Inform Form Perform

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Initial Idea
Initial Idea

In recent years architects have developed and employed parametric design strategies to both improve their production and simplify the creation of complex forms. Parametricism refers to the design of the interrelations between pieces and the set of rules and variables that define their connections to each other. Though these parametric strategies have improved the speed of the design process and the overall sustainability of the built environment, they are not being used to their full extent in the design process. In contrast aggregate systems are completely manifested in the design process as they relate to the internal and external efficiencies of each piece of the system. Webster's dictionary defines aggregate as "formed by the collection of units or particles into a body, mass or amount."(Aggregate) The combination of these two concepts creates a parametric aggregate system in which it is possible to grow a building through generative algorithms comprised of aggregates.

The proposed building 'units' or 'particles' used in aggregate systems already exist on one level. Bricks, cargo container structures and Structurally Insulated Panels (SIPs) already act as parts which assembled together create a whole that is more than the sum of its parts. There are a myriad architectural possibilities that exist in the exploration of combining both volumetric and material aggregates. One promising advance is in the possibilities provided with mass customization through Computer Aided Manufacturing (CAM) and the existing relationships and material efficiencies between pieces. The next stage in aggregate design is to bring together a parametric total building system able to respond to environmental and social input/stresses through aggregate relations within the building. Each change in input yielding a different result.

Using local redundancies within the aggregate system increases the overall adaptability of the building. There are three fundamental types of redundancies: 1) Using the same element to perform multiple roles, or in multiple systems, 2) Duplication without a specific intent or reason, and 3) Strategically built in excess capacity. It is this third type of redundancy that is worth investigation. Michael Weinstock explains that "biology has evolved redundancy as a deep strategy within hierarchical arrangements of cells and tissues producing sufficient excess capacity for adaptation to environmental stress."(WeinStock) This redundant efficiency found in biology is particularly applicable to an aggregate building system. Whereas the traditional concept of building efficiency looks at each component/system of the building individually and tries to make each one as efficient as possible before compiling them together, redundant efficiency looks at the relations between the components or aggregates, and creates the redundancies necessary to absorb stresses and environmental change.

Urban environments are an example of a social aggregate system in which the action of one component has a local influence over those it has direct contact with. Over time the collection of these local interactions is able to shape the form of the entire urban social environment. Within this system the mixed use development is a physical example of how these aggregates relate to and interact with each other. Therefore, a mixed use structure allows most design flexibility in exploring the extents of both aggregate systems and redundancy as design strategies. Though these design strategies could be replicated to create a prototype for a variety of equally successful urban structures, this thesis will focus on a design strategy for a single building in an urban environment.
Problem

“Within contemporary architectural design, a significant shift in emphasis can be detected - a move away from an architecture based on purely visual concerns towards and architecture justified by its performance.” (Digital Morphogenesis) In a world of scarcity, economy and efficiency become key decision makers. It is the role of architects to recognize this shift in the demands of society and respond with newer, better integrated design practices focused on reducing waste and life-cycle cost of buildings. In recent years architects have developed and employed parametric design strategies to both improve their production and simplify the creation of complex forms. Though these new strategies have improved design speed and the sustainability of the built environment, a gap still exists between what our growing society wants and what current design practices provide.

Idea

The primary focus of this thesis will be on a morphogenetic design process, combining structural and surface systems, resulting in the creation of a buildable project. As this is an experimental design method, much of my time will be invested in research geared primarily towards the creation of a single design. The resultant building will prove the benefit of this type of design process through its use of local redundancies for efficient adaptation.

I will use an aggregate building system based on the growth of differentiated systems in which individual units vary slightly in their role and physical characteristics depending on local influences within the environment. “Thus the understanding [of the aggregate building system] extends beyond the visible effect towards the thermodynamic, acoustic and luminous modulation of the natural and built environment. As these modulations can now be anticipated as actual behaviour rather than textbook principles, the design of space, structure and climate becomes inseparable.” (Inclusive Performance AD) When building systems blend together and rely upon one another to perform multiple roles, traditional views of efficiency become difficult to implement. Natural, biological systems use a certain redundant efficiency to allow for
flexibility in use and effective adaptation to various roles within the system. Michael Hensel states, “To instrumentalise multiple-performance capacity it is necessary to understand material elements and systems in a synergetic and integral manner, in terms of their behavioural characteristics and with respect to the purpose they serve both locally and within the behavioural economy of a larger system.” (Morpho-Ecologies p. 22)

The nature of this type of research places emphasis on design experimentation and research. In order to understand and design with such complex systems, physical model building will compose a vital part of my research agenda looking at local relationships and connections capable of forming the building blocks of a multi-system integrated building. “Morphogenesis driven by analysis thus requires creativity, intelligence and instrumentality in devising integral analytical methods.” (Inclusive Performance) In addition to physical form finding, my design based research will also focus on the application of and possibilities found in digital computation and scripting. Following the identification of a principle logic and generative growth system, my research will lead me to the vertical integration of this logic through the various scales and systems of the building.

In proposing this thesis project the exact site and program are less relevant than their characteristics because of the way this type of building system interacts with its context. The primary site condition is a dense urban fabric, rich with cultural activity, life, and history. A site with varied environmental conditions and local context will better inform the design parameters. The site should be well integrated into multiple modes of transportation, as well as in a mixed use neighborhood, providing for site access and a variety of inhabitants. Because it is located in a dense urban fabric, the resulting program will likely be vertically oriented and of high density. The site and program specifics will be continuously defined throughout the project based on the digital parameters and spatial characteristics required in setting up the growth algorithm. Though the building will likely be mixed use in nature, I want to focus my attention on housing, entertainment, and urban life in a setting outside of the Midwest.

Though this proposal focuses on a single building, many of the ideas and relationships derived through it could form the basis of an aggregate design process. The single use of this process of design provides a chance to fully explore its potential and prove the viability of these design ideas as a means to bridge the gap of what clients expect in a building and what current practices are able to provide.
Terms

**Morphogenesis**
“Used initially in the realm of biological sciences, the term refers to the logic of form generation and pattern-making in an organism through processes of growth and differentiation.” (Digital Morphogenesis) Architecturally the term relates to the growth and physical adaptation of building systems as a response to changing stimuli.

**Parametricism**
“Architecture and urbanism are called upon to organize and articulate the increased complexity of a post-fordist society.” (Schumacher) One of the evolving tools used by avant-garde architects is parametric software such as Grasshopper or Generative Components. One may find that in firms employing these programs, architects are less focused on designing the physical form of buildings but work extensively to design the code necessary to set up building relationships, resulting in a better building solution based on parametric logic. “It is not that the architect here is any less imaginative; rather the architectural imagination has been displaced into a different arena - into the imaginative use of various processes.” (Digital Morphogenesis)

**Aggregates**
In the last few years designers have identified aggregate systems as a potential design strategy for further integrating architectural designs. Webster's dictionary defines aggregates as “formed by the collection of units or particles into a body, mass or amount.” (Aggregate) In architectural terms this refers to a collection of similar building units working together to create a system which is more than the sum of its parts, similar to the way cells combine to form the body.

**Generative systems**
Digital computation and exploration of the complex logic found in biological and environmental systems led to the creation of digital algorithms to mimic these systems. “Computation - a term derived from the Latin ‘computare’ (to think together) - refers to any system where individual components are working together.” (Digital Morphogenesis) It is the relationships between the parts and their logic of ‘thinking together’ that allows these simple systems to create complexity through the repetition of simple rules. The first of the two primary methods, L-systems, mimic the branching nature found in plants and other cellular structures. Cellular Automata (CA) refers to a binary system of 1’s and 0’s, which mimics the logic of population patterns. Other algorithms have been generated to rationalize swarm and flock behavior. Architects are only beginning to harness the power of these systems to generate form and rationalize the interrelations of their designs.

**Redundant Efficiency**
“An alternative understanding of performance [is] one that is based on multiparameter effectiveness rather than single parameter optimisation and efficiency.” (Inclusive Performance) Michael Weinstock's research expands on this dichotomy showing that natural living systems use “redundancy and differentiation” not “optimisation and standardisation” (Towards Self-Organisational) as a means of material/energy reduction. Redundant efficiency is an extension of this multi-performance capacity. It works through strategically built in excess capacity to respond to environmental stresses and perform additional roles within the system. Designing for flexibility and adaptation allows buildings to maintain their design integrity (and efficiency) even as their program and users change from the vision of the original client.
Precedents

When researching these topics, some architectural work can be found that begins to prod the surface of what is possible. Many of these morphogenetic strategies have been explored by architects, but none of the relevant projects capture the true potential of a fully morphogenetic design. These precedents can be broken into four generic base systems: volume, structure, surface and material. The following are a synopsis of the best examples projects using these different systems.

Volume

Habitat 67, a modular structure by Moshe Safdie, looked to create a solution for the inhuman, stagnant apartment blocks found in larger cities. “The resulting ziggurat was made up of independent prefabricated boxes with fifteen different plan types.” (Sharpe) Moshe Safdie employed one simple rule, each unit’s roof would be the garden for another unit, as a generative system to create this uniquely complex form made from prefabricated volumes.

Team Chimera’s Mangal City uses many of the same principles over 40 years later with a digital twist. “The project is an ‘urban ecological system’ composed of modular pod capsules that shift to adapt to environmental and contextual conditions.” (Chino) Based on structure of mangrove trees, this project employed digital algorithms “to define a parametric machine which is able to create a responsive ecology.”(Team Chimera)

Structure

Antonio Gaudi used mechanical computation to determine the structural form of his Colonia Guell Crypt. He created a 1:10 model set up in a shed near the site using a grid of strings and weighted bags. “The logic held that a cohesive network of articulated nodes and connections with accurately scaled representations of loading applied to the nodes would pull the resulting mesh into a self-determining gravity-respecting shape.”(Bury) This manual form finding method gave him control over the process of design which in turn generated more appealing, logic based, structural forms.

The eiform structure designed and built at the Academie van Bouwkunst, Amsterdam used advanced scripting logic to determine a structural form that followed set inputs. “The programme generates new structural forms that intelligently respond to given design conditions, e.g. courtyard dimensions and buildable area (avoid the tree!),
required heights for flow of people through the structure, and maximum strut length, using a combination of structural analysis and optimisation." (Digital Landscape) The process behind this project is quite interesting because the software generated multiple solutions that all fit the required criteria allowing the designers to work within the program to create the most desirable form.

Surface

Michael Hensel’s research continues Frei Otto’s work in minimal surfaces. Where Otto set up physical experiments to recreate and rationalize the complex structural nature of minimal surfaces, Hensel works through digital means to find the morphogenetic potential of various surfaces. His Bylgia membrane, constructed of an array of similar surfaces, created “an exceedingly differentiated canopy.” (Schmie) This and other experiments search for higher levels of complexity using minimal surfaces and simple rules as the primary building blocks of a larger surface.

Transitional Morphologies, a studio project from the AA School’s Diploma Unit 4, focused on creating a “smooth transition from space-frame to surface active folded structural system” (Morpho-Ecologies p196) as a structural surface system. The resulting project “cannot only be manipulated in response to different structural requirements, but can also be informed by critical environmental parameters as to modulate airflow and interact with luminous flow.” (Morpho-Ecologies p197) This investigation implemented a parametric relationship between the various input/stimuli and the resulting form of the surface. The overall character of the surface was generated through the differential transitions in the environmental interactions with the surface.

Material

Meta Patch, another project from Diploma Unit 4, studied the relation between material properties and the physical form of the project. The project was built from an array of small rectangles attached to larger pieces (see image) that together form a self supporting surface. “As the smaller elements are incrementally actuated, the larger patch acquires curvature too. As all the larger patches become curved, so does the overall surface.” (Morpho-Ecologies p184) This ‘bottom up’ method of design focuses on the smallest physical connection and based on its variation across the surface, a larger combined force bends and shapes the global network of pieces.
Thesis Statement
“Within contemporary architectural design, a significant shift in emphasis can be detected - a move away from an architecture based on purely visual concerns towards an architecture justified by its performance.” (Leach) In recent years architects have developed and employed parametric design strategies to both improve their production and simplify the creation of complex forms. Parametricism refers to the design of the interrelations between pieces and the set of rules and variables that define their connections to each other. Though these strategies have improved the speed of the design process and the overall sustainability of the built environment, they are not being used to their full extent in the design process. The use of computers still provides vast areas of research for architects to improve both their design and the production of built form.

I propose taking the use of computers in aiding architectural design one step further; information and data should INFORM the project, driving the creation of a building FORM enabling it to PERFORM at higher levels than traditional design.

As architects continue to improve these tools, owners and developers tend to choose an opposing strategy. They often finance cheaply built (and designed) projects in an effort to reduce the up front costs of the building. However, in economics, reducing costs is only part of a financial decision. The other half of the equation is increasing the revenue generated by the project. Focusing on only half of the equation eliminates half of the solutions. I further propose that the design strategy of inform-form-perform should be employed by developers seeking to increase the profitability of a project. By investing more time in the design of a building developers would be able to fund projects that perform better and sustain significantly higher revenues.
The Traditional Workflow

When considering how architects incorporate computers into the design process, typically designers work by thinking of an idea, and then use the computer as a representational tool to output that idea to themselves and others. They take the output from the computer and begin a manual design process on that material. This process may happen physically through printouts and meetings with either the client or members of the design team or digitally as the architect works through design concepts in the computer, repeatedly coming up with ideas then adjusting the computer model accordingly. Within this traditional workflow, the computer is relegated to the role of a tool, comparable role of a pencil, modeling clay or drafting board. This ‘representation only’ design strategy prevents the computer’s massive capacity for making quantitative decisions from influencing the design process.
Information

- Site Data
- Footprint Area
- Program Data

User Preferences

- Height Preference
- Program % Preference

Computation

- Divide Site
- Locate Public Plates
- Set Circulation/Retail Base
- Cull Unnecessary Surfaces

- Set Heights
- Generate Floor Plates

- Assign Program Zones
- Alter Floor Plates

- Generate Skin
- Generate Structure

Selection

- Selection of Best Informed Result(s)

Development

- Program Development
- Material Systems
- Tectonic Expression
- Structure
- Floorplane
- Balconies

Cost Estimation

Value Estimation

Appearance

Traditional Workflow

Designer

Computer
The Integrated Design Team

What I propose, through this thesis, is an integrated approach to the design process where the designers make decisions side by side with the computer passing key design roles back and forth based on ability. As Carlos Marcos described it “Digital consciousness is a design strategy to be found in different degrees among [...] architects or designers that rely on the computer not only as a tool but as part of the team” (Marcos). Designers have the advantage of a creative and intuitive mind, but they lack the superior numeric analysis of multi-core processors. As the quantity of information incorporated in each building project continues to increase, architects will need help sorting, analyzing and tracking that information throughout the design process. Additional designers working as teammates often add to the complexity and size of the information stream within the design environment. Computers are able to make decisions based on quantitative comparisons and analyses with greater precision in less time than their human counterparts. Rather than replace human designers, the prosed process allows for a discussion between computers and architects where one proposes a design solution and the other adjusts it, working back and forth until both are satisfied with the result formally and performatively. Assigning pivotal roles to each will allow them to maximize their potential as a design team and will create a new breed of architectural design that is both well informed and visually interesting.
Economic Design

Most building owners and developers follow the simple business principle of working to increase profit. The issue is that many companies focus on minimizing costs in order to increase profit. However, costs are only half of the financial equation. Profit is equal to revenues minus costs. If a company can increase its revenues at a rate greater than their costs increase, they can still increase the overall profit of the building project. This gives architects/designers the increased roll and potentially rewarding value for uncovering new ways for good, aesthetically pleasing architecture to increase the revenues of a building project. By focusing in on real estate research, this project looks at how balconies and views can effect residential values, as well as how proximity to retail, transportation and usable plazas increase the value of new retail spaces. Understanding and designing these performative spaces will provide new design opportunities for architects, developers and project owners.
Profit = Revenues - Costs

Business Goal

Minimize Costs or Maximize Revenues
Theory
History of Computers in Architecture

Architects have looked to the computer to improve their design process since the beginning of programmable computers in the 1940’s. The primary research has been in Computer Aided Drafting (CAD) in order to speed up the drafting process. In the 1960’s and early 70’s architects experimented with the idea of harnessing the generative potential of computers to analyze and solve complex equations. The focus of the generative research was in floorplan layout through bubble diagrams and space generators. The computer could solve complex adjacency matrixes and follow set rules. Most of the generative research stopped with the advent of AutoCAD. 3-D modeling/rendering and BIM have since surpassed AutoCAD as the primary use of computers in architecture. Most of the current design programs and research are still focused on the drafting and representational side of the computer’s potential. Since about 2000 there has been a renewed interest in the generative potential of computers in architecture which is rapidly gaining popularity. As computers are now completely accepted within the design world as drafting tools the research into their use in architecture will continue to shift towards their generative potential.
1970 CLUSTER grouped rooms by similar requirements and printed hierarchy tables
1972 Harness system arranges blocks of hospital space along a central corridor
1974 West Sussex System produced a chart of relations and adjacencies for the architect to consider
1975 Eastman produces a book on spatial synthesis in CAD, most programs optimized distance traveled.
1978 Julia Ruch creates an interactive space layout software that works with the architect to create unique solutions

1981 Per Galle wrote an algorithm which generates all possible rectangular plans on modular grids, subject to constraints on room areas, wall lengths, adjacencies, etc.
1982 AutoCAD Version 1.0 Released to automate the process of drafting
1989 AutoCAD Version 9.0 Released

1990's Japan Experiments with automated robots for construction
1990's 3D CAD programs developed for modeling and Rendering

2003 Peter Wonka et al. published "Instant Architecture." This program created an urban environment by generating streetscapes with thousands of unique facades.
2004 Kristina Shea, the Eifform project that is able to generatively develop its own shape and structure
2008 Patrik Schumacher delares parametricism the next architectural style

2000's Generative Components and Grasshopper facilitate simple parametric design
2000's RhinoScript and MelScript introduce generative scripting potentials into Rhino and Maya
Digital Evolution

The idea of evolution is that through repeated generations of trial and error a more successful solution will occur. In biology natural selection states that only the fittest organisms will survive to breed and pass their genes along. Within the idea of evolution two possibilities exist. Linear evolution where mutation is introduced at each stage and the object is gradually transformed. The second is evolutionary optimization where the fittest options from the first generation are bred together to create a second generation which is then analyzed. The fittest options from the 2nd generation are bred together and the process continues until the fitness level stops improving. Digital evolution follows these same principles of analyzing characteristics(parameters) and either mutating them or breeding them with other successful options. However, as Rachel Armstrong states, this evolution “would not be a random event like the arbitrary, wasteful processes described in ‘natural selection’, but a refined and deliberate relationship that is forced to occur by human intervention.” (Armstrong)
This Block of components creates a variable point. The two sliders allow the X and Y values to become any number between a set minimum and maximum (-15 and 25). The Z value is fixed at 0.

Grasshopper/Galapagos

Parametricism is the latest advancement in architectural computing. It allows for relationships to be established between objects, transformations, and data. Grasshopper harnesses this power through a graphic interface, which is easier for architects to work with. Each component represents either an object, numeric data or a transformation. The lines between these components establish the relationships between them. This type of modeling is similar to raw computer code in many regards except everything is computed continuously so changes are represented immediately in the output. Galapagos is one of tools within Grasshopper that runs an evolutionary optimization process. Galapagos is connected to sliders which it can control, thus changing the output which is interpreted as a single number. Galapagos can compare to previous results and generations. The power of this tool is that it allows Grasshopper to become a generative tool, suggesting informed solutions to the architect.
The pink box runs an optimization script called Galapagos. What it does is systematically shift the two sliders and measure the distance output. The script recognizes which number combinations have the largest distance and bases future tests on the results.

This block of components calculates the distance between the first point and the moveable point at any given time and displays the distance in the yellow panel.
This early set of diagrams shows a simplified building optimization process based on a limited number of variables. The building is represented by a series of floorplates from which a total building area can be calculated. When the building is taller than its neighbors it can expand outward into their skyrights. The goal is to optimize the profit of this building by negotiating the optimal number of floors. A value/s.f. is assigned to the floor area as well as a cost/s.f. however, the cost/s.f. is exponential, increasing as the massing gets taller. Galapagos expedites the decision making process by testing the various slider positions and breeding the results that have the highest fitness, in this case building profit, until the best solution is found.
Project Background
### Forbes: Fastest Growing Metros

1. Austin, TX
2. Cape Coral-Ft. Myers, FL
3. Atlanta, GA
4. Seattle, WA
5. San Francisco, CA
6. Dallas, TX
7. San Jose, CA
8. Houston, TX
9. Orlando, FL
10. Palm Bay-Melbourne FL

### Fastest Dying Urban Metros

1. New Orleans
2. Cleveland, Ohio
3. Buffalo, N.Y.
5. Dayton, Ohio
6. Hialeah, Fla.
7. Toledo, Ohio
8. Rochester, N.Y.
10. Jackson, Miss.

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### Site Selection

Seattle is a growing city with a need for residential units in the downtown area. The city density supports tall buildings and a definitive “good view” can be identified as the waterfront. Within the city three primary site were selected for preliminary testing to test and increase the flexibility of the design process. Of these a specific site was chosen based on its context and zoning restrictions.
Program Development

As a primarily residential project, much of the building program is already established. However, being in a downtown environment having both office and retail adds to the monetary and contextual value of the building. Retail should be located within the first three floors and/or any large public spaces within the building. Office space prefers a more consistent floor plan layout, but at the same time allows for deeper floorplates. It should be located in the mid/lower levels gradually transitioning to residential. The sizing and number of residential units was based on downtown sales data for the previous year. The number of single bedroom units sold was more than double the number of double bedroom units, but the total revenue for the two types was almost equal. This project will focus on an increased number of two bedroom units while trying to achieve a mixed balance of unit sizes on each floor.
Number of Units

- Studio - 4
- 1 bed - 46
- 2 Bed - 20
- 3+ Bed - 4

Total Sales Value (In Thousands)

- Studio - $1,000
- 1 bed - $19,600
- 2 Bed - $19,400
- 3+ Bed - $6,000
Optimization

Maximization — Minimization of benefits — Minimization of costs

Market Value — Construction Cost  
Structural Strength — Material Use  
Movement — Circulation  
efficiency  
Space  
Independence — Travel Distance  
# of Units — Density

Spatial

Arrangements of spaces and their densities.

Building Size and Envelope  
Interior Density  
Circulation  
Relation to Public Transportation  
Public Space  
% Program

Digital Precedence

Looking at different projects that incorporate the generative potential of the computer into the design process, one can break down the role of the computer and classify its use into four main categories.
Understanding the relation between the desired output and the digital algorithms becomes key into setting up new design goals. Each of these precedent studies was analyzed for its potential to influence my project.
Process Development
Information Input

As projects become increasingly complex and owners continue to press for higher performance and outcomes, the levels of information integrated into the project grow rapidly. When working through a design process heavily loaded with information organizing and navigating the data can bog down design decisions. Allowing the computer to weigh different options and make proper choices based on optimal solutions and given parameters substantially improves the design workflow. The informed design process begins with gathering data and organizing it as various inputs. Good, accurate information is vital to this process because each change in inputs can produce drastically different results. The primary communication between the designer and computer in this process is a 3D model of the immediate site and its conditions. Additionally, this process uses both functional and aesthetic preferences from the designer and owners to make appropriate decisions.
Information

Program/User Requirements

Aesthetic Preferences
Retail Formation

The key design strategies for laying the retail base focus on increasing access and proximity to potential customers. The Grasshopper script negotiates four conflicting qualities to achieve these strategies; proximity to public transportation, access to sunny outdoor space (a premium in Seattle), proximity to existing retail, and the distance from existing public plazas. Other more practical design requirements in the script are the floor area, zoning requirements, and maintaining a compact layout with maximum exterior access. The integrated team generates the profile of the base level from the intersection of several squares based on programmatic data. Galapagos iteratively adjusts the location of these squares by moving two sliders for each square, trying and maximize the benefits and proximities of the base level. Each pair of sliders controls the x and y values for the center of that particular square.
Zoning: DMC UL
Maximum Height: Unlimited
Max F.A.R.: 14

Existing Plaza
Retail
Bus Stop
Retail
Bus Stop
Retail
Solar Access

+430'
+410'
+180'
+180'

Attractor Points

6,500 s.f.
6,500 s.f.
4,000 s.f.
4,000 s.f.
5,000 s.f.
4,000 s.f.
Retail Formation

As each square moves Grasshopper continuously performs multiple calculations and combines them into a single weighted fitness level based on set user preferences. As the squares begin to overlap their area is combined into a single profile providing more information to the computer about the fitness of the base. As Galapagos optimizes it starts from a random selection of possibilities and gradually narrows down the selection set making smaller and smaller adjustments until a static level of fitness is achieved. This type of optimization can lead to a type of inbreeding where Galapagos finds a locally maximized result as opposed to the absolute maximum. This gives designers the opportunity to rerun the script and evaluate multiple optimized solutions from the same input. By stopping the solver occasionally to adjust a slider manually, the designer can seed the system by setting it in a new direction and restarting it from a more intuitive base point, which the computer can optimize.
Retail Formation

The result of this base level retail generation is a flexible building footprint informed by its direct context. By manually placing a rectangular shaped base level on the site designers will often only be able to optimize its location towards a limited number of parameters. In this case by placing the building mass slightly farther away from existing plazas and public transportation the optimization process gains proximity to existing retail and creates a large sunny plaza. Though many of these design concepts could be conceived traditionally, this type of digital evolution provides statistics for the argument and sets the stage for generating the rest of the building form.
Residential Formation

Within residential real estate there are many value determining factors beyond location which the architects can control. The most directly correlated with value increases are views, balconies and unit sizes. According to Mark Wade, a residential analyst, a unit with a good view (i.e. a luscious green park, Ocean view, or a terrific skyline) can demand twice the sales price as a comparable unit with a bland view (Wade). This study uses the coastline along the edge of downtown Seattle, as the primary view. The Seattle skyline wasn’t included as a valuable view because the three potential site locations are all too close to see more than the nearest adjacent buildings. Using a similar optimization process to control the profile of the top floor, Galapagos adjusts a matching set of squares to maximize the potential the length of the perimeter that has a direct line of sight to the waterfront, thus ensuring that more units have windows oriented towards good views. Other factors influencing the upper profile are the distances between the squares and zoning requirements.
Residential Formation

Each time Galapagos runs it becomes an opportunity for the designer to work with the computer in determining the best solutions. For example one might set the geometry in a position that logically works before letting the solver run to further optimize their locations. More specifically in the optimization of the upper floor plate, as the solver narrowed in on a given solution it often leaves small awkward gaps between squares or excludes a square from the primary cluster for whatever reason. The designer can easily stop the script, slide the square into a more intuitive alignment and restart the Galapagos process, saving both time and processing power.
**Residential Formation**

As the architects and Galapagos arrange the various squares. Grasshopper continuously provides feedback on floor area, height, total perimeter length, and both blocked and unblocked views. With real time statistical feedback along with the 2/3d visualizations the design team can make both quantitative and qualitative decisions based on project information.
Loft Type

Using these two optimized floor plate profiles, one for the retail and another for the residential, Grasshopper creates the massing of each building by blending the two profiles together. Each square from the base floor plate is lofted with its twin on the upper level and then boolean unioned together with the other pairs to create a single generic form for the building.
Blend Type

The primary criticism of the loft massing type is that only two of the floors are truly optimal and that the remaining floors could potentially achieve a higher value. Optimizing each floor individually becomes overwhelming due to restraints in time and processing power. Because the results of optimizing additional floor plates follow the law of diminishing returns, using only one or two additional optimal floor plates becomes a viable solution. The Blend Type follows a very similar logic to the loft type by creating a smooth loft between the multiple floorplates.
Multi - Loft Type

This type incorporates two additional floorplates, each optimized separately, besides the base and top levels. Each floorplate is directly lofted to the one above it creating a much more segmented appearance. This typology creates a unique potential for self shading and rooftop balconies due to the drastic shift between levels.
**Extrude Type**

A fourth typology also exists by extruding these four profiles vertically until they meet each other. This process results in very abrupt shifts in the form of the building at each of these levels, which gives a much more direct representation of how the surrounding context effects the massing. The benefit to this type is that only a limited number of floorplans need to be developed the rest can be duplicated.
A table of computer generated massing options grouped and sorted for presentation to the project architect

<table>
<thead>
<tr>
<th>Number</th>
<th>Volume</th>
<th>Height</th>
<th>Width</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>15,139</td>
<td>36,900</td>
<td>18,758</td>
<td>51%</td>
<td></td>
</tr>
<tr>
<td>15,641</td>
<td>50,630</td>
<td>27,724</td>
<td>55%</td>
<td></td>
</tr>
<tr>
<td>19,073</td>
<td>56,884</td>
<td>30,099</td>
<td>53%</td>
<td></td>
</tr>
<tr>
<td>15,621</td>
<td>49,554</td>
<td>24,779</td>
<td>50%</td>
<td></td>
</tr>
<tr>
<td>19,516</td>
<td>67,414</td>
<td>33,025</td>
<td>49%</td>
<td></td>
</tr>
</tbody>
</table>
Analysis and Selection

The quick speed of this process allows the design team to generate dozens or more study iterations of optimized building masses. The process also generates 3D printed models and tables of information to accompany each iteration. Through digital processes, the computer can sort and present to the designers the top versions for further analysis. Designers have the choice during the generation and formation processes of working directly with the computer on each iteration, or allowing the computer to independently generate design options. Once a sufficient range of results has been generated the design team can narrow down the selection and move forward with only the best options to develop and further analyze. Each project will require a different balance between computer generated ideas and manual processes alongside the digital.

**Version 1**

- Total s.f.: 1,100,000
- Cost / s.f.: $404
- Total Cost: $444,900,000
- L.f. of Perimeter: 38,500
- L.f. with View: 21,400

Cost Increase
35%

Revenue Increase
45%
Version 5b

Total s.f.: 1,120,500
Cost / s.f.: $390
Total Cost: $437,107,000
L.f. of Perimeter: 39,800
L.f. with View: 21,100

Cost Increase
33%
Revenue Increase
42.3%

Version 9

Total s.f.: 984,890
Cost / s.f.: $533
Total Cost: $525,500,000
L.f. of Perimeter: 47,300
L.f. with View: 25,000

Cost Increase
60%
Revenue Increase
77%
Both additional value and cost increases are calculated in order to determine any potential gain in profit. Using Grasshopper to perform these evaluations requires additional information from the designer. The cost of the building is determined by the overall area multiplied by a base cost/s.f. and a variety of cost multipliers to represent the different cost increases such as cantilevered areas, height, and form complexity.
Circulation and Core Locations

Optimizing core locations within the massing helps generate both structure and circulation. A minimum of two cores are located within the mass. The vertical cores must run continuous from the top to the bottom and should attempt to maximize their distance apart, as well as their distances to the exterior facade.
Floorplate Generation

Once a building form has been selected for further development the next step is to sequentially slice the massing to generate the intermediate floor plates based on a set floor to floor height. Then the design team can work with the computer to build the floorplates back up into floor plans and eventually into an architectural design. The process starts by creating a double loaded corridor in the center of the floorplate stretching between the primary elevator/stair core locations.
Level 50 - Elevation 612
Area.......................18,700 s.f.
Perimeter....................739 l.f.
Total Units.......................14
Floorplate Division

Then the computer draws a series of division lines through the floor plate radiating out from the centralized hallway and cores delineating the room separations. Galapagos adjusts their locations along the hallway sequentially testing the results against the user input requirements for minimum, maximum and desired room sizes along with the length of exterior windows. The residential floor plate division process allows the computer and designers to excel as a team. If the designer doesn't like the layout the sliders can be adjusted manually to seed Galapagos with a solution and the process can repeat until both are satisfied.
Exterior Glazing
739 l.f. perimeter
50 l.f. Average/Unit
17 l.f. Minimum
100 % Units with View
Unit Analysis

As the designer and the computer derive an appropriate solution Grasshopper separates the rooms into categories based on their size and how many bedrooms their proportions permit to provide feedback through charts and a cumulative spreadsheet. Data such as view, l.f. of exterior windows, area, and number of bedrooms helps designers understand the value of each floorplan option.
14 Total Units .................. 18,700 s.f.
0 x Studio Units..................0 s.f.
3 x 1 Bedroom Units.....2,150 s.f.
9 x 2 Bedroom Units..12,500 s.f.
2 x Suite Units............4,050 s.f.
Unit Subdivision

A secondary Grasshopper script parametrically applies a series of flexible room layout prototypes to the different sized units, choosing the appropriate style based on the location, size and proportion of the room. This process creates a rough bubble diagram of room layouts within the space that the designers can use to provide drawings/data to the owners and later develop into floor plans.
Room 5003 ...................... 1,700 s.f.
  2 Bedrooms .................. 600 s.f.
  2 Bathrooms ................. 150 s.f.
  Living Room ................ 400 s.f.
  Kitchen ..................... 230 s.f.
  Dining Room ............... 200 s.f.
  Other ....................... 120 s.f.
Results/Analysis
Result Comparison

Through each phase of this design process the integrated effort between the Galapagos solver and the designer produced successful results. However, the summation of these optimizations begins to differentiate between the value of the results. Each iteration can be compared both formally and statistically. The DNA of each iteration is also tracked through slider positions in order to potentially breed successful results at a later time.
<table>
<thead>
<tr>
<th>Number</th>
<th>Description</th>
<th>Total Cost</th>
<th>Cost/Floor</th>
<th>Floor Area</th>
<th>Number of Rooms</th>
<th>FL/Floor</th>
<th>Perimeter Length</th>
<th>Perimeter Length With View</th>
<th>Site Area</th>
<th>Actual FAR Value</th>
<th>Allowable FAR</th>
<th>FGI of Place</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>unoccupied</td>
<td>1,056,700</td>
<td>515</td>
<td>2,034</td>
<td>465</td>
<td>21,818</td>
<td>61,360</td>
<td>56,206</td>
<td>56,206</td>
<td>1531,606</td>
<td>1531,606</td>
<td>1531,606</td>
</tr>
<tr>
<td>2</td>
<td>Double Sided Retail - Church</td>
<td>458,615,200</td>
<td>813</td>
<td>560,000</td>
<td>45</td>
<td>21,818</td>
<td>61,360</td>
<td>56,206</td>
<td>56,206</td>
<td>1531,606</td>
<td>1531,606</td>
<td>1531,606</td>
</tr>
<tr>
<td>3</td>
<td>Double Sided Retail - Church</td>
<td>461,451,450</td>
<td>922</td>
<td>570,000</td>
<td>45</td>
<td>21,818</td>
<td>61,360</td>
<td>56,206</td>
<td>56,206</td>
<td>1531,606</td>
<td>1531,606</td>
<td>1531,606</td>
</tr>
<tr>
<td>4</td>
<td>Double Sided Retail - Church</td>
<td>564,264,700</td>
<td>1,120</td>
<td>620,000</td>
<td>45</td>
<td>21,818</td>
<td>61,360</td>
<td>56,206</td>
<td>56,206</td>
<td>1531,606</td>
<td>1531,606</td>
<td>1531,606</td>
</tr>
<tr>
<td>5</td>
<td>2x Retail - Church</td>
<td>515,878,215</td>
<td>1,120</td>
<td>620,000</td>
<td>45</td>
<td>21,818</td>
<td>61,360</td>
<td>56,206</td>
<td>56,206</td>
<td>1531,606</td>
<td>1531,606</td>
<td>1531,606</td>
</tr>
</tbody>
</table>

**Notes:**
- FL/Floor is the floor area per floor.
- Perimeter Length and Perimeter Length With View are measurements in feet.
- Site Area is the area of the site in square feet.
- Actual FAR Value and Allowable FAR are ratios of the actual and allowable floor area to the site area.
- FGI of Place is a calculated value based on the site area and FAR value.
### Building Stats

<table>
<thead>
<tr>
<th>Description</th>
<th>Box</th>
<th>Split Y</th>
<th>Split Y/Box</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base floorplate area</td>
<td>27,500</td>
<td>31,000</td>
<td>113%</td>
</tr>
<tr>
<td>Avg. distance from floorplate to nearest retail</td>
<td>233</td>
<td>144</td>
<td>62%</td>
</tr>
<tr>
<td>Closest distance to existing retail</td>
<td>169</td>
<td>92</td>
<td>54%</td>
</tr>
<tr>
<td>Avg. distance from floorplate to nearest transportation</td>
<td>118</td>
<td>145</td>
<td>123%</td>
</tr>
<tr>
<td>Closest distance to transportation</td>
<td>72</td>
<td>110</td>
<td>153%</td>
</tr>
<tr>
<td>Avg. distance from floorplate to nearest plaza</td>
<td>198</td>
<td>225</td>
<td>114%</td>
</tr>
<tr>
<td>Closest distance to nearest plaza</td>
<td>132</td>
<td>180</td>
<td>136%</td>
</tr>
<tr>
<td>% sun persevered</td>
<td>26</td>
<td>82</td>
<td>315%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Description</th>
<th>Box</th>
<th>Split Y</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Perimeter of top floor with view</td>
<td>250</td>
<td>440</td>
<td>176%</td>
</tr>
<tr>
<td>Perimeter of top floor</td>
<td>646</td>
<td>1180</td>
<td>183%</td>
</tr>
<tr>
<td>% of top floor with view</td>
<td>39%</td>
<td>37%</td>
<td></td>
</tr>
<tr>
<td>Area of top floor with view</td>
<td>27,500</td>
<td>33,000</td>
<td>120%</td>
</tr>
<tr>
<td>Area/length with view</td>
<td>110:1</td>
<td>75:1</td>
<td></td>
</tr>
</tbody>
</table>

### Cost

<table>
<thead>
<tr>
<th>Description</th>
<th>Box</th>
<th>Split Y</th>
<th>Split Y/Box</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Cost</td>
<td>394,921,875</td>
<td>388,388,000</td>
<td>98%</td>
</tr>
<tr>
<td>Cost/ft2</td>
<td>312.5</td>
<td>364</td>
<td>116%</td>
</tr>
<tr>
<td>Total ft2</td>
<td>126,375</td>
<td>106,700</td>
<td>84%</td>
</tr>
<tr>
<td>Number of Floors</td>
<td>46</td>
<td>46</td>
<td></td>
</tr>
<tr>
<td>ft2/Floor</td>
<td>27473</td>
<td>23196</td>
<td>84%</td>
</tr>
<tr>
<td>Perimeter Length</td>
<td>31,000</td>
<td>38,700</td>
<td>125%</td>
</tr>
<tr>
<td>Perimeter Length With View</td>
<td>9900</td>
<td>13,350</td>
<td>135%</td>
</tr>
<tr>
<td>Site Area</td>
<td>56,205</td>
<td>56,205</td>
<td></td>
</tr>
<tr>
<td>Actual FAR Value</td>
<td>22</td>
<td>19</td>
<td></td>
</tr>
<tr>
<td>Allowable FAR</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ft2 of Plaza</td>
<td>28,705</td>
<td>25,205</td>
<td>88%</td>
</tr>
<tr>
<td>Total cantilevered area</td>
<td>0</td>
<td>31,000</td>
<td></td>
</tr>
<tr>
<td>Building Height</td>
<td>564</td>
<td>564</td>
<td></td>
</tr>
<tr>
<td># of faces</td>
<td>184</td>
<td>947</td>
<td></td>
</tr>
<tr>
<td>Avg. length per face</td>
<td>168</td>
<td>41</td>
<td></td>
</tr>
<tr>
<td>Orientation at base</td>
<td>0 degrees</td>
<td>0 degrees</td>
<td></td>
</tr>
<tr>
<td>Orientation at roof</td>
<td>0 degrees</td>
<td>52 degrees</td>
<td></td>
</tr>
</tbody>
</table>

| Increase in value | 156%               |
Massing Analysis

Spreadsheets and output data are able to track a variety of aspects about the building through the design process. The data can be passed along at various stages in order to provide program verification, cost estimation and real estate estimates.
Solar Analysis

Solar studies performed within Grasshopper using a script from Atelier nGai help to define the external material system. Louvers only appear on the South facing portions of the building with high solar gain. Due to the design strategy of maximizing solar access on the ground level and increasing the total area for living units on the upper floors, the massing is largely self shading during the hottest months of the year. During the cool months direct southern sun helps to warm the large south facade.
**Cost/Benefit Analysis**

This thesis project tested an informed design process on three different sites within downtown Seattle each of different shapes, sizes and zoning restrictions. Two of the three sites generated mostly successful results, meaning the increase in value surpasses the increase in costs. The site that failed to produce successful results had a lower maximum building height, and thus didn't allow the form to grow tall enough to capture views of the waterfront. In the other two sites all of the massing types showed positive results, though a clear distinction existed between them strongly favoring the Loft and Extruded Types. From the multiple successful output options, I chose to develop a loft type massing on the 2nd site for both its statistical qualities along with its formal appearance.
Optimization Cost vs. Benefit

Increase in Views (Value)
Formal Appearance

The loft typology elegantly shows the design process within the building mass. Each individual loft between squares merges with the others to create a unified building mass.

Plumbing/Mechanical

Many of the traditional concepts for plumbing, heating and cooling in tall buildings work within this type as well: staged water pumps, localized VAV air handlers, and rooftop cooling towers.
Balconies

Shared and individual balconies are formed in the folds of the building floor plates to provide an exterior escape and green space for residents.

Circulation

Two central cores provide the primary circulation within the building. Express elevators stop at two sky lobbies which separate program, create public retail space and facilitate rapid vertical movement.
Structural Analysis

The primary structural concept is a bundled tube design. Each individual loft becomes a tube with load bearing support in the corners and cross bracing to provide rigidity. At each of the sky lobbies a condition exists for a two story truss acting as a large belt holding the tubes in place. The belts also act as a means to transfer vertical loads from one support to another.
Balcony Formation

The balcony conditions in the creases of the mass are based on sheltering the residents from the wind. As the wind wraps around the form of the building eddies are formed as pockets of slow moving wind in the creases of the form. Placing the balconies in these areas of slower wind speed makes them a much more usable space.
Floorplate Typologies

This study also led to the discovery of new typologies or groups of building shapes that maximize views of the waterfront. This type of finding within the generative process allows designers to see different possibilities outside of their preconceived notions. Within this case three distinct types became evident; a wedge shape with the slightly larger end facing the view, the ‘W’ shape and a diagonal type. Designers can now use statistical evidence to justify the formal attributes of these typologies.
**View Depth**

As information becomes more manageable through the informed design process new design considerations become important for architects to understand. One additional design consideration that becomes possible through digital design is the location of optimal views within each unit. If a value is placed on seeing a particular point, computers can geometrically determine how far back in each unit that point can be seen based on eye height, blocked views and the height of the floor.
Total Rooms
516
Total Perimeter
40,000 L.F.

Rooms with Good Views
413 - 80%
Perimeter With View
21,000 L.F. - 53%
Room 5012 ..................... 1,675 s.f.
Perimeter Windows..............90 l.f.
  2 Bedrooms ...................475 s.f.
  2 Bathrooms..................120 s.f.
 Living Room....................600 s.f.
 Kitchen/Dining...............250 s.f.
Room 2311 ...................... 620 s.f.
Perimeter Windows ............... 30 l.f.
  1 Bedrooms .................. 175 s.f.
  1 Bathrooms ................ 175 s.f.
  Living Room ................. 175 s.f.
  Kitchen/Dining ............. 135 s.f.
Room 5309 .................... 2,220 s.f.
Perimeter Windows .......... 90 l.f.
  3 Bedrooms .................. 900 s.f.
  2 Bathrooms ................ 120 s.f.
  Living Room ................ 600 s.f.
  Kitchen/Dining .............. 400 s.f.
### Project Data

Though the statistics may reveal one solution to be significantly better than the rest according the weighted performance criteria, architects should still use caution and approach the massings and data with a critical eye. The quality of information obtained from the simulation is directly related to the quality of the information put into it and the code used to interpret that information. When comparing statistical data determining and average and base point and looking for outliers will help to prevent mistaken assumptions.
Physical Models
Physical Models
Physical Models
Role of Architect as Curator

The primary discussion following my final presentation was on the role of the architect within the design process. Some critiques argued that this type of process encourages architects to act as curators, picking and choosing from computer generated forms rather than acting in a more creative role. The counter argument is that this process allows architects to intuitively design alongside the computer with control over both the final outcome, as well as the scripted digital processes used to get there. What is essentially being called into question through this critique is the understanding of who will play what roles during the design process. Just as in a traditional design team, the balance between who contributes how and when needs to be decided on a project by project basis. The workload may shift between multiple designers and multiple computers through the course of a single project.

Critique/Continued Learning
Design for Design Sake

Another discussion centered around the idea of design in architecture. My argument throughout the presentation and discussion was that the informed design process allowed architects to justify their design choices through statistical evidence and that architects should, as good stewards of the built environment, provide building design that performs (environmentally, functionally, or visually) based on the clients needs. The counter argument from those who take a more phenomenological or object based approach to design is that not every decision needs to be justified. Architects as designers should be able to make a decision because they feel its right and it improves the project design in their trained eye. This conversation centered around the direction of architectural design as much as my particular thesis. I hope that my project does not provide a clear cut solution to this question and that architects continue to design under both premises to provide visual and conceptual variety to our cities.

Areas for further Research

As with most idea based thesis projects cut short by time restrictions, this project leaves many areas unexplored or under explored. The areas I see for continued research, as influenced by my reviews, are:

- In the floorplate division and subdivision process. This model works on a single typology of a residential double loaded corridor. The subdivision process uses only a handful of flexible prescribed configurations as opposed to true generative layout design.
- The addition of more environmental/sustainable variables within the design parameters. One could conceive this entire project reconfigured to optimize based on LEED design or other sustainable metrics.
- The multi site/multi program flexibility explored in the first semester was dropped due to time restraints and design focus. Given the opportunity I would like to develop this system to become increasingly applicable across a multitude of design projects.
- Finally, improving the flexibility of optimization goals and their integration into the Galapagos solver would greatly improve the functionality of this design process. As Galapagos is a relatively new tool in the Grasshopper workset, its functionality has not been as fully explored in the design process. Giving designers more access to successful precedents will spawn continued creativity.

Final Thoughts

This project has been an amazing endeavor into the potential of digital design. In the coming years I hope to continue this pursuit through new projects and new understandings of information and form generation. I am grateful for all of the resources available to me in this design exercise. I encourage others to continue this line of research as I believe it will unlock new potentials in building design.
Acknowledgements
I dedicate this project to my wife Kayci. Thank you for all of the love and support during this busy time.

A special thank you to Steve Hardy for all of his hard work and encouragement as an adviser.

Also a special thank you to my parents, Tim and Jonna Holland, for all of their support in my life and education.

**Guest Critics:**
Chris Barnwell
Janghwan Cheon
Jeff Day
Chris Ford
Tim Hemsath
Peter Hind
Mark Hoistad
Duc-Huy Huynh
Nate Krug
Works Cited


