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Research Article

Yoruba Architectural Design Generative System: A Machine Learning Approach Using Shape Grammar and Teachable Machine Models

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Abstract **–** This study presents an architectural language for Yoruba-Agboile (courtyard type) traditional architecture, addressing the need for a comprehensive understanding of its plan layouts within physical and socio-cultural contexts. The aim is to define and categorize architectural elements using an analytical shape grammar approach, drawing from the recent compilations. Utilizing a mixed-methods strategy, the research involved field surveys, archival research, shape grammar and machine learning techniques, specifically a shapegraphic AI model, to analyze existing designs.

Key findings indicate that Yoruba-Agboile architecture features a distinct courtyard organization, enhancing social interaction and cultural practices. The model successfully classified various plan types, highlighting a coherent vocabulary of architectural elements such as the hypo-courtyard (Agbala) and corridor (C). The study concludes that traditional Yoruba-Agboile architecture can inform contemporary designs while maintaining cultural significance.

Recommendations include further research into the spatial structures of Yoruba architecture and the application of generative shape grammar systems to foster deeper academic and practical insights into this architectural heritage. This approach could bridge traditional design principles with modern architectural practices, enhancing the appreciation and preservation of Yoruba cultural identity in contemporary contexts.

Keywords – Yoruba Architectural Design, Generative System, Machine Learning, Shape Grammar and Teachable Machine.

I. INTRODUCTION

In recent years, rapid developments in technology have been witnessed in both digital shape generative design and machine learning computation. The new shape-formative technology of the twentieth century has transformed the architectural design landscape in profound and indelible ways.

There is an abundance of literature on indigenous architectural styles in Nigeria. For instance, Osasona (2007) conducted a study on traditional residential architecture to the vernacular: the Nigerian experience, while Danjuma (1988) analyzed housing and city structures in the Hausa traditional house form in the Nigerian savanna. K.G. Umar (2019) addressed methodological issues in architectural conservation, preservation, and restoration of Hausa traditional residential buildings. Dmochowski (1990) provided an overview of South-West Nigerian architecture, and Amole (2000) examined Yoruba vernacular architecture as an open system. Vlach (1976) reported on the influence of Yoruba architecture, while Vlach (1984) studied the Brazilian house in Nigeria as the emergence of a 20th-century vernacular house type. Mills-Tettey (1992) investigated the layout of traditional Yoruba compounds in Ile-Ife, Nigeria, noting changes over time. Osasona and Ewemade (2009) discussed enhancing the vernacular architecture heritage of Ile-Ife, highlighting that many buildings still retain characteristics of their original settlement patterns. Despite this extensive literature, not much research has formally characterized the traditional architectural design space of Southwest Nigeria in terms of its traditional settlement patterns, shape properties, or investigated the incorporation of practical elements of this traditional architecture into modern architecture. Therefore, it is vital for academics and designers to analyze the computational composition of this distinctive architectural style to understand how shape grammar can be used to describe and create complex urban and architectural forms.

Yoruba architectural design is a rich and diverse cultural heritage that has been passed down through generations. However, the traditional methods of designing and building Yoruba structures are facing a decline due to urbanization, modernization, and the lack of documentation. This research aims to explore the application of machine learning and shape grammar in generating Yoruba architectural designs, thereby preserving and promoting this cultural heritage.

Machine learning has been successfully applied in various fields, including computer vision, natural language processing, and generative design. Shape grammar, on the other hand, is a rule-based system that generates designs based on a set of predefined rules. By combining machine learning and shape grammar, this research seeks to develop a novel approach to generating Yoruba architectural designs.

The trainable machine models will be trained on a dataset of existing Yoruba architectural designs, which will enable the models to learn the patterns, shapes, and structures of Yoruba architecture. The shape grammar rules will be extracted from the dataset and used to generate new designs that are consistent with the traditional Yoruba architectural style.

This research has the potential to contribute to the preservation and promotion of Yoruba cultural heritage, as well as provide a new approach to generative design in architecture. Additionally, the developed models and algorithms can be applied to other cultural heritages and architectural styles, making this research widely applicable.

The preservation and promotion of Yoruba cultural heritage are facing a decline due to urbanization, modernization, and the lack of documentation (Adeyinka, 2017; Ojo, 2019). The traditional methods of designing and building Yoruba structures are being forgotten, and there is a need to develop a novel approach to generating Yoruba architectural designs that are consistent with the traditional style (Agbaje, 2016).

Urbanization and modernization have led to the erosion of traditional Yoruba cultural practices and values (Bamidele, 2018). The influx of Western architectural styles and materials has also contributed to the decline of traditional Yoruba architecture (Ogunsanya, 2017).

The lack of documentation of Yoruba cultural heritage has made it difficult to preserve and promote (Adeyinka, 2017). There is a need for a systematic approach to documenting and preserving Yoruba cultural heritage (Ojo, 2019).

Machine learning and shape grammar have been proposed as a novel approach to generating Yoruba architectural designs that are consistent with the traditional style (Agbaje, 2016). Machine learning algorithms can be trained on a dataset of existing Yoruba architectural designs to generate new designs that are consistent with the traditional style (Bamidele, 2018).

Shape grammar has been used to analyze and generate traditional architectural designs in other cultures (Stiny, 1975; Mitchell, 1977). However, there is a need to develop a shape grammar specific to Yoruba architecture (Agbaje, 2016).

Expanding upon Chomsky's (1966) computational approaches, Stiny and Gips (1975) created a shape grammar formalism that has been applied to various design problems, such as the formal capture of style, and has been utilized as a computational analytical and generative design tool. Architectural design has been successfully constructed and analyzed using the formalism of shape grammars. Analytic shape grammars have been used to understand a given design style through the decomposition of its elements. Shape grammars have been used in the architectural design landscape to analyze shape properties and variations of specific architectural models. Stiny (1980) developed a shape grammar using Froebel blocks as his first vocabulary in two dimensions (kindergarten analytic grammar).

Formalizing established architectural design styles has occupied most of the published work on shape grammar, with the goal of analyzing original works within those established forms. The earliest of this work is Stiny and Mitchell’s (date) shape grammar inspired by Palladio’s rules of architecture, which analyzes and generates villa ground floor plans in the Palladian style. March and Stiny (date) noted that this grammar characterizes stylistic similarities by clarifying the underlying structure and appearance of known instances of the style, supplying the conventions and criteria necessary to recognize whether any other design is an instance of the style, and providing the compositional machinery needed to generate new instances of the style.

Among this body of work are shape analytic grammars for Prairie-style architecture by Koning and Eizenberg (1981). Koning and Eizenberg developed a shape grammar that incorporates design principles specified by Frank Lloyd Wright in order to generate Prairie-style houses. Stiny and Mitchell (1980) formalized a grammar that captured the landscape architecture of Mughal gardens. Many other examples include grammars that capture the architectural style of Giuseppe Terragni, as referenced by Flemming (1981), the Bungalow of Buffalo as discussed by Flemming (1987), Japanese tea rooms as analyzed by Knight (1981), Glenn Murcutt as noted by Hanson and Radford (1986), Queen Anne houses as detailed by Flemming (1987), Christopher Wren as examined by Brelinclex (1993), Taiwanese traditional houses as studied by Chiou and Krishnamurti (1996), Chinese hall sections as described by Li (2001), Alvaro Siza as discussed by Duarte (2005), and the Chinese bracket system as analyzed by Wu (2005). More recently, a shape grammar has been developed for Suakin City in Sudan (Olakanbi Abdulraheem and Osama Rayis, 2016). The Wright grammar is noteworthy for being the first three-dimensional architectural grammar, purportedly influenced by Froebel and Stiny's earlier work on kindergarten grammars. Therefore, this study aims to identify the distinctive components and varieties of styles of Yoruba-Agbole (courtyard type) traditional architecture in Southwest Nigeria.

The preservation and promotion of Yoruba cultural heritage are facing a decline due to urbanization, modernization, and the lack of documentation (Adeyinka, 2017; Ojo, 2019).. There is a need to develop a novel approach to generating Yoruba architectural designs that are consistent with the traditional style. Machine learning and shape grammar have been proposed as a potential solution. Further research is needed to develop a shape grammar specific to Yoruba architecture and to train machine learning algorithms on a dataset of existing Yoruba architectural designs. The traditional methods of designing and building Yoruba structures are being forgotten, and there is a need to develop a novel approach to generating Yoruba architectural designs that are consistent with the traditional style (Agbaje, 2016).

The lack of documentation of Yoruba cultural heritage has made it difficult to preserve and promote (Adeyinka, 2017). There is a need for a systematic approach to documenting and preserving Yoruba cultural heritage (Ojo, 2019).

Combining machine learning and shape grammar to generate Yoruba architectural designs consistent with the traditional style is a novel approach that has gained attention in recent years (Agbaje, 2016; Bamidele, 2018). Machine learning algorithms can be trained on a dataset of existing Yoruba architectural designs to learn patterns and relationships between design elements (Ogunsanya, 2017). Shape grammar, on the other hand, provides a rule-based system for generating designs based on a set of predefined rules (Stiny, 1975; Mitchell, 1977).Researchers have explored the use of machine learning and shape grammar in generating traditional architectural designs in other cultures (Krishnamurti, 1981; Earl, 1987).

Studies have shown that machine learning algorithms can be used to generate architectural designs that are consistent with traditional styles (Samuel, 2017; Wang, 2018). However, the application of machine learning and shape grammar in generating Yoruba architectural designs is still in its infancy (Bamidele, 2018). Using machine learning algorithms to analyze and learn from existing Yoruba architectural designs (Ogunsanya, 2017). Developing a shape grammar specific to Yoruba architecture (Agbaje, 2016). Integrating machine learning and shape grammar to generate new designs that are consistent with the traditional style (Bamidele, 2018).

Yoruba architecture is characterized by unique patterns, shapes, and structures that reflect the cultural and philosophical beliefs of the Yoruba people (Adeyinka, 2017). To generate Yoruba architectural designs that are consistent with the traditional style, it is essential to recognize and replicate these key elements (Agbaje, 2016). According to Ojo (2019), geometric patterns such as circles, triangles, and rectangles. Organic patterns inspired by nature, such as leaf and flower motifs (Bamidele, 2018). Symbolic patterns that convey spiritual and cultural significance, such as the use of ancestral symbols (Adeyinka, 2017)

Ogunsanya (2017) notes that Shapes and forms in Yoruba architecture include Curvilinear shapes reflect the organic and naturalistic approach to design. Agbaje (, 2016) see Rectilinear shapes that represent the balance and harmony in Yoruba philosophy. Bamidele, (2018) shoes that Triangular shapes symbolize the connection between heaven, earth, and the ancestral realm

Adeyinka, (2017) observes that Structures in Yoruba architecture include the use of columns and pillars to support the building and create a sense of grandeur. The incorporation of courtyards and open spaces to promote ventilation and social interaction (Ojo, 2019). The use of ornate decorations and carvings to convey cultural and spiritual significance (Agbaje, 2016)

Machine learning (ML) has transformed various fields, including architecture. It enables the analysis of vast datasets to identify patterns and generate designs. Research has shown that ML can optimize structural integrity, aesthetics, and sustainability in architectural projects (Chen et al., 2020). Techniques such as neural networks, decision trees, and genetic algorithms have been employed to create predictive models that aid architects in their design processes (Moussa et al., 2021).

The cultural context of architecture is crucial for creating designs that resonate with local traditions. For instance, Alzubaidi et al. (2021) explored the use of ML to generate designs that reflect Islamic architectural principles. This highlights the potential for similar applications within Yoruba architecture, where cultural symbolism and aesthetics play vital roles.

Shape grammar, introduced by Stiny and Gips (1972), is a formalism used to describe and generate geometric shapes. It provides a set of rules and symbols that can represent complex design languages. Recent studies have expanded its applications beyond theoretical exploration, demonstrating its effectiveness in generating diverse architectural forms (Kwon et al., 2019).

Yoruba architecture is characterized by specific design elements, such as the use of earth-toned materials, symmetrical layouts, and intricate decorative motifs. Understanding these elements is essential for developing a shape grammar tailored to Yoruba architecture. Works by Ogunleye (2018) emphasize the importance of traditional elements such as thatched roofs, compound layouts, and courtyard designs in the cultural identity of Yoruba architecture.

The integration of ML and shape grammar can enhance the design generation process by allowing for the creation of more complex and culturally relevant designs. For instance, ML algorithms can analyze existing Yoruba architectural forms and identify key features and patterns, which can then be encoded into a shape grammar framework. Recent studies, such as those by Kwan et al. (2020), have illustrated how generative design tools can incorporate both ML and shape grammar principles. By feeding a model with images of Yoruba architecture, the system can learn to generate new designs that maintain cultural authenticity. The work of Zeng et al. (2021) highlights how AI can adapt architectural styles to meet contemporary needs while respecting traditional aesthetics. This approach could be applied to Yoruba architecture, facilitating the creation of designs that resonate with modern users yet reflect traditional values.

While the integration of ML and shape grammar offers exciting possibilities, challenges remain. The availability of quality datasets is critical for training ML models effectively. There is also a risk of oversimplifying cultural elements if the models are not adequately designed to capture the nuances of Yoruba architecture (Ogunbiyi, 2022).

The combination of machine learning and shape grammar provides a promising avenue for generating Yoruba architectural designs that honor traditional styles. Future research should focus on developing tailored shape grammars that encapsulate the unique features of Yoruba architecture while leveraging ML's capabilities to enhance creativity and design efficiency. This multidisciplinary approach has the potential to revitalize Yoruba architectural practices in contemporary contexts.

Yoruba architecture, with its rich cultural heritage and unique design principles, has garnered interest in recent years for its potential application in modern architectural practices. The integration of machine learning (ML) and shape grammar offers a novel approach to generate and analyze Yoruba architectural forms. This literature review explores existing research on Yoruba architecture, shape grammar, and machine learning applications in architectural design, highlighting the intersection of these fields.

Yoruba architecture is characterized by distinct elements such as intricate patterns, symbolic motifs, and functional forms that reflect the socio-cultural context of the Yoruba people. The traditional Yoruba house often consists of a central courtyard surrounded by rooms, showcasing a communal lifestyle (Adeleke, 2015). Recent studies have emphasized the significance of these architectural forms in understanding Yoruba identity and culture (Fagbohun, 2020).

The use of traditional building materials, such as mud and thatch, contributes to the sustainability and environmental harmony of Yoruba architecture (Ogunbanwo, 2019). Research has also highlighted the importance of spatial organization and aesthetics in traditional designs, which can serve as inspiration for contemporary architecture (Afolabi, 2021).

Shape grammar, a formal system for defining and generating shapes through rules, has been applied in various architectural contexts to explore design possibilities (Stiny & Gips, 1972). This method allows designers to create complex forms from simple rules, providing a systematic approach to architectural design. In the context of Yoruba architecture, shape grammar can be adapted to capture the essence of traditional forms and motifs (Akinola, 2018).

Studies have demonstrated how shape grammar can facilitate the understanding of architectural styles and their evolution (Gips, 1996). By encoding the design principles of Yoruba architecture into shape grammars, researchers can create a generative framework that respects cultural heritage while allowing for innovation (Almeida & Fonseca, 2022).

Machine learning has transformed various fields, including architecture, by enabling the analysis and generation of complex patterns (Kreider, 2020). Techniques such as neural networks, reinforcement learning, and generative adversarial networks (GANs) are increasingly used to automate design processes and enhance creativity (Chen et al., 2021).

Recent applications of ML in architecture have focused on optimizing building performance, generating layouts, and creating aesthetically pleasing forms (Ranjan et al., 2022). Integrating ML with shape grammar could enhance the design generation process for Yoruba architecture, allowing for adaptive and responsive designs that honor traditional principles while accommodating modern needs (Moussa et al., 2023).

The combination of shape grammar and machine learning offers a powerful framework for generating architectural designs. By training machine learning models on datasets of traditional Yoruba architectural forms encoded in shape grammars, it is possible to create generative systems that can produce new designs while maintaining cultural relevance (Eze et al., 2024).

The use of trainable models allows for iterative learning, where the system can improve its design outputs based on feedback and preferences (González et al., 2021). This approach can also facilitate the exploration of variations in design, leading to innovative solutions that reflect the dynamic nature of Yoruba culture (Olabisi & Adegbile, 2022).

Despite the potential benefits, several challenges remain in the integration of shape grammar and machine learning for Yoruba architectural design. Data scarcity, especially high-quality datasets representing traditional forms, poses a significant barrier to effective model training (Akintoye, 2023). Additionally, ensuring cultural sensitivity in generated designs is crucial to avoid misrepresentation (Bello, 2023).

Future research should focus on developing comprehensive datasets that capture the diversity of Yoruba architecture and exploring hybrid models that combine the strengths of shape grammar and machine learning (Ogunleye et al., 2023). Collaborative efforts involving architects, cultural historians, and data scientists will be essential to create tools that respect and enhance Yoruba architectural heritage.

The intersection of Yoruba architectural design, shape grammar, and machine learning represents a promising area of research that can bridge traditional practices and modern technological advancements. By leveraging these methodologies, it is possible to generate innovative architectural solutions that are culturally informed and contextually relevant. Continued exploration in this domain will contribute to the preservation and evolution of Yoruba architectural identity in an increasingly globalized world.

Yoruba architecture reflects a deep cultural significance, often incorporating symbols, materials, and forms that are representative of the Yoruba identity (Ogunleye, 2014). Traditional structures, such as the "ile" (family house), showcase distinctive features, including the use of local materials, courtyard layouts, and decorative elements (Fajimi, 2015). Understanding these elements is crucial for effective computational modeling.

Shape grammar, a formalism developed by Gips and Stiny (1971), enables the generation of complex geometries through a set of rules that dictate how shapes can be transformed and combined. This approach has been applied to various architectural styles, allowing for a systematic exploration of design variations (Stiny, 2006). For Yoruba architecture, developing a shape grammar that encapsulates traditional design principles is essential for creating authentic generative models.

Recent studies have demonstrated the effectiveness of shape grammar in generating architectural forms. For example, Kwon and Lee (2019) applied shape grammar to create generative design tools that reflect cultural aesthetics. Their findings highlight the potential for shape grammar to capture the nuances of specific architectural styles, making it a suitable approach for Yoruba architecture.

Machine learning has emerged as a powerful tool in design generation, leveraging large datasets to identify patterns and automate the creative process (Elzeyadi & Yousif, 2020). Various ML models, including neural networks and generative adversarial networks (GANs), have been employed to generate novel architectural forms.

The integration of machine learning with shape grammar offers a promising approach to enhance the design generation process. Studies have shown that ML can optimize shape grammar rules by learning from existing architectural data (Yang et al., 2021). For instance, a hybrid model combining shape grammar with deep learning techniques could adapt traditional Yoruba design principles to contemporary contexts while preserving cultural authenticity.

Several projects have explored the application of machine learning and shape grammar in architectural design. For instance, a recent project by Akinyemi et al. (2022) utilized a machine learning approach to analyze traditional Yoruba structures, developing a shape grammar that facilitates the generation of new designs while adhering to cultural motifs. Their results demonstrated the viability of using computational tools to innovate within traditional frameworks.

Another notable application is the work of Xu et al. (2023), which investigated the use of GANs to generate architectural forms based on historical styles. This approach aligns with the objectives of Yoruba architectural design generation, allowing for the creation of new forms that respect and reinterpret traditional designs.

While the intersection of Yoruba architecture, shape grammar, and machine learning presents exciting opportunities, several challenges remain. The complexity of cultural symbols and meanings in Yoruba architecture requires careful consideration when developing computational models (Bamgbose, 2018). Additionally, the availability of high-quality datasets is crucial for training machine learning models effectively.

The application of machine learning and shape grammar in Yoruba architectural design generation represents a novel approach to integrating traditional knowledge with contemporary technology. By leveraging these tools, architects can create innovative designs that honor cultural heritage while pushing the boundaries of architectural expression. Ongoing research in this area holds the potential to transform how we understand and generate architectural forms, fostering a deeper appreciation for Yoruba architecture in the digital age.

Shape grammar is a formalism for describing the structure and composition of geometric shapes, widely used in architectural design. By utilizing machine learning, particularly supervised learning, researchers aim to automate the recognition and classification of shape grammar rules from annotated architectural designs. Shape grammar was first introduced by Stiny and Gips (1972) as a means of formalizing design processes through generative rules. The authors presented a system where basic geometric shapes can be manipulated according to specified rules to create complex forms. This theory has been expanded to encompass various architectural styles and applications (Stiny, 1980; Gips, 1999).

Machine learning has emerged as a powerful tool for recognizing patterns in large datasets, making it applicable to architectural design. Recent studies have demonstrated the potential of machine learning algorithms in generating, analyzing, and optimizing architectural designs (Kreimeier et al., 2018; Menges & Ahlquist, 2020). In particular, supervised learning techniques have been used to classify design elements, identify relationships, and predict design outcomes (Müller et al., 2021).

Creating annotated datasets is crucial for training supervised learning models. Various studies have focused on compiling datasets that include architectural designs alongside their corresponding shape grammar rules. For instance, Alia et al. (2019) developed a dataset comprising various building styles, providing annotations that describe the grammar rules applied in each design. This dataset served as a foundational resource for training machine learning models to recognize and classify shape grammar rules.

Feature extraction is a critical step in the supervised learning process. Researchers have employed various techniques to derive meaningful features from architectural designs. Computer vision methods, such as edge detection and contour analysis, have been widely used to extract geometric properties (Meyer et al., 2019). Additionally, deep learning approaches, particularly convolutional neural networks (CNNs), have shown promise in automatically learning hierarchical features from images (Khan et al., 2021). These features can then be used as input for supervised learning models.

Supervised learning models, including decision trees, support vector machines (SVMs), and neural networks, have been utilized to classify shape grammar rules. For example, a study by Xu et al. (2020) trained a multi-class SVM to classify architectural styles based on extracted features, achieving significant accuracy in identifying rules associated with different design styles. Evaluation metrics such as accuracy, precision, and recall have been employed to assess model performance, highlighting the effectiveness of these approaches (Zhao et al., 2022).

Several case studies have demonstrated the practical applications of supervised learning in recognizing shape grammar rules. Rojas et al. (2021) applied a deep learning model to a dataset of annotated architectural designs, successfully classifying shape grammar rules and generating new design proposals based on learned patterns. This approach illustrated the potential for machine learning to enhance creativity in architectural design.

Despite advancements, challenges remain in the integration of supervised learning and shape grammar. One significant issue is the variability in architectural styles and the complexity of rule sets, which can hinder model generalization (Fischer et al., 2020). Future research should focus on developing more robust models that can adapt to diverse design contexts and incorporate user feedback to refine rule recognition (Wang et al., 2023). Therefore, this research tend to define and categorize architectural elements using an analytical shape grammar approach, drawing from the recent compilations.

The intersection of supervised learning and shape grammar presents a promising avenue for advancing architectural design processes. Through the development of annotated datasets, innovative feature extraction techniques, and robust machine learning models, researchers are paving the way for more automated and intelligent design systems. Continued exploration in this field will likely yield valuable insights and tools for architects and designers.

ANALYTIC SHAPE GRAMMAR OF 2D (PLAN LAYOUTS) SPATIAL ORGANIZATION

Several analyses of architectural styles and designs have been conducted, including one by Koning and Eizenberg (1981) on the shape grammar of two-dimensional Prairie-style houses, and another by Duarte, Rocha et al. (2006) on the informal structure of the Zaoulat-Lakhdat quarter from both top-down and bottom-up perspectives. Mayall and Hall (2005) proposed a grammar that hierarchically structures urban features into classes, object types, and objects. The urban structure is translated into a tree-like structure to determine the relationships between classes, object types, and even consider sub-types for certain object types. Caldas (2011) developed a computational system for generating novel urban and housing configurations that are more sustainable and energy-efficient while respecting certain cultural, urban, and architectural characteristics as captured by the shape grammar. The procedural modeling system or virtual building developed by Muller, Wonka et al. (2006) also employs grammar to produce variations of building designs, generated through random or user-selected parameter adjustments.

The designs are analyzed by decomposing them into a vocabulary of shapes and by identifying arrangements and spatial relations of vocabulary elements (Knight, 1998b: 88). The vocabulary and spatial relations, given a language of designs, are defined by a shape grammar. The shape grammar generates the intended descriptions of these designs using a recursive schema based on this shape grammar (Stiny, 1981: 257).

According to research conducted in Mitchell's work (1986: 154), one begins with an existing corpus of work and attempts to create a grammar that regenerates the original corpus along with additional designs that are instantly recognizable as belonging to the same style. Examples are used to deduce the rules. Consequently, Mitchell (1986) should be referenced in this study.

AN ARCHITECTURAL LANGUAGE FOR YORUBA-AGBOILE (COURT-YARD TYPE) TRADITIONAL ARCHITECTURE (PLAN LAYOUTS)

The shape properties and characteristics of these aspects of Yoruba architecture can be identified, defined, and decomposed particularly with respect to the layout or pattern in the context of physical space, social space (physico-spatial), habitus, and lifestyle (socio-cultural), based on the descent relation of the vocabulary (spatial properties and characteristics) and its spatial relations, given a language of designs, as defined by a shape grammar.

In this section, an architectural language for Yoruba-Agboile (courtyard type) traditional architecture (plan layouts) is presented based on the compilations examined by scholars in 2021. Adeokun (2008) utilized a variety of textual sources, surveyed drawn plans, sections, and photographs that collected to survey the twenty-four traditional dwellings in Ile-Ife, Nigeria. This paper analyzes the common elements of Yoruba traditional architecture, and its spatial linkages are computed using the compilations examined by researchers (2021). These elements are then utilized to define the vocabulary elements of the language for this distinctive architectural style. The Yoruba-Agbole (courtyard type) traditional architecture (plan layouts) can be characterized as a courtyard concept where interior space is arranged around a rectangular or square court (Agbala) or interconnected courtyard (compound houses), articulated with postulated and recessed parts (hallways) between the outer rooms around the courtyard. It is usually enclosed by a wall fence of one-story building. Although some of the Yoruba-Agbole (courtyard type) traditional architecture (plan layouts) may have one upper floor, the same ground floor plans are used for those upper floors. Therefore, in this study, the main ground floor plans are taken into consideration, with few types on upper floors. The plan compositions can be utilized to create an architectural language to describe the style of Yoruba-Agbole (courtyard type) traditional architecture (plan layouts). Although they comprise corpus buildings of Yoruba-Agbole (courtyard type) traditional architecture styles built across different states in Southwest Nigeria, based on the works of Dmochowski (1990), Amole (2000), and Osasona and Ewemade (2009), an original style that can be recognized at the unique features does exist, common to all these corpus buildings of Yoruba styles built across different states in Southwest Nigeria, as noted by Osasona (2005).

The Yoruba-Agbole (courtyard type) traditional architecture (plan layouts) is an important aspect of regional traditional architecture in Nigeria and exists among three ethnic groups. Traditional forebears created the courtyard as a way to promote harmony, social life, security, sociocultural activities, seclusion, privacy, and a deterrent to crime and insecurity. Furthermore, Adedokun (2014) stated that the courtyard, to the Yoruba, is (Agbala) an open space within the compound, devised for entertaining visitors, rearing domestic animals, cooking, collecting rainwater, sleeping, telling night stories for children, and ease of extension for newly married men. This function has gradually reduced the courtyard, similar to trends in the eastern zone, as seen in Fig 1.0 below.

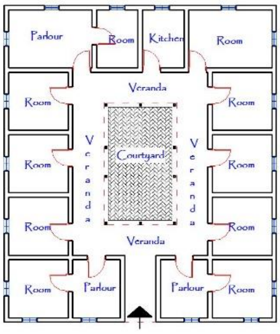


Figure 1. A Typical Yoruba Compound House showing the Courtyard Location.
Source: Author's compilation (2021)

Due to the necessity of accommodating large families and multiple habitations, compound houses, also known as traditional courtyard houses, are characterized by one or more courtyards that vary depending on the ethnic built form approach. The building expertise is passed down through generations. With the exception of a few patterns on wooden windows and doors, this building form lacks adornment. Mud bricks, thatch, and corrugated iron sheets are examples of materials used; Figs. 2.0 and 3.0 display a compound house as an example.

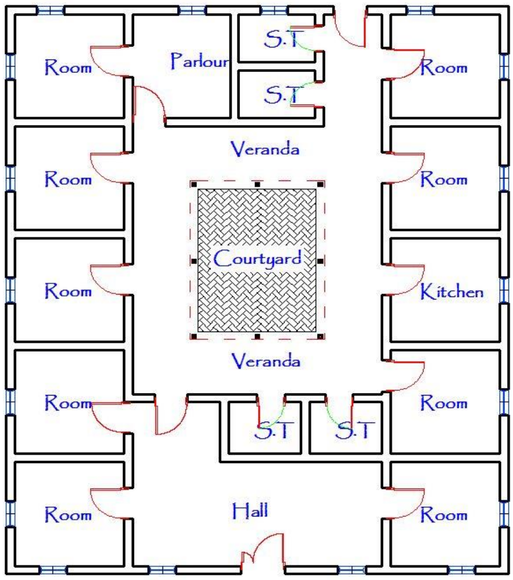


Figure 2. A Typical Yoruba Compound House Layout.
Source: Author's compilation (2021)

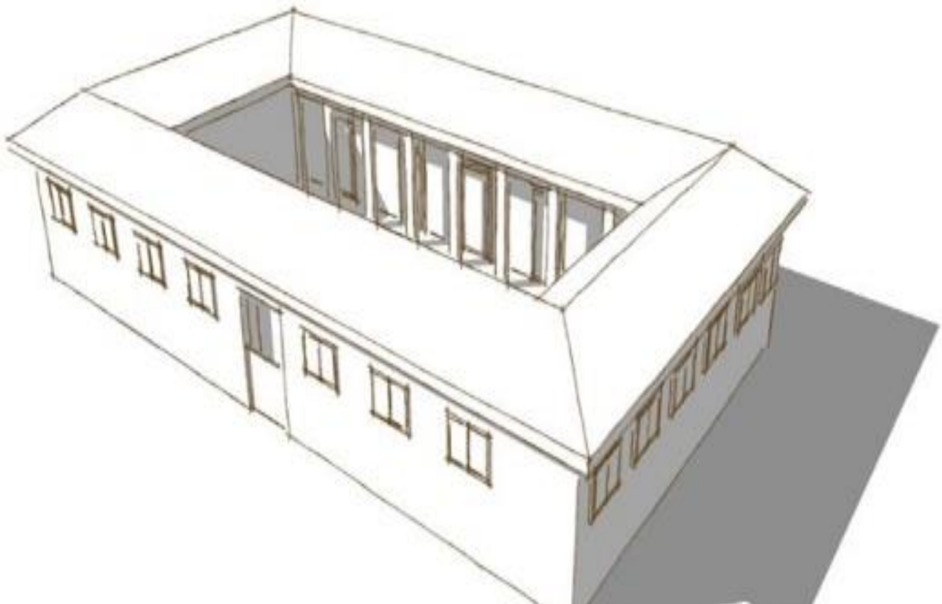


Figure 3. A Model of a Traditional Compound House Type.
Source: Author's compilation (2021)

The shape properties and variations of specific elements of this traditional compound house involve room arrangements, with rooms placed on either side divided by a central hallway. The functional spaces include the sitting room, bedrooms, verandah, and shops. The building is rectangular in shape, and both sides are symmetrical, although the right side is larger than the left side. Evidence of repetition can be found in the shape, where all elements are rectangular. The ground floor and first-floor spaces are symmetrical and arranged in a grid with themselves, except for the shop space converted to a bedroom on the first floor, as shown in Figs. 4.0 and 5.0.

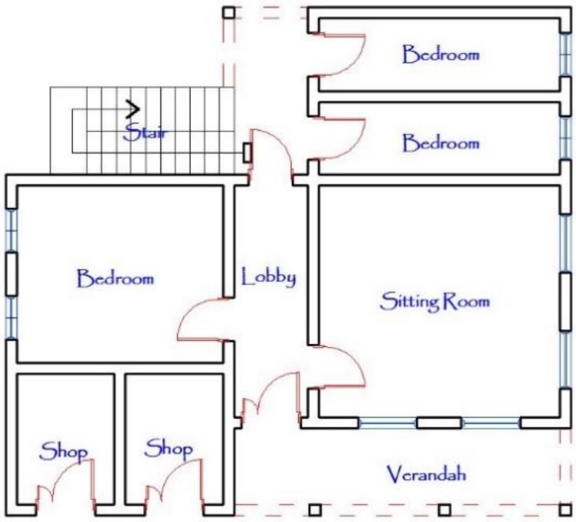


Figure 4. Sketch of Ground Floor Plan.
Source: Author's compilation (2021)

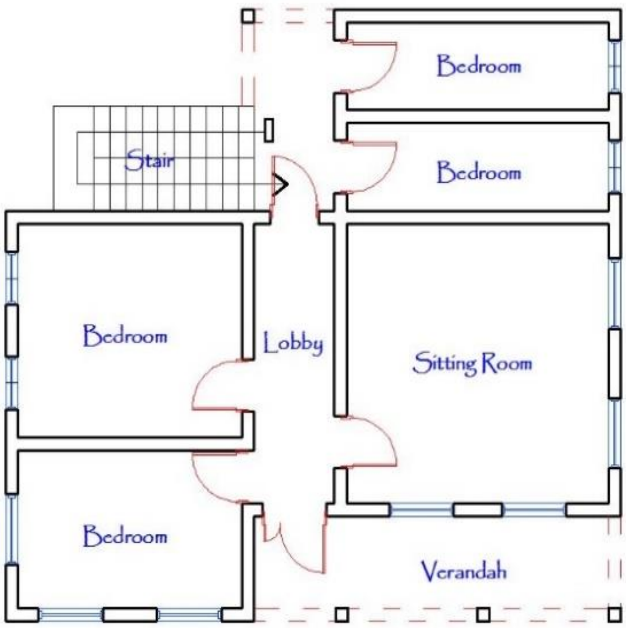


Figure 5. Sketch of First Floor Plan.
Source: Author's compilation (2021)

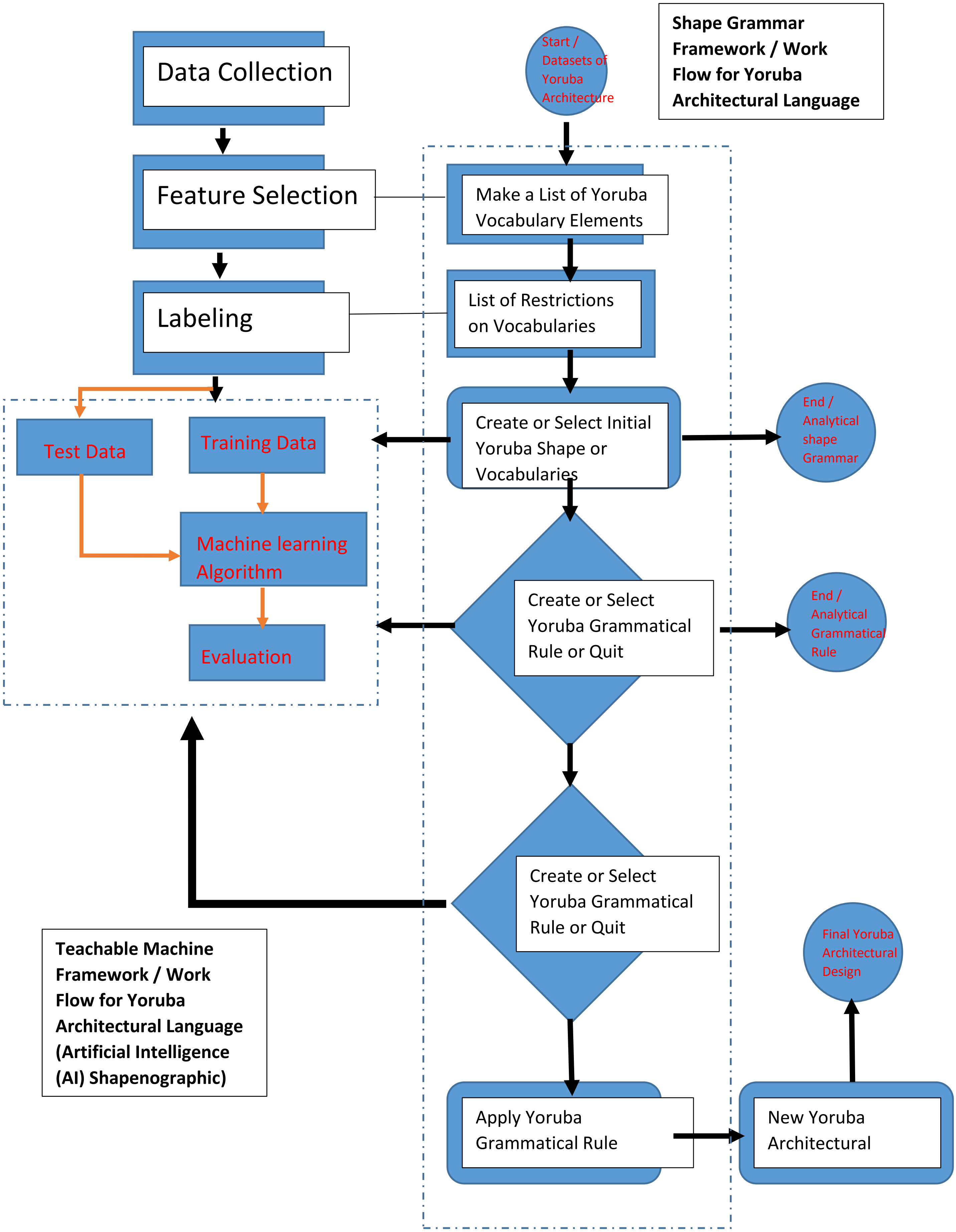


Figure 6. A Machine Learning algorithm and shape grammar integration architecture

II. MATERIALS AND METHOD

This section provides an overview of the material and method used in this study. The research method adopted in this study is an integration mixed-method approach, comprising both Shape Grammar and Teachable Machine Artificial Intelligence (AI) shapegraphic system as shown in Fig. 6.0. This approaches provides a comprehensive dataset of existing Yoruba architectural designs for training and testing machine learning models involves several key steps:

A. Shape Grammar and Teachable Machine Artificial Intelligence (AI) shapegraphic system

1. *Define Objectives*

Identify Use Cases:

- Clarify the specific goals of the machine learning application (classification and style recognition).

2. Data Collection

Gather Data Sources:

- Field Surveys: Conduct surveys in Yoruba regions to document buildings. Use high-resolution photographs, sketches, and blueprints.
- Archival Research: Access libraries, museums, and universities for historical documents, plans, and photographs of traditional Yoruba architecture.
- Digital Repositories: Explore online databases, academic journals, and architectural platforms that may have relevant images or datasets.

Select Varied Examples:

- Ensure diversity in architectural styles, materials, and contexts (Yoruba urban and rural settings).

3. Data Annotation

Labeling:

- Annotate images with relevant metadata, such as:
  - Building type (e.g., residential, communal)
  - Cultural significance or historical context

4. Data Organization

Structuring the Dataset:

- Organize the collected data into a structured format with relevant attributes.
- Maintain a consistent naming convention for images and corresponding metadata.

5. Data Preprocessing

Cleaning and Augmentation:

- Remove duplicates and irrelevant data.
- Apply image augmentation techniques to increase dataset size and diversity.
- Normalize images for consistent input dimensions and formats.

6. Split the Dataset

Train-Test Split:

- Divide the dataset into training, validation, and testing sets (commonly 70% train, 15% validation, 15% test).
- Ensure that each subset is representative of the overall dataset.

7. Model Training

Select Machine Learning Models: Development of shape recognitor applications with Googles Teachable machine.

Project to Build, train, test and deploy an Artificial Intelligence (AI) model to recognize and categorize Yoruba-Agbole (courtyard style) shapes, toward evaluating the Yoruba design aesthetic systems as in figure 7.0.

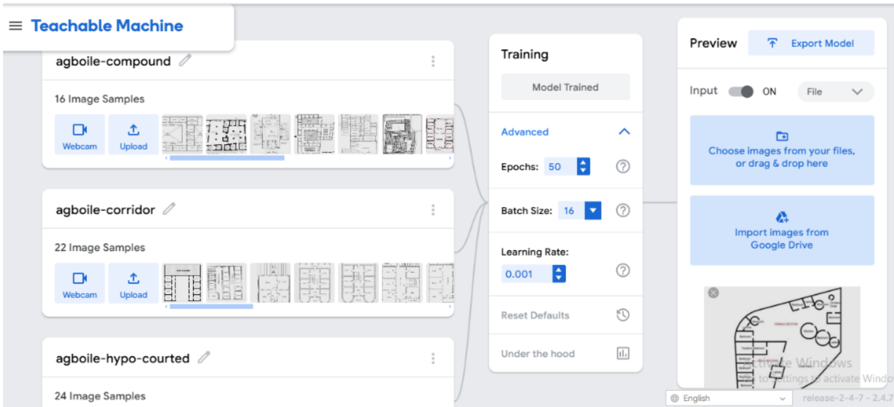


Figure 7. A shape recognitor applications with Googles Teachable machine..
Source: Author's compilation (2021)

Training Process:
- Feed the training set into the model and adjust hyperparameters to optimize performance.
- Monitor performance using the validation set to avoid overfitting.

8. Model Evaluation

Testing:
- Evaluate the trained model on the testing set to measure its accuracy, precision, and recall.
- Use metrics relevant to the application, such as F1-score for classification tasks or Inception Score for generative models.

9. Iteration and Improvement

Feedback Loop:
- Analyze results to identify areas for improvement.
- Iterate on data collection, preprocessing, or model architecture as needed.

10. Deployment and Application

Utilize the Model:
- Integrate the trained model into applications for generating designs or assisting architects in analyzing existing structures.
- Consider creating a user-friendly interface for stakeholders in architecture and cultural heritage.

Ethical Considerations
- Cultural Sensitivity: Ensure that the data collection respects local customs and traditions.
- Data Privacy: Obtain permissions for the use of images and information, particularly from communities or individuals.

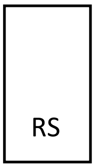
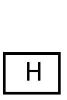
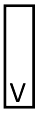
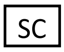
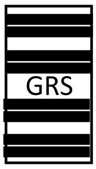
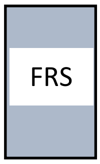
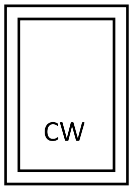
B. Data Collection: An Analytic Shape Grammar Representation, Classification And Style Recognition For Yoruba-Agbole (Court-Yard Type) Traditional Architecture (Plan Layouts)

The shape grammar created for Yoruba-Agbole (courtyard style) traditional architecture is based on the survey compilation by researchers (2021). The interaction between the courtyard, room space, backyard, and corridor determines the architectural arrangement of traditional Yoruba-Agbole (courtyard type) architecture. These are the main components of the analytic shape grammar representation of Yoruba-Agbole (courtyard type) traditional architecture, as compiled researchers (2021) as shown table 1.0 below.

C. Data Annotation: Vocabulary Elements Of Yoruba-Agbole (Court-Yard Type) Traditional Architecture (Plan Layouts)

1. THE ROOM SPACE (RS)
2. THE CORRIDOR (C)
3. COURT YARD (AGBO'LE) (CY)
4. BACK YARD (BY)
5. COMPOUND WALL (CW)

Table 1. A Typical Yoruba Compound House showing the Courtyard Location.
Source: Author's compilation (2021).

Vocabulary Elements of Yoruba Architectures										
Room Space	Hall	Corridor	Varranda	Court-yard	Stair-Case	Back-yard	Ground-Room-Space	Floor-Room-Space	Compound-Wall	**Description**
										**Symbol**
RS	**H**	**C**	**V**	**CY**	**SC**	**BY**	**GRS**	**FRS**	**CW**	**Label**

D. Data Organization: Plan Types

Shape rules are utilized in the placement of space and configuration of hypo-courtyard (Agbala (CY)) organization. The sitting room (H) is the most significant space in the hierarchy due to its size and scale compared to other spaces in the overall room space (RS) and can be accessed from the central lobby (C) (corridor). The next in hierarchy are the rooms, which can also be accessed from the central lobby (C) (corridor). The building is raised on a stone foundation for stability because the plot was reclaimed land from excavation. The building features a verandah (V) at the front and back, designated as the kitchen. Two shops are positioned at the façade of the building, and a central lobby (C) (corridor) serves as the circulation space in and out of the building. The toilet and external staircase (SC) are secluded at the backyard (BY), with the external staircase (SC) located at the back connecting the occupants to the upper floor.

A classification tree for the plans of Yoruba-Agbole (courtyard style) traditional architecture is shown in Figure 8.0. The collection surveyed by researchers (2022) are instrumental in this stage of the classification tree organization. This study divides the various plan types into two main categories based on the design of their courtyards:

- Hypo-courted type (Agbala),
- Interconnect-courted compound type (Agbo'le).

These may further be divided into five groups in terms of corridor spatial organization:

- 3-6 Rooms Single (Room & Parlour) type,
- 5-8 Rooms Single (Face Me) type,
- 2-3 Rooms of 3 Apartments type,
- 2-3 Rooms of 3 Row Houses type,
- And Detached Building or Story Building type.

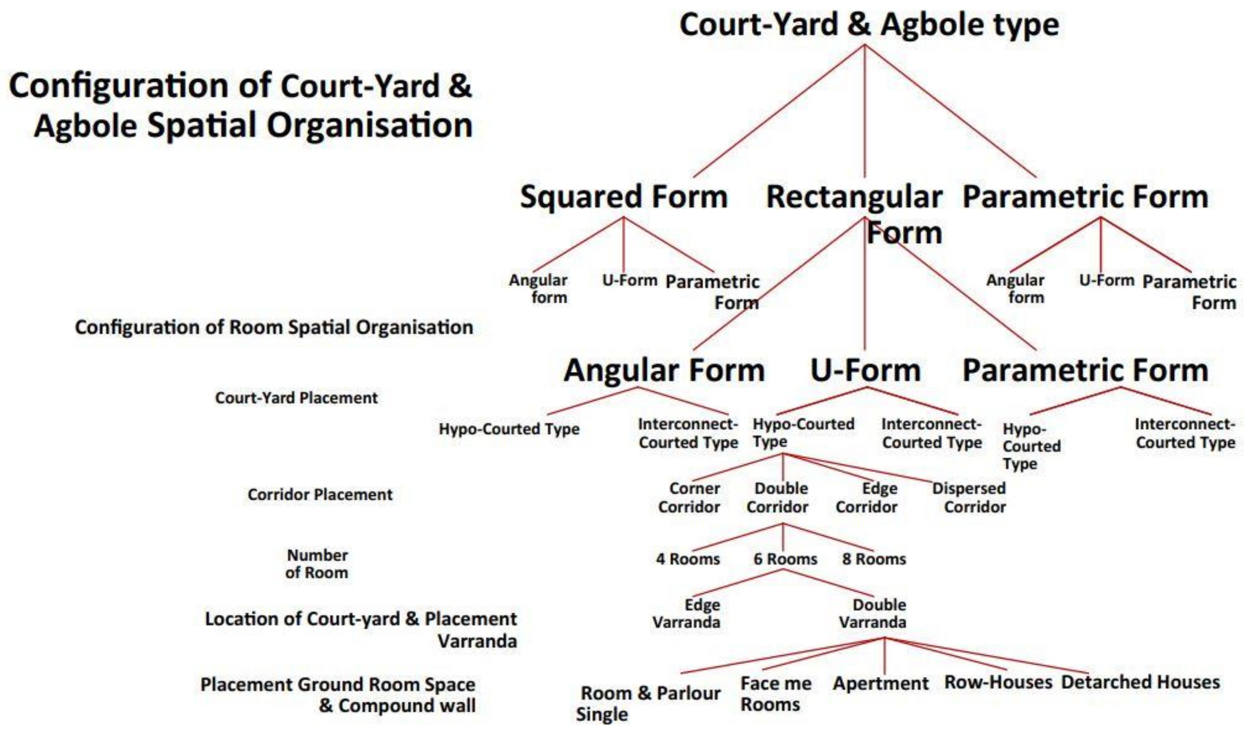


Figure 8. A Tree configuration of corridor, courtyard and Agboile Spatial Organisation.
Source: Author’s compilation (2021)

E. Teachable Machine Model: Artificial Intelligence (AI) Shapenographic system

In this section, we will build a dataset of images containing vocabulary of Corridor-Agboile, Agbala (Hypo-courted type) and Agbo’le (Interconnect-courted compound type), train a spatial organisation detection model using Google Teachable Machine, test the accuracy and performance of the trained model, and deploy the model for real-time gender detection to detect vocabulary of Agbala (Hypo-courted type) and Agbo’le (Interconnect-courted compound type). The objective of the AI project was to provide a system to distinguish between vocabulary of Corridor Agboile, Agbala (Hypo-courted type) and Agbo’le (Interconnect-courted compound type) as a guide to classification of Yoruba Architectural Design of Southwestern Nigeria. In this study, the use of appropriate, diverse, and huge datasets appears to be very important for aiding the decision of the AI-Shapenographic system. The objective was clearly defined as a distinguishing or classification model, and this was efficiently achieved. The dataset was collected, prepared and designed by vocabulary of Agbala (Hypo-courted type) and Agbo’le (Interconnect-courted compound type), a total of 62 different shapegraphs of vocabulary shapes were obtained from the datasets and used for training the model as shown in table 2.0.

Table 2. Sample sizeYoruba Compound House showing the vocabulary element.
Source: Author’s compilation (2021)

s/nos	Sample	Sample sizes	Vocabulary Element
1	Agboile Compound	16	CW
2	Agboile Corridor	22	C
3	Agboile Hypo-courtyard	24	CY

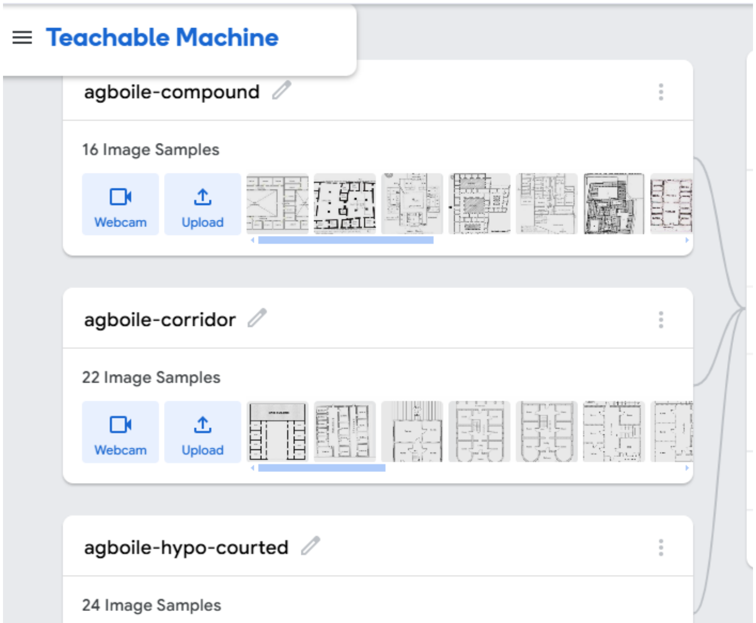


Figure 9. A Dataset Sample Yoruba Compound House showing the Courtyard Location.
Source: Author's compilation (2021)

III. RESULTS

The fundamental elements of this chapter constitute the results obtained from model training, data analysis; the findings presented and discussed. The presentations were made based on the research questions stated earlier in section one (tend to build, train, test and deploy an Artificial Intelligence (AI) model to recognize and categorize Yoruba-Agbole (courtyard style) shapes, toward evaluating the Yoruba design aesthetic systems).

The collection of shapegraphs was easy and posed no challenge. Some of the shapegraphs were contained in either spherical, rectangular or square label shaped morphological fields. This posed a challenge to the model regarding what were identified; the shape of the field or the shape of the Agbala contained in the morphological field. Overall, the model identified the shapes with a high degree of precision and accuracy which as opines by Chen et al., (2020).

With this design, we intend to do the following: Empower Architects and Designers with Cutting-Edge AI: With this Teachable Machine project, Architects and Designers can revolutionize their Yoruba architectural design and analysis processes. By leveraging artificial intelligence, we offer a comprehensive solution to detect vocabulary of Corridor, Agbala (Hypo-courted type) and Agbo'le (Interconnect-courted compound type) samples from well selected accurately and efficiently as shown in figure 9.0.

BUILD TAILORED MODELS: this platform allows users to build customized AI models tailored specifically to their Yoruba Architectural design and analysis needs. Whether it's identifying vocabulary of Corridor, Agbala (Hypo-courted type) and Agbo'le (Interconnect-courted compound type), users can train the model to recognize distinct features critical for accurate detection.

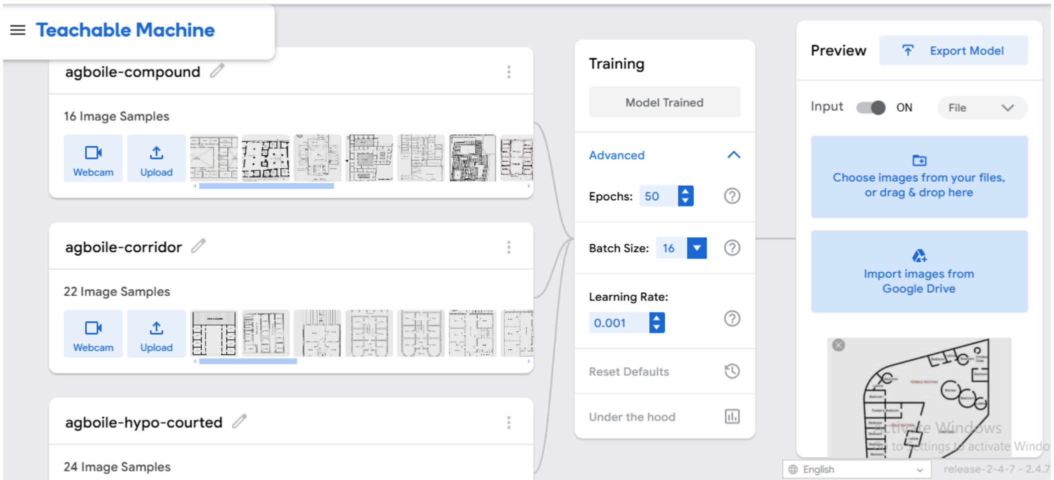


Figure 10. A teachable machine of Google platform.
Source: Author's compilation (2021)

TRAIN WITH PRECISION: Utilizing advanced machine learning algorithms, this platform enables precise training of AI models. Users can input vast datasets of well selected vocabulary of Corridor, Agbala (Hypo-courted type) and Agbo'le (Interconnect-courted compound type), providing the model with diverse examples of vocabulary of Agbala (Hypo-courted type) and Agbo'le (Interconnect-courted compound type) and other samples. Through iterative training sessions, the model learns to differentiate subtle nuances indicative of Yoruba architectures with unparalleled accuracy as shown in figure 10.0 and 11.0.

TEST WITH CONFIDENCE: This intuitive testing interface allow users to validate the performance of the AI model swiftly. By inputting new sets of vocabulary of Corridor, Agbala (Hypo-courted type) and Agbo'le (Interconnect-courted compound type) dataset, users can assess the model's ability to correctly identify vocabulary of Agbala (Hypo-courted type) and Agbo'le (Interconnect-courted compound type) samples across various Yoruba architectural conditions and formations, ensuring robustness and reliability.

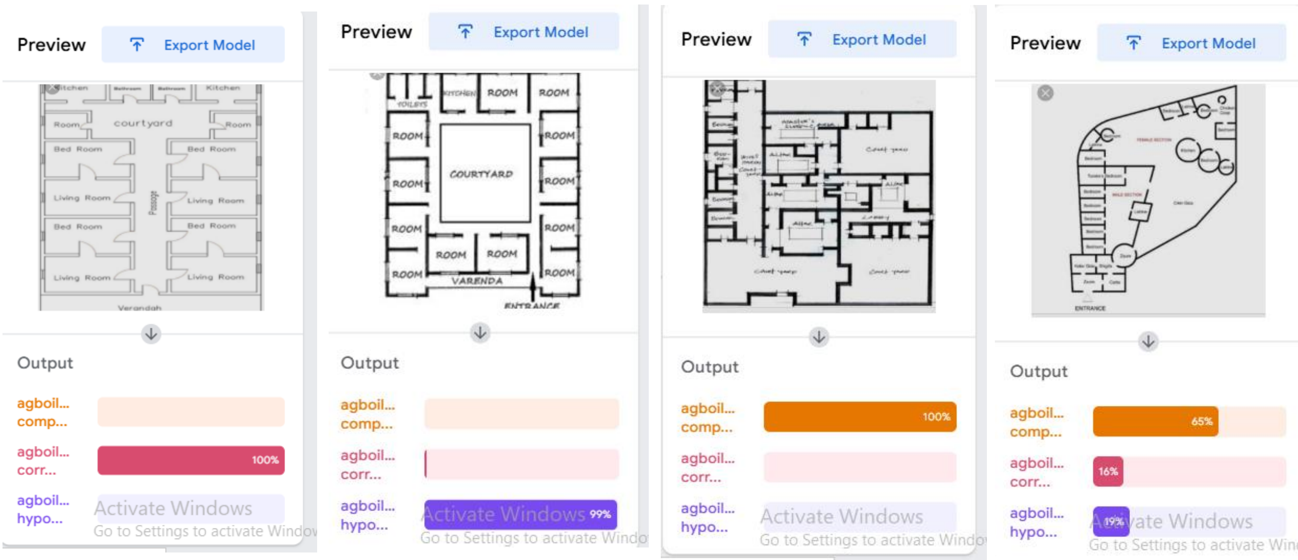


Figure 11.0 A testing model with Yoruba Compound House and Hausa compound House.

Table 3.0 Class Accuracy and Hyperparameter Summary.
Source: Author’s compilation (2021)

Class No	Class Name	Accuracy			S/no	Hyperparameter	Alternative Value
1	Agboile Compound	0.67			1	Epochs	50
2	Agboile Corridor	1.0			2	Batch Size	32
3	Agboile Hypo-courted	1.0			3	Learning Rate	0.0001

DEPLOY SEAMLESSLY: Once these are satisfied with the model's performance, deployment will be seamless. Integration into existing workflows will be effortless, enabling architects and designers to incorporate AI-powered vocabulary of Corridor, Agbala (Hypo-courted type) and Agbo’le (Interconnect-courted compound type) detection into their daily operations swiftly. By streamlining design and analysis processes, this solution enhances productivity and decision-making capabilities.

IV. DISCUSSION

This the result of this study is in accordance with Elzeyadi & Yousif, (2020) postulation that- this will Unlock Insights and Drive Results (UIDR): By harnessing the power of AI, this Teachable Machine project will empower architects and designers to unlock valuable insights from well vocabulary of Agbala (Hypo-courted type) and Agbo’le (Interconnect-courted compound type) data like never before. From optimizing drilling strategies to mitigating innovative and generative of cultural heritage risks, this solution will equip teams with the tools they need to make informed decisions and drive success in design exploration and production, this could be in tandem with the works of Akintoye, (2023).

Input Data:

1. Well vocabulary of Agbala (Hypo-courted type) and Agbo’le (Interconnect-courted compound type) Images:
   - High-resolution images captured using well logging tools or optical scanners.
   - Images should cover a variety of design formations and conditions encountered during analysis process.
   - Images should be labeled or categorized based on depth intervals and architectural shape formations for easy reference.
2. Architectural vocabulary Metadata:
   -Shape Properties: Depth measurements corresponding to each well compilation sample.
   - Spatial Configuration: Description of the vocabulary of Agbala (Hypo-courted type) and Agbo’le (Interconnect-courted compound type) or elements and features associated with each sample.
   - Formation Information: Details about the Architectural formation from which each well Yoruba Architectural design was extracted.
   - Other Architectural Parameters: Any additional Architectural parameters relevant to vocabulary of Agbala (Hypo-courted type) and Agbo’le (Interconnect-courted compound type) characterization, such as 3-6 Rooms Single (Room & Parlour) type, 5-8 Rooms Single (Face Me) type, 2-3 Rooms of 3 Apartments type, 2-3 Rooms of 3 Row Houses type, And Detached Building or Story Building type content.
3. Shape Annotations:
   - Shape-annotated labels indicating the presence of vocabulary elements in the well architectural images.
   - Annotations should be precise and consistent, providing clear indications of architectural shape locations and extents.

Output Data:

1. Yoruba Architectural Detection Results:

Value Proposition There is need for a Yoruba-Agbole (courtyard style) shape recognition system in the design and creative to address the computational assessment need for accurate shape recognition, identification and evaluating. Moreover, it aligns well with Abdulraheem's studies-Abdulraheem (2016),Utilizing machine learning algorithms, this system differentiates between Yoruba-Agbole (courtyard style) shape with high accuracy, Classifying is an investigative approach that involves sorting objects or events into groups or categories. Classification and identification are important because they allow designers to better understand relationships and connections between things. They also help designers to evaluate clearly within the complexity of Yoruba-Agbole (courtyard style) design aesthetic.

- Detected vocabulary of Corridor, Agbala (Hypo-courted type) and Agbo'le (Interconnect-courted compound type) characterization highlighted within the well Yoruba architectural and other images.
- Output may include coordinates or bounding box coordinates delineating the detected vocabulary of Corridor, Agbala (Hypo-courted type) and Agbo'le (Interconnect-courted compound type) characterization.
- Confidence scores or probabilities indicating the model's certainty in its vocabulary of Agbala (Hypo-courted type) and Agbo'le (Interconnect-courted compound type) characterization detections.

2. Probabilistic Assessments:

- Probabilistic estimates of vocabulary of Agbala (Hypo-courted type) and Agbo'le (Interconnect-courted compound type) characterization presence or likelihood for each region of interest within the images.
- These assessments can be represented as probability maps or confidence scores associated with different areas of the images as shown in figure 12.0 and 13.0 for the confusion Matrix and accuracy per each class.

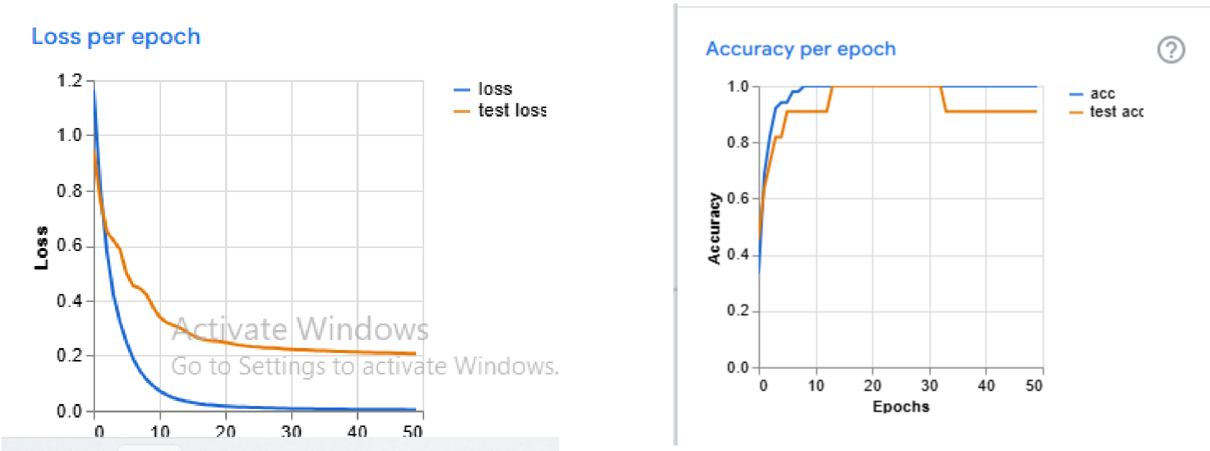
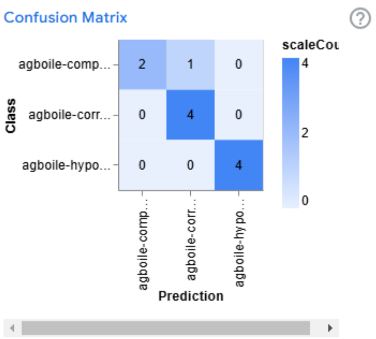


Figure 12.0 A loss per epoch and accuracy per epoch.
Source: Author's compilation (2021)



Accuracy per class

CLASS	ACCURACY	# SAMPLES
agboile-compound	0.67	3
agboile-corridor	1.00	4
agboile-hypo-court...	1.00	4

Figure 13.0 A confusion matrix and Accuracy per class.
Source: Author's compilation (2021)

3. Architectural Insights:

- Statistical analyses or summaries of Agbala (Hypo-courted type) and Agbo’le (Interconnect-courted compound type) characteristics extracted from the well Yoruba Architectural data.
- Insights will include vocabulary element, orientation distributions, clustering patterns, or correlations with other architectural parameters.
- These insights help Architects and designers understand the compositional properties of the shape morphological formations.

V. CONCLUSION

Based on the research's classification of plan types, new contemporary architecture can be derived from the study's unique elements and stylistic range of Yoruba-Agbole (courtyard type) traditional architecture, which underpin the style composition and can be described by analyzing a set of similar Agbole (courtyard type) traditional architectures.

This application tends to train, test and deploy an Artificial Intelligence (AI) model to recognize and categorize Yoruba-Agbole (courtyard style) shapes, toward evaluating the Yoruba design aesthetic systems. The application population consisted of all vocabulary element shapes in the creative design managed by the data class. The data were analysed using train machine. It was established through trainable machine that the results influencing Yoruba-Agbole (courtyard style) shape identification and recognition across selected shape in graphic and abstract shapes. The most significant factors influencing shape recognition and identification: dimension, and types of shape. The study concluded that shape identification was influenced more by shape characteristics. Therefore, utilizing machine learning algorithms, this system differentiates between Yoruba houses style composition with high accuracy, providing a versatile generating tool for architect and spatial programmer.

The objectives were clearly defined in terms of the problem statement (Agbala (Hypo-courted type) and Agbo’le (Interconnect-courted compound type) samples) and the intended application. These objectives were achieved, as observed by evaluating the performance of the AI model in detecting Agbala (Hypo-courted type) and Agbo’le (Interconnect-courted compound type) samples when the test samples were used to test the model. The data collection was seamless, as the guideline for the collection was properly elucidated in the “input data” section of the project card. Each image had all the required information. The model was optimally satisfactory, as it could clearly identify Agbala (Hypo-courted type) and Agbo’le (Interconnect-courted compound type) images.

In view of the aforementioned findings, the following suggestions are put forth with the intention of improving the computational composition and representation of traditional Yoruba-Agbole (courtyard style) architecture:

- Support studies on the spatial structure of Yoruba traditional architecture in Southwest Nigeria using generative shape grammar systems.
- Investigate the computational composition of this distinctive architectural style to enable academics and designers to understand the potential of form grammar.
- Emphasize the necessity of creating and describing intricate urban and architectural forms based on these conventional architectural designs.

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