// Revealing the Simple Complexity
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Abstract

{ In a world were original ideas are hard to find, it is important to speculate the excising methods and seek inspiration. }

/“Revealing the simple complexity” is a series of explorations which investigates the wonders of Persian patterns and develops its principles through generative and interactive design.

//The exploration consists of four main stages of studies and manifestations.

[1] Fundamental studies, delves into the mathematical detail and principle of traditional Persian patterns, looking at the underlaying rules of the construction and composition of the patterns.

[2] Generative coding and modeling, investigates ways in which traditional pattern algorithms can be simplified and reconstructed. This stage declares the main body of my thesis and includes producing work which explores techniques for form-finding using algorithm and code.

[3] Interactive studies, are another important component of the process. The interaction between designer/user, code/design has been investigated though motion and light sensors in this phase.

[4] A conclusion of all the previous stages have been gathered in the form of architectural manifestations and future application in this chapter.

//My explorations have tried to uncover simple ways in which we could rethink complicated form finding strategies, and suggests a new direction for future explorations in interactive and generative architecture.
Acknowledgment

// I would like to dedicate my thesis to my loving parents, Abbas and Afsaneh, my wonderful sister Arezoo and brother Ahmadreza, for their endless love, support and sacrifice. I could not have done this without you.

// Thank you to my caring and true friend Ahmadreza for all the love, patience and motivation and for standing beside me through my toughest times.

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Dane, for his encouragements and believing in me, to code my way through.
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// And thank you to all my friends and extended family here in the United States and back home for their kindness and understanding.
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}
1 // Fundamental Studies
Persian Patterns as Precedents
Tomb of Hafez [Shiraz]
// Shah Mosque [Isfahan]
Fig 3. // Nasir Al Molk Mosque [Shiraz]
Dolatabad [Yazd]

// Fig 5.
Agha Bozarg Mosque [Kashan] // Fig 6.
// Yazd Bazzar [Yazd]
{ How can we use these precedents to influence the ways we think about form? }
Many research have proven the existence of a profound relationship between mathematics and Persian patterns. Patterns from both Pre-Islamic and Islamic periods have followed a set of geometrical rules and algorithms to construct the most complicated compositions found in architecture and cultural heritage[^1].

Today, we are using computers as tools to provide us with simple algorithms to create complex and unimaginable shapes and forms.

In this research, the first step toward bridging the gap between the traditional and the contemporary way of thinking about form and space, is understanding the underlying principles of Persian patterns.

[^1]: Initial shapes
[^2]: Pattern construction principles
[^3]: Construction process
[^4]: Interplay between planar space and spatial depth

Fig 8. Hammam House [Kashan]

Fig 10. Grid composition

Fig 9. Pattern construction steps
In addition to the basic construction process, geometric symmetries such as scale, rotation, translation and reflection have also been extracted.\[2\]

**Underlaying Rules of Persian Patterns**

// In addition to the basic construction process, geometric symmetries such as scale, rotation, translation and reflection have also been extracted.\[2\]

//Translation

// Vertical Reflection

// Translation + Vertical Reflection

// Rotation

// Rotation + Vertical Reflection

// Rotation + Horizontal Reflection

//Fig 11. Pattern construction |
// Through time, pattern variations show a significant development in complexity of the overall shapes and compositions.[3]

//Fig 12. Time chart of evolution of Islamic Geometric Patterns throughout history |
The following matrices show the process for drawing a simple shape using traditional method of calculation.

**Rotation:**

\[
\begin{pmatrix}
\cos \theta & -\sin \theta \\
\sin \theta & \cos \theta
\end{pmatrix}
\begin{pmatrix}
x \\
y
\end{pmatrix}
\]

1. \[
\begin{pmatrix}
\cos 45 & -\sin 45 \\
\sin 45 & \cos 45
\end{pmatrix}
\begin{pmatrix}
1 \\
0
\end{pmatrix}
= \begin{pmatrix}\sqrt{2}/2 \\
\sqrt{2}/2
\end{pmatrix}
\]

5. \[
\begin{pmatrix}
\cos 45 & -\sin 45 \\
\sin 45 & \cos 45
\end{pmatrix}
\begin{pmatrix}
-1 \\
0
\end{pmatrix}
= \begin{pmatrix}-\sqrt{2}/2 \\
-\sqrt{2}/2
\end{pmatrix}
\]

2. \[
\begin{pmatrix}
\cos 45 & -\sin 45 \\
\sin 45 & \cos 45
\end{pmatrix}
\begin{pmatrix}\sqrt{2}/2 \\
\sqrt{2}/2
\end{pmatrix}
= \begin{pmatrix}0 \\
1
\end{pmatrix}
\]

6. \[
\begin{pmatrix}
\cos 45 & -\sin 45 \\
\sin 45 & \cos 45
\end{pmatrix}
\begin{pmatrix}-\sqrt{2}/2 \\
-\sqrt{2}/2
\end{pmatrix}
= \begin{pmatrix}0 \\
-1
\end{pmatrix}
\]

3. \[
\begin{pmatrix}
\cos 45 & -\sin 45 \\
\sin 45 & \cos 45
\end{pmatrix}
\begin{pmatrix}0 \\
1
\end{pmatrix}
= \begin{pmatrix}-\sqrt{2}/2 \\
\sqrt{2}/2
\end{pmatrix}
\]

7. \[
\begin{pmatrix}
\cos 45 & -\sin 45 \\
\sin 45 & \cos 45
\end{pmatrix}
\begin{pmatrix}0 \\
-1
\end{pmatrix}
= \begin{pmatrix}\sqrt{2}/2 \\
-\sqrt{2}/2
\end{pmatrix}
\]

4. \[
\begin{pmatrix}
\cos 45 & -\sin 45 \\
\sin 45 & \cos 45
\end{pmatrix}
\begin{pmatrix}-\sqrt{2}/2 \\
\sqrt{2}/2
\end{pmatrix}
= \begin{pmatrix}-1 \\
0
\end{pmatrix}
\]

8. \[
\begin{pmatrix}
\cos 45 & -\sin 45 \\
\sin 45 & \cos 45
\end{pmatrix}
\begin{pmatrix}\sqrt{2}/2 \\
-\sqrt{2}/2
\end{pmatrix}
= \begin{pmatrix}1 \\
0
\end{pmatrix}
\]

// Construction of an 8 pointed star using rotation |
{ Pen and Paper Algorithm | }

// In order to create a simple shape, the following "pen and paper" algorithm had to be written in code. "Processing" is considered as the programming language and software, since it offers a great potential for designers to code within the context of the visual arts.[4]

void setup() {  
    size (800, 800, FX2D);  
    background (50);  
}

void draw() {  
    float radius = 100;  
    float center_x = width/2;  
    float center_y = height/2;  
    stroke(10);  
    fill(20, 20, 20);  
    rect(center_x, center_y, 200, 200);  
    fill(110, 20, 20);  
    rect(center_x, center_y, 200, 200);  
    rectMode(CENTER);  
    strokeWeight(1);  
    ellipse(center_x, center_y, 200, 200);  
    ellipse(center_x, center_y, 200, 200);  
    line(center_x-radius, center_y, center_x+radius, center_y);  
    line(center_x, center_y-radius, center_x, center_y+radius);  
    line(center_x-radius, center_y, center_x, center_y-radius);  
    line(center_x+radius, center_y-radius, center_x+radius, center_y+radius);  
}

void draw() {  
    float a = sqrt(2)/2;  
    PVector p1 = new PVector(center_x+a*radius,  
                              center_y-a*radius);  
    PVector p2 = new PVector(center_x-a*radius,  
                              center_y+a*radius);  
    PVector p3 = new PVector(center_x-a*radius,  
                              center_y-a*radius);  
    PVector p4 = new PVector(center_x+a*radius,  
                              center_y+a*radius);  
    PVector p5 = new PVector(center_x, center_y-radius);  
    PVector p6 = new PVector(center_x, center_y+radius);  
    PVector p7 = new PVector(center_x-radius, center_y);  
    PVector p8 = new PVector(center_x+radius, center_y);  
    stroke(10);  
    fill(110, 20, 20);  
    strokeWeight(1);  
    ellipse(p1.x, p1.y, 10, 10);  
    ellipse(p2.x, p2.y, 10, 10);  
    ellipse(p3.x, p3.y, 10, 10);  
    ellipse(p4.x, p4.y, 10, 10);  
    ellipse(p5.x, p5.y, 10, 10);  
    ellipse(p6.x, p6.y, 10, 10);  
    ellipse(p7.x, p7.y, 10, 10);  
    ellipse(p8.x, p8.y, 10, 10);  
    rectMode(CENTER);  
    strokeWeight(1);  
    ellipse(p1.x, p1.y, 10, 10);  
    ellipse(p2.x, p2.y, 10, 10);  
    ellipse(p3.x, p3.y, 10, 10);  
    ellipse(p4.x, p4.y, 10, 10);  
}

// The algorithm and code are written using a similar logic to the pattern construction, where coordination of lines and points had to be defined and constructed. Many calculations had to be done to write the code which suggests, having the strategy and using similar algorithms would not be efficient for operating a generative approach.

{ Pen and Paper Algorithm | }

void draw() {  
    float a = sqrt(2)/2;  
    PVector p1 = new PVector(center_x+a*radius,  
                              center_y-a*radius);  
    PVector p2 = new PVector(center_x-a*radius,  
                              center_y+a*radius);  
    PVector p3 = new PVector(center_x-a*radius,  
                              center_y-a*radius);  
    PVector p4 = new PVector(center_x+a*radius,  
                              center_y+a*radius);  
    PVector p5 = new PVector(center_x, center_y-radius);  
    PVector p6 = new PVector(center_x, center_y+radius);  
    PVector p7 = new PVector(center_x-radius, center_y);  
    PVector p8 = new PVector(center_x+radius, center_y);  
    stroke(10);  
    fill(110, 20, 20);  
    strokeWeight(1);  
    ellipse(p1.x, p1.y, 10, 10);  
    ellipse(p2.x, p2.y, 10, 10);  
    ellipse(p3.x, p3.y, 10, 10);  
    ellipse(p4.x, p4.y, 10, 10);  
    ellipse(p5.x, p5.y, 10, 10);  
    ellipse(p6.x, p6.y, 10, 10);  
    ellipse(p7.x, p7.y, 10, 10);  
    ellipse(p8.x, p8.y, 10, 10);  
    rectMode(CENTER);  
    strokeWeight(1);  
    ellipse(p1.x, p1.y, 10, 10);  
    ellipse(p2.x, p2.y, 10, 10);  
    ellipse(p3.x, p3.y, 10, 10);  
    ellipse(p4.x, p4.y, 10, 10);  
}

// The algorithm and code are written using a similar logic to the pattern construction, where coordination of lines and points had to be defined and constructed. Many calculations had to be done to write the code which suggests, having the strategy and using similar algorithms would not be efficient for operating a generative approach.
Generative Explorations
Cultivating the Imagination
In the generative method, it is important to find an efficient set of algorithms to write as code and produce a wide range of variations. Although there are many principles such as rotation and translation which must be borrowed, the ways we think about shape and pattern using lines and points, must be revised.

As a result, re-thinking the algorithms play an important role in the process of this exploration.

For example for producing a 4 point star shape, we can use the following set of rules:

1. Two circles in different ratios
2. Assigning 4 points on one circle in an equidistant manner
3. Assigning 4 points on the other circle with a 45 phase difference alternatively to the 4 points on the first circle
4. Overlapping the two sets of points
5. Connecting the points

```cpp
void setup() {  
  size(640, 360);
}
void draw() {  
  background(102);
  star(100,100,30,70,4);
}
void star(float x, float y, float radius1, float radius2, int npoints) {  
  float angle = radians(360)/ npoints;
  float halfangle = angle/2.0;
  beginShape();
  for (float a = 0; a < radians(360); a += angle) {  
    float sx = x + cos(a) * radius2;
    float sy = y + sin(a) * radius2;
    vertex(sx, sy);
    sx = x + cos(a+halfangle) * radius1;
    sy = y + sin(a+halfangle) * radius1;
    vertex(sx, sy);
  }
  endShape(CLOSE);
}
```

Re-thinking the algorithm means:

1. Taking advantage of the built-in functions which generative tools (such as Processing) offer.
2. Finding the alternative algorithms which would produce a similar output but in a more efficient manner.

// Diagram of the 4 point star algorithm
{ Re-thinking the Algorithm

  // Borrowing the initiative
  // Questioning the default
  // Looking for a better option }
All the explorations are based on 3 or 4 main algorithms. Also, all the explorations include a shared initial shape (polygon) which produces a wide set of forms, compositions and graphics. The reason behind this is to create a consistent series of forms which can be manipulated and altered easily and coherently.

The following images are part of the series of explorations. The codes have been written and ran in Processing.

In producing all images line weight, color, opacity and movement have been considered and coded.

The side count for the polygons can be changed in the code.
Grid Studies

// In the grid study process, the intention was to replicate the grid composition seen in the precedent.

// As the number of sides in the polygon increases, the space between them becomes tighter and more circular. Perception is challenged to recognize the white spaces as well as the colored spaces.
Layering

// Another characteristic seen in the Persian patterns is layering, which has also been investigated through code.

// By layering the polygons, without any intersection, three dimensional cluster looking forms appear. Different tones of the dominant color are created due to the opacity of each polygon.
Another interesting aspect of generative design is that it allows the integration of other attributes, such as movement, into the design development of architectural concepts and form.

These explorations, rather than being two-dimensional and decorative, borrow the two-dimensional principles from Persian patterns to produce three-dimensional constructs that suggest spatial form.
The three dimensional movement has also been investigated in a more complex composition.
Integrating ambient light into the design environment changes the perception of the form as it moves, appearing to switch color from one side to the other.
Frozen frames of movements would allow interesting forms and compositions to be observed and selected for further development.
// This example presents different manners and suggests different forms as it is moving in more than two dimensions in space.
To explore variety in the movement and to challenge the outputs, in some cases like this example, random numbers were used in parts of the code. In examples where a particular form was desired, a specific numbers had to be
// This example uses specific numbers to create the overall structure which is a combination of a fixed rod grid and a dynamic polygon grid. The movement, however, uses randomized numbers.
Form Follows Movement

// Plan Views

// Side Views
Form Follows Movement

// Plan Views

// Side Views
// Interesting graphics appear when the code allows for movement to be tracked, leaving a 
foot print behind.
This method of creating form, suggests a new drawing technique for conceptual illustrations.
Preserving Memories | Part 1

// Side Views
Preserving Memories | Part 2

// Plan Views
Preserving Memories
// A collection of the generative coding outputs
The explorations suggest // increase in the accessibility of new ideas and possibilities in the design process
Interactive Explorations

Integrating code with micro controllers and sensors
Arduino is an open-source electronics platform based on easy-to-use hardware and software and is intended for interactive projects. Arduino senses the environment by receiving inputs from many sensors, and affects its surroundings by controlling lights, motors, and other actuators.\[3\]

Processing is compatible with Arduino, allowing them to connect and exchange information and data.

In these explorations, Arduino was considered as the interactive aspect and Processing as the generative component.
Interactive studies consist of 4 components:
[4] Light sensors

The light sensors were placed in a circuit and connected to the Arduino Uno which then had to be plugged into the computer to transfer the brightness information which each Red, Blue and/or Green light sensor collected. The Arduino code allowed the data to show on the computer, as it operated the processing code to control the movement and color of the design.

Green sensor activated

Blue sensor activated

Red sensor activated

No light | No sensor activated
4 // Manifestations
Visualization and Development
This visualization suggests possibilities for the design development of a public arena. The spaces can be adjusted based on the activity type and the crowd population.
Various Layouts of the Interactive Arena
This visualization hints the possibility for an environmental interaction with the cone shaped huts. The shelters are sensitive to temperature and light with the louver system adjusting to changes in the environment.
Generation

Plan Views of the interactive hut system shows the generative aspect of the design.
Virtual Reality is becoming more tangible and interactive design is finding a place in this area. Virtual and augmented reality frees architects and designers from structural and physical constraints and allows them to create spaces with a new perspective.

Stepping in the world of virtual reality, heightens possibilities for developing generative designs and enhancing the experience of space for users and audience.
In the entertainment industry, concerts and performing arts, Audio-visual systems and projection mappings are becoming more common and approachable.

Architecture could also be created with this approach. With the use of generative and interactive design, the quality of spatial characteristics could be enhanced and a more pleasant user experience may become possible.
5 // Future Explorations
For the Years Ahead
For architects and designers, taking advantage of virtual and augmented reality, audio-visual systems, projection and projection mapping, would mean reaching towards a wider range of possibilities to integrate design principles with technology. The benefits of interactive and generative design in these areas are that with fewer physical constraints, ultimately uncountable design choices would be possible to imagine, develop and produce. The hope is to answer to as many various user needs as possible and improve spatial experience for a wider range of people and activities.

However, some important questions remain for further exploration and research.

Many questions could be taken to further investigation. Architecture will always carry a profound physicality and materiality and it is important to recognize the physical constrains.

[How could a physical impulse become part of the written code and how designers become aware of it during the coding phase?]
[How material could manifest its characteristics in the sense of virtual reality?]
[How does architecture become a virtual space which could provide physical characteristics?]
[In what ways can architects rethink compositions and forms in the context of code and algorithms to develop a broader range of concept and design possibilities?]
[How could interactive design enhance spatial experience and create opportunities for a wider range of purposes?]
Interactive Design is \{ The Future of Architecture

Architecture is \{ Revealing the Simple Complexity
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{All images are by the author unless noted otherwise}

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