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Computational Rule-Based Modeling of Hausa Architectural Patterns Using Plan Layouts from Kano Metropolis Urban Traditional Houses Forms, Nigeria

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Abstract **Review Article**

Traditional Hausa architecture embodies rich cultural and spatial values that are rapidly diminishing due to urbanization and modern architectural practices in Nigeria. This study aims to develop a computational rule-based model using shape grammar methodology to analyze, preserve, and regenerate the architectural patterns of Hausa traditional houses in Kano Metropolis. The objectives are to extract spatial rules from existing house plans, encode these into a generative grammar system, and model new culturally consistent layouts.

The study adopts a computational rule-based shape grammar approach that formalizes the spatial organization of Hausa house elements, including room spaces (RS), Zaure (Z), courtyards (CY), forecourt (FY), inner court (IY), and internal staircases (SC). A purposive sample of 30 traditional house plans from Kano was analyzed to extract vocabulary elements, spatial relations, and shape rules. These were translated into a family of generative rules capable of producing variations of Hausa housing layouts. Data analysis combined spatial rule extraction with visual syntax modeling and computational simulation.

Findings reveal that Hausa architecture follows a distinct spatial hierarchy and culturally driven logic, where the courtyard plays a central circulation and functional role. The rule-based modeling effectively captured layout types such as single-storey courtyard compounds, story-type layouts, and parametric courtyard forms. These findings align with similar applications of shape grammar in Suakin (Sudanese) architecture studies and confirm its potential for cultural conservation and contemporary design adaptation.

The study concludes that computational shape grammar provides a robust framework for preserving and generating traditional Hausa house forms. It is recommended that urban planners, architects, and heritage conservationists integrate rule-based modeling in design practice. Additionally, future studies should expand this framework through parametric tools and digital fabrication technologies to ensure cultural continuity in the face of modernization.

Keywords: Computational Rule-Based Modeling, Hausa Architectural Patterns, Urban Traditional, Houses Forms.

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INTRODUCTION

Throughout history, architectural patterns have played a crucial role in shaping built environments worldwide. From the intricate courtyard houses of China to the compact urban riads of Morocco, vernacular architecture reflects cultural values, climatic responses, and socio-economic structures (Oliver, 2006). Across the globe, rule-based modeling has become an essential approach in understanding, preserving, and generating traditional architectural designs. This approach involves the formalization of design rules derived from traditional practices, which are then used to reconstruct or simulate architectural forms based on predetermined principles (Mitchell, 1990). In contemporary research, computational rule-based modeling has proven effective in analyzing architectural typologies, as seen in studies on Islamic, Asian, and African indigenous architectures.

These applications emphasize how traditional knowledge systems, encoded in spatial organization and design principles, can be systematically analyzed and replicated using formalized modeling techniques (Steadman, 1983).

On the African continent, architectural traditions have long been defined by localized construction materials, climatic adaptability, and socio-cultural influences. Traditional African dwellings often feature spatial configurations that promote social cohesion, environmental comfort, and sustainable resource utilization (Denyer, 1978). Across West Africa, architectural patterns exhibit a strong adherence to cultural norms, often characterized by enclosed courtyards, hierarchical spatial zoning, and intricate geometric designs (Prussin, 1995). Specifically, Hausa architecture, a dominant architectural form in northern Nigeria, is renowned for its distinctive spatial layouts, decorative motifs, and structural resilience. Hausa traditional houses in Kano Metropolis, for instance, follow strict spatial organization principles that have been passed down for generations, reinforcing both functional and aesthetic values. These houses are structured around a central courtyard, with interconnected rooms and passageways reflecting cultural and gender dynamics (Falola & Salm, 2004).

Regionally, Kano Metropolis is a significant urban center in northern Nigeria, historically recognized for its rich architectural heritage. The city's traditional houses are deeply rooted in Hausa cultural norms, with their design reflecting a balance between privacy, social interaction, and environmental considerations (Gusau, 2012). The plan layouts of these houses demonstrate a hierarchical spatial order, where courtyards (ShikGida) serve as primary organizing elements, and rooms are arranged in accordance with functional and symbolic considerations. The adaptive use of earthen materials, thick walls, and intricate façade decorations further illustrates the embedded rules governing Hausa architectural patterns (Adamu, 2005). Despite modernization and urbanization, many traditional houses in Kano still retain their original configurations, making them an invaluable reference for rule-based modeling studies aimed at preserving indigenous architectural knowledge (Kankara & Danjuma, 2018).

The concept of rule-based modeling in architectural studies involves identifying and formalizing the principles that dictate spatial organization, material use, and design aesthetics (Knight, 1999). In the case of Hausa traditional houses, these rules include guidelines on spatial hierarchy, room connectivity, circulation patterns, and courtyard configurations. By extracting these implicit design principles, computational methods can be used to generate architectural forms that adhere to Hausa traditional standards (Olakanbi Abdulraheem, 2025) (Bafna, 2012). The integration of rule-based modeling allows for the systematic study of Hausa architecture, ensuring that the knowledge embedded in traditional designs is preserved and can be applied in contemporary architectural practices (Timmermans, 1993).

Architectural rules and patterns, consists of formalized principles governing the design and organization of Hausa traditional house layouts. These rules include proportional relationships, spatial zoning guidelines, and decorative conventions. The principles governing these patterns are deeply rooted in historical precedents and socio-cultural imperatives, ensuring that space is utilized efficiently while maintaining aesthetic harmony (Oliver, 2006). Rule-based modeling relies on these pre-established norms to generate authentic architectural representations, emphasizing the importance of codifying indigenous design wisdom into computational frameworks (Steadman, 1983).

Plan layouts of traditional houses in Kano Metropolis, represents the spatial arrangement of rooms, courtyards, and other architectural components based on the identified rules. These layouts reflect a structured approach to organizing living spaces, with each area assigned specific functions based on cultural customs. The central courtyard (ShikGida), for example, serves as a multipurpose space for domestic activities, social interactions, and climate regulation (Prussin, 1995). The arrangement of rooms around this courtyard follows a predetermined hierarchy, ensuring privacy, accessibility, and social order within the household (Falola & Salm, 2004).

The relationship between the formalized design rules and spatial organization is fundamental to understanding Hausa architectural modeling. The formalized design rules directly influence the spatial organization by dictating how elements such as courtyards, entrances, and room orientations are structured. For instance, the principle of hierarchical spatial zoning ensures that private areas are shielded from public view, while communal spaces remain accessible (Denyer, 1978). This interdependence highlights the necessity of rule-based modeling in capturing and reproducing traditional Hausa house layouts accurately (Mitchell, 1990).

One of the key elements under architectural rules and patterns is the set of formalized rules that define Hausa house layouts. These rules include geometric proportions, spatial sequencing, and circulation flow, all of which contribute to the overall coherence of the built form (Gusau, 2012). By analyzing these design principles, researchers can create computational models that replicate traditional housing patterns while allowing for adaptability in contemporary applications (Olakanbi Abdulraheem, 2016) (Bafna, 2012).

Another significant element is the spatial arrangement of traditional houses, which determines the functional relationships between different spaces within the dwelling. This arrangement is influenced by factors such as family size, gender roles, and religious customs, all of which dictate how rooms are allocated and accessed (Adamu, 2005). The use of enclosed courtyards as central organizing elements exemplifies the structured approach to spatial planning in Hausa architecture (Kankara & Danjuma, 2018).

Understanding these relationships is essential for

developing accurate rule-based models that can generate traditional house layouts based on established Hausa architectural principles. By formalizing the underlying rules, computational tools can simulate variations of traditional designs while preserving their cultural integrity (Timmermans, 1993). This approach is particularly relevant in urban contexts, where rapid modernization threatens the continuity of indigenous architectural traditions (Falola & Salm, 2004).

In addition to preserving architectural heritage, rule-based modeling offers practical applications in contemporary housing design. By incorporating Hausa architectural principles into modern construction methods, architects can create sustainable and culturally appropriate housing solutions (Oliver, 2006). This integration ensures that traditional knowledge remains relevant in evolving urban environments, bridging the gap between past and present architectural practices (Steadman, 1983).

Furthermore, the application of rule-based modeling facilitates heritage conservation efforts by providing digital reconstructions of historic structures. These models serve as valuable resources for academic research, urban planning, and architectural education, fostering a deeper appreciation of Hausa architectural heritage (Prussin, 1995).

As cities like Kano continue to experience urbanization, the need for systematic documentation and modeling of traditional house layouts becomes increasingly urgent. Rule-based modeling provides a means to capture the essence of Hausa architectural patterns, ensuring that they remain an integral part of Nigeria's built environment (Gusau, 2012).

By bridging traditional knowledge with modern computational techniques, this study contributes to the broader discourse on architectural preservation and sustainable urban development. The formalization of Hausa architectural rules into digital models enhances the ability to analyze, adapt, and implement these designs in contemporary housing projects (Bafna, 2012).

Traditional Hausa architecture in Kano Metropolis is a critical part of Nigeria's built heritage, embodying cultural identity, environmental adaptability, and social organization. However, rapid urbanization, socio-economic changes, and modernization have significantly altered the spatial arrangements of these traditional houses, threatening their continuity and functional relevance (Adamu, 2005). The indigenous plan layouts, once governed by well-defined architectural rules and patterns, are now being replaced by unplanned, generic structures that do not reflect the cultural and climatic considerations embedded in Hausa architectural traditions. This problem necessitates a structured approach to documentation, analysis, and preservation through computational rule-based modeling, which can help formalize and restore the lost architectural wisdom inherent in traditional Hausa house layouts.

One of the major challenges affecting the plan layouts of traditional houses in Kano Metropolis is the erosion of spatial hierarchy and zoning principles. Hausa houses historically maintain a strict spatial hierarchy, where private, semi-private, and public spaces are clearly delineated to ensure privacy and proper social interaction (Gusau, 2012). However, with increasing population density and land-use changes, the original organization of spaces within traditional homes is being disrupted. Modern housing developments often ignore the traditional courtyard system, leading to inefficient spatial arrangements that compromise social cohesion and privacy (Falola & Salm, 2004) and by employing rule-based modeling, these zoning principles can be systematically documented and applied to contemporary house designs, ensuring that traditional spatial hierarchies remain functional while adapting to modern needs.

The increasing influence of Western and contemporary architectural styles poses another challenge to the spatial arrangement of traditional Hausa houses. Many modern structures in Kano Metropolis are being designed with little regard for indigenous architectural principles, leading to the proliferation of layouts that do not reflect the region's socio-cultural dynamics (Kankara & Danjuma, 2018). This shift has resulted in the loss of gender-sensitive spatial organization, where men's and women's spaces were traditionally structured to respect Islamic customs and social norms (Prussin, 1995). The application of rule-based modeling allows for the extraction and adaptation of these indigenous design rules into contemporary planning, ensuring that modern houses retain the cultural logic of Hausa spatial arrangements while accommodating evolving lifestyles.

Addressing these challenges requires a concerted effort to formalize and apply Hausa architectural rules and patterns through computational and rule-based modeling approaches. By analyzing the spatial organization of traditional houses and extracting the underlying principles, it is possible to create adaptable frameworks that preserve the cultural, environmental, and functional integrity of Hausa architecture. This approach not only ensures the continuity of historical house layouts but also provides a foundation for sustainable and culturally appropriate urban development in Kano Metropolis.

LITERATURE REVIEW

The plan layouts of traditional houses in Kano Metropolis reflect the deeply ingrained cultural, social, and environmental considerations of the Hausa people. The spatial arrangement consists of elements such as the zaure (entrance hall), courtyards, and private living quarters, which are meticulously organized to adhere to cultural norms, particularly those related to privacy and gender segregation (JSTOR, 2025). The zaure acts as a transitional space, leading into the main courtyard, which serves as the nucleus of family activities. These courtyards enhance ventilation and provide thermal comfort, a crucial feature in the hot climate of Northern Nigeria (Springer, 2025).

Traditional Hausa house layouts also incorporate hierarchical zoning, with public, semi-private, and private

spaces. The male visitors' reception area is typically separated from family quarters to uphold purdah, a cultural practice emphasizing privacy for women (Agboola, Modi, 2014). Architectural patterns in Hausa traditional houses emphasize harmony between functionality and aesthetics. The arrangement of spaces follows a modular pattern, often determined by factors such as family size and social status (Springer, 2025).

The rules governing Hausa traditional architecture emphasize symmetry, proportionality, and adaptability. Hausa builders traditionally employ locally sourced materials such as mud bricks and thatched roofing, which influence the structural design and spatial organization of rooms (U. H. BAMALLI, 2020). The use of thick earthen walls contributes to natural cooling, reducing reliance on artificial ventilation methods. The flexibility of traditional layouts allows for modifications based on family needs, demonstrating an adaptive approach to architecture (Iasmin, 2024).

Several scholars have analyzed the symbolic meanings embedded in the spatial organization of Hausa homes. According to Batagarawa and Tukur (2025), the courtyard-centered design signifies unity, as it facilitates communal interaction among family members. The hierarchical room arrangement reflects the structured social order within Hausa society, where seniority and gender roles influence the placement of spaces (M.B. Shehu, 2016). The spatial organization of traditional homes ensures not only physical comfort but also aligns with religious and social obligations.

Furthermore, the architectural rules governing Hausa traditional houses are closely tied to Islamic principles. The orientation of buildings often follows the Qibla (direction of Mecca), ensuring that prayer areas within the home align with religious obligations (Springer, 2025). The use of decorative motifs on walls, doors, and ceilings, often featuring geometric patterns and calligraphy, serves both aesthetic and symbolic functions (JSTOR, 2025). These patterns reflect Hausa cultural identity while reinforcing Islamic artistic traditions.

Hausa architecture has evolved over time, integrating modern elements while retaining core traditional principles. While contemporary homes in Kano incorporate cement blocks and metal roofing, many still maintain the fundamental layout principles seen in traditional designs (M. Adamu, 2005). The adaptation of traditional architectural patterns in modern housing developments ensures that cultural values are preserved despite urbanization and modernization pressures.

The spatial arrangement of rooms in Hausa houses also accommodates seasonal climatic changes. The orientation of windows and doors is carefully planned to optimize cross-ventilation, a necessity in the arid Sahelian climate (I.I. Danja, X. Li, S. Dalibi, 2017). The deep eaves of traditional roofs provide shade, further reducing indoor temperatures. Such design considerations illustrate the Hausa people's deep understanding of sustainable architectural principles.

Several studies highlight the social significance of house layouts in Kano. The separation of male and female spaces reinforces traditional gender norms, ensuring that women maintain a degree of seclusion within the home (G.K. Umar, 2008). Additionally, extended family structures influence housing arrangements, as multiple generations often reside within a single compound, necessitating an organized spatial hierarchy to accommodate different family units (Springer, 2025).

The preservation of Hausa architectural traditions is increasingly challenged by rapid urbanization and Western architectural influences. However, efforts to document and revive traditional housing principles underscore their importance in maintaining cultural heritage and promoting sustainable design practices (G.K. Umar, 2008). Modern architects and urban planners in Kano are encouraged to integrate indigenous knowledge into contemporary housing projects to ensure continuity in traditional spatial arrangements.

Shape computation theory was founded by George Stiny in 1975, introducing a formalized method for defining and generating shapes through computational rules. The theory is rooted in the idea that design processes can be systematically analyzed using shape grammars, which are sets of transformation rules applied to geometric elements (Stiny, 1975). This theory extends beyond simple geometric manipulations to encompass complex architectural forms, artistic compositions, and even urban planning, emphasizing the dynamic evolution of designs rather than static representations (Knight, 2003). The rationale behind the theory lies in its ability to formalize design logic and automate creative processes, allowing for the exploration of a vast range of design alternatives systematically (Stiny, 2006).

Several researchers of shape computation theory argue that it provides a robust framework for capturing and reproducing architectural styles through rule-based transformations. Stiny and Gips (1978) demonstrated how shape grammars could be applied to classical architectural styles, establishing a generative approach to design. Similarly, Duarte (2005) applied the theory to housing design, illustrating how computational rules can lead to adaptive and context-sensitive architectural solutions. The ability of shape computation to model traditional and contemporary architectural forms makes it valuable for preserving cultural heritage while enabling innovative design solutions (Mitchell, 1990). These proponents emphasize that the theory bridges the gap between traditional design knowledge and computational efficiency, facilitating design automation without losing the essence of architectural identity (Glymph et al., 2004).

However, critics argue that shape computation theory overly simplifies the design process by reducing it to rule-based manipulations, neglecting the subjective and intuitive aspects of architecture. Some authors contend that the theory assumes a deterministic approach to design, which may not fully capture the complexity and ambiguity inherent in architectural creativity (Gero, 1996). Additionally, Oxman (2006) criticizes the theory's

reliance on formalized rules, suggesting that it may not be flexible enough to accommodate non-visual aspects of design such as material properties, user experience, and cultural significance. These arguments highlight the limitations of shape grammars in addressing the broader socio-cultural and experiential dimensions of architecture, which extend beyond pure geometric transformations (Schön, 1983).

Despite these criticisms, shape computation theory provides a valuable foundation for rule-based modeling of Hausa architectural patterns in Kano Metropolis. Traditional Hausa architecture follows well-defined spatial configurations, including zaure (entrance vestibule), courtyards, and hierarchical room arrangements (Umar, 2018), which can be aligned with the structured logic of shape grammars. By employing shape computation, these traditional spatial rules can be formally encoded and digitally replicated, preserving indigenous knowledge while allowing for modernization and scalability (Gado & Mohammed, 2017). This approach enables the systematic documentation and reinterpretation of Hausa architectural principles within a computational framework, ensuring their continued relevance in contemporary urban development.

Olakanbi Bolaji AbdulRaheem and Osama Abdulwahab Rayis (2016) conducted a study aimed at introducing a shape grammar framework as a generative tool for Suakin architecture, focusing on the architectural styles present in Suakin, Sudan. Using a deductive analysis methodology, the study examined a corpus of five traditional architectural styles, including Turkish, Anglo-Egyptian, Mumluk, and traditional styles, to extract and compose new Suakin plan layouts. The findings revealed that Suakin architecture possesses a rich generative mechanism that informs architectural rule specification, demonstrating its creative ambiguity. The study concluded that Suakin architecture serves as a valuable source of design generation, emphasizing the potential of shape grammars in capturing its architectural essence. The authors recommended further exploration of generative tools in architectural design to preserve and innovate within Suakin's architectural heritage.

Dima Abu-Aridah and Heather Ligler (2024) conducted a study to examine the transformation of refugee shelters into long-term housing in Irbid Camp, Jordan, using shape grammar as an analytical tool. The study aimed to explore the evolution of refugee housing from emergency shelters to transitional and permanent structures. Through a parametric shape grammar methodology, the researchers analyzed the physical characteristics of ten diverse housing units, revealing patterns of adaptation and self-built modifications. The findings highlighted the dynamic nature of refugee housing, demonstrating how residents alter their living spaces to meet evolving needs. The study concluded that shape grammar provides a valuable framework for understanding and supporting sustainable refugee housing transformations. The authors recommended integrating shape grammar principles into refugee settlement planning to anticipate self-build processes and enhance housing adaptability.

Olakanbi Bolaji AbdulRaheem and Osama Abdulwahab Rayis (2016) conducted a study to develop a parametric shape grammar for traditional Suakin houses in the Red Sea State, Sudan. The study aimed to generate appropriate plan arrangements that satisfy functional spatial relationships by analyzing the topological and geometrical properties of old Suakin houses. Using a systematic methodology, the study extracted shape rules, dimensional attributes, and geometric and topological patterns from historical Suakin architecture to construct a generative model for its architectural language. The findings highlighted that these properties have been integral to Suakin buildings for the past ten centuries, preserving their distinct style. The study concluded by emphasizing the creative and generative potential of parametric shape grammars in capturing the formal composition of traditional Suakin architecture. The authors recommended the application of this framework in reviving contemporary Suakin architectural styles while maintaining their historical essence.

Bojan Tepavčević and Vesna Stojaković (2012) conducted a study examining the role of shape grammar in contemporary architectural theory and design, focusing on its application in computer-aided architectural design (CAAD). The study aimed to assess the impact of digital technologies, particularly CAD/CAM, on architectural practice and explored how shape grammars function as rule-based generative systems for producing geometric shapes. The authors reviewed early applications of shape grammars from the 1970s and 1980s, analyzing their influence on design processes and their limited practical adoption despite academic interest. The findings indicated that while shape grammars have significantly contributed to computational design methodologies, their full potential has not been realized in architectural practice. The study concluded that shape grammars remain underutilized as generative and analytical tools, with challenges in integrating them into mainstream CAAD workflows. The authors recommended further research into overcoming implementation barriers and developing more user-friendly applications to enhance their practical usability in contemporary design.

In conclusion, the plan layouts of traditional houses in Kano Metropolis are deeply rooted in cultural, environmental, and religious principles. The spatial arrangement follows well-defined architectural rules that promote social harmony, privacy, and climate adaptability. As contemporary housing developments continue to emerge, it is crucial to balance modernization with the preservation of traditional Hausa architectural elements, ensuring that the cultural essence of Kano's built environment remains intact.

Shape computation theory serves as a powerful analytical and generative tool for studying architectural patterns, despite its limitations. Its application to the rule-based modeling of Hausa architecture provides a structured means of capturing and reproducing traditional house layouts in Kano Metropolis. By leveraging computational rules, researchers can both preserve historical architectural knowledge and explore innovative design

adaptations that respect cultural heritage. While acknowledging the criticisms of shape grammars, integrating them with other computational and experiential approaches may enhance their applicability in architectural design research (Knight, 2003). Therefore, shape computation remains a significant theoretical foundation for understanding and modeling architectural forms in a systematic and generative manner.

It is acknowledged that the development of Hausa traditional architecture has shown a thorough comprehension and meaningful response, in which the styles are linked to collective neighborhood design rather than just individual structures. Consequently, it is essential to fully preserve, safeguard, and advance the discipline of Hausa traditional residential architecture (Umar et al., 2019).

A traditional Hausa home is conceptually divided into three sections or layouts, according to Sa'ad (1986), including an inner core (private area), a central core (semi-private area), and an outer core (public areas). The women's area is located in the center and consists of the ward, a guest/servant area, and a backyard with space for animal care and waste disposal.

The majority of the central core is a courtyard used for domestic and other related social activities, as well as lighting and ventilation. Around 500 CE, Egyptian domestic architecture introduced these ideas to the world. This is why Hausa traditional village layouts of shelter and settlements that eventually became villages and towns have such morphology.

In Hausa traditional facades, '*Zankwaye*' (Pinnacles) are an inevitable feature of Hausa architecture coming in different shapes and sizes and imparting character and beauty to a traditional building. The pinnacles (Zankwaye) have come to be recognized as a mark of aesthetics; without them, master masons compare them to a bull without a horn or, more accurately, a chief without his headgear. The exterior decoration of buildings, which typically surrounds exterior doors and outer wall fences that face the street, is one of the most striking aspects of Hausa architecture(Umar et al., 2019).

The use of locally accessible, practical materials like soil and vegetation was preferred by the Hausa. To improve the plasticity of the mud, grass binders, cow dung, and locust bean pod must be added to the mixture before it is molded because the soil in their region is loose and less plastic(Paul & Zango, M.S, 2014).

Traditional architecture has always been an integral part of the whole Northern societies in Nigeria. Even though, it was disorganized by unforeseen circumstances due to some activities beyond control. However, the Hausa speaking people in the northern region formed the largest cultural group in the country and they are characterized by large social grouping such as Kano. In generally, they are predominantly Muslims, with religious dictates, conditioning mode of dressing, social interactions and even affecting spatial disposition in their traditional architecture.

Kano people accepted new culture in architectural designs with a manner that allowed contemporary buildings to appear in a sense to outshine the long inherited culture(Aliyu, 2019).

Hausa traditional residential architecture is characterized by "cultural and traditional expressions, such as flat roof, sometime with shallow dome, ribbed vaulting and decorated wall with external pointed pinnacles on parapets" (Dmochowski 1990; Sa'ad 1981). The external walls are decorated with geometric patterns and finished with Hausa cultural symbols and decorative motifs. In logically harmonious with approach, the residential buildings were composed of individual "egg-shaped units of adobe (called tubali) which have been earth-plastered, as well presenting a monolithic character in physical appearances" (Osasona, 2002).

BRIEF HISTORY OF KANO STATE

Kano was one of the 12 states carved out of the former Northern Region in May 1967. The state was whole until Jigawa State was split off of it on August 27, 1991. It is situated in Nigeria's northwest geopolitical region. Kano State is inhabited by Muslim-majority Hausa and Fulani. The 2006 census put the population of Kano State at 9,383,682, making it one of the most populous states in Nigeria. It covers an area of 20,479.6 square kilometers and has 44 local governments.

There are roughly 458 people per square kilometer in the area. The commercial hub of Kano State is the walled city of Kano, which also serves as the state capital. It is a home to numerous immigrants, primarily Yoruba and Igbo. Kano metropolis, has six local government areas (Fagge, Gwale, Tarauni, Kano Municipal, Nassarawa, and Dala). Hausa is the state of Kano's official language, although majority of locals can read Arabic literature.

Kano State has a long history as an industrial and agricultural state that is well-known for its production of groundnuts. The state has over 18, 684 square kilometers of cultivable land and it is the most extensively irrigated state in Nigeria. Kano State is noted for its famous markets and it is the most leading industrial center in the north. Trading articles in the Kano City include leather goods, local crafts, dyed textile materials as well as camels. Giant industrial plants include textile, oil, motor assembly, bicycle assembly and many agro -based industries. Kano City is linked by rail, road, and air to all parts of the country and internationally

Kano metropolitan city has a physical identity, a built environment identity with strong architectural morphology that articulated certain cultural values(Aliyu, 2019)

COMPUTATIONAL RULE-BASED SHAPE GRAMMAR METHODOLOGY

This study adopts a computational rule-based shape grammar methodology to model the architectural patterns of Hausa traditional houses in Kano Metropolis, Nigeria. Shape grammar, as a computational design tool, provides a structured framework for generating, analyzing, and reproducing architectural layouts based on predefined rules. The research design involves extracting formalized spatial rules from existing Hausa house plans, including the spatial arrangement of rooms, courtyards, and entrances (Zaure). These rules will then be encoded into a shape grammar system that can generate new

layouts reflecting the traditional design logic. By systematically analyzing a corpus of existing house plans, the study will establish a generative model that can produce variations while maintaining cultural and functional integrity. This methodological approach ensures that the design principles embedded in Hausa architecture are preserved, understood, and adapted for contemporary applications.

The choice of a rule-based shape grammar methodology is significant for its ability to formalize and automate the design process while maintaining historical and cultural authenticity. Unlike conventional architectural analysis methods, which often rely on qualitative interpretation, shape grammar provides a structured and replicable framework for understanding and reproducing architectural patterns. This is particularly useful in Hausa architecture, where spatial organization follows well-defined cultural norms and functional hierarchies. The application of this method allows for a deeper exploration of how design rules govern the transformation and evolution of traditional house layouts. Additionally, by using computational modeling, the study can facilitate architectural conservation, inform modern housing designs inspired by traditional forms, and contribute to urban planning strategies that integrate heritage elements with contemporary needs.

Architectural organization of the Hausa traditional architecture stems from the relationship between the court (fore court (**FY**) and inner court (**IY**)), the Room Space (**RS**), the Zaure (**Z**) and a courtyard (**CY**) serves as circulation space in and out of the Room Space (**RS**), the toilet and internal staircase (**SC)** is included at the court-yard (**CY**) for storey type of Hausa traditional architecture.

Vocabulary Elements of Hausa Architectures									
Room Space	Zaure	Court-Yard	Fore-yard	Inner-Yard	Stair-Case	Ground-Room-Space	Floor-Room-Space	Compound-Wall	Description
RS	Z	CY	FY	IY	SC	GRS	FRS	CW	Symbol
RS	Z	CY	FY	IY	SC	GRS	FRS	CW	Label

Figure 2.1: vocabulary elements of Hausa traditional architecture

The table presents a structured vocabulary of geometric elements that define the spatial organization of Hausa traditional houses in Kano Metropolis. Each element, such as **Room Space (RS), Zaure (Z), Courtyard (CY), Fore-yard (FY), Inner-yard (IY), Staircase (SC), Ground Room Space (GRS), Floor Room Space (FRS), and Compound Wall (CW)**, represents a fundamental architectural component. These elements serve as building blocks for modeling and analyzing the spatial arrangements of Hausa architecture. The consistent use of symbols and labels in the table highlights the systematic approach required to understand and replicate these traditional housing forms through computational design techniques. By categorizing these spaces, the study can identify specific spatial relationships and patterns that define Hausa architectural layouts.

The justification for using geometric vocabulary elements and the shape grammar methodology lies in their ability to formalize architectural rules into a computational model. Shape grammar provides a structured framework for encoding spatial configurations and generating new layouts that adhere to traditional design principles. This methodology enables an analytical and generative approach to studying Hausa architecture, ensuring that the cultural and functional integrity of traditional houses is maintained. The implications for this study include the potential for developing rule-based models that can inform heritage conservation, contemporary architectural adaptations, and urban planning strategies that integrate indigenous spatial logic. By employing shape grammar, the study contributes to the documentation, preservation, and evolution of Hausa architectural heritage in a systematic and reproducible manner.

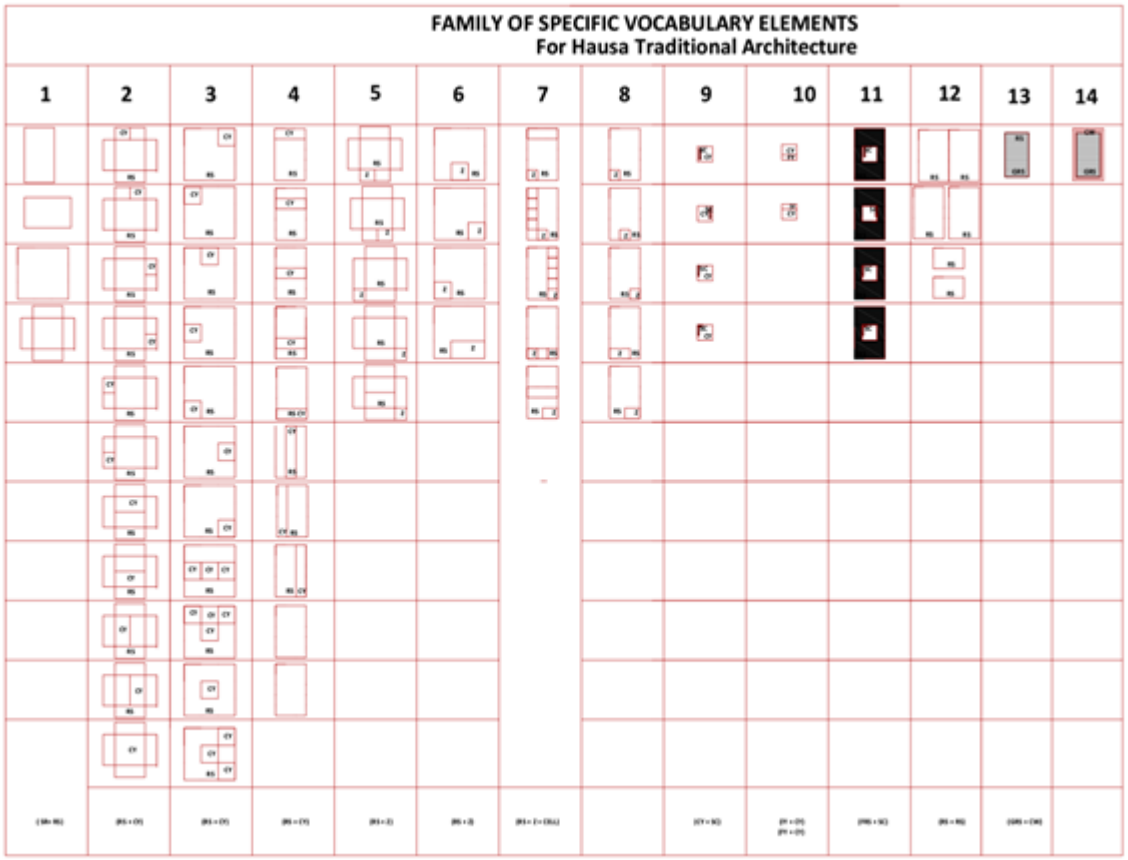

Figure 2.2: Family of spatial relations between vocabulary elements of **Hausa traditional architecture**

The table presents a structured vocabulary of spatial elements in Hausa traditional architecture, showcasing various architectural components such as **Room Space (RS), Zaure (Z), Courtyard (CY), Fore-yard (FY), Inner-yard (IY), Staircase (SC), Ground Room Space (GRS), Floor Room Space (FRS), and Compound Wall (CW)**. The systematic repetition and combinations of these elements highlight the standardized yet adaptable nature of Hausa house layouts. The geometric and symbolic representations in the document suggest an effort to formalize the spatial rules governing traditional Hausa architecture, making them suitable for computational modeling. The inclusion of compound spatial relationships, such as **(RS + CY), (RS + Z + CELL), and (IY + CY)**, indicates the hierarchical and functional zoning embedded within Hausa housing traditions. These spatial configurations provide insights into how room placements, circulation patterns, and privacy considerations shape the built environment, ensuring cultural and environmental appropriateness.

Table 2.2 defines spatial relations between vocabulary elements. Spatial relations are compositional ideas for making Hausa traditional houses. Thirteen of these spatial relations are illustrated in table 2.2. Spatial relations are defined in the following ways:

(1) Courtyard and Room Space compositions: a room space (shown as square, rectangle and parametric shape) surrounds the courtyard (a square) at upper and center sides of room space are illustrated in table 2.2 (column 2, 3 and 4).

(2) Zaure and Room Space: defines where the Zaure is situated on the Room Space. The Zaure is in relation to the room space (shown as square, rectangle and parametric shape), labeled, RS that can be a front part of the ground floor room space as illustrated in table 2.2 (column 5, 6 and 7).

(3) Foreyard, inner yard and courtyard wall: defines the way in which the Foreyard and inner yard of the house is located in the courtyard, with respect to the compound wall are illustrated in table 2.2 (column 9 and 11).

(4) First floor room space and stairs: describes the connection between the stairs and the first floor room space as illustrated in table 2.2 (column 11).

(5) Compound wall between two houses: defines the way in which houses can be connected by their neighborhood houses as illustrated in table 2.2 (column 10).

(6) Ground floor and Room Space wall: defines the way in which the ground floor (rooming) of the house is divided in the room space, with respect to the compound wall as illustrated in table 2.2 (column 12 and 13).

The justification for using a shape grammar methodology in this study stems from its ability to encode these

geometric vocabulary elements into a generative model that can replicate and adapt Hausa architectural patterns. Shape grammar, by systematically defining transformation rules for spatial arrangements, ensures that traditional layouts can be analyzed, preserved, and adapted for contemporary architectural design. The implication of this approach is significant, as it allows for rule-based modeling of Hausa houses that align with cultural, climatic, and functional needs. By leveraging this methodology, architects and researchers can develop computational tools for heritage conservation, urban planning, and architectural innovation, ensuring that traditional Hausa housing forms remain relevant in modern developments. Additionally, this approach facilitates automated design generation, enabling efficient exploration of spatial configurations while maintaining authenticity and adaptability.

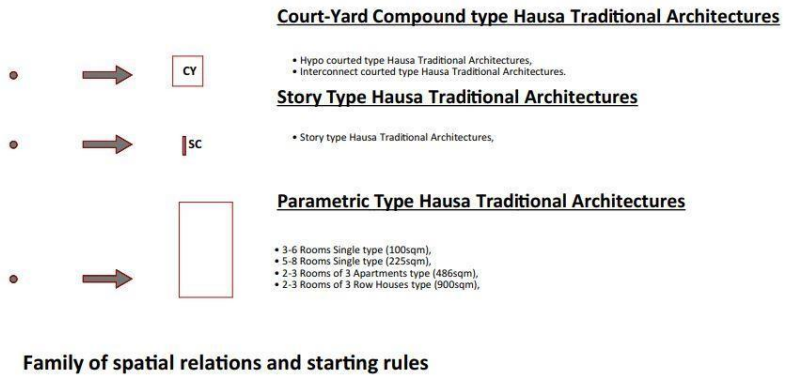

Figure 2.3: Family of spatial relations and starting rules of specific type of **Hausa traditional architecture**

The document presents Figure 2.3: Family of Spatial Relations and Starting Rules of Hausa Traditional Architecture, which outlines the initial spatial configurations and starting rules for generating different types of Hausa traditional houses. The geometric vocabulary elements such as Courtyard (CY), Staircase (SC), and Room Spaces (RS) define the spatial hierarchy and organization of Hausa architecture. The starting rules categorize Hausa traditional houses into three main types: Courtyard Compound Houses, Story-Type Courtyard Compound Houses, and Parametric-Type Courtyard Compound Houses. These classifications highlight the diverse spatial arrangements used in Hausa architecture, where courtyards function as central organizing elements and staircases define vertical transitions in multi-story structures. The spatial relations described in the document provide insights into the variability of room configurations, ranging from single-type layouts (100sqm and 225sqm) to complex apartment and row house arrangements (486sqm and 900sqm). These variations demonstrate the adaptability of Hausa traditional houses to different family structures and urban settings.

Figure 2.3 defines the initial shape and starting rules as shown in figure 2.3, and shape rules in terms of spatial relations as shown in figures 2.1 and 2.2. The starting rules define which type of house of Hausa traditional architecture is going to be generated and the shape rules specify the ways in which vocabulary elements of each type of house are going to be put together. The shape rules are defined in terms of a spatial relation. Each rule specifies different compositional actions.

There are three different types of starting rules that define three different types of Hausa traditional architecture extracted from the analysis:

- **Courtyard Compound type of Hausa traditional architecture** (a house with a court at the ground or at both first floor levels),
- **Story type Courtyard Compound House of Hausa traditional architecture** (a house with a stair at both ground and first floor levels),
- Parametric type **Courtyard Compound type of Hausa traditional architecture** (a house with a specific and defined area of shape at the ground or at both first floor level.

The justification for using the family of spatial relations and starting rules lies in its ability to provide a structured foundation for rule-based modeling of Hausa architectural patterns. The spatial rules outlined in the document ensure that the generated designs adhere to traditional spatial logic, preserving key architectural features while allowing for parametric adjustments. The implications of this study are significant, as it enables computational replication and adaptation of Hausa traditional houses for contemporary applications. By integrating these spatial rules into a shape grammar framework, the study ensures that Hausa architectural layouts can be systematically analyzed, digitally preserved, and adapted for modern housing solutions. This structured approach supports heritage conservation, urban planning, and culturally responsive design, allowing for the continuity of indigenous architectural principles in modern contexts.

Figure 2.4: Family of shape rules of specific type of Hausa traditional architecture

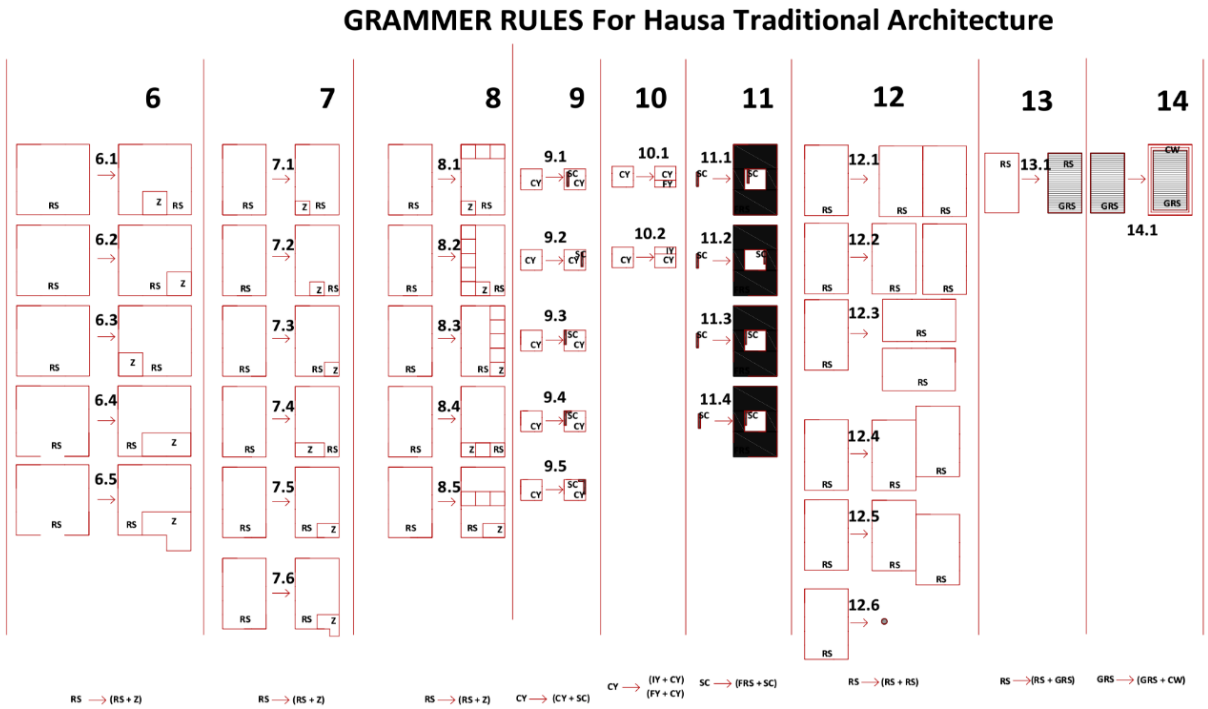

Figure 2.5: Family of shape rules of specific type of **Hausa traditional architecture**

The document presents **grammar rules** for Hausa traditional architecture, providing a systematic approach to understanding the spatial relationships within traditional Hausa houses. The **geometric vocabulary elements**, such as **Room Space (RS), Zaure (Z), and Courtyard (CY)**, form the core components of these grammar rules, demonstrating their hierarchical organization. The repetition of these elements and their combinations, such as **(RS + CY), (RS + Z), and (RS + RS)**, highlights the structured nature of Hausa architectural layouts. These combinations define the spatial logic that governs Hausa house designs, where rooms and courtyards interact in a predictable yet flexible manner. The **family of shape rules** presented in the document serves as a **generative framework** that encodes the architectural patterns of Hausa traditional houses, ensuring that new layouts adhere to historically and culturally significant spatial arrangements.

The justification for using these **shape rules** lies in their ability to formalize and **digitally encode Hausa architectural patterns** within a **rule-based modeling system**. The document's structured approach to spatial relationships allows for the creation of **computational models** that replicate and adapt Hausa traditional layouts for contemporary use. The **implication of this study** is significant, as it provides a means to **preserve, analyze, and generate new architectural designs** that maintain the cultural integrity of Hausa housing. This approach enables **automated design generation**, supporting both heritage conservation and modern architectural adaptations. By using **shape grammar methodology**, the study ensures that Hausa architectural principles are **not only documented but also integrated into urban planning and housing policies**, promoting **cultural sustainability** in modern development.

The shape rules used are divided into these thirteen groups:

1. **Parametric of Shape**: Rules 1.1, 1.2, 1.3 and 1.4 defines the parametric shape and labeled **RS** in terms of a transformational actions **(RS + (x) t).** These rules determine which type of house of **Hausa traditional architecture** is going to be generated and the parametric shape rules specify the ways in which vocabulary elements of each type of house are going to be put together.

2. **Location of court**: The central design element on the plan schema is the court: whether hypo-courted or interconnected, all the exterior and interior spaces are located around it. The most important difference between hypo-courted and interconnect courted types is seen in the form of the court and the dimension of the connection with others. The court in some type is a square and in others type is a rectangle. The interconnect court dictates the dimension of the compound type since its dimension depends on the diameter of fore and inner part of the court. The proposed shape grammar was designed to reflect this principle and explore its implications. The first rule R0.1 is the starting rule that has to be first used in the generation of every plan. It inserts the court rule R2, R3 and R4.

3. **Location of rooms around the court**: Rooms

are arranged around the court. Relatively compact plans around the court and the tendency towards zoned arrangements specify the principles on the placement of rooms around the court. First, every plan element is in easy reach from every other plan element through the court. Second, the spaces that have common use are placed generally at front and rear sides of the court while left and right hand sides are used to place Mai-Gida cells. All the rooms allocated at this stage are uniformly labeled RS, since the more precise identification will be given in later stages. The rules R2.0, R3.0 and R4.0 locate rooms around the court

(RS) ⟶ **(RS + CY)**.

4. **Allocation of Zaure**: The rules R5.0, R6.0 and R7.0 allocate the Zaure, labeled Z, generally one at the center or corner of room space. The rules R5.0, R6.0 and R7.0 select a room at the fore of the court and replace as the main entrance and seclusion of outsider from the building. Then depending on the spatial organization of the particular type of house of **Hausa traditional architecture**, the entrance Zaure is replaced the fore room space. In the interconnect courted compound type of house of **Hausa traditional architecture**, a room is selected from either center or left or right hand sides of the room space of the fore court and replaced as the Zaure by the rule R5.0, R6.0 and R7.0 **(RS)** ⟶ **(RS + Z)**.

5. **Location of Stair**: The rule sets R8.0 locate the Stair, which are labeled **(SC)**, around the sides of the court already determined. The rules R8.1, R8.2, R8.3 and R8.4 place stair respectively at insides of the court **(CY)** ⟶ **(CY + SC)**.

6. **Allocation of floor room space with the stair already determined**: Generally the floor rooming, labeled FRS, is allocated at both sides of the main court and ground floor space configuration. The rule R61 allocates the upper floor space configuration **(SC)** ⟶ **(FRS + SC)**.

7. **Allocation of room cells in the ground floor room space**: the same sized square and rectangular room cells labeled GRS are located regularly and generally symmetrically on left and right hand sides of the court. The rooms are freely allocated on both sides. The rules R12.0 place ground room cells and then divide them into equally sized rooms of two/five in relation with the dimension of the parametric shape **(RS)** ⟶ **(GRS + RS)**.

8. **Housing Rule:** In **Hausa traditional house,** a number of buildings in the city (Geri and Sabo-geri) are row housing allocated for socio-cultural purpose. Compound wall between two houses: defines the way in which houses can be connected by their neighborhood houses. The rules R11.1, R11.2, and R11.3 allocate the housing planning.

The geometric vocabulary elements in the document represent the fundamental spatial components that define the architectural patterns of Hausa traditional houses in Kano Metropolis. These elements include Room Space (RS), Zaure (Z), Courtyard (CY), Fore-yard (FY), Inner-yard (IY), Staircase (SC), Ground Room Space (GRS), Floor Room Space (FRS), and Compound Wall (CW). Each element functions as a building block in the spatial configuration of Hausa housing, where specific rules govern their arrangement and interaction. For example, the Zaure (Z) serves as an entry space, offering both transitional and security functions, while the Courtyard (CY) acts as a central open-air space crucial for ventilation and social activities. Similarly, the Fore-yard (FY) and Inner-yard (IY) reflect hierarchical divisions in spatial zoning, ensuring privacy and efficient circulation. The inclusion of Compound Wall (CW) further emphasizes the enclosed nature of Hausa housing, a key feature that enhances security and thermal comfort.

The labels and symbols used in the document provide a structured approach for encoding these elements into a rule-based modeling framework using shape grammar methodology. By defining how elements such as (RS + CY), (RS + Z + CELL), (IY + CY), and (FRS + SC) combine, the study establishes a generative system that mirrors the logical organization of traditional Hausa houses. This approach is essential for analyzing spatial hierarchy, functional connectivity, and transformation rules governing Hausa architectural forms. The implication of this structured labeling system is significant, as it enables computational replication, urban planning adaptations, and heritage conservation. Through rule-based modeling, the study contributes to the development of automated tools for designing contemporary Hausa-inspired housing layouts while preserving cultural integrity. The systematic classification of these elements enhances the ability to analyze, generate, and modify traditional housing plans, ensuring their adaptability in modern architectural applications.

The geometric vocabulary elements in the document represent the fundamental spatial components of Hausa traditional architecture, serving as a structured framework for understanding and modeling traditional house layouts in Kano Metropolis. These elements, including Room Space (RS), Zaure (Z), Courtyard (CY), Fore-yard (FY), Inner-yard (IY), Staircase (SC), Ground Room Space (GRS), Floor Room Space (FRS), and Compound Wall (CW), form the basis for spatial organization within Hausa housing. Each element is integral to the design logic of traditional homes, ensuring functionality, cultural appropriateness, and environmental sustainability. The presence of repeated labels and combinations of these elements in the document suggests a rule-based approach to capturing and formalizing the inherent structure of Hausa architecture.

The FAMILY OF SPECIFIC VOCABULARY

ELEMENTS provides a systematic representation of how these spatial elements interact and combine to form complete architectural layouts. The repetitive occurrence of elements such as (RS + CY), (RS + Z + CELL), (CY + SC), (IY + CY), and (FRS + SC) highlights the hierarchical organization of spaces and their functional relationships. This structured classification supports the development of a shape grammar model, enabling computational generation and analysis of Hausa traditional house forms. By codifying these relationships, the document facilitates the creation of adaptable architectural models that respect indigenous building practices while allowing for modifications in response to modern needs.

The description column in the document provides a conceptual understanding of each vocabulary element, defining their purpose and significance within Hausa architecture. For instance, Zaure (Z) is not just an entry passage but also a social and security buffer, while Courtyard (CY) functions as a thermal regulator and communal space. The Staircase (SC) is a structural transition element, especially relevant in multi-story Hausa buildings. These descriptions highlight the functional essence of each architectural component, ensuring their correct application in generative modeling.

The symbol column assigns unique identifiers to each architectural element, simplifying their representation in computational models. By using abbreviations such as RS, Z, CY, and SC, the document enhances the ability to encode, analyze, and generate new designs using a rule-based system. This symbolic representation aligns with the principles of shape grammar methodology, allowing for the automated transformation and adaptation of Hausa traditional house layouts.

The label column further refines the classification by providing a structured tagging system for each spatial element. These labels facilitate the categorization and hierarchical arrangement of spaces, ensuring that the rule-based model adheres to the spatial logic of Hausa architecture. This level of detail is critical for computational modeling, enabling the preservation, analysis, and adaptation of traditional architectural forms.

The implication of this structured vocabulary for the study is significant, as it provides a foundation for rule-based modeling of Hausa architectural patterns. By employing shape grammar methodology, the study can systematically decode and regenerate traditional housing layouts, ensuring their continuity in contemporary architectural applications. This approach is particularly valuable for heritage conservation, sustainable urban planning, and modern housing design, offering a computationally-driven framework for integrating traditional Hausa architecture into contemporary built environments.

THE DISCUSSION OF FINDINGS

The findings from the analysis of Hausa traditional architecture in Kano Metropolis align with previous research on shape grammar as a generative tool for architectural modeling. Similar to the study by AbdulRaheem and Rayis (2016) on Suakin architecture, the Hausa architectural study demonstrates how shape grammar can formalize spatial rules and generate new layouts based on traditional housing forms. Both studies emphasize the importance of preserving cultural architectural heritage while enabling adaptive modifications. Likewise, the parametric shape grammar methodology used in the Irbid Camp study by Abu-Aridah and Ligler (2024) resonates with the findings on Hausa housing, as both highlight how spatial relations evolve dynamically in response to social and environmental needs. The studies collectively reinforce the effectiveness of rule-based modeling in capturing and replicating indigenous architectural principles, though practical implementation remains a challenge, as noted by Tepavčević and Stojaković (2012), who highlighted the underutilization of shape grammar in computer-aided architectural design (CAAD).

While previous studies, such as those by AbdulRaheem and Rayis (2016), focused on stylistic diversity in Suakin architecture, the Hausa architectural study places greater emphasis on spatial relations and hierarchical zoning within housing layouts. The family of spatial relations and starting rules in Hausa architecture provides a more structured computational approach compared to the more flexible transformations observed in refugee housing (Abu-Aridah & Ligler, 2024). Furthermore, the Kano Metropolis study supports the argument that shape computation is crucial for maintaining social order, privacy, and climate adaptability in traditional housing, reinforcing the broader implications of computational design in architecture (Knight, 2003). Thus, the findings validate past research by demonstrating the applicability of shape grammar in preserving and adapting architectural traditions, while also extending the discussion on rule-based modeling as a tool for both cultural conservation and contemporary architectural innovation.

CONCLUSION AND RECOMMENDATION:

The this study on Computational Rule-Based Modeling of Hausa Architectural Patterns Using Plan Layouts from Kano Metropolis Urban Traditional Houses Forms, Nigeria has demonstrated that shape grammar provides an effective framework for understanding, preserving, and generating traditional Hausa house layouts. The findings from the family of spatial relations, shape rules, and vocabulary elements confirm that Hausa architecture follows a structured spatial hierarchy, where elements such as room spaces (RS), Zaure (Z), courtyards (CY), and staircases (SC) are systematically arranged based on functional, cultural, and climatic considerations. The integration of rule-based modeling and computational design ensures that these architectural patterns can be replicated and adapted,

allowing for the preservation of traditional Hausa housing principles while enabling contemporary innovations.

Each key finding has significant implications for both heritage conservation and architectural innovation. The family of shape rules and spatial relations ensures that Hausa house layouts can be systematically analyzed, allowing for computational generation of culturally responsive housing designs. The identification of different types of Hausa traditional houses, such as courtyard compound houses, story-type courtyard houses, and parametric-type courtyard houses, further validates the applicability of rule-based modeling in capturing diverse architectural forms. These findings align with previous research by AbdulRaheem and Rayis (2016) and Abu-Aridah and Ligler (2024), which emphasized the importance of shape grammar in documenting and generating traditional housing styles. Furthermore, by encoding Hausa spatial configurations into a computational system, the study facilitates urban planning strategies, adaptive reuse of traditional housing principles, and sustainable architectural development.

In conclusion, the use of computational rule-based modeling in analyzing and reproducing Hausa architectural patterns presents a transformative approach to preserving and adapting traditional housing designs. The findings reinforce the role of shape grammar as a tool for formalizing indigenous spatial knowledge, ensuring that Hausa architectural principles remain relevant amidst modernization and urban development. The implications extend beyond academic research, influencing policy-making, sustainable housing development, and digital heritage conservation. Future research should explore further computational refinements, parametric design applications, and integration with digital fabrication technologies, ensuring that Hausa architectural identity is preserved and evolved within contemporary architectural discourse. The researcher suggested some useful recommendations that can help both designers and researchers to learn the capacity of shapes grammar to describe and generate complex urban form through the computational composition of this unique architectural style. Therefore, there are no limitations to what can be expressed using this rule-based method in architectural design.

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