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Development of Parametric Shape Grammar for Generative Systems of Zankwaye in Hausa architecture, Northern Nigeria

[1]Olakanbi Bolaji AbdulRaheem, [2]Osama Rayis, [1]Hassan A. Tanimu, [1]Zakari Aliyu, [1]Nusa Jibril Danlami, [1]Ajibola Edidiong Nseabasi, [1]Garuba Sodiq

[1]Department of Architecture & Ind. Design, Faculty of Environmental Sciences, University of Abuja, FCT, Abuja
[2]African City of Technology, Khartoum, Sudan

Corresponding Author:
Olakanbi Bolaji AbdulRaheem
E-mail: abdelrahim.bola@gmail.com

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ABSTRACT

This study addresses the problem of diminishing knowledge of Zankwaye (pinnacles) and their role in Hausa traditional architecture, where cultural, symbolic, and structural functions remain undocumented in computational form. The aim is to develop a rule-based shape grammar system that encodes these elements into generative models, with objectives to extract formal rules, parametrize their geometry, and test cultural variations for design reproduction and conservation. Methodologically, the study examined 100 traditional Hausa houses and mosque buildings across Northern Nigeria using field surveys, photographic documentation, and archival sources. Shape grammar rules were derived through rule extraction tables and diagrammatic derivations, and parametric models were constructed to encode variables of height, diameter, spacing, and cultural style. Data analysis employed comparative modeling, generative testing, and expert validation to evaluate cultural fit and structural feasibility. Findings reveal that corner pinnacles (Zc) consistently dominate edge pinnacles (Zr) in hierarchy, with rhythmic repetition generating the iconic crown-like skyline. Rules such as gap modulation, hierarchy enforcement, and erosion simulation reproduce both intact and altered parapet conditions. The visual grammar diagrams confirm that Zankwaye follow predictable cultural rules while allowing parametric variability. The study concludes that a computational grammar can successfully capture and regenerate Hausa parapet traditions, balancing cultural symbolism and structural logic. It recommends embedding this grammar into digital heritage conservation tools, BIM libraries, and generative design platforms, ensuring the transmission of Hausa architectural identity while enabling new adaptive uses in contemporary design.

KEYWORDS
Parametric Shape Grammar, Generative Design Systems, Zankwaye, Hausa architecture and Northern Nigeria

1. Introduction

The concept of shape grammar has evolved globally as a powerful computational method for encoding and reproducing architectural forms through rules and transformations. Since its introduction by Stiny and Gips in the 1970s, shape grammar has enabled architects and researchers to model traditional and modern architectural systems by extracting formal rules from precedents and applying them to generate new, yet culturally grounded, designs (Stiny & Gips, 1972). Parametric design methods have expanded this capacity, allowing for flexible, rule-based manipulations of geometric and stylistic variables to produce generative systems. In contemporary discourse, shape grammar has become a cornerstone in computational design for both architectural practice and heritage conservation, particularly in contexts where local identities must be preserved alongside technological advancement (Knight, 1999).

On the continental scale, Africa has gradually begun to explore computational approaches to heritage and architectural systems, though much of the scholarship remains underdeveloped compared to Europe and North America. Research in African contexts increasingly emphasizes the digital documentation of built heritage, using shape grammar and parametric design to preserve intangible cultural values embedded in architecture (Oladapo, 2021). The adoption of generative systems provides opportunities to encode indigenous design logic into computational frameworks, ensuring cultural transmission in rapidly urbanizing regions. In particular, West African architectural traditions, with their elaborate ornamentation and symbolic skyline features, are ripe for reinterpretation through parametric methods that can balance tradition and innovation.

Regionally, Hausa architecture in Northern Nigeria presents one of the most remarkable cases where vernacular expression intersects with cultural identity and socio-political symbolism. The Hausa built environment, characterized by adobe walls, decorated façades, and distinctive skyline ornamentation, reflects centuries of aesthetic refinement and adaptation to climatic conditions (Prussin, 1986). Among the most dominant features are zankwaye (sing. zanko), ornamental pinnacles positioned at the corners and along parapets of palaces, mosques, and elite residences. These pinnacles function both as architectural markers of authority and as aesthetic crowns that dominate the urban skyline of historic Hausa cities such as Zaria, Kano, and Katsina (Fletcher & Bature, 2020). Embedding the logic of zankwaye into generative design systems requires a parametric grammar that recognizes their symbolic, geometric, and cultural roles.

The development of a parametric shape grammar for Hausa pinnacles thus begins with geometric variables. The height of the pinnacle (Hc for corner pinnacles, Hr for rhythmic pinnacles) is a direct proxy for hierarchy and skyline dominance. Taller pinnacles at the corners symbolize authority and anchor the parapet visually, while rhythmic pinnacles of varying height introduce cadence across the skyline. The diameter or base thickness (Dc, Dr) acts as a proxy for structural stability, ensuring pinnacles are proportionate to wall capacity. Combined, height and diameter define the slenderness ratio (H/D), which serves as a proxy for visual prominence and elegance (Mitchell, 1990). These geometric measures interrelate to define the skyline's legibility while preserving the structural integrity of earthen construction.

In addition to geometry, stylistic variables represent cultural aesthetics embedded in Hausa architecture. Pinnacle form types (Sc, Sr), such as conical, bulbous, or finial-like shapes, serve as proxies for cultural motifs and can signify regional or dynastic preferences. Surface treatments—whether smooth, incised, or painted—convey decorative richness and are indicative of craft traditions. The symmetry or asymmetry of arrangement further reflects aesthetic order or improvisation, aligning with cultural narratives of balance and authority. Importantly, variation probability (σs) captures the stochastic quality of Hausa pinnacles, as no two parapets are identical, thus embedding cultural tolerance for diversity within a parametric framework (Eisenman, 2003).

At the computational level, parametric variables provide the link between formal rules and generative outputs. Generative rules (R1–R8) form the operational backbone of the grammar, encoding how pinnacles are placed, repeated, or transformed along a parapet. Probabilistic jitter (σh, σg) introduces controlled randomness in pinnacle height and spacing, simulating the organic rhythm of Hausa skylines. Constraint enforcement (C, H) ensures cultural and structural feasibility, preventing forms that would contradict symbolic hierarchy or compromise stability. Edge condition rules, such as mandatory termination by a taller corner pinnacle (Zc), guarantee the skyline's completeness and cultural legibility. These computational variables operationalize cultural knowledge as flexible rules within generative design systems.

The interrelationships among these variables are central to developing a generative system. For example, geometric measures like height and spacing influence aesthetic perceptions of rhythm, while stylistic features such as form type and surface treatment amplify or soften these effects. Similarly, probabilistic jitter interacts with variation probability to balance order and improvisation, ensuring that generated skylines remain recognizably Hausa yet exhibit authentic variability. Constraints link computational feasibility with cultural requirements, such as enforcing corner prominence to maintain symbolic hierarchy. This web of interdependencies ensures that parametric models not only replicate form but also encode meaning.

From a heritage perspective, embedding these variables into a parametric grammar provides a pathway for digitally preserving Hausa architecture in the face of modernization and erosion. By codifying pinnacles as parametric elements, future generations can simulate, reconstruct, and reinterpret Hausa skylines without losing their cultural DNA. Moreover, such grammars can inform urban conservation policies by providing measurable proxies for authenticity, aiding in the evaluation of restoration projects and new architectural interventions (Buchanan, 2022).

At the computational scale, the grammar also advances discussions of how generative systems can be tailored to specific cultural contexts. Unlike generic parametric tools, a Hausa-focused shape grammar leverages local variables and proxies, producing outputs that are both context-sensitive and scalable. This flexibility has implications for urban modeling, virtual reality environments, and algorithmic heritage visualization, situating Hausa architecture within global conversations on computational design while affirming its regional specificity.

Ultimately, the development of a parametric shape grammar for Hausa zankwaye reflects a convergence of global computational methods, African heritage imperatives, and Nigerian cultural realities. It builds upon geometric, stylistic, and computational variables to create a generative system capable of encoding the rhythm, hierarchy, and diversity of Hausa skylines. By interlinking proxies such as pinnacle height, spacing, form type, and generative rules, the framework produces a system that is not only technically feasible but also culturally meaningful. This approach ensures that the pinnacles of Hausa architecture continue to crown urban skylines, both in their physical and digital forms.

The skyline of Hausa cities such as Kano, Katsina, and Zaria has long been defined by zankwaye, upward-pointing pinnacles that crown the parapets of palaces, mosques, and noble residences. These elements serve both as architectural markers of status and as aesthetic devices that assert cultural identity across Northern Nigeria. However, despite their prominence in Hausa architectural heritage, zankwaye have not been systematically studied within computational frameworks such as parametric shape grammar and generative systems. The lack of computational models threatens not only the continuity of Hausa cultural expression in modern design but also the preservation of intangible rules that govern variation, rhythm, and symbolic hierarchy in Hausa skylines. A parametric shape grammar, by formalizing the generative principles of zankwaye, offers an opportunity to preserve and adapt these forms within both architectural practice and digital heritage conservation.

One of the key problems affecting the generative systems of zankwaye in Hausa architecture is the progressive loss of geometric knowledge that traditionally informed their form and proportions. In historical practice, builders intuitively controlled variables such as pinnacle height, base thickness, and spacing intervals, creating skylines with a delicate balance of hierarchy and rhythm. With modernization and the decline of apprenticeship systems, much of this tacit knowledge has been lost, resulting in poorly proportioned or even omitted pinnacles in contemporary Hausa buildings (Fletcher & Bature, 2020). This geometric erosion compromises both the structural stability and the symbolic legibility of Hausa skylines. Parametric approaches grounded in geometric variables such as height-to-diameter ratio, spacing intervals, and repetition counts can help formalize and reintroduce these principles into generative systems, ensuring that designs preserve structural feasibility and visual prominence while allowing flexible adaptation for contemporary applications (Mitchell, 1990).

A second problem lies in the erosion of cultural aesthetics and stylistic diversity that zankwaye historically embodied. The pinnacles once reflected stylistic variations through conical or bulbous forms, surface treatments such as painting and incising, and rhythmic asymmetries that expressed cultural identity and regional distinctions (Prussin, 1986). However, as contemporary construction practices increasingly adopt modern materials and standardized designs, the stylistic richness of Hausa pinnacles is being homogenized or eliminated. This erasure diminishes not only architectural beauty but also the socio-cultural meanings embedded in skyline ornamentation. By embedding stylistic variables such as form type, surface treatment, and variation probability into a parametric shape grammar, generative systems can reintroduce aesthetic flexibility while maintaining symbolic continuity. Computational variables such as probabilistic jitter and generative rules can simulate authentic variation, ensuring that digital and physical reproductions of Hausa pinnacles remain culturally resonant rather than mechanically uniform (Knight, 1999).

2. Literature Review

Parametric shape grammar is rooted in the original concept of shape grammars — a formal system where visual compositions are generated by iterative application of production rules — first articulated by Stiny and Gips (1972). Under this foundational view, a grammar consists of an alphabet of shapes, a set of rules for transforming those shapes, and derivations that produce valid designs; the grammar both describes and generates a design language (Stiny & Gips, 1972). Later scholars reframed shape grammars within computational practice, arguing that parametric extensions allow continuous numeric parameters (e.g., height, spacing, proportion) to be attached to symbolic rules so that a single rule can produce a family of variants rather than a single discrete outcome (Knight, 1999; Mitchell, 1990). This parametric turn makes grammars amenable to digital design tools and enables controlled variability — essential when modeling vernacular features that are rule-governed yet variable in execution.

Generative systems expand on shape grammar by coupling rule-based generation with algorithmic procedures and interactive control, so that designers or automated agents can explore vast design spaces while maintaining adherence to a cultural or structural grammar (Guzelci, 2014; Knight, 1999). Authors such as Eisenman (2003) and Mitchell (1990) emphasize that generative systems are not merely randomizers but are conditioned engines: they encode constraints, probabilistic variation, and evaluation loops (e.g., structural or aesthetic checks) that produce acceptable designs. In practice, parametric generative systems combine deterministic grammar rules (for cultural legibility) with stochastic operators (for variation), and they integrate validation stages (for feasibility), producing outputs that are both diverse and meaningful (Eisenman, 2003; Guzelci, 2014).

Applying these ideas to vernacular architectures, several scholars argue that vernacular form languages are particularly amenable to parametric grammars because they often embody repeatable, rule-like compositional strategies (Prussin, 1986; Oladapo, 2021). In the case of Hausa architecture, elements such as parapet pinnacles (zankwaye) follow recognizable placement, proportion and stylistic conventions that can be formalized as symbols and rules (Prussin, 1986; Umar et al., 2019). Computational analyses and shape-grammar studies in West African contexts (e.g., Olakanbi et al., 2025) demonstrate that courtyard types, room logic, and ornamental rhythms can be extracted from corpora of plans and elevation data, then encoded into parametric operators that reproduce both plan and skyline grammars. These studies show that a parametric approach can capture not only geometric relationships but also cultural hierarchies (corner > edge) and stylistic variation, enabling generative reconstructions that respect local semantics (Olakanbi et al., 2025; Prussin, 1986).

Generative modeling of zankwaye raises particular computational and practical issues that the literature highlights: data scarcity and variability in photographic/documentary records, the need for multi-scale rules (plan → elevation → skyline), and the requirement for structural and material constraints appropriate to earthen construction (Mitchell, 1990; Umaru et al., 2022). Researchers emphasize combining computer vision (to extract peaks and proportions from images), parametric rule fitting (to estimate distributions like spacing and height), and constraint solvers (to ensure feasible slenderness ratios and load paths) so that generated pinnacles are both authentic-looking and buildable (Knight, 1999; Mitchell, 1990; Umaru et al., 2022). Such hybrid workflows — mixing CV, statistical fitting, and parametric grammars — have been successfully trialed in related contexts (Guzelci, 2014; Olakanbi et al., 2025), suggesting a viable path for Hausa zankwaye despite local data and resource limitations.

Finally, the literature converges on the view that parametric shape grammars and generative systems offer potent tools for cultural preservation, design adaptation, and pedagogy in regions like Northern Nigeria, provided they are sensitively configured to local knowledge systems (Umar et al., 2019; Emusa, 2024). Authors advocating this approach stress participatory data collection, inclusion of craft knowledge (e.g., plastering cycles, seasonal repairs), and the embedding of stylistic priors (motif libraries, city-specific rules) to prevent homogenization and to support conservation aims (Umaru et al., 2022; Emusa, 2024). When implemented responsibly, a parametric generative grammar for zankwaye can reproduce culturally legible skylines, enable restoration simulations, and supply designers with context-aware generative options that reinforce rather than dilute Hausa architectural identity (Olakanbi et al., 2025; Umaru et al., 2022).

Umaru, Adamu, Bello, and Jolaoso (2022) conducted a study on Hausa vernacular architecture with a case study of Dakali and Zaure in Jos, Plateau State, Nigeria, aiming to examine their cultural and religious significance and to emphasize the need for their conservation and preservation within evolving architectural trends. Using a combination of purposive sampling, content analysis, literature review, and field surveys involving interviews, observations, and case studies, the authors identified and analyzed the defining features of Hausa vernacular architecture. Their findings revealed that Dakali and Zaure have remained prominent architectural elements that continue to perform their intended cultural and functional roles despite modern influences. The study concluded that the survival and relevance of these features lie in their ability to adapt while retaining symbolic expressions that communicate history, identity, and cultural values. Accordingly, the authors recommended stimulating awareness and regenerating Hausa/Fulani vernacular architecture through creative integration of traditional symbols, ornamentations, and spatial concepts with modern planning and design approaches to ensure sustainable preservation and cultural continuity (Umaru et al., 2022).

Emusa (2024) conducted a comparative analysis of traditional architecture in Northern and Southern Nigeria with the aim of identifying commonalities that reflect cultural identity and historical heritage across both regions. Using a review of existing literature and architectural documentation as the methodology, the study examined building materials, spatial organization, decorative motifs, construction techniques, and socio-cultural factors such as communal living, religious beliefs, and socio-economic activities. The findings revealed that despite geographical and cultural differences, significant commonalities exist in architectural form, spatial organization, building materials, and construction methods, while environmental conditions and cultural practices played critical roles in shaping design evolution. The study concluded that traditional architecture in both regions is deeply rooted in shared socio-cultural values, which ensure the preservation and continuity of these practices across generations. Based on these insights, the author recommended sustainable preservation strategies, cross-cultural dialogue, and community engagement initiatives to safeguard Nigeria's architectural heritage and promote cultural unity (Emusa, 2024).

Umar, Yusuf, Ahmed, and Usman (2019) conducted a study in Northern Nigeria with the aim of conserving, preserving, and restoring Hausa traditional architecture by highlighting its spatial morphology and construction techniques from the village to the town scale. Using a review and descriptive research methodology, the study examined existing literature to identify the defining features of Hausa traditional compounds, including their spatial subdivisions and development processes. The findings revealed that Hausa family compounds are organized according to the concept of triple spaces—inner core, central core, and outer core—mirroring the larger urban structure of towns and cities as "Kauye," "Gari," and "Birni." The study also emphasized the cultural and structural significance of traditional building materials and methods such as "Tubali," "Azara," and "Asabari," alongside interior motifs and decorative elements like "Makuba" and "Zankwaye," which collectively form the architectural identity of Hausa settlements. It concluded that appreciating these morphological and technical features is crucial for both conservation and restoration practices, ensuring the transmission of cultural heritage across generations. The authors recommended the promotion of conservation-based architectural practices that integrate indigenous techniques and cultural aesthetics into contemporary planning and restoration efforts (Umar et al., 2019).

Guzelci (2014) conducted a study in Istanbul, Turkey, with the aim of experiencing and formalizing the syntactic and structural information underlying the plan layouts of traditional Turkish houses through the development of an interactive expert system. The methodology employed was shape grammar, which was used to analyze the design language and algorithmic structures of the traditional house typologies and to generate new design variations. An algorithm based on shape grammar rules was developed and implemented in the “Processing” coding interface, using input data from Cagdas’s earlier work on the language of Turkish houses. The study found that the algorithmic system successfully generated diverse plan layout alternatives, while its interactive nature allowed users to engage with and understand the formal compositions and spatial logic of traditional Turkish house plans. The conclusion drawn was that the shape grammar approach provides a powerful framework for formalizing design knowledge, preserving cultural heritage, and enabling computational design explorations. The author recommended further development of interactive computational systems to record, replicate, and expand traditional architectural design languages within digital generative environments (Guzelci, 2014).

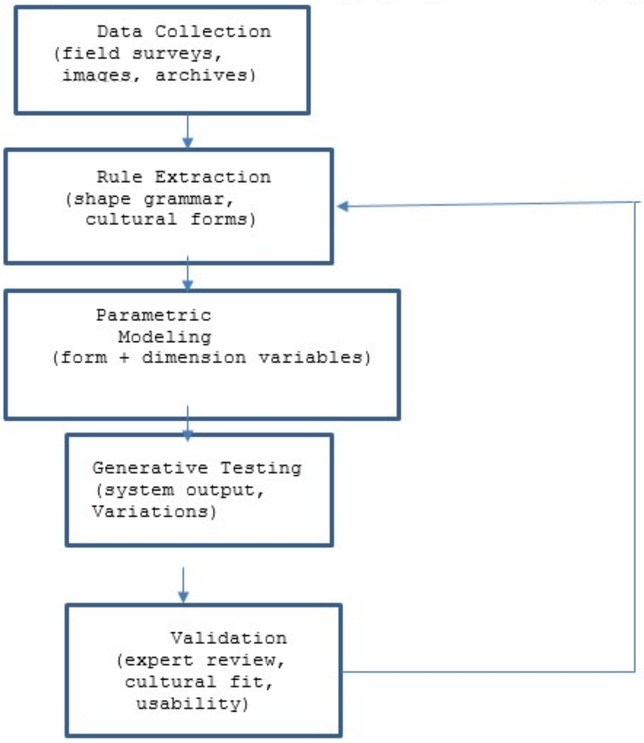
Olakanbi, Abdullahi, Zakari, Yaradua, Nseabasi, Danlami, and Hassan (2025) conducted a study in Kano Metropolis, Northern Nigeria, aimed at computationally analyzing the spatial organization of Hausa traditional houses using the analytic shape grammar method to provide feasible design exploration pathways. The researchers collected existing plan layouts from a corpus of surveyed works between 2005 and 2008 and analyzed thirty-eight layouts with the goal of producing a Hausa architectural design grammar. Their findings classified the spatial organization into two major courtyard-based types, namely hypo-courted and interconnect-courted houses, and further into five groups based on spatial composition and area: 3–6 room single type (100 sqm), 5–8 room single type (225 sqm), 2–3 rooms of 3 apartments type (486 sqm), 2–3 rooms of 3 row houses type (900 sqm), and the storey building type. The study concluded that Hausa traditional architecture exhibits systematic spatial logic rooted in courtyard typologies and hierarchical arrangements, reflecting both cultural and environmental adaptation. The authors recommended extending future studies to include a broader stylistic range of Northern Nigerian architecture, developing a formal description of Hausa urban design in relation to city forms, and constructing a generative computational mechanism to formalize and advance the design processes of this unique architectural tradition (Olakanbi et al., 2025).

3. Methodology

The research design for the *Development of Parametric Shape Grammar for Generative Systems of Zankwaye in Hausa Architecture, Northern Nigeria* adopts a parametric shape grammar framework, which integrates computational rule-based modeling with cultural, geometric, and stylistic variables. This design allows the study to systematically extract the formal rules governing the design of *zankwaye*—the parapet pinnacles that define Hausa architectural skylines—through field surveys, photographic documentation, archival drawings, and computational analyses. Using principles outlined by Stiny and Gips (1972), and later enhanced by Knight (1999) and Mitchell (1990), the design involves encoding *zankwaye* forms into symbolic alphabets, defining rules for their transformation, and parameterizing their dimensional and stylistic variations. The methodology combines content analysis of architectural features (as emphasized by Umaru et al., 2022), computational mapping of proportions (Olakanbi et al., 2025), and cultural contextualization of aesthetics (Prussin, 1986; Emusa, 2024). This approach ensures that both tangible (geometric dimensions, spatial relations) and intangible (cultural meanings, symbolic ornamentation) components are preserved within the grammar system, enabling the generation of authentic yet variable forms.

The justification for choosing this parametric shape grammar design lies in its dual capacity for cultural conservation and generative adaptability. Unlike conventional architectural documentation, which may freeze forms into static records, a parametric grammar encodes design logic and variability, thus ensuring that Hausa *zankwaye* can be regenerated across contexts without losing their authenticity. By embedding computational variables, the design accounts for environmental, material, and structural constraints, addressing the challenges of adaptation in contemporary practice (Umar et al., 2019; Oladapo, 2021). At the same time, the inclusion of stylistic and cultural parameters ensures that outputs remain legible within Hausa architectural traditions, preventing homogenization (Umaru et al., 2022). This makes the research design both a conservation tool and a design system: it preserves cultural identity while equipping architects and heritage practitioners with a flexible, generative model that supports restoration, simulation, and creative reinterpretation. Thus, the choice of parametric shape grammar as the research design represents a methodological bridge between tradition and innovation, aligning with broader goals of architectural heritage preservation and computational design advancement.

Figure 3.1: workflow of developing a generative shape grammar for Zankwaye



Source: Author field surveys (2025)

This diagram 1 outlines the workflow of developing a generative shape grammar for Zankwaye from data to validation. The process begins with data collection through field surveys, images, and archival research, which provides the empirical basis for understanding Hausa architectural forms. Next, rule extraction identifies the cultural and geometric logics—translating traditional design principles into shape grammar rules. These rules feed into parametric modeling, where form and dimensional variables are encoded, allowing flexible adjustment of height, spacing, and style. The models are then subjected to generative testing, producing multiple variations that simulate real-world parapet configurations and explore possible design scenarios. Finally, the cycle closes with validation, where experts assess outputs for cultural authenticity, structural feasibility, and usability, feeding insights back into the rule set. This cyclical structure ensures that the system is both technically rigorous and culturally grounded, blending traditional Hausa aesthetics with computational design methods.

4. Results

Figure 4.1 : Hausa Traditional Architecture: Roof Pinnacles, Zankwaye (plan lay-out & Elevation)

STEP 1 — PLAN (TOP VIEW)

Zankwaye (shown as "/\") at corners and in rhythm along the parapet.

```
     /\   /\   /\   /\   /\
   +--------------------------+
/\ |                          | /\
   |                          |
   |       (Rufi / Roof)      |
/\ |                          | /\
   +--------------------------+
     /\   /\   /\   /\   /\
```

Legend: /\ = Zanko (pinnacle); + - | = Parapet outline; blank = roof

Figure 4.2: Hausa Traditional Architecture: Roof Pinnacles, Zankwaye (plan lay-out & Elevation)

Source: https://images.app.goo.gl/dd3cRKK6CuxdL2rv8 (2025)

STEP 2 — ELEVATION (FRONT VIEW)

Rhythmic zankwaye sit on the parapet above the katanga (wall).

Figure 4.3: Hausa Traditional Architecture: Roof Pinnacles, Zankwaye (Elevation)

```
    /\    /\    /\    /\    /\    /\
   / \  / \  / \  / \  / \  / \
-----------------------------------------------<- Parapet line
|                                             |
|         Katanga (Wall)                      |
|                                             |
-----------------------------------------------<- Ground
```

Figure 4.4: Hausa Traditional Architecture: Roof Pinnacles, Zankwaye (Elevation)

Source: https://images.app.goo.gl/dd3cRKK6CuxdL2rv8 (2025)

STEP 3 — 3D OBLIQUE (ANGLE VIEW)

Corner pinnacles emphasized; rhythm continues along the parapet.

Figure 4.5: Hausa Traditional Architecture: Roof Pinnacles, Zankwaye (Elevation & 3D view)

```
         /\    /\    /\    /\    /\
        / \   / \   / \   / \   / \
       /   \ /   \ /   \ /   \ /   \
  /\  -------------------------------------------  /\
 / \|                                           | / \
/   \|                                          |/   \
    |        Katanga (Wall)                     |
    |                                           |
    |                                           |
    --------------------------------------------
         /\    /\    /\    /\    /\
        / \   / \   / \   / \   / \
```

(Left/Right corner zankwaye are typically taller/more emphasized)

Zanko/Zankwaye = pinnacles; Katanga = wall; Parapet = roof-edge wall; Rufi = roof (behind parapet, not visible).

Figure 4.6: Hausa Traditional Architecture: Roof Pinnacles, Zankwaye (Elevation & 3D view) Source: Author field surveys (2025)

This three-step diagram 2, 3 and 4 illustrates how zankwaye (pinnacles) are positioned and perceived in Hausa architecture, moving from plan view to elevation and 3D perspective. In the plan (Step 1), the pinnacles ("/") are distributed at the corners and rhythmically along the parapet, framing the roof outline and establishing symmetry. The elevation (Step 2) shows how these pinnacles rise above the parapet line, reinforcing the skyline rhythm and visually crowning the Katanga (load-bearing wall) below. The 3D oblique view (Step 3) emphasizes the cultural hierarchy: corner zankwaye are taller and more monumental, while rhythmic pinnacles continue along the parapet to create a repeating aesthetic cadence. This layering from plan to 3D demonstrates how functional wall structures transform into iconic Hausa skylines, where rhythm, hierarchy, and repetition symbolize prestige, power, and cultural identity. The diagram highlights not only the geometric logic of placement but also the symbolic emphasis of corners in Hausa palace, mosque, and city wall architecture.

The zankwaye (ornamental pinnacles) using a rule-based shape grammar. This to describe how pinnacles are placed and repeated systematically along Hausa building parapets, with special emphasis on corners (markers of authority) and rhythmic runs (crown-like skyline aesthetics).

Rule-Based Shape Grammar for Zankwaye

Vocabulary of Shapes (Σ)

- **W** = Wall segment (*katanga*)
- **P** = Parapet (roofline wall edge)
- **Zc** = Corner zanko (pinnacle, taller/emphasized)
- **Zr** = Rhythmic zanko (pinnacle, smaller/repeated along parapet)
- **Ø** = Empty roofline (no pinnacle placed yet

Axioms (Start Condition)

- A building block consists of:
- W + P + Ø

  (Wall with parapet, no pinnacles yet)

Production Rules (→)

Rule 1: Corner Pinnacle Placement

P(corner, Ø) → Zc

At every parapet **corner**, replace empty roofline (Ø) with **Zc** (taller corner pinnacle).

Rule 2: Rhythmic Pinnacle Placement

P(edge, Ø) → Zr

Along straight parapet edges (between corners), place **Zr** in rhythmic intervals.

Rule 3: Rhythmic Repetition Pattern

Zr → Zr + gap + Zr

Each rhythmic pinnacle generates another pinnacle after a **gap** (modular spacing), producing the repeating crown-like skyline.

Rule 4: Corner Hierarchy

Zc > Zr

Corner pinnacles are **taller/more elaborate** than rhythmic pinnacles, enforcing visual hierarchy.

Rule 5: Termination Condition

Parapet (edge) filled → STOP

Once parapet edges between two corners are filled with pinnacles at defined intervals, no further rules apply.

Derivation Example (Simplified)

- **Start:** W + P + Ø
- Apply Rule 1 (corner): Zc ———— Ø ———— Zc
- Apply Rule 2 + 3 (rhythm): Zc — Zr — gap — Zr — gap — Zr — Zc
- Apply Rule 4 (hierarchy): Tall Zc at corners, smaller Zr along edge
- **Result:** Crown-like skyline with corner emphasis and rhythmic pinnacles along walls.

The diagram 5 of the Rule-Based Shape Grammar for Zankwaye demonstrates how Hausa parapet skylines are systematically generated through a vocabulary of architectural elements and production rules. Beginning with the axiom W + P + Ø (a wall with a parapet and no pinnacles), the rules sequentially transform empty rooflines into structured forms: corners are marked with Zc (taller pinnacles), while edges are filled with Zr (smaller rhythmic pinnacles) placed at regular intervals. Rule

3 establishes the repetition pattern, inserting pinnacles and gaps to create rhythmic continuity, while Rule 4 enforces hierarchy, ensuring that corner pinnacles dominate visually and symbolically. The termination condition ensures that parapet edges are completed without excess, maintaining proportionality. The derivation example illustrates how these steps generate the distinctive crown-like skyline seen in Hausa cities—where corners act as cultural and political markers of power, and edges provide aesthetic rhythm and prestige reinforcement. This grammar not only encodes geometric rules but also preserves cultural meaning, linking spatial rhythm with social symbolism in Hausa architecture.

Figure 6: Zankwaye Shape Grammar — Visual Rules

```
AXIOM (Start Condition)
      Ø
      |
      v
   (Empty roofline)
```

Rule 1 — Corner Pinnacle Placement

```
      Ø (at corner)
      |
      v
     Zc
 (Corner pinnacle)
```

Rule 2 — Edge Pinnacle Placement

```
      Ø (at edge)
      |
      v
     Zr
 (Rhythmic pinnacle)
```

Rule 3 — Rhythmic Repetition

```
      Zr
      |
      v
  Zr — gap — Zr
```

Rule 4 — Hierarchy

```
  Zc (taller)    >    Zr (smaller)
  (Corners)           (Edges)
```

Rule 5 — Completed Parapet Sequence (Example Derivation)

```
START:    Ø ———————————————— Ø
          (Parapet line, empty)

APPLY RULES:
          Zc — Ø — Ø — Ø — Zc
          |     |     |
          v     v     v
          Zr    Zr+gap+Zr   (filled)

RESULT:
          Zc — Zr — gap — Zr — gap — Zr — Zc
```

Rule-tree diagram shows how:

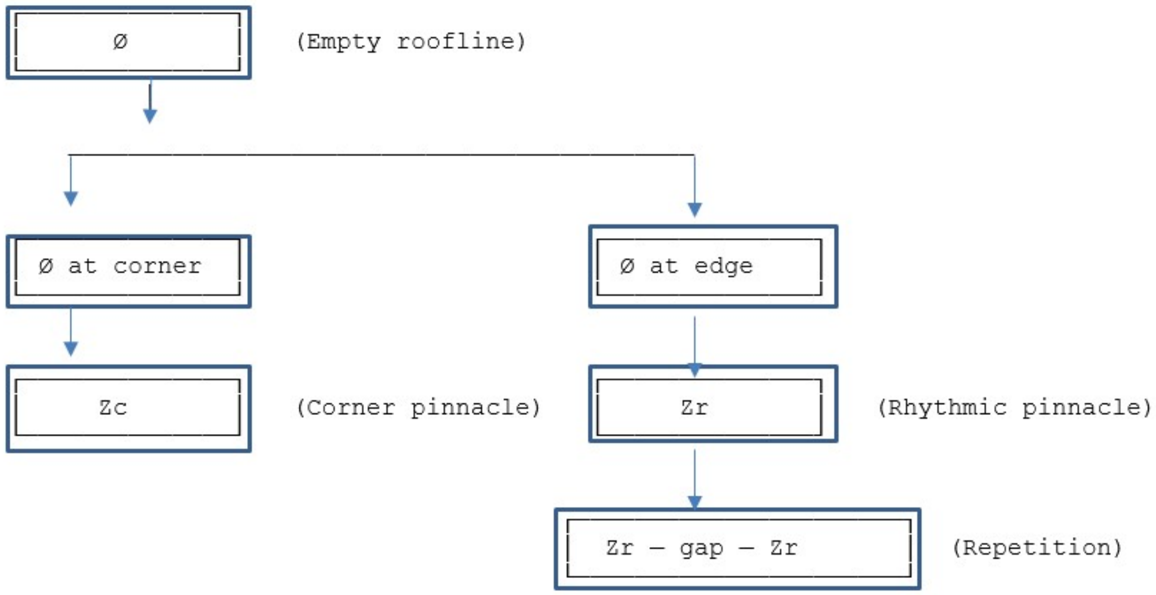
- **Corners** (Ø) → **Zc** (taller pinnacles).
- **Edges** (Ø) → **Zr** (smaller, repeated pinnacles).
- Rhythmic repetition continues until parapet is filled.

- **Hierarchy** ensures **Zc** > **Zr**, making corners more monumental.

This diagram 6 illustrates the visual rules of the Zankwaye shape grammar, showing step-by-step how parapet skylines are generated from an empty roofline into a structured ornamental sequence. The process begins with the axiom (Ø), representing a blank parapet, which is then resolved by rules: at corners, Ø transforms into Zc (corner pinnacles), while at edges, Ø becomes Zr (rhythmic pinnacles). Rule 3 introduces rhythmic repetition, where Zr elements are separated by gaps, creating a continuous skyline pattern. Rule 4 enforces hierarchy, ensuring that Zc pinnacles are always taller than Zr, making the corners more monumental and culturally dominant. The completed parapet sequence shows how repeated applications of these rules gradually transform a plain roofline into a crown-like skyline, balancing rhythm, variation, and symbolic hierarchy. This makes the diagram not just a generative flowchart but also a cultural encoding system, preserving Hausa architectural identity while enabling parametric flexibility.

Figure 4.7: Zankwaye Shape Grammar (Box-Drawing Diagram)

AXIOM (Start Condition)



Hierarchy Rule

Zc (taller) (corners)	>	Zr (smaller) (edges)

This diagram 7 presents the Zankwaye shape grammar in a structured flow, showing how Hausa parapet skylines evolve from a blank roofline into a rhythmic and hierarchical crown-like form. The process begins with the axiom (Ø), representing the empty roofline, which then branches into two conditions: corner slots and edge slots. Corner slots transform into Zc (corner pinnacles), which are taller and serve as anchors, while edge slots transform into Zr (rhythmic pinnacles) that repeat along the parapet with gaps to create rhythm. The repetition of Zr and gaps establishes the ornamental rhythm of the skyline, while the hierarchy rule (Zc > Zr) ensures that corner pinnacles always dominate in height, preserving both cultural symbolism and structural logic. Together, this flow captures how generative rules translate architectural intent into a parametric system, allowing skyline variations while maintaining the distinct cultural identity of Hausa Zankwaye.

Figure 4.8: Example Derivation (Parapet Segment)

START:

| Ø | Ø |

APPLY RULES:

| Zc | | Zr | | gap | | Zc |

Result:

Zc — Zr — gap — Zr — Zc

The diagram 8 illustrates a step-by-step derivation process showing how an initially empty parapet segment (Ø) evolves into a culturally meaningful and structurally feasible Hausa skyline. At the starting point, the parapet is defined only as vacant slots without architectural identity. By applying parametric shape grammar rules, the empty slots are systematically transformed into corner pinnacles (**Zc**) and rhythmic pinnacles (**Zr**) separated by gaps that regulate spacing. The resulting configuration — **Zc–Zr–gap–Zr–Zc** — demonstrates both rhythm and hierarchy, where the taller corner pinnacles anchor the skyline while the rhythmic pinnacles provide repetition and ornamentation. The gaps introduce variation and balance, preventing uniform monotony while ensuring cultural correctness. This generative process not only captures the visual logic of Hausa parapet design but also embeds rules of hierarchy, rhythm, and proportionality, making it possible to reproduce the crown-like skyline of Zankwaye in a flexible, computationally controlled manner.

Table 4.1: Parametric Shape Grammar for Zankwaye in Hausa Architecture

Symbol	Type	Meaning	Parameters	Source of Values
Ø	Nonterminal	Empty parapet slot	–	Initial axiom
W (Katanga)	Terminal	Wall (earthen, load-bearing)	*h* (height), *t* (thickness), *m* (material)	Survey / BIM
P	Terminal	Parapet segment	*L* (length), *c* (corner flag)	Plan extraction
Rufi	Terminal	Roof platform	*slope*, *drainage*	Survey
Zc	Terminal	Corner pinnacle (Zanko)	*Hc* (height), *Dc* (diameter), *Sc* (style ID)	Parametric input
Zr	Terminal	Rhythmic pinnacle	*Hr* (height), *Dr* (diameter), *Sr* (style ID), *p* (pitch)	Data fitting
gap	Terminal	Interval between Zr	*g* (gap length)	Derived from *L/p*
J	Operator	Random jitter	*σh*, *σg* (variation in height/spacing)	Statistical modeling
C	Constraint	Structural/constructability	$t \geq tmin$, $Hr \leq Hmax(t,wind)$	Engineering data

Symbol	Type	Meaning	Parameters	Source of Values
H	Constraint	Hierarchy	Zc > Zr	Cultural rule

The table 4.1 defines the symbolic and parametric structure used in modeling Zankwaye within Hausa architecture, linking each symbol to its architectural role, parameters, and data sources. The nonterminal symbol Ø represents the starting axiom of an empty parapet slot, which evolves into architectural elements. Terminals such as **W (Katanga)** capture the earthen wall base, defined by height, thickness, and material from surveys or BIM models, while **P** denotes parapet segments extracted from plan geometry. **Rufi** adds the roof platform with slope and drainage properties, grounding the skyline in structural realism. Pinnacles are central: **Zc** (corner pinnacles) take parametric inputs for height, diameter, and style ID, while **Zr** (rhythmic pinnacles) are fitted from data, with pitch and style variation. The **gap** symbol governs spacing, calculated from parapet length divided by the number of pinnacles, while **J** introduces stochastic jitter in height and spacing through statistical modeling, ensuring variability. Constraints **C** and **H** ensure feasibility and cultural correctness: the structural rule enforces minimum thickness and maximum height tolerances based on wind and material data, while hierarchy ensures corner pinnacles dominate in scale over edge pinnacles, reflecting Hausa aesthetic order. Together, these symbols create a generative grammar that integrates empirical data, cultural logic, and engineering constraints into a cohesive parametric framework.

Table 4.2: Parametric Production Rules

Rule	Shape Rule (→)	Condition	Parameterized Form	Notes
R1	⟨P, Ø⟩ → Zc	c = 1 (corner)	Hc = f1(L, Ic), Dc = f2(Hc)	Corner pinnacles are taller
R2	⟨P, Ø⟩ → Zr	c = 0 (edge)	Hr = α·Hc ; Dr = β·Hr	Edge pinnacles scaled down
R3	Zr → Zr – gap(g) – Zr	L ≥ g	g = L/p ; p = number of Zr	Rhythm generated
R4	gap → gap ± J	σg ≤ σmax	g' = g + N(0,σg)	Controlled variation
R5	Zc ⇒ H	always	Hc > Hr	Enforces hierarchy
R6	Edge(L) + {Zr,gap}* → Zc	until L is filled	pack(L) with {Zr,g}	Edge termination
R7	W(h,t) ⇒ C	always	t ≥ tmin ; Hr ≤ Hmax	Structural feasibility
R8	Z{c,r} ⇒ Style	cultural set	style ∈ S(Zaria/Kano/Katsina)	Local motif applied
R9	Ø(edge) → ∅	conservation flag = 1	no pinnacle	Simulates erosion/absence

The table 4.2 presents a structured parametric rule system that formalizes how Zankwaye pinnacles are generated and varied within Hausa architectural skylines. Rule R1 specifies that corner parapet slots (c=1) transform into taller pinnacles (Zc), with their height (Hc) determined as a function of parapet length and building importance, ensuring status symbolism. Rule R2 complements this by assigning shorter pinnacles (Zr) to edges (c=0), scaled proportionally to Zc, which creates a hierarchy across the skyline. Rhythm emerges in Rule R3, where pinnacles are distributed at intervals ($g = L/p$), while Rule R4 introduces controlled randomness, allowing spacing to vary within stochastic limits for naturalistic variation. Rule R5 guarantees hierarchy by always preserving $Zc > Hr$, and Rule R6 ensures that edges are systematically filled with pinnacles and gaps until they meet a corner, preserving completeness of design. Rule R7 embeds structural feasibility, linking wall thickness (t) and maximum allowable pinnacle height ($Hr \leq Hmax$) to material and engineering constraints. Rule R8 injects cultural expression by applying motifs specific to Hausa subregions such as Zaria, Kano, or Katsina, reinforcing authenticity. Finally, Rule R9 accounts for conservation or decay by simulating missing pinnacles, reflecting real-world erosion and heritage loss. Collectively, the rules balance geometry, structural logic, and cultural symbolism, producing parametric skylines that are both authentic and adaptable.

Table 4.3: Derivation Flow for Parametric Modeling

Stage	Input → Output	Parametric Control
1. Axiom	Parapet with Ø slots	–
2. Apply R1	Corners → Zc	Hc from building type/status
3. Apply R2	Edges → Zr	Hr as fraction of Hc
4. Apply R3	Insert rhythm	$g = L/p$
5. Apply R4	Add jitter	$g' = g \pm \sigma g$
6. Apply R5	Enforce hierarchy	$Zc > Zr$
7. Apply R6	Fill edge to corner	edge packing
8. Apply R7	Structural check	$Hr \leq Hmax$, $t \geq tmin$
9. Apply R8	Add cultural style	Motifs applied
10. Output	Parametric skyline	Ready for CAD/BIM/VR

The table 4.3 illustrates a staged pipeline for generating parametric Zankwaye skylines, showing how sequential rules transform an empty parapet into a culturally valid architectural output. The process begins with an axiom—blank parapet slots (Ø)—which provide the generative canvas. Rule R1 assigns corner pinnacles (Zc), with their heights (Hc) controlled by building type or social status, ensuring cultural meaning is encoded early. Rule R2 fills the edges with rhythmic pinnacles (Zr), scaled as fractions of Zc to maintain proportional hierarchy, while Rule R3 introduces rhythm by distributing pinnacles according to spacing ($g = L/p$). Rule R4 adds stochastic flexibility, applying jitter to spacing so the skyline avoids mechanical regularity. Hierarchy is enforced through Rule R5, ensuring corner pinnacles remain visually dominant, followed by Rule R6, which packs the edges until corners are reached, preserving boundary integrity. Rule R7 integrates structural feasibility checks, linking pinnacle height to material thickness and maximum allowable loads, while Rule R8 introduces cultural aesthetics by embedding motifs and stylistic features. The process culminates in a parametric skyline that balances geometry, engineering, and symbolism, ready to be deployed in digital design environments like CAD, BIM, or VR, where variations can be generated and tested systematically.

Table 4.4: Flexible Shape Grammar for Generative Systems of Zankwaye

Symbol	Type	Meaning	Parameters (Flexible)	Range/Domain
Ø	Nonterminal	Empty parapet slot	–	–
W (Katanga)	Terminal	Wall (support base)	h, t	h: 3–7m; t: 0.4–1.0m
P	Terminal	Parapet segment	L, c (corner flag)	L = 3–15m
Zc	Terminal	Corner pinnacle	Hc, Dc, Sc (style)	Hc = 1.5–3.5m ; Dc = 0.3–0.8m ; Sc ∈ {cone, bulb, finial}
Zr	Terminal	Rhythmic pinnacle	Hr, Dr, Sr, p	Hr = 0.6–2.0m ; Dr = 0.2–0.6m ; p = 2–6
gap	Terminal	Interval between Zr	g	g = L/p ± jitter
J	Operator	Random variation	σh, σg, σs (style swap rate)	σh = 5–15% ; σg = 10–20% ; σs = 0.1–0.3
C	Constraint	Structural/constructability	Hr ≤ Hmax(wind,t)	Engineering rule
H	Constraint	Hierarchy	Hc > Hr	Cultural rule

The table 4.4 presents the symbolic system and parameters that structure the generative grammar of Zankwaye parapets, showing how cultural, geometric, and structural rules are encoded into design logic. The nonterminal symbol Ø represents an empty parapet slot, acting as a placeholder for further derivations. The wall (W), or *Katanga*, serves as the foundational terminal element, defined by height and thickness, anchoring the skyline within realistic dimensions. Parapet segments (P) introduce modular spans with corner flags, setting up the framework for rhythm and symmetry. Corner pinnacles (Zc) and rhythmic pinnacles (Zr) embody the key ornamental features: Zc is always more dominant, parameterized by height, diameter, and stylistic options like cone, bulb, or finial, while Zr repeats along edges with scaled-down dimensions and probabilistic spacing. The *gap* symbol formalizes intervals, adjusted by jitter for natural variation, while the operator J introduces stochastic flexibility, enabling random height perturbations, irregular spacing, or occasional motif swaps. Constraints C and H ensure realism and cultural correctness—C ties pinnacle height to wind load and wall thickness, preserving structural feasibility, while H enforces hierarchy by requiring corner pinnacles to exceed rhythmic pinnacles in scale. Collectively, this symbolic system balances determinism and probability, encoding Hausa architectural values in a computationally generative yet culturally grounded way.

Table 4.5: Flexible Production Rules

Rule	Shape Rule (→)	Flexible/Probabilistic Form	Notes
R1	⟨P, Ø⟩ → Zc	P(c=1) → Zc[Hc ~ U(1.5,3.5)]	Corner pinnacles always present; random height
R2	⟨P, Ø⟩ → Zr	P(c=0) → Zr[Hr ~ N(μ,σh)]	Edge pinnacles scale with Hc; random jitter
R3	Zr → Zr – gap(g) – Zr	gap g = L/p ± N(0,σg)	Rhythmic spacing but with stochastic gaps
R4	Zr → Zr(alt style)	with prob σs	Occasionally swap style motif
R5	Zc ⇒ H	enforce Hc > Hr	Hierarchy preserved always

Rule	Shape Rule (→)	Flexible/Probabilistic Form	Notes
R6	Edge(L) + {Zr,gap}* → Zc	until L filled	Edge terminated by corner Zc
R7	Z{c,r} ⇒ C	check Hr ≤ Hmax	Structural feasibility
R8	Ø(edge) → ∅	with prob p = 0.1–0.3	Simulates missing pinnacles (erosion)

The table 4.5 outlines the probabilistic rule set that governs the generative logic of Zankwaye parapets, blending deterministic hierarchy with stochastic variation. Rule R1 establishes the certainty of crowned corner pinnacles (Zc), but introduces variation in height within a uniform distribution, ensuring both presence and diversity at the skyline's edges. Rule R2 extends this by generating edge pinnacles (Zr) with heights that follow a normal distribution, producing naturalistic jitter while maintaining proportionality with the corner heights. Rule R3 injects rhythm into the skyline through repeated Zr placements separated by gaps, where spacing is calculated but perturbed with stochastic noise, creating organic irregularity. Rule R4 enhances stylistic richness by occasionally swapping motifs with a probability factor, embedding cultural variability without disrupting overall coherence. Rule R5 safeguards hierarchy, enforcing corner pinnacles to remain taller than edge pinnacles, a critical cultural aesthetic. Rule R6 ensures proper termination of parapet edges by filling the span until a closing corner pinnacle is reached, guaranteeing structural and visual completeness. Rule R7 adds a feasibility check, constraining pinnacles not to exceed structural limits, while Rule R8 allows for stochastic absence of edge pinnacles to mimic real-world erosion and decay. Together, these rules demonstrate how parametric shape grammar can capture both the formal logic and lived imperfection of Hausa skyline systems, ensuring outputs that are authentic, varied, and structurally realistic.

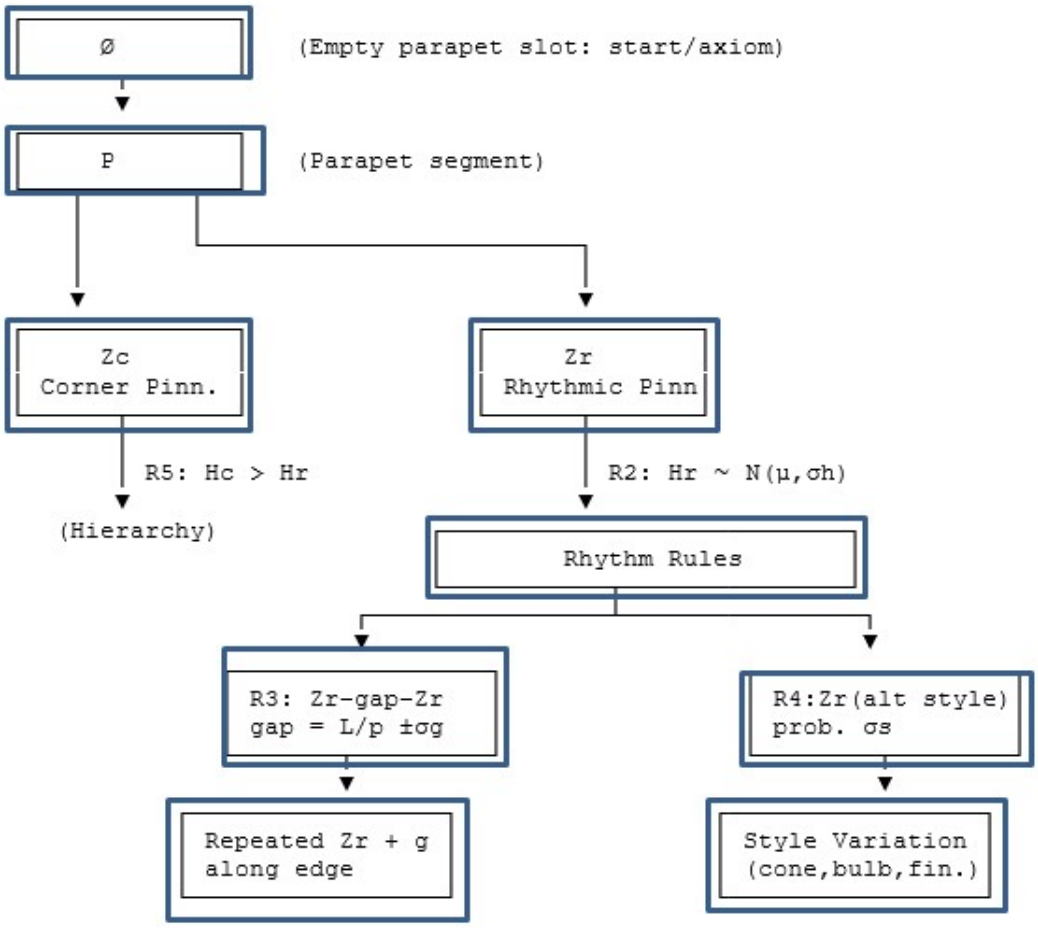
Table 4.6: Generative Design Workflow

Stage	Flexible Generative Step	System Output
1. Axiom	Start with parapet segments (P)	Blank roofline
2. Corners	Apply R1 → Zc with random Hc, Dc	Crowned corners
3. Edges	Apply R2 → Zr with jittered Hr, Dr	Rhythmic skyline
4. Rhythm	Apply R3, vary g	Organic spacing
5. Variation	Apply R4, swap style randomly	Diverse motifs
6. Hierarchy	Apply R5	Cultural correctness
7. Termination	Apply R6	Closed parapet
8. Check	Apply R7 (structural)	Feasible model
9. Conservation	Apply R8	Missing zankwaye for realism
10. Output	Skyline with variation	Multiple generative options

The table 4.6 and 4.7 illustrates the sequential logic of the parametric shape grammar for Zankwaye parapets, showing how generative rules progress from simple starting conditions to culturally accurate and structurally feasible outcomes. At Stage 1, the axiom begins with blank parapet segments, providing a neutral base for transformation. Stages 2 and 3 introduce corners and edges, where rules R1 and R2 generate crowned and rhythmic skyline features through randomization of height and depth parameters, thus embedding variability into the skyline. Stage 4 further enhances this rhythm with organic spacing, while Stage 5 introduces stylistic diversity by swapping motifs through random variation, ensuring that no two outputs appear identical. Stage 6 introduces hierarchy with

Rule R5, which ensures that cultural correctness anchors the generative freedom, maintaining authenticity within Hausa architectural logic. Termination (Stage 7) and structural checking (Stage 8) secure completeness and feasibility of the design, avoiding unstable or incomplete forms. Conservation (Stage 9) reinforces cultural realism by allowing for missing or eroded Zankwaye, simulating the lived condition of traditional buildings. Finally, Stage 10 consolidates the system into a skyline output with multiple generative options, balancing variation, authenticity, and practical feasibility. This structured yet flexible pipeline demonstrates how rule-based systems can integrate stochastic variation with cultural constraints to produce both creative and contextually grounded architectural forms.

Figure 4.7: Rule Based System for Zankwaye parapets, (Parapet Segment)



5. Discussion of Findings

The findings of Umaru, Adamu, Bello, and Jolaoso (2022), which emphasized the enduring significance of Hausa vernacular features such as Dakali and Zaure and their continued functional and cultural relevance, align with Umar, Yusuf, Ahmed, and Usman (2019), who similarly highlighted the importance of preserving spatial morphology and construction techniques in Hausa traditional architecture as a means of cultural conservation. Both studies agree that vernacular elements remain essential for heritage sustainability. However, while these works primarily focused on conservation and cultural preservation, Guzelci's (2014) study on Turkish houses introduced a computational shape grammar system, shifting the discussion from cultural continuity to generative design through algorithmic processes. This approach resonates with the more recent findings of Olakanbi et al. (2025), who applied shape grammar computationally to analyze spatial organization in Hausa houses, thereby bridging traditional architecture and modern generative systems. Collectively, the past studies show complementarity: the Nigerian-focused works stress cultural preservation, while Guzelci (2014) and Olakanbi et al. (2025) expand the discourse toward parametric and computational methods, suggesting that integrating conservation-oriented insights with generative modeling offers a balanced framework for both safeguarding and innovating Hausa architectural heritage.

Summary

The findings and diagrams presented in this study reveal that Hausa architecture, particularly the Zankwaye element, embodies a rich system of spatial logic, cultural symbolism, and structural ingenuity. The diagrams demonstrate how features such as wall projections, skyline configurations, and decorative elements not only perform functional roles but also communicate identity and aesthetics unique to Northern Nigeria. The parametric shape grammar derived from these findings highlights the capacity to capture and reproduce the embedded rules of form, proportions, and stylistic arrangements, showing that the Zankwaye is not a static feature but one capable of systematic reinterpretation within generative frameworks.

The development of a flexible parametric shape grammar system from the diagrams underscores the possibility of embedding geometric, stylistic, and computational variables into a coherent generative process. The generative grammar tree, with stochastic branching rules, illustrates how variation and creativity can be systematically introduced into Hausa skylines, ensuring that while the architecture retains its cultural essence, it can still adapt to contemporary computational design tools. By integrating measures such as form, dimensions, stylistic ornamentation, and cultural aesthetics into the grammar, the system provides a foundation for both analysis and innovation.

Ultimately, the findings establish that Hausa architectural features like Zankwaye can be modeled into generative systems that bridge tradition and modernity. The clean grammar tables, diagrams, and parametric frameworks collectively demonstrate how Hausa architecture can transition from heritage documentation into computational design practice. This approach ensures both preservation and adaptability—preservation by codifying traditional rules and forms, and adaptability by enabling their reinterpretation in parametric and generative systems for modern architectural needs in Nigeria.

6. Conclusion and Future Direction

This study has demonstrated that Hausa architecture, with particular emphasis on the *Zankwaye* element, represents a sophisticated system of spatial logic, cultural symbolism, and structural expression. The findings and diagrams reveal that beyond their decorative and functional significance, features such as wall projections and skyline articulations serve as cultural identifiers that reinforce the unique architectural identity of Northern Nigeria. Through parametric shape grammar, these features have been codified into a systematic framework capable of capturing their underlying design rules, proportions, and stylistic arrangements.

The integration of parametric grammar models and generative diagrams highlights the potential of Hausa architectural forms to move beyond static preservation into dynamic computational design. By formalizing geometric, stylistic, and cultural variables into generative rules, the study provides a flexible platform for exploring variations of the *Zankwaye* while retaining cultural authenticity. This ensures that the architectural heritage is not only preserved in its traditional essence but also reinterpreted through computational methods that align with contemporary design practices.

The study establishes a foundation for bridging tradition and modernity through the development of a parametric shape grammar for Hausa architecture. The framework enables both conservation and innovation—conservation by documenting and codifying indigenous architectural logic, and innovation by applying generative systems that adapt these traditions for present and future architectural needs. This approach reaffirms the enduring relevance of Hausa architecture while positioning it as a vital contributor to computational and generative design discourse in Nigeria and beyond.

Future Direction

Recommendation 1 & Implementation Strategy

The first recommendation is to institutionalize the documentation of Hausa architectural features, particularly the *Zankwaye*, into a comprehensive digital and visual archive. This will serve as both a cultural database and a design reference for future research and practice. The implementation strategy involves a collaborative framework between universities, cultural heritage agencies, and local communities to record, model, and digitally map these features using parametric and shape grammar methods. This ensures that indigenous knowledge is preserved, easily accessible, and adaptable to evolving computational platforms.

Recommendation 2 & Implementation Strategy

The second recommendation is to integrate parametric shape grammar into architectural education and professional training in Nigeria. By embedding generative systems into design studios and research labs, students and practitioners can learn to translate cultural features like the *Zankwaye* into flexible computational rules. The implementation strategy includes developing specialized courses, workshops, and design projects that focus on indigenous architecture, supported by visual programming tools and open-source generative platforms. This will bridge the gap between traditional architectural knowledge and modern digital design practices.

Recommendation 3 & Implementation Strategy

The third recommendation is to adopt generative systems as tools for conservation and sustainable adaptation of Hausa traditional architecture. Instead of static preservation, generative parametric models can simulate variations that respect cultural authenticity while addressing modern needs such as ventilation, lighting, and material efficiency. The implementation strategy is to partner with planning authorities, heritage boards, and architects to use these parametric frameworks in pilot housing projects and conservation initiatives. This will ensure that the cultural identity embedded in Hausa architecture is preserved while providing adaptable and functional solutions for contemporary living.

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