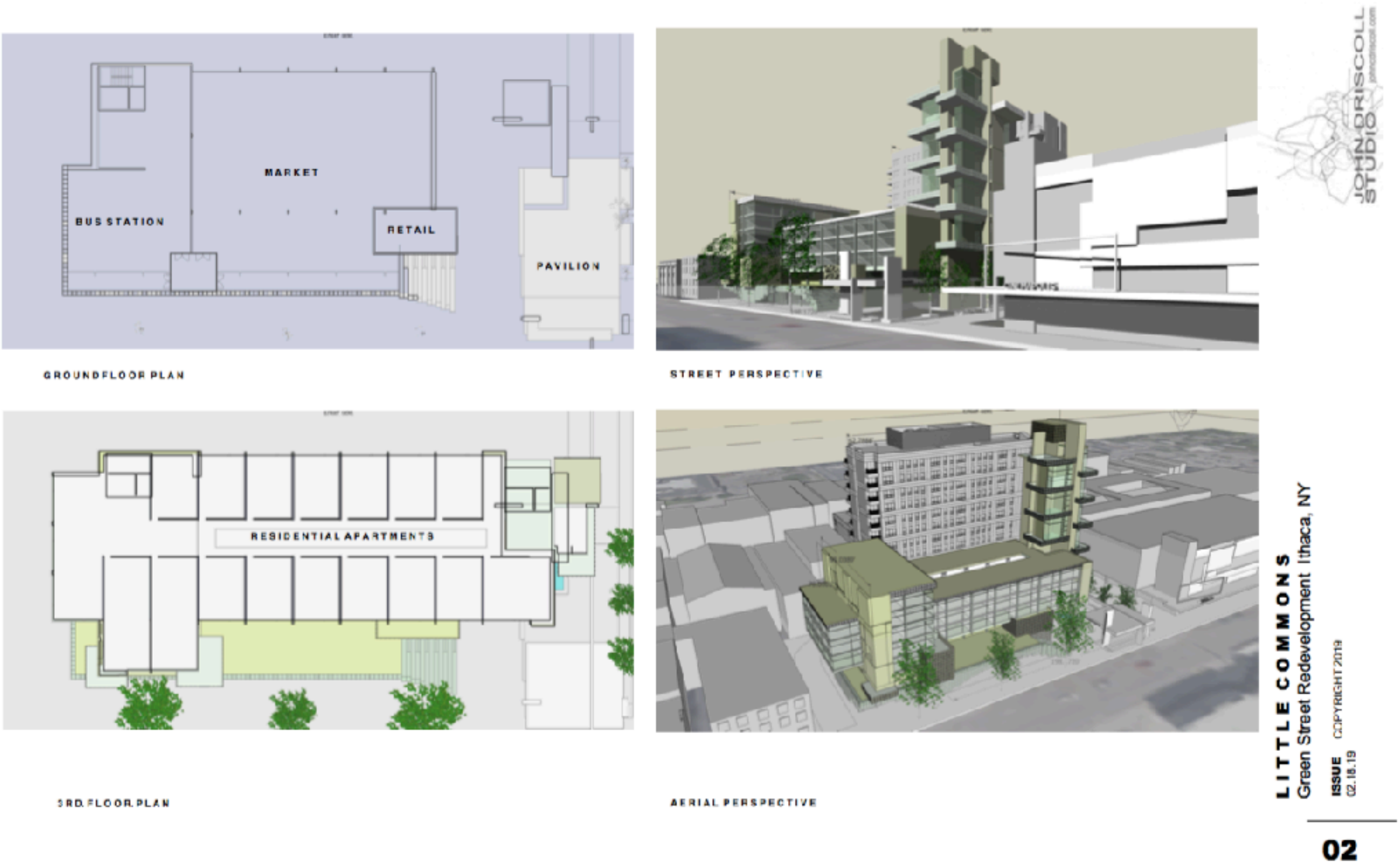


FIG 19.1. Schematic floor plans and exterior perspectives.

M A C R O

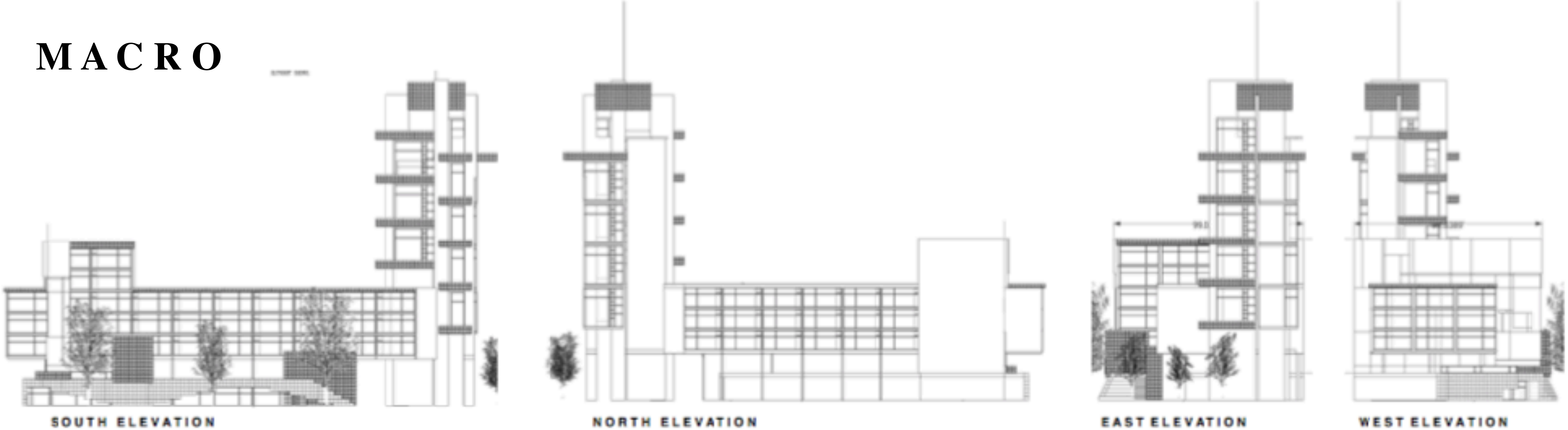


FIG 20. Showing access way to the Commons.

MACRO

PAVILION

PERSPECTIVE

FIG 21.

A N A L Y S I S (design process morphology)

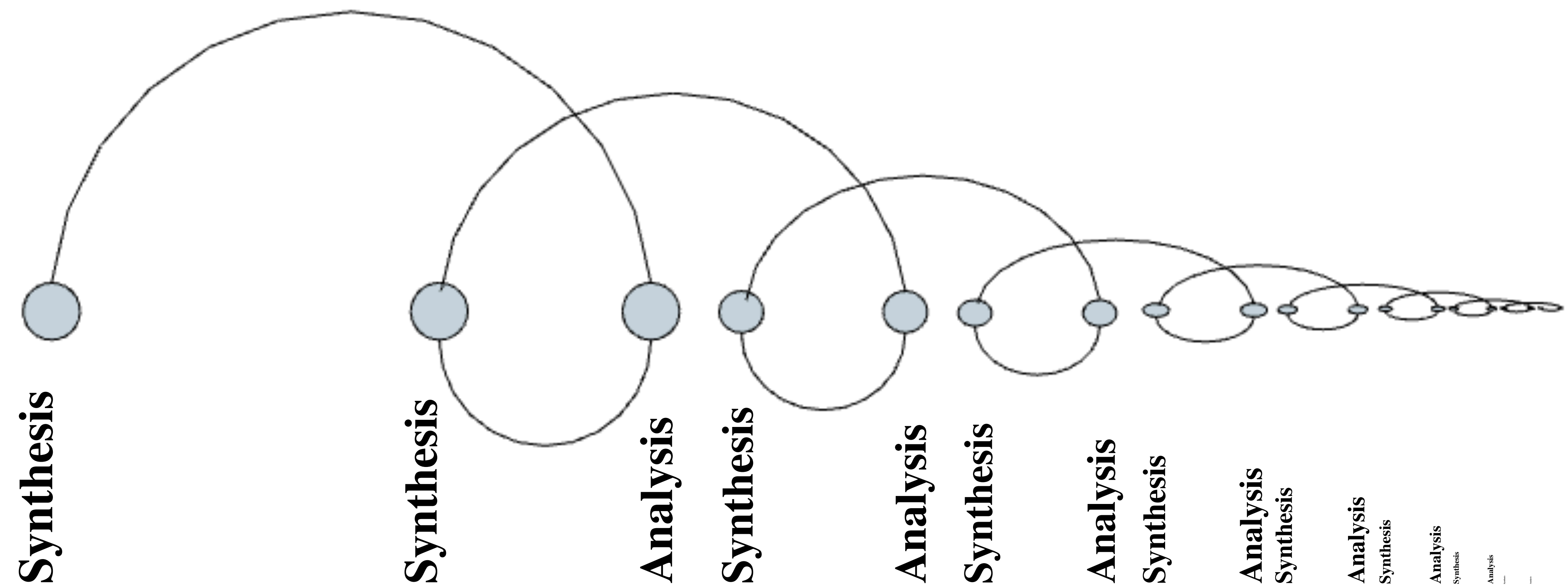


FIG 24.

Most design process morphologies define an *analysis* phase and then a *synthesis* phase. Hall's morphology is different in this regard. We present a design process where the bringing together of ideas into a schematic design involves simultaneous synthesis and analysis of the form. The design is also measured after a schematic charrett using an applied box-counting dimension tool. These steps will be repeated as many times as possible until the design converges towards a final scheme.

MICRO ANALYSIS

Pin-up #2 represents one iteration of the analysis/synthesis diad. The 3 levels of detail were separately analyzed for FD after the schematic design was roughly developed as shown above. These measures and the analytic process is presented next.

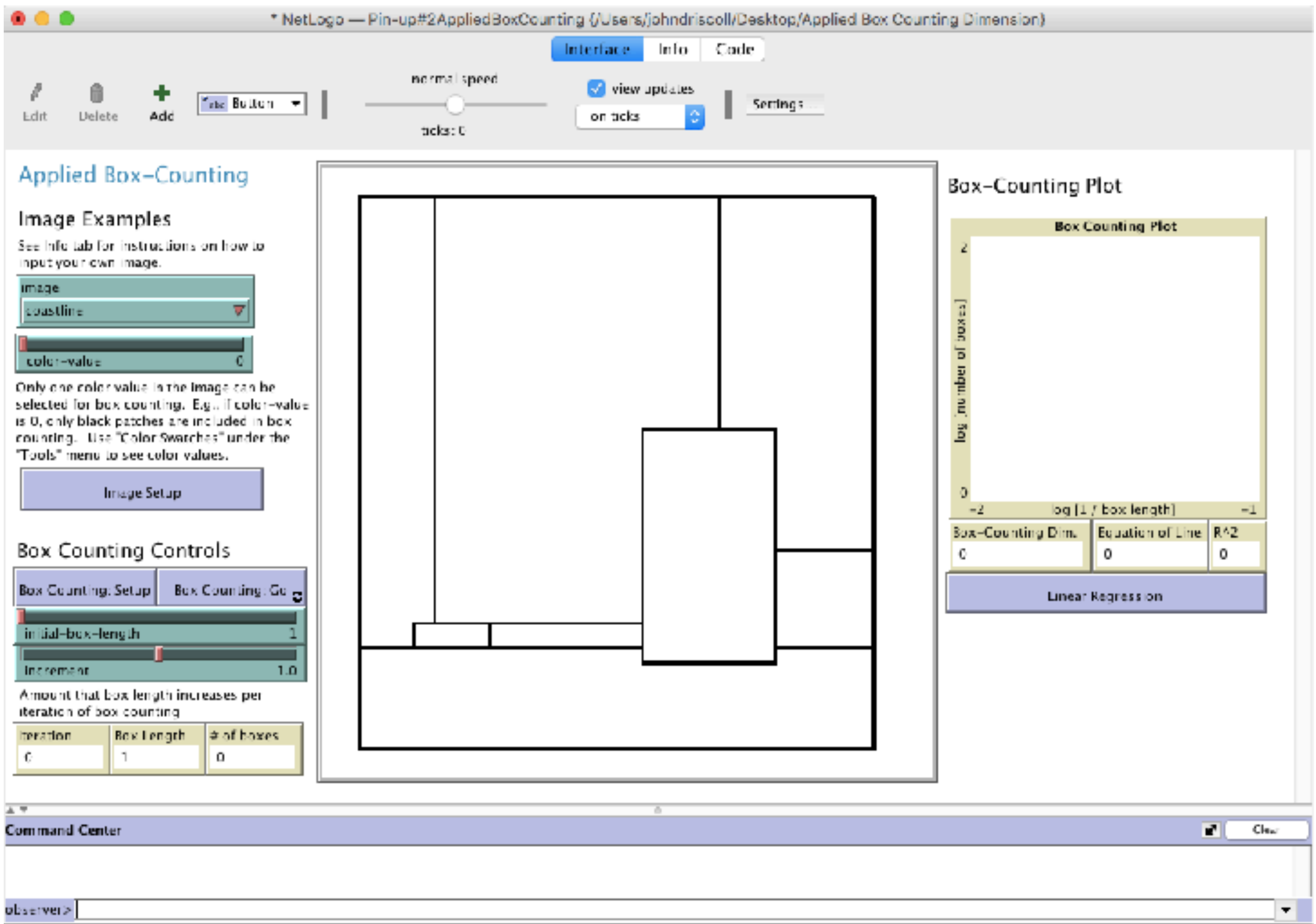


FIG 25. FD analysis.

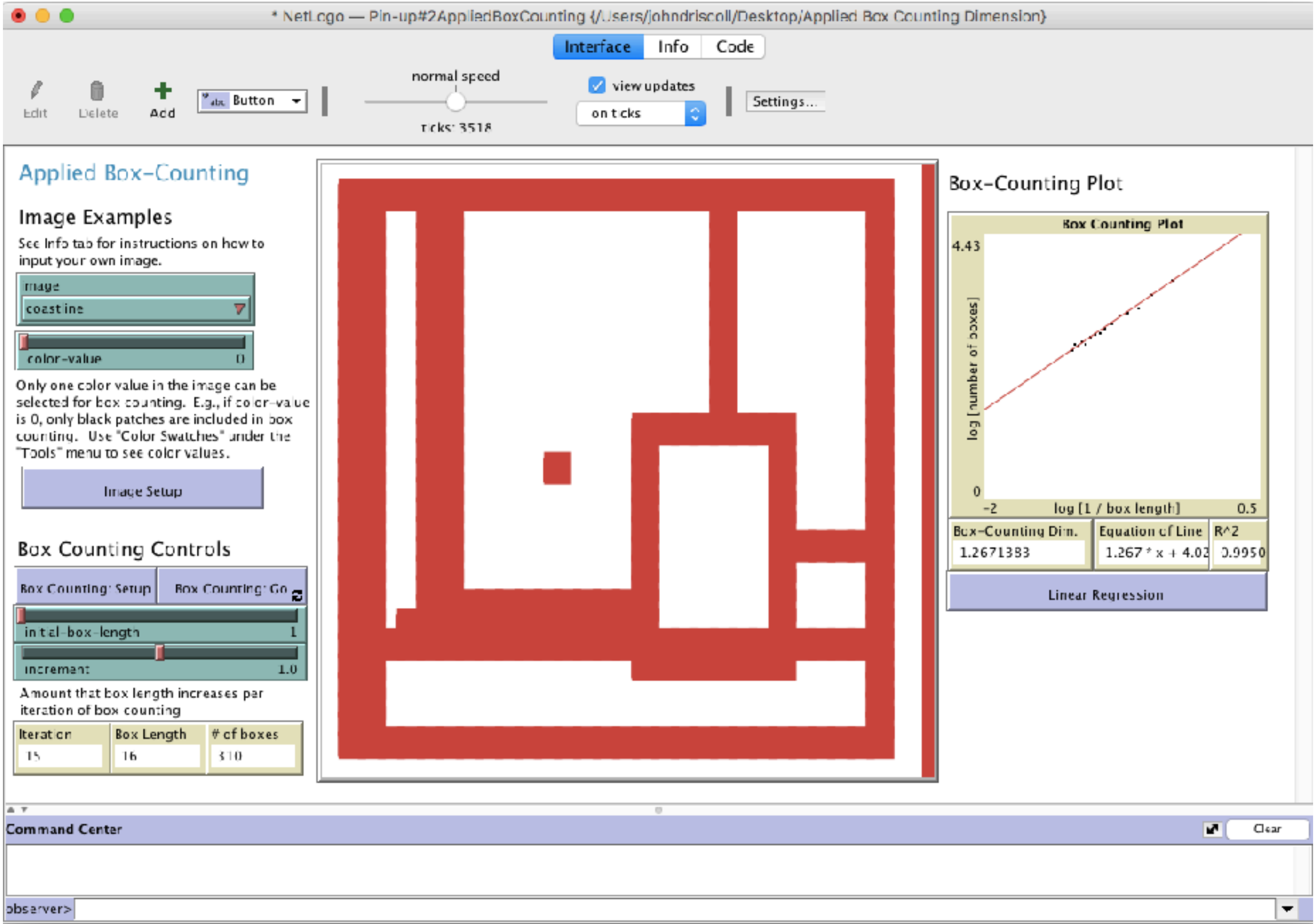


FIG 26. In this instance a block element is being used as the unit of analysis. **FD = 1.26…**

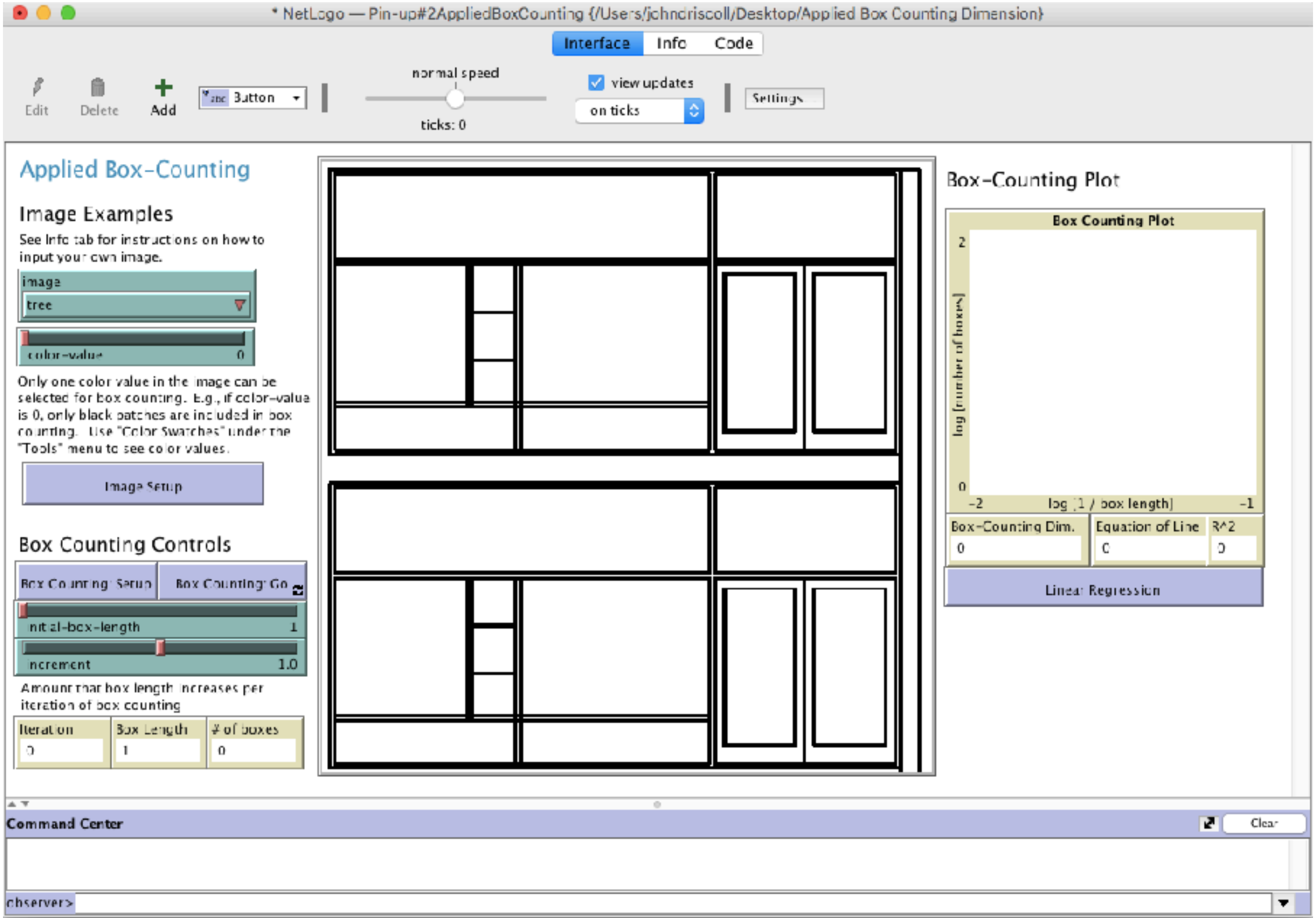


FIG 27. FD analysis at the mezzo level.

MEZZO ANALYSIS

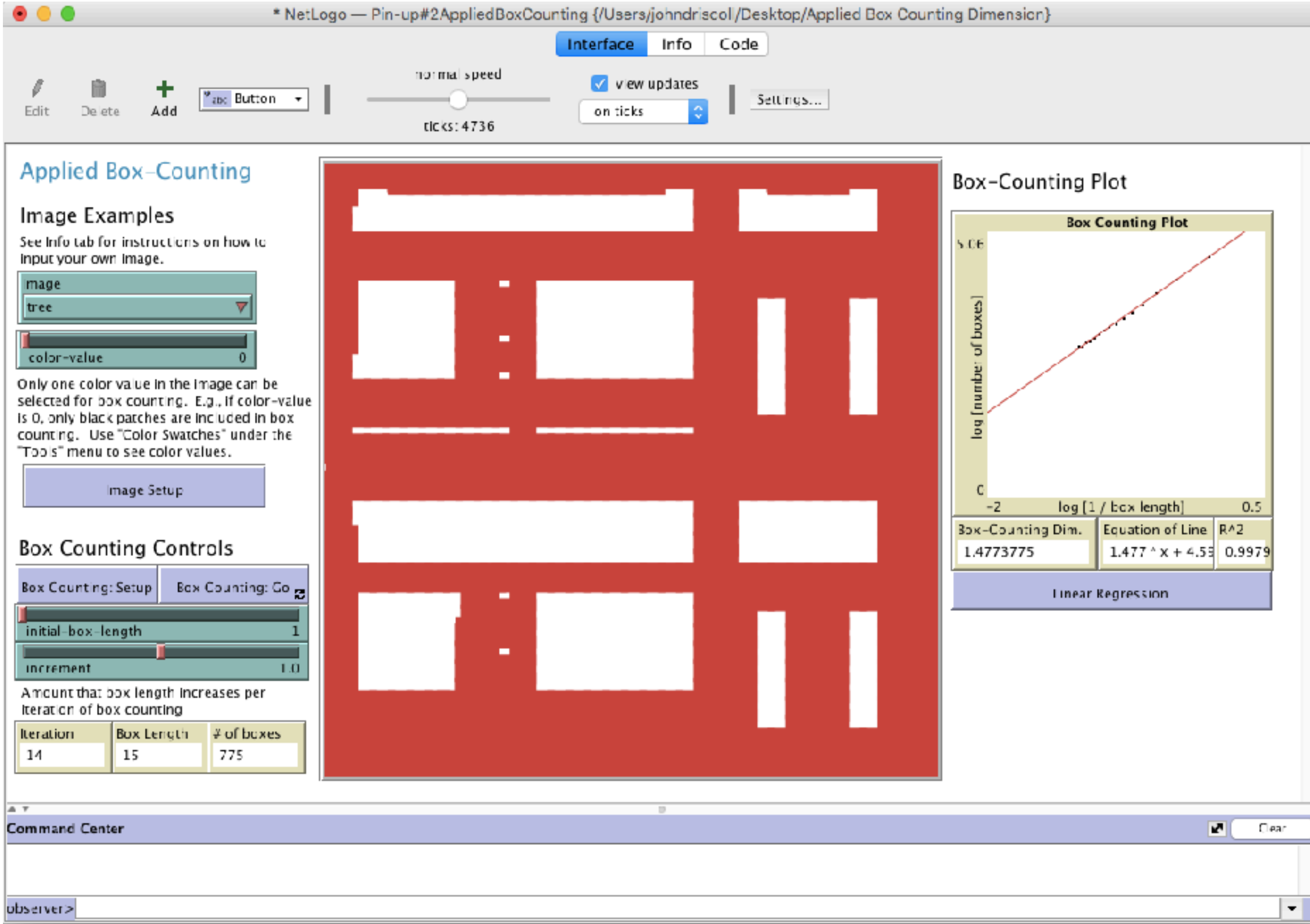


FIG 28. FD analysis at the mezzo level, in this instance a fenestration element is being used as the unit of analysis. FD is 1.477…

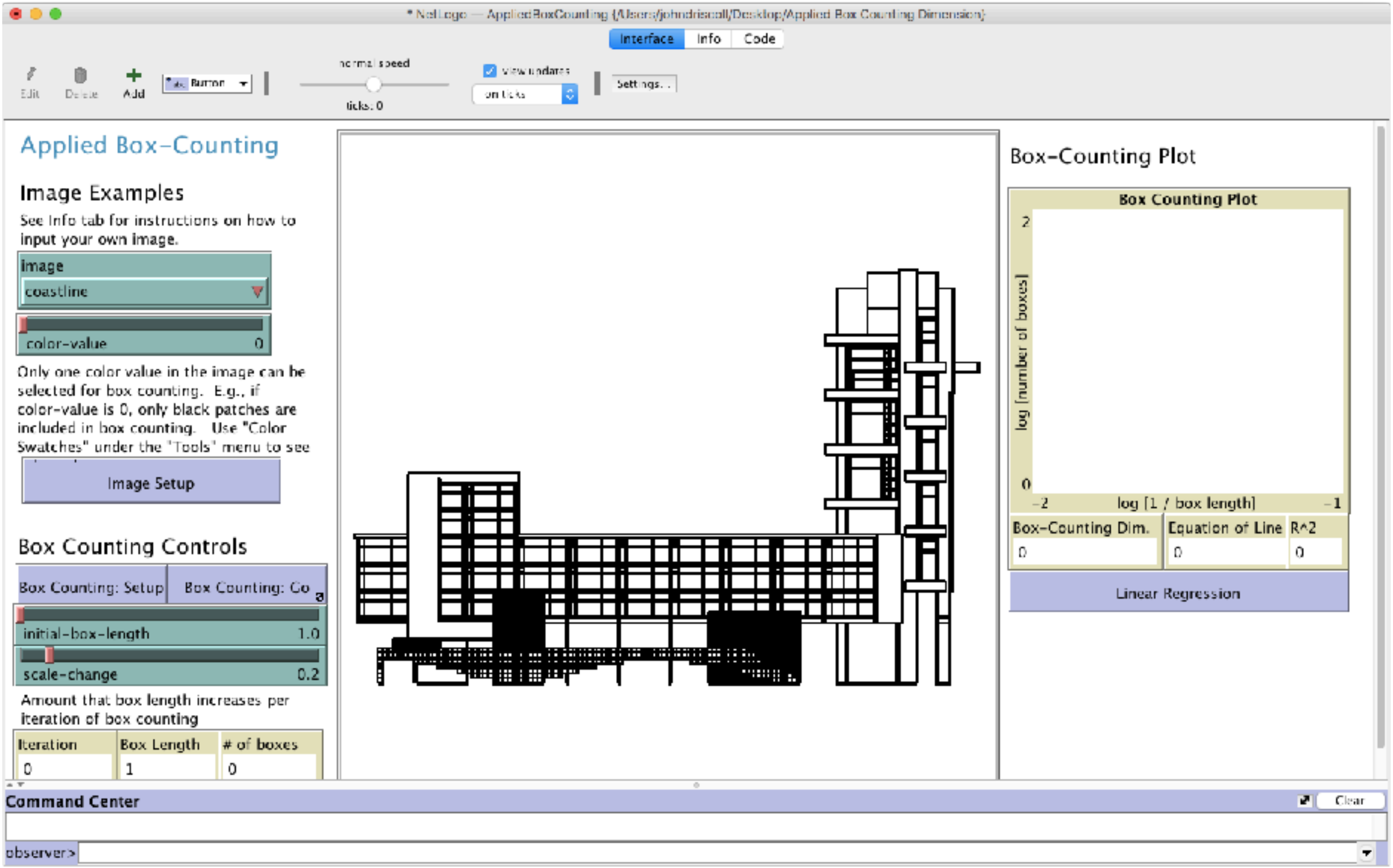


FIG 29. FD analysis .

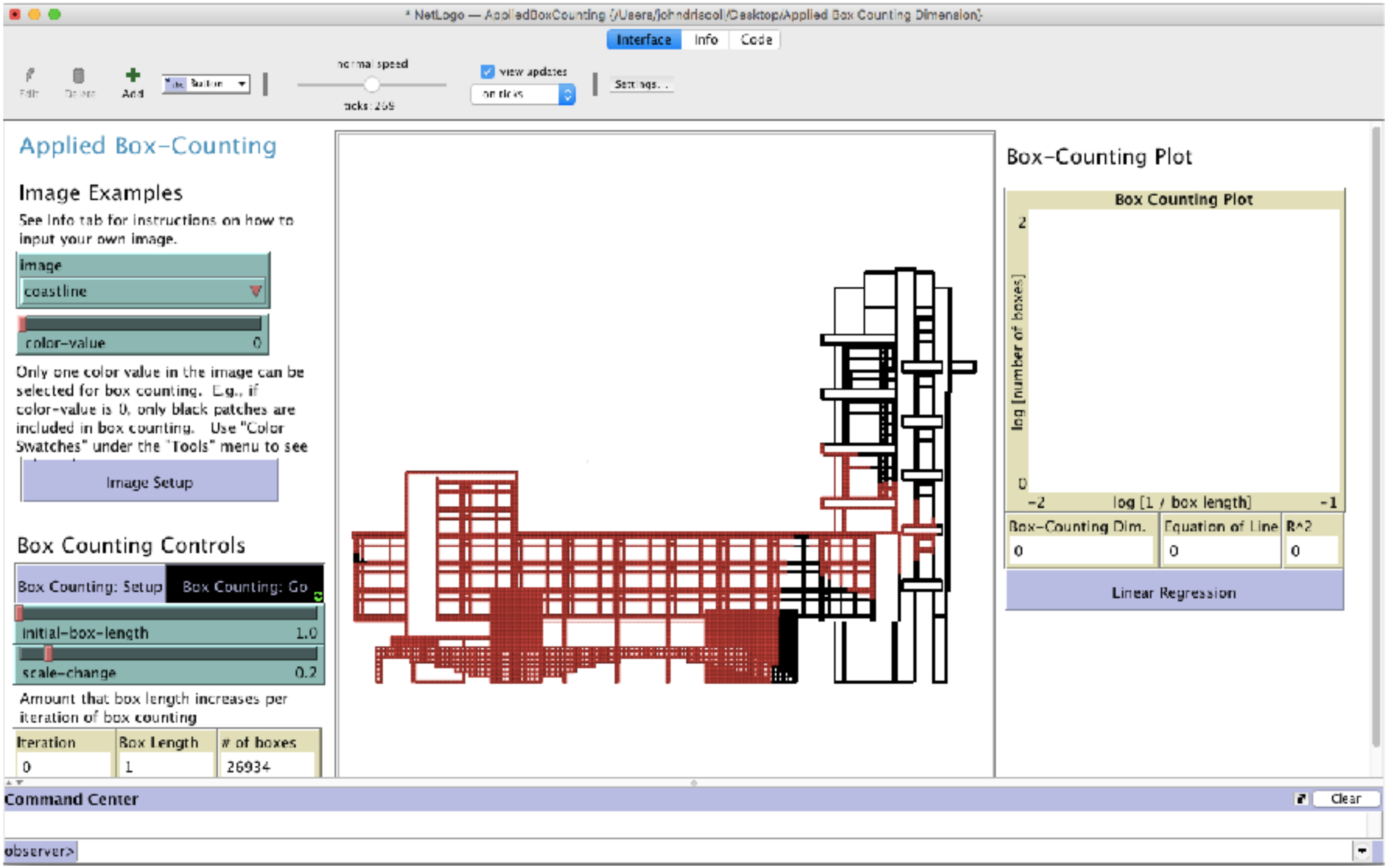


FIG 29. FD analysis.

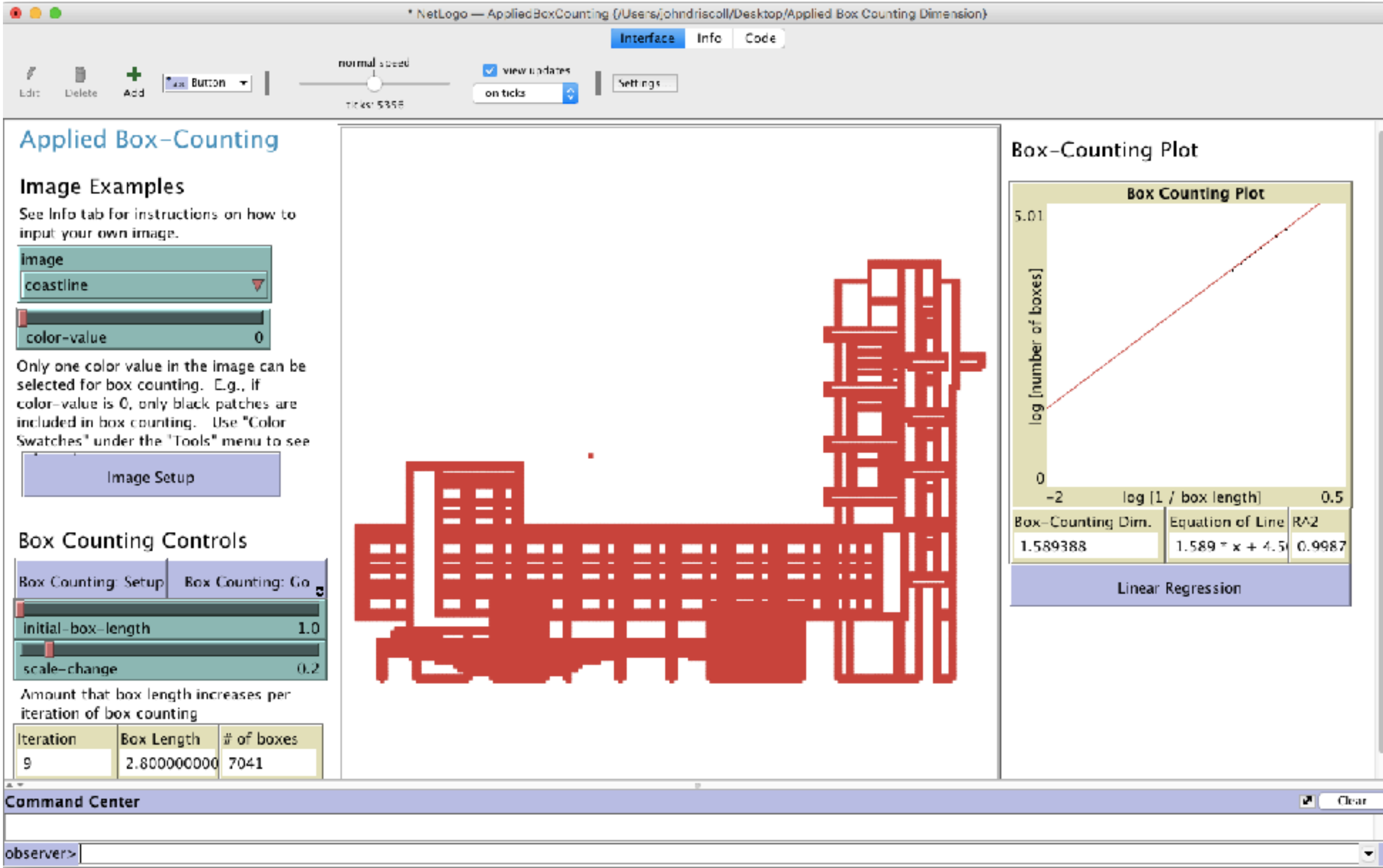


FIG 30. In this instance the South Elevation is being used as the unit of analysis. I set the scale change down to 0.2 and did only 10 iterations because the lines were so close together they were causing the boxes to always be filled instead of leaving important empty space. **FD is 1.589…**

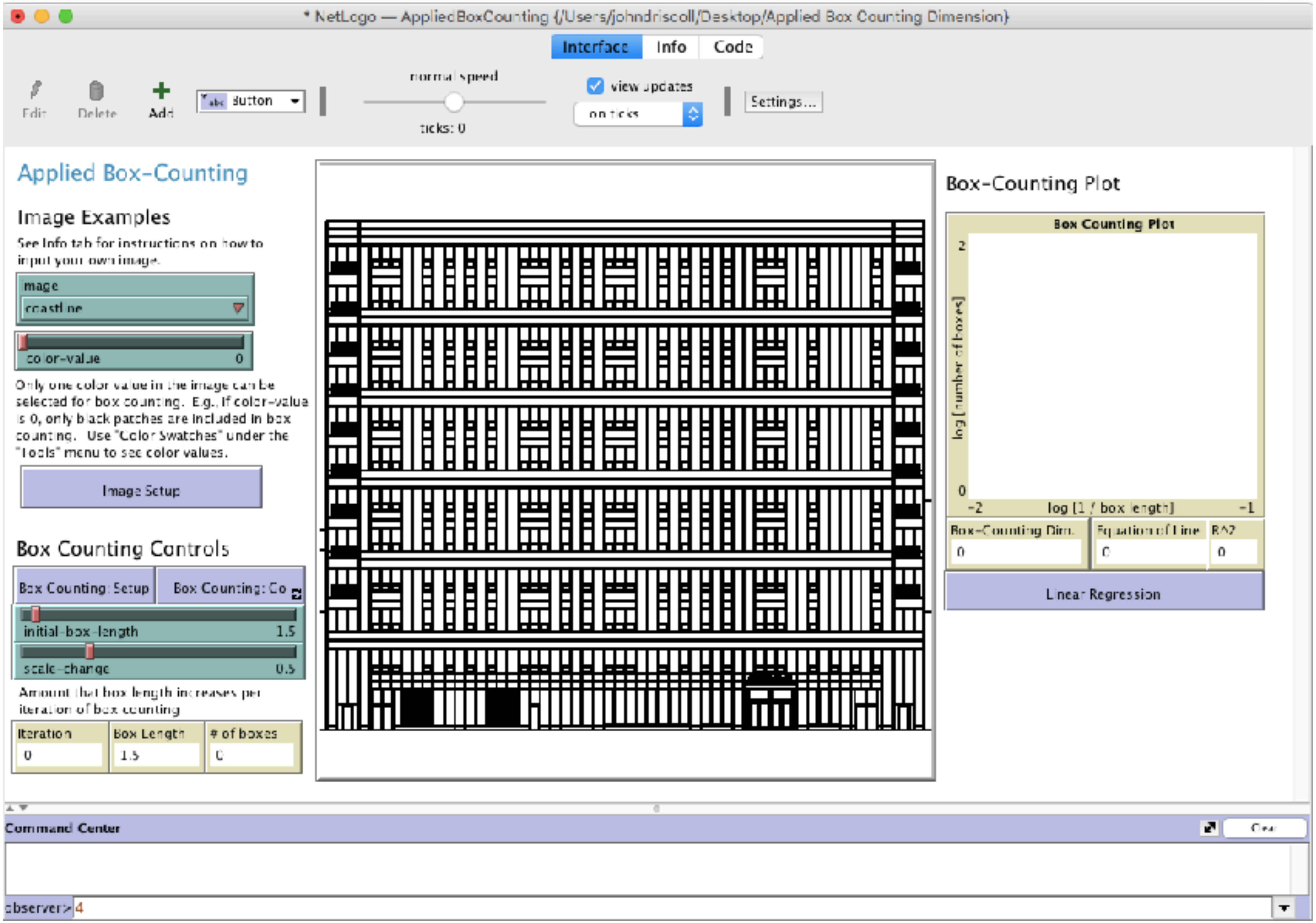


FIG 31. Image clean up: Eliminated stray lines. For the Herald Square building I deleted the mechanical bulkhead because it was showing up as a black blob. I set the scale change down to 0.2 and did only 10 iterations because the lines were so close together they were causing the boxes to always be filled instead of leaving important empty space.

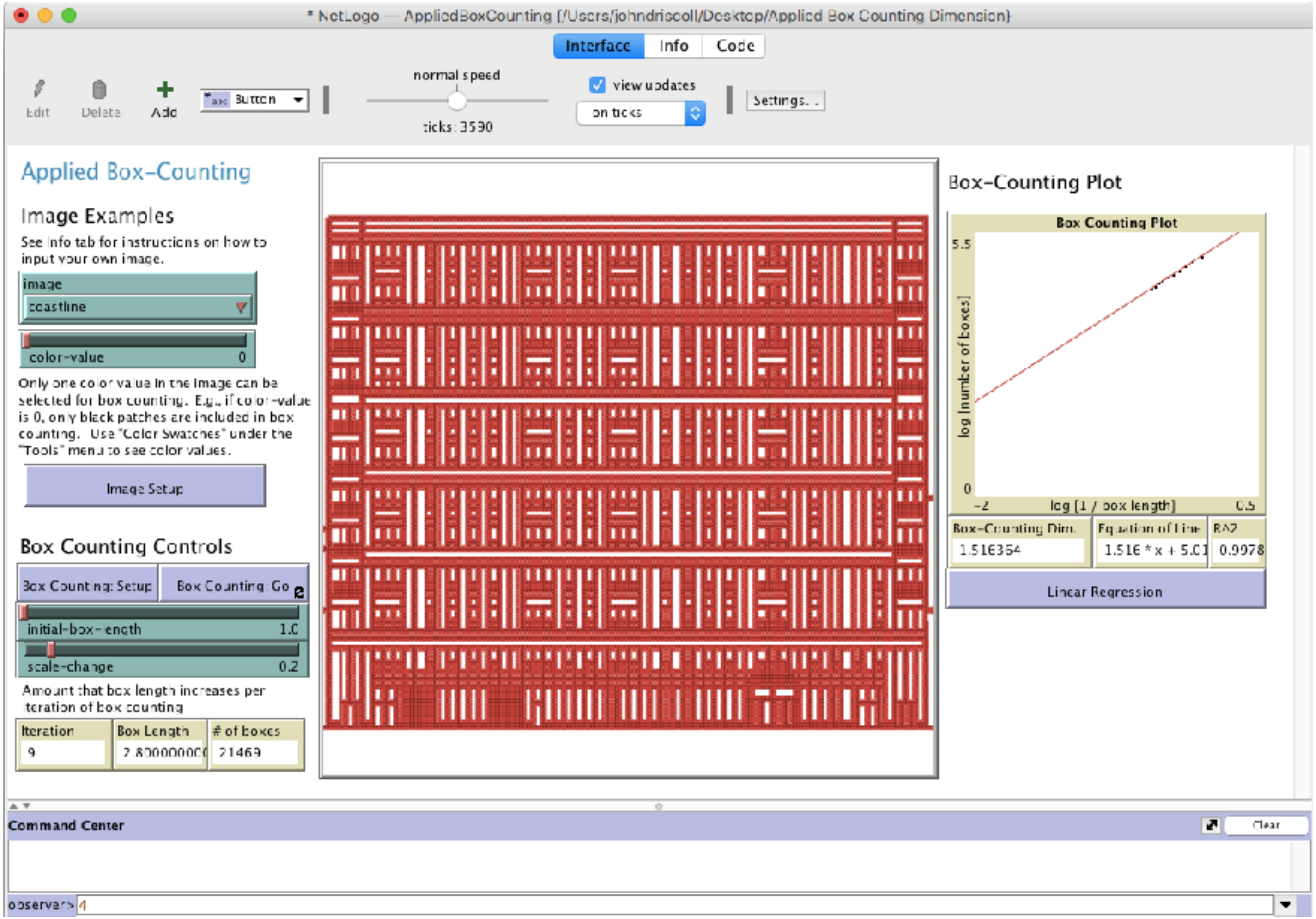


FIG 32. FD analysis of CONTEXT, in this instance the South Elevation of the Herald Square Building is being used as the unit of analysis.

FD is 1.516…

PIN-UP #2 CONCLUSION

Pin-up #1 represented the development of the FD tool and it's implementation in the creative design act as an analytic measure of general complexity back and forth with modification by the human designer (myself).

Pin-up #2 represented one iteration of the analysis/synthesis diad using the FD tool implemented in SketchUp as a design aid as well as post facto discriminative analysis using the Applied Box-Counting tool developed in Netlogo.

Pin-up #3 coming soon…

3 levels of the design were analyzed.

* The micro scale was smaller than a human, i.e., the size of a brick or masonry unit – tactile level or level of *pattern* and/or *texture*. FD = 1.26

* The mezzo scale was at the scale of the human such as fenestration elements, stairs and rails, outdoor pavilion? – functional or utility level. 1.47

* The macro level was at the scale of the overall building or the space plan / parti level. This level is perceived from a distance, down the block or across the street or from a bird's eye perspective. FD = 1.589

PIN-UP #2 CONCLUSION

The fractal dimension increased as the scale of the building elements increased. It was my intention to keep the different levels at the same FD so that as one approached or receded from the building the detail would continue to be expressed and at roughly the same level of articulation. This could aid in generating an abstract common thread throughout the building, helping the user to identify space and form as well as creating the feeling of an integrated whole. Another application of FD was to create harmony with the surrounding context, in this case other buildings. The Herald Square building to the north of the site had a FD of ~ 1.5. This was close to the FD of the fenestration element I was using to represent the mezzo level. When I was measuring this element at first it had a lower FD but I added and rearranged the mullions by hand to bring the FD up. This is drawn on the latest elevation. Shown below as a separate piece and with the Herald Square building behind. To my eye, this did seem to unite the two buildings together more.

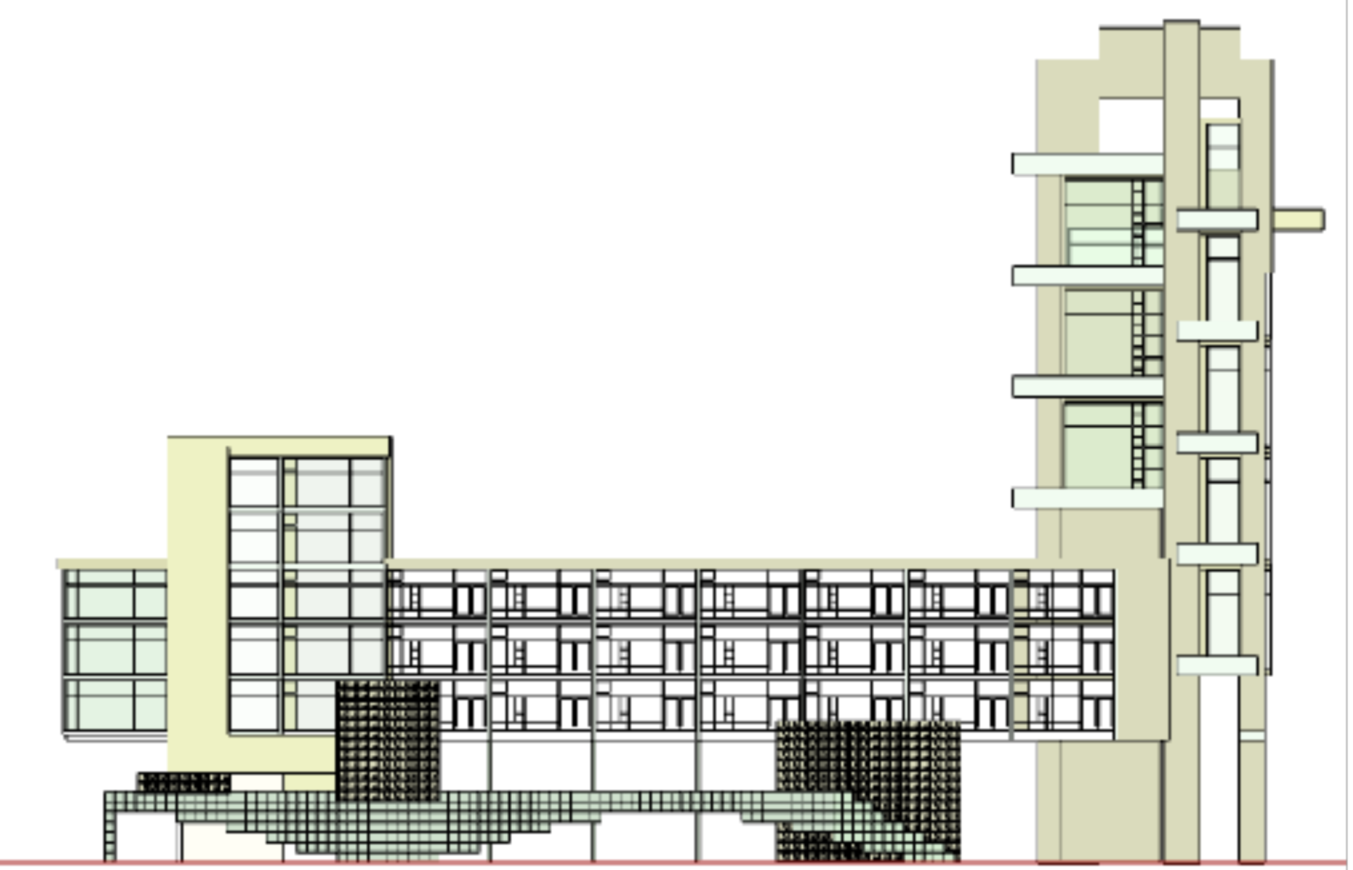


FIG 33.

FIG 34.

APPENDIX

Follows is a description and instructions on how to use the applied fractal dimension tool available at Complexity Explorer (https://www.complexityexplorer.org/). The *Applied Box-Counting* tool can be found by navigating to the virtual laboratory (https://www.complexityexplorer.org/explore/virtual-laboratory/142-applied-box-counting)

There is also a writeup on Fractals that explains and walks one through a variety of models here (https://www.complexityexplorer.org/system/explore/model_series/pdf_files/000/000/004/original/FractalsLaboratory.pdf?1474143486)

The tool is written in Netlogo and is able to output the fractal dimension and r^2 for any 2 dimensional image.

* The model was written in Netlogo v 5.1.0 but will work without modification in the latest version 6.0.4. A window will appear that reads, “This model was created in Netlogo 5.1.0. You may need to make changes for it to work in NetLogo 6.0.4”, press continue and the model will open.

* The image must be cropped square and saved as a .png file in the same folder as the Netlogo application. In the code tab for the model the name of the image must be appended with .png even if “.png” is not appended to the image’s label. Here are screen shots of the image I used and how they appear in the code. A lazy time saver trick is to keep the drop down menu in the interface the same and only change the file name in the code as shown on the image to the right.

FIG 35.

```
;;;;;;;;;;;;;;;;;;;;;;;;
;;;;;;import image;;;;;;
;;;;;;;;;;;;;;;;;;;;;;;;

to setup
  clear-all
  if image = "coastline"
  [
    import-pcolors  "Herald_Square.png"
    ask patches with [pcolor != white]
    [set pcolor black]
  ]
```

FIG 36.

One of the goals of The Green New Deal Resolution reads, "upgrading all existing buildings in the United States and building new buildings to achieve maximal energy efficiency, water efficiency, safety, affordability, comfort, and durability, including through electrification." (https://ocasio-cortez.house.gov/sites/ocasio-cortez.house.gov/files/Resolution%20on%20a%20Green%20New%20Deal.pdf). How can this realistically be done given the sheer number of buildings in the united States to say nothing of the infrastructure and other urban crises we face?

One hope for solving this wicked problem comes from systems theory. Solutions to the global challenges we face require an approach that treats the problem not as one that can be simplified to a few variables that can be 'maximized' but as a complex adaptive system. Jane Jacobs writes, "…While city planning has thus mired itself in deep misunderstandings about the very nature of the problem with which it is dealing, the life sciences… have been providing some of the concepts that city planning needs... And so a growing number of people have begun, gradually, to think of cities as problems in organized complexity--organisms that are replete with unexamined, but obviously intricately interconnected, and surely understandable, relationships…" (Jacobs, The Death and Life of Great American Cities).

Thank You

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FIG 22.