Heritage-Inspired Interactivity: Traditional Geometric Patterns as an Inspiration for Interactive Architectural Prototypes

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Abstract. Coding and visual programming are becoming an important component of design education, with focus on algorithmic thinking, form finding, and generative design. Programming languages like Processing are increasingly explored within shape studies in architecture, thus opening unique possibilities for creative design exploration. Most pedagogical approaches that integrate coding in exploring heritage-inspired geometric patterns focus on shape grammars and rule-based design. This exploratory paper further examines the potential of traditional geometric patterns as inspiration sources for interactivity in architectural design. We discuss the process and outcomes of an undergraduate architectural computing course at the American University in Cairo, Egypt, where students implement visual programming using Processing to develop interactive architecture prototypes based on cultural heritage. Results demonstrated a variety of abstraction and translation strategies for both tangible and intangible heritage inspirations, and generation of emergent concepts for diverse architectural prototypes including urban grids, movable structures, and responsive façades.

Keywords: Generative design, Programming, Pattern generation, Heritage, Interactivity

1 Introduction

Programming and coding are becoming increasingly an inherent component of design education, and are being exploited in several aspects of the design process, including algorithmic thinking, form finding, generative design, creativity, and optimization (Reas and McWilliams, 2010; Burry, 2013; Caetano, 2020; Leitao et al., 2016; Terzidis, 2006). Processing, the open-source programming language originally developed for the electronic and visual arts and design communities (Reas and Fry, 2006), has been recently explored in architectural teaching and research, especially in the area of shape studies (Ahlquist and Menges, 2012), opening up unique possibilities for architects with respect to creative design exploration, formation, and interactivity.

Recent studies on the design exploration of geometric patterns and shapes with respect to tangible cultural heritage demonstrate the potential of computational methods through programming in terms of both analysis and form generation (Agirbas, 2017; Barrios and Alani, 2015), especially as relates to the challenges associated with understanding, simulating, and reconstructing the conditions and rules under which these patterns were created traditionally by the original craftsmen and artists.

This exploratory paper examines the role of traditional geometric patterns – specifically related to Arabic and Islamic heritage – as an inspiration source for interactivity in architectural design. Most pedagogical approaches to integrate computational methods, coding and visual programming in the understanding of traditional geometric patterns in architecture are limited to the theoretical framework of shape grammars and rule-based design (Colakoglu et al., 2008; Abdelsalam, 2012; Alani & Barrios, 2015; Sayed et al., 2016), with little attention to the analysis and understanding of the analogies and interpretations of tangible (and possibly intangible) heritage elements and inspirations. The aim of this paper is to extend the investigation of heritage-inspired geometric patterns in the design and making of interactive architectural prototypes, using the process and outcomes of an undergraduate senior-level elective course at the Department of Architecture at the American University in Cairo, Egypt.

2 Methodology

The aim of the “Advanced Architectural Computing” course was to introduce senior undergraduate students to concepts of advanced computing in architecture including interactive and responsive architecture, where students implement coding and visual programming using Processing to develop interactive prototypes. Samples from the Fall 2020 and Spring 2021 semesters were chosen for the purpose of this paper. Students enrolled in the course had been exposed to two other computing courses; a foundational course involving digital representation, modeling and visualization, and another course involving parametric design using Rhino/Grasshopper, and digital fabrication techniques.

Throughout the course, the students engaged in a series of discussions with expert researchers and professionals in the area of visual programming and interactivity, for a duration of 4 weeks, in addition to 6 weeks of intensive tutorials and assignments in Processing. The tutorials covered fundamentals of coding and visual programming including data, functions, variables, conditionals, loops, object-oriented programming, classes, and arrays, in addition to principles of interactivity including images, pixels, and libraries.

For the remaining 5 weeks of the semester, the students were assigned a project where they were asked to develop an interactive prototype based on an element of tangible cultural heritage that involved a specific geometric pattern and configuration. The main question that the project aimed to answer was "How could heritage be an inspiration for interactive design?". In this heritage-inspired interactive design approach, the aim was to explore the potential of geometric patterns and shapes inspired by different historical examples in architecture as a source of interactive design.

Students were required to develop an interactive Processing "sketch" that best translates the creative and technical skills they acquired. It was required that the project would convey strong relevance to heritage as an inspiration, in addition to demonstrating a deep understanding of the fundamentals of coding through creating a unique, thorough and efficient script. Deliverables were in the form of a video presentation, a short paper, and source code showing the interactive element in terms of both process and product.

The students were asked to explicitly demonstrate their process as follows: (a) departure point (inspiration & concept), (b) pattern abstraction, (c) translation to coding (in the form of pseudocode), and (d) demonstrating the element of interactivity in the design. They were also asked to describe the relevance of their prototypes to potential architectural applications. The students were evaluated based on successful integration of coding fundamentals, logic of design and algorithmic process, design complexity, and relevance to heritage as inspiration. We hypothesized that student outputs would exhibit: (1) diversity of schemes that attempt to abstract the selected geometric pattern(s), and (2) emergent variations of the selected patterns.

3 Results

Upon analyzing the works of 11 students from both semesters, interesting findings related to both process and product were identified. The students extracted multiple analogies and departure points from their selected inspirations, and developed a variety of interactive prototypes that had potential in terms of architectural application.

3.1 Approach and process

As shown in Table 1, the students exhibited a thorough process of defining a specific heritage-related source of inspiration, formulating a process of shape/pattern abstraction, devising strategies for translating these abstractions into pseudocode and scripts in Processing, and finally identifying a logic for interactivity within the developed prototype for user interaction.

Table 1. Summary of student process and approaches

	Inspiration	Abstraction	Translation	Interactivity
S1	Recursion in Islamic patterns	Points and construction lines	Cycles of oscillations	Keyboard press
S2	Islamic rosette	Centralization and symmetry	Derivation of unique geometry	Keyboard and mouse press
S3	Fractal geometry of Islamic star	Subdivision of basic geometry/star	Fragmentation and re-assembly	Keyboard and mouse press
S4	Multi-angled patterns of Mihrab	Spherical modules	Varying pattern density	Keyboard press
S5	Patterns of chaos in Cairo	Lines, zig-zag curves	Oscillation and morphing	Mouse press, song audio
S6	Dome pendentive morphing	Triangles, vertices and circles	Morphing and varying density	Keyboard and mouse press
S7	Infinity/symbolism of the circle	Centralism, motion, spreading	Polygonal sectioning	Keyboard and mouse press
S8	Urban growth in neighborhoods	Nodes, networks	Cellular automata, expansion	Keyboard press
S9	Mihrab geometry	Radiating lines	Rotation, varying lines/positions	Mouse press
S10	‘City of thousand minarets’ skyline	Mapping heritage/modern buildings	Color/size variation and overlay	Mouse press
S11	Islamic Muqarnas in different contexts	Shape changing, 3D illusion	Varying subdivisions and alignments	Keyboard press

The inspiration sources that the students chose to analyze were diverse in nature. One included the reading and analysis of existing geometries and patterns found in Islamic Cairo (e.g. the rosette, star, dome, Mihrab, Muqarnas) as in the case of S2, S3, S6, S9, and S11 respectively. Another source of inspiration involved, as opposed to a straightforward geometric feature, a deeper reading of a conceptual idea that pertains to phenomena or intangible aspects of heritage in a building, neighborhood, or city. Recursion in Islamic patterns, patterns of chaos in the city, urban growth in neighborhoods, and the minaret skyline and heritage/modern building landscape are examples of these conceptual understandings, as observed in S1, S5, S8 and S10 respectively. Other inspirations focused on re-interpreting existing geometries or phenomena like the tracking of Mihrab patterns from different viewpoints and using that feature as a unit of analysis (as in S4), or using infinity in a simple geometry like the circle and its symbolic and spiritual nature in Islamic architecture (as in S7).

In terms of abstraction and translation, the students demonstrated a wide variety of approaches. Some focused on direct extraction of geometry and deriving emergent patterns (e.g. using centralization and symmetry in the Islamic rosette for deriving unique geometries as in S2). Others involved 2D simplification of complex 3D geometries (e.g. abstracting the dome pendentive morphing into triangles, vertices and circles that undergo a continuous cycle of oscillation and morphing as in S6). Other approaches used existing generative systems to adapt and express their concepts (e.g. self-organization and cellular automata to demonstrate branching and growth as in S8, and fractal systems, tiling and subdivision to express fragmentation and re-assembly as in S3).

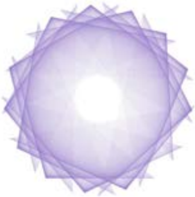
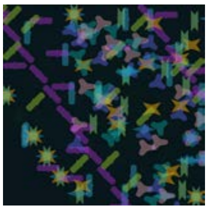
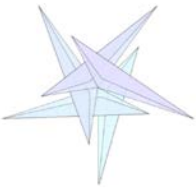
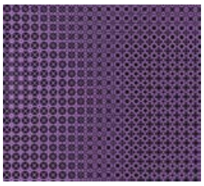
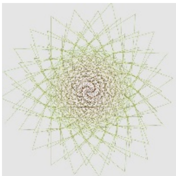
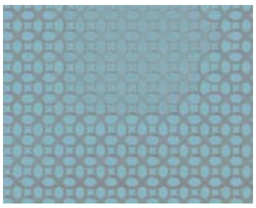
Another set of approaches extracted and represented partial data from the geometry (e.g. selecting radiating lines from the Mihrab geometry and applying various rotations, additions, and alterations in positions and alignments as in S9). Other approaches conducted yet a higher, more sophisticated and far less straightforward abstractions (e.g. choosing spherical modules that undergo continuous variation in pattern density based on imagining different instances of user eye movement/tracking of the multiple patterns of Mihrab geometry as in S4, using oscillations of points and construction lines base don a recursion concept as in S1, applying shape/color changing and 3D illusion strategies based on the Muqarnas hierarchical configurations as in S11).

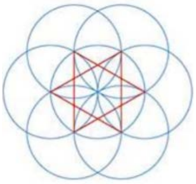
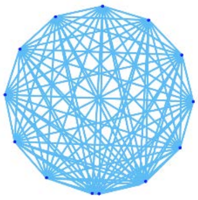
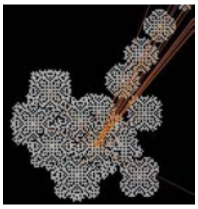
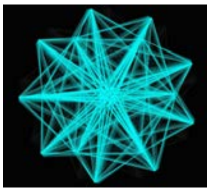
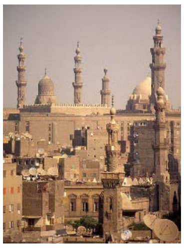
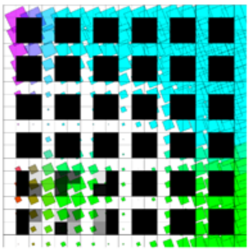
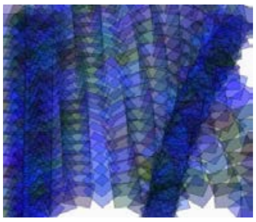
3.2 Outputs and potential applications

With regards to the student prototype outputs, most of the work was in the form of 2D generative art that demonstrated prospects of 3D geometry and architectural elements. Table 2 shows a visual illustration of inspiration samples followed by the students, in addition to samples of the prototype outputs and their corresponding potential architectural applications, as perceived and communicated by the students in their final presentations and papers.

Some prototypes corresponded directly geometrically to the sources of inspiration, as in S2, S6, S7, and S8. Others had a more sophisticated derivation of novel and emergent geometrical modules and interactivity concepts. S1 for example utilized the concept of recursion in Islamic patterns to generate custom designs unique to each user interacting with the system interface. Different parameters were triggered to induce varying inputs per user, like the rotation angle, oscillation angle, number of source points, and number of segments. By virtue of using different keyboard triggers and types of presses, a variety of output patterns and cycles of oscillation would be generated, resulting in unique complex geometries all derived from the initial inspiration. The architectural purpose of this unique mode of interactivity was to allow for potentially unique diverse patterns of responsive louvers, kinetic apertures and solar screens that are simultaneously harmonious and exhibiting subtle diversity for a rich, contemporary and heritage-inspired building facade design.

Table 2. Samples of student inspirations, outputs and potential applications

	Sample inspiration	Sample prototype output	Keywords and Potential architectural applications
S1			*Keywords*: Recursion, oscillations *Potential applications*: Responsive louvers, kinetic apertures, and solar screens
S2			*Keywords*: Centralization, symmetry Potential applications: Responsive sheds and screens
S3			*Keywords*: Fractal geometry, subdivision, fragmentation Potential applications: Kinetic modular unit in a responsive façade
S4			*Keywords*: Multi-angles, spherical module, varying density *Potential applications*: Kinetic apertures in a responsive façade
S5			*Keywords*: Chaos, oscillation, morphing *Potential applications*: Urban grids/patterns
S6			*Keywords*: Pendentive morphing, varying density *Potential applications*: Shape-changing mechanical shading system

S7			*Keywords*: Infinity, symbolism, centralism, spreading *Potential applications*: Structural component, kinetic shading device
S8			*Keywords*: Growth, self-organization, nodes, networks *Potential applications*: Urban grids/patterns, building façade skin patterns
S9			*Keywords*: Radiation, rotation, position variation *Potential applications*: Large-span structures, lattice structures and building skins
S10			*Keywords*: Multiplicity, mapping, variation, overlay *Potential applications*: Double skin façade patterns, urban grid patterns
S11			*Keywords*: Shape-changing, 3D illusion, subdivision *Potential applications*: Shape-shifting responsive screens, interactive media walls

S3 used the Islamic star, usually an element that results from subdividing a circle or hexagon, to create an origami-like array of triangles joined and re-assembled in different ways based on interactively triggering variations in angles, number of edges, and star state, thus creating infinite possibilities for kinetic modular units. S10 created a visual dialogue between two hypothetical geometrical sets denoting “heritage” and “modern” buildings (independent from and dependent on mouse position respectively). By virtue of the continuous overlay between the sets, instances of visually prominent heritage buildings versus color-changing buildings continue to emerge, as a representation of the authenticity of heritage buildings in contemporary urban settings.

3.3 Interactivity

Each of the students in the course was asked to introduce an element of interactivity to their projects in a way that exemplifies and demonstrates the richness of the heritage inspiration. The purpose was to encourage the students to introduce both diversity in the number of alternatives and emergence and novelty in the resulting output. Once the basic structure and logic of the identified geometry and pattern were established, the students were encouraged to apply different interactivity triggers such as keyboard and mouse presses to induce variations of emergent patterns based on the abstracted heritage-inspired concepts. As an example, S1 used basic points and construction lines to generate oscillation cycles. However, using different combinations and sequences of keyboard and mouse presses in Processing, a wide variety of emergent patterns was generated, to allow designers at the user end to come up with novel generative patterns, as shown in Figure 1.

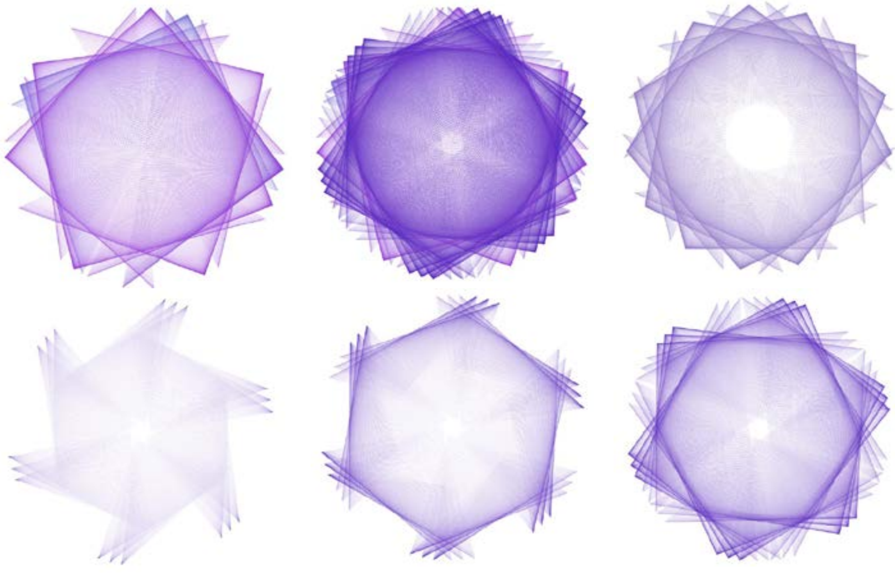


Figure 1. Sample of geometric variations induced by different interactivity triggers. Each pattern is generated upon applying a different sequence of oscillation cycles (S1)

S7 reimagined the circle in Islamic architecture to develop different variations denoting the essence of the shape symbolically, structurally and spiritually (Figure 2). Once the main concept related to centralism, motion and multi-path spreading was established, a set of interactivity triggers were formulated.

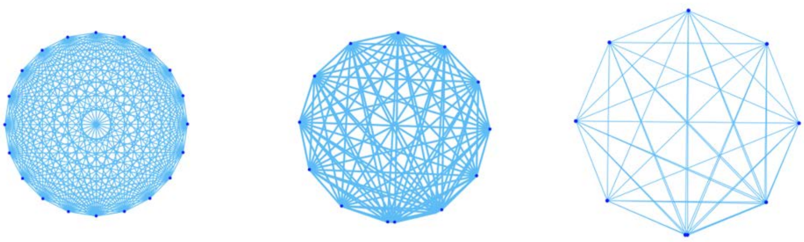


Figure 2. Sample of geometries induced by different interactivity triggers in S7

Based on specific keyboard and mouse presses, the stroke thicknesses, number of intersecting points, and circumference divisions could be altered. Two nested loops were developed to map line coordinates based on the angles and to draw a circle at the extremity of the line as a node with specific sizes. The pseudocode and workflow chart for this process is shown in Figure 3.

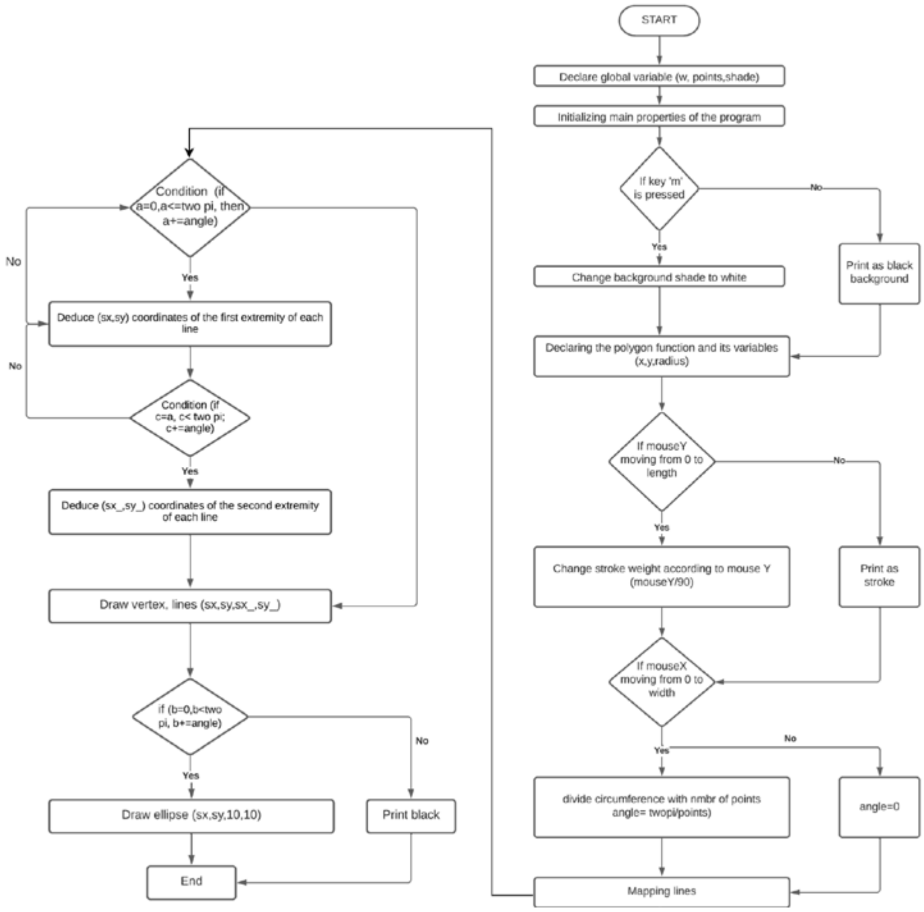


Figure 3. Pseudocode and workflow chart for S7

For S11, the Islamic Muqarnas was a key factor in determining aspects of lightness, structure, flexibility, scaling, hierarchy, and 3D illusion. All these dimensions acted as inspirations for the interactivity concept. Figure 4 shows pattern and color variations resulting from these different interactivity triggers. Keyboard and mouse presses in this case resulted in a variety of sequences of rotation angles, translations, module sizes, and color schemes, therefore reflecting the complexity of the Muqarnas and re-interpreting its formal logic into patterns conducive to structural, spatial, and double facade skin settings.

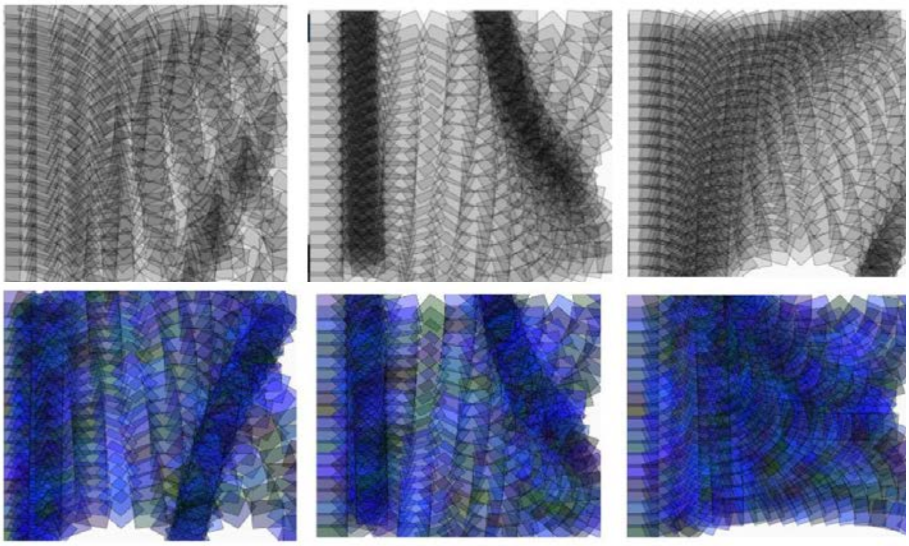


Figure 4. Sample of pattern and color variations induced by different interactivity triggers in S11. Patterns are generated based on sequences of rotation angles and key presses.

The code for this pattern allowed for creating a double grid 20X20 square array forming a matrix of varying shapes. These were flexibly arranged by a nested loop for a hierarchical scaling/positioning of squares, where integers “i” and “j” refer to the indices in the X & Y matrix directions. Using a pushMatrix and popMatrix function, a translation and angle rotation was initiated at the shape corners to allow for a variety of emergent patterns. Upon key press, both scale and angle of rotation are varied to create pattern overlaps, which is further visualized using a “color” constructor. An excerpt of the code is shown below:

```
Shape[][]shapes = new Shape[20][20];
void setup(){
  size(1000,1000,P3D);
  for(int i=0;i<20,i++){
  for(int j=0;i<20,j++){
    shapes[i][j]= new Shape(50*i,50*j,50-i*2,50-i*2,0);}}}
void draw(){
```

```
  background(250);
  for(int i=0;i<20,i++){
  for(int j=0;i<20,j++){
     pushMatrix();
     translate(50*I,50*j);
     rotate(radians(shapes[i][j].angle*i));
     shapes[i][j].display();
     popMatrix();}}}
void keyPressed(){
  for(int i=0;i<20,i++){
  for(int j=0;i<20,j++){
     shapes[i][j]=
     new Shape(110*i,110*j,110,0.05*i*j,color(0,38));}}}
```

4 Discussion and Future Work

The results of this exploratory work confirmed the initial hypothesis in the paper, where the students extracted multiple analogies, re-imaginations and iterations related to the selected inspirational patterns and geometric configurations (e.g. Muqarnas, dome, Mihrab, Islamic rosette) and developed emergent concepts for a variety of architectural prototypes including movable structures, dynamic façades, responsive systems, interactive media walls, kinetic shading devices, and others. This presented a supporting argument for the positive potential of visual coding and programming in the process of creative design exploration and in unpacking the rules and conditions of traditional geometric patterns as a source of inspiration for interactivity.

The methodical process in this paper, which comprised a thorough analysis of heritage-based inspiration, formal abstraction process, systematic translation into pseudocode, and definition of interactivity triggers based on the established formal logic, was shown to allow for: (a) authenticity and grounding of prototypes based on both a genuine inspiration and a traceable process, (b) diversity of alternatives and schemes that all embody a true representation of the heritage-based conceptual and geometrical departure, (c) a wide variety of emergent patterns that extend and expand traditional geometries into a larger pool of possibilities, allowing designers to develop unique schemes for exploration from basic modules, (d) developing schemes that are conducive to architectural notions of space, structure, facade envelopes, and other endless multi-scalar possibilities including urban networks, structural details, etc.

Future work will focus on (a) developing a heritage-inspired framework for generating interactive architecture prototypes based on traditional geometric patterns, and (b) integrating scripting capabilities with mainstream architectural modeling software to develop 3D interactive architectural prototypes.

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