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Mathematics of Ornaments and Architecture

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INTRODUCTION

The effort to make mathematics more relevant to the student and to bridge the gap between subject areas has been the task of the mathematics curriculum designers.

In geometry efforts need to be made to bring more real life activities into it's teaching. Students need to be made more aware of the utility of geometric concepts, and how these concepts have been used by different cultures and have been utilized in their every day lives.

The Mathematics Standards call for mathematics that provide experiences that deepen student's understanding of shapes and their properties; with an emphasis on their wide applicability in human activities. The curriculum should be filled with examples of how geometry can be used in recreation, in practical tasks; in the sciences, and in the arts.

The development of this unit will provide students with the ability to use geometry in the arts and in recreation, while at the same time developing students' intuition, and their creativity. African ornaments will be studied and used as the hallmark for creating their own designs, and at the same time using the geometric concepts of tessellation, translation, and reflection.

The unit will use these ornaments and designs to provide practice for students learning to manipulate geometric instruments such as the compass, the ruler and the straight edge.

The unit will introduce the student to African traditional architecture, and examine how African ornaments, wall painting and motifs use geometric shapes to express and explain the culture.

The students will be encouraged to discuss the ornaments and architectural designs in the setting and period they were executed and use these as examples in developing ornaments for their own use.

General Objectives

The unit will be developed in two sections. The first section will focus on the history of African traditional architecture and ornaments. Where necessary efforts will be made to explain the meanings of the designs and the occasions of their use.

In the second part an effort will be made to make connections between the designs and their geometric representation of the ornaments and motifs. Ornaments or motifs that lend themselves to geometric properties will be reproduced. (Features such as line designs, designs with circles, motifs and designs that are repetitive or use the properties of reflection, translation, and tessellation.)

The unit is designed to:

(a) provide students with information about traditional African culture and motivate students to explore aspects of this vast culture for themselves.
(b) provide students with mini projects that will involve the use of geometric instruments, and the execution of their unique design.
(c) provide students with the sources for the information so that they can use existing ornaments as examples to create their own designs.
(d) to encourage students to use their mathematics ability, and apply these concepts to the development of practical usable crafts.

This unit is designed to reaffirm the beliefs that I share that mathematics should be made relevant so that students are involved and therefore get them to learn the content. If students are to enjoy mathematics, then they must find meaningful ways of using the information.

SECTION I

AFRICAN TRADITIONAL ARCHITECTURE

African traditional architecture can be dated back to early times, sometimes referred to as vernacular architecture, has demonstrated how architecture is designed to respond to society’s needs and at the same time to be sensitive to it’s environment.

To the same degree that the continent boosts diversity in climatic conditions, regions, peoples and traditions, these differences are accommodated in it’s architecture.

The designs of buildings that were found across Africa ranged from the windbreakers used as shelters by the Bushmen; the simple round n beehive huts made of flexible branches and covered with leaves, made by the Pygmies, to the circular huts with conical roofs called home by the agricultural peoples that live on the grasslands.

African architecture was also defined by the religious and social order of the people. This was evident in the temporary nature of the buildings. Permanent housing would have been an embarrassment for many people,

for example the bushman; the migrant pastoralist, such as the Fulani and the Masni; or the people who practiced land rotation and moved from place to place every four years. The lifestyles and the social customs necessitated that the houses changed to suite the social arrangements of the people.

Another factor that affected the architecture is the climatic conditions of the area, the lack of or the abundance of rainfall, the desert, semi- desert, the high forests, and the grasslands. Houses were made to protect from the scorching sun, the range in temperature between day and night, and areas where houses had to withstand heavy rainfall.

The architectural designs were also distinctive, and this distinction was decided by the location of the major rivers. Each river basin had several distinctive building characteristics. There were no evidence of specially trained architects, much of the information and building designs were passed down from generation to generation by word of mouth. The building of the houses were a community affair where every one gave their assistance, and the only renumeration was a feast.

The architecture was adapted to suite the needs of the groups. The houses that were erected reflected the style worked out by the community, and perfected over many generations. As a result of this there did not exist any homogeneous material culture, or house plan throughout Africa.

The sampling of African architecture produced many technology, from the shape and method of construction, to the ornaments used to distinguish the roles in construction between men and women.

THE EFFECTS OF THE SOCIAL STRUCTURE ON ARCHITECTURE

The landscape of early Africa was made up of small societies, with one commonality that their livelihood was dependent on their farms, or herds of cattle, and with almost no specialization of labor.

The societal constraints dictated the distribution of wealth, and the conformity of each member to a set of norms. For example no great social privileges were attached to wealth and its accumulation was frowned on. Religion was often emphasized in the communities, there was little distinction made between the living and the dead.

The plan (pattern) of layout of the buildings was influenced by many different forces.

> (I) The nature of the crops: those that required a long growing season and maturity; those that were short term cash crops; or slow maturing crops, tied the owners to one plot for a longer time.
> (2) the seasonal nature of the activity , for example pastoral people followed specific routes , and was adapted to the climatic conditions. The needed buildings that were easily moved. They sometimes erected permanent dwellings in a location and then made temporary ones made as they moved to new sites.
> (3) kinships were also important in determining the layout of the village. Members of one clan would live in a defined territory, with family units close by. These kinships were defined by the physical nearness of the buildings.

Since the term ‘village’ indicated family groupings rather than buildings, some villages were not evident from the ground, but expressed physically the social structure of the group of people living in them.

Because the composition of the village depended on the birth, death, and divorce rate, the impermanent nature of the buildings meant that there was a quick response to changes in the family structure. The orientation of the village was dependent on the location of the chief’s house, thus, the death of a chief brought about a new orientation of the village as new houses were built to face the chief’s residence. The physical layout was also based on religious reasons. The decision on whether or not to build villages on hills rested in part on the presence of the omnipresent spirit; houses were not built near grave sites, battle fields, or places connected with an ancestral taboo.

Imaginary lines separated relations. For example, in some villages son-in-laws and mother-in-laws lived in separate sections of the village, in other villages the division was made along generational lines. Proximate generations built separately, and alternate generations built together.

In summary, the layout of the village was usually symbolic. Villages were either laid out in a square that had specific significance, or were symmetrical with the houses around the circumference and open spaces in the middle for cattle.

(figure available in print form)

Elements of Construction: The Building Process

The process of building was a cooperative venture, and a major special occasion. In this process males and females had clearly defined roles. Women were not allowed to mark out the ground plans. It was believed that they would make it too small. Their responsibility was to do the thatching for the roof.

Construction skills were passed down from one generation to the other. One of the chief elements (materials) used for construction was the material found in the environment. The mud used had the consistency of clay, consisting of varying proportions of sand and clay. Because clay is pliable any basic shape can be expressed, and various shapes of roofs can be designed.

The preparation of clay for construction took many forms. In the Sudan, sun-dried mud bricks were made. In the building process the bricks were cemented in place with more mud, and the walls smoothed over with a mud mixture. Pear-shaped bricks were made using a mixture of mud and straw by the tribes of Hausaland. These bricks were laid horizontally then cemented into place with more mud. The wet regions bricks were not used. After the mud was moistened by the rain, it was pounded and left to mature, then used for building in the dry season. In the other parts mud was used with a combination of stakes (wattle and daub). The stakes formed the frame of the house. The walls were then filled in with mud.

Because of the nature of mud, the outer surface of the buildings must be treated to make it durable to withstand the weather. Plastering was done often, and potash, the locus bean pod, or for the wealthy, mimosa imported from Egypt, was added to the base mud mixture. The walls were maintained by scrubbing them smooth with various liquid mixtures. The internal walls of sleeping rooms were often plastered with a mixture of mud and cow dung. This was done to eliminate or prevent the infestation of jiggers.

The mud floors were specially prepared. They were hard as cement and very smooth. The roofs were made of a combination of mud and timber beans. The roofs were either flat (terraced), domed or vaulted. These types were created through different techniques. Vegetable materials were used as the major element of

construction by the pastoralist. They needed a house that could be dismantled and transported easily. The plan of these houses was a basic framework of hoops caused with either mats, thatch, skin, or a combination of all. These fall into the category of a tent, and many configurations of tent construction were identified. Other houses built above the ground had thatched roofs. Reeds, grass, and banana and bamboo beams were used to do the thatching. The basic framework of these houses were angular, dome having the shape of a beehive. Houses with thatched roofs above the walls had great variation in shape, materials, and construction technique. Stone was also used for construction and was found in four areas: East Africa, Abyssinia, Upper Niger, and the Upland areas. In some buildings a combination of stone and mud was used; in some, the stone walls were completely covered in mud.

(figure available in print form)

The Compound

In general the African architecture incorporates the mythical and cultural aspects, such as animist and Islamic, as well as the individual's own concepts of form and space. This is reflected is the culture of both sedentary and nomadic people. The settlements, often isolated, did consist of a male head of the household and his wives, their offspring, and the sons with their families. Within the settlement could be found a number of compounds, one for each male and for each of his wives and her children. These compounds were connected by walls creating a secure and compact plan.

Within the compound were a building for sleeping, covered storage areas, and a detached or semi-detached dry and wet season kitchen. The compound was the focus of social organization. This responded to the needs of the group. It could be altered to accommodate the fluctuation in family size, extending for a growing family or reducing when someone dies.

In the settlement was a place for keeping animals, and for housing tall mud granaries for storing surplus production. Often in the compound were found ancestral shrines. These were erected at the entrance of the compound.

Sacred, Ceremonial, and Community Buildings

Because of the year-round warmth and sunshine, and the predictability of the wet weather, many religious and community activities took place outside. Therefore pieces of land were set aside for these activities. These areas were kept sacred and were embellished with ritual objects. However, in some cases the shrines were alters inside ordinary houses.

In some cultures, Ibo for example, constructed buildings that were considered shrines, but once built they were ignored. The Asante temples were built in the courtyard pattern with four buildings joined in a square. Three of the buildings were used by participants in the worship, while the other housed the shrine and was used only by the high priest.

The Christian churches were of two designs and building techniques. Most of the churches had between three and five aisles, and were either Basilican in plan with a western aerated porch and an eastern sanctuary, or they had a cross-in-square plan with a well marked transverse axis. These early churches were made of either stone or wood. In the rural areas the churches were more modest. They were rectangular in plan and made of stone with flat roofs.

With the influence of Islam there was also the dedicated space for the purpose of worship. There were the

open air spaces, and the mosques. One of the few mosques remaining is found in East Africa. It is built on a square plan divided into square bays, each roofed with a dome resting on pillars edged with coral. In contrast, the mosque in West Africa consists of a full tower on a square base. The mosque building is rectangular and divided into square bays. The roof is supported in the center on square pillars, with very low roofs.

Ornament: House Decorating

The architecture form can be considered a product of environment and social circumstances, but ornaments and decorations are bounded up in the social values. It is established to assert personal and community identity, and can signal different messages to those who are able to read them. If architecture expresses the public face of a society, then ornaments provide the opportunity for impressing the outsider, promoting morals, pride, and the solidarity of a people.

The use of decoration was not a function of the climate conditions, population changes, or the size and composition of the family unit as did architecture. It was more flexible and adaptable, and was more influenced by contacts with other cultures. Decoration implies the conscious effort of the creator to order his or her materials into a kind of design that will be pleasing to the eye, and at the same time have some magisterial or religious significance. It is this significance that this section of the paper seeks to develop.

Decoration was not the product of one person's imagination. The designs had become standardized through generations of use. Some architectural features were more decorated than others. These include the compound and homestead entrances; granaries and grinding sheds; the wives rooms; sacred, ceremonial, and community buildings; doorways; inner walls; and roof pinnacles.

Decoration is considered of psychological significance and occurs at points of potential social stress: the chief's house, temples, shrines, and clubhouses were more highly decorated. Decoration was also used to indicate changes in the life span of individuals; for example rites of passage for birth, initiation, marriage, and death.

Unlike the building methods carried out by men, the women engaged in wall painting where individual style was shown. Therefore wall art was the domain of the women. Wall decorating was usually done during the dry season after the crops have been stored, and it is the time for restoring the walls. The decoration was not only pleasing to the eye but also had utilitarian functions. Both external and internal walls benefited from a protective layer of paint, and the sculptured mud decoration of the Hausa doorways served to reinforce the edges of the walls. The techniques used varied across tribes and regions. Mural paintings were found in the Upper Guinea coast. Relief mud decorations were used by the Fulani of the Guinea, the Asante, and Ibo. Incised mud decorations were confined to the Upper Volta but the practice of pressing natural objects into the wet clay was quite widespread.

The origin of mural decoration is not clear. This is a tradition handed down from mother to daughter, generation after generation. Sometimes there is knowledge of what lies behind it, but only the significance of certain patterns and motifs. The explanation for this lack of specificity would be in the fact that later decorations resulted from a cultural and religious mix over time, through which some of the original meanings were lost.

The following are common decorative motifs found throughout Africa. They fall into the following categories:

l. Cellular design made up of two alternating, serially repeated units, one positive, the other negative. The design is based on geometric shapes and completely covers the surface.
2. Intricate linear designs based on curved lines, often with interlacing. This is usually applied to the ground.

The decoration also had symbolic meaning. The meaning of several of these decorations have been passed down, but in many cases the significance has been forgotten. Evidence of meanings are demonstrated in the decoration of sanctuary facades cornered with small niches containing skulls and bones of animals, or in entrances surrounded by conical ornaments. In Ibo houses dedicated to the gods can be found clay statues and mural paintings depicting both religious and profane subjects. The Dagons had similar sanctuaries with facades ornamented with paintings in white that symbolically represent the elements of life; the sun, moon, stars, men, animals, and man-made objects. The chief's house was heavily ornamented. The doors and door posts were decorated with beautiful carvings.

The doors and wooden locks were important because they protected the entrance, the most important part of the house where communication was made with the within and the outside, and they are exposed to the eye of the people. In the Sudan the Palmers had facades, and the interior walls and ceilings were decorated with geometric sculpted motifs.

The art of wall painting occurred among many ethnic groups in Africa. This was primarily the work of the women done during the dry season when they refinished the walls. The walls were decorated using white, black, yellow, and red ochre, and various earth colors including a green and grey-blue. These paintings were usually done with the fingers or with brushes made of vegetable material. The traditional patterns are purely geometric, but recently motifs based on plant forms, and flowers, have been used.

For the women, the art of wall painting is a natural gesture and is incorporated into the lifestyle. It is also a magical form of creativity, the magic not in the meaning, but from the art of applying the paint to the walls. When young women marry and leave their homes, they take with them this art to their new family and thus it is incorporated into the designs of another family.

(figure available in print form)
Motifs, which are an extension of walls decorations, are more individualized. They depict either an object, an event, or a belief familiar to the woman's world. Motifs can be figurative, non-figurative, or a combination of the two. Non-figurative patterns are used to enhance skin texture on the representation of snakes, crocodiles, and lizards.

Some of these figurative representations have particular meaning to the clan. Pythons are considered sacred among the Kassena women. It is used as a symbol of protection. The criss-cross bohinbore used around the door is said to protect the inhabitants. The crocodile and lizard were sometimes used in a more complex three-dimensional form. The Boasi's representation of the dove is to send a message to the god when the woman is worried. No special meaning is attached to the criss-crosses and figurative designs used by the Kusasi woman. These designs are used only for their beauty. In the Ibo culture the motif designs are developed through the complex process of the mind and have nothing to do with mysticism. The women

derived the names of the motif patterns from things in their domestic world. These motifs enabled them to respond to their world, communicate information, and adorn their home.

SECTION II: DESIGNS IN GEOMETRY

Line Designs

Many African designs were made by using simple lines with the combination of symmetry and translation. These can be reproduced using simple geometric tools; the ruler and straight edge. The following are simple African line designs:

(figure available in print form)

Designs Showing evidence of reflection. In using a mirror to teach the concept of reflection, the following African designs can be used to demonstrate the properties.

(figure available in print form)

Daisy Design

Some African designs show evidence of flowers in the execution of the design. These designs were found on the Ashanti bronze urn in Ghana.

(figure available in print form)

There is no evidence that geometric tools were used by the African artist, but the daisy design can be reproduced using these steps.

Step l. Construct a circle. Select a point on the circle. Place the compass point at any point on the circle.
Step 2. Without changing the compass setting, make an arc with center at the selected point.
Step 3. Make arcs from each of the two new points of intersections located.
Step 4. Make arcs from each of the two points of intersection.
Step 5. Make arcs connecting the last two points of intersection.
Step 6. Cut out the spaces between. Color to decorate. These daisy designs can be found in some Egyptian ornaments. This design was used in combination with other designs.

Mandelas or Circular Designs.

Mandelas are circular designs arranged in layers radiating from the center. The word comes from Hindu Sanskrit, the language of India. Mandelas were used by the Hindus in meditation. Evidence of these circular designs can also be found in African design. The circles seem to be drawn without the use of any instruments.

The difference between these and the Hindu mandela is that in the Hindus' mandela the center of the circles are decorated, whereas the Africans' are void of designs. The following show examples of a Hindu circle design and an African circular design.
(figure available in print form)

Evidence of Tessellation in African Designs

Mathematicians call tiling patterns tessellation. A tessellation is an arrangement of figures that fill the plane but do not overlap or leave gaps or spaces. If the same figure is used throughout the tiling it is called pure tessellation. The following show tessellation with spherical shapes.

Some shapes are better for tessellation than are others. These are triangles and the polygon. Many tessellation in African designs are shown using different objects.

The theory of tessellation is extended to the creation of wall paper and pattern designs. Coordinate systems called lattices can be developed using polygonal shapes. These are examples.

(figure available in print form)
These are known as parallelograms, rectangles, diamond,(rhombus),equilateral triangles or hexagonal, and squares nets. These lattices form a natural coordinate system.

With these lattices and a combination of operations manipulating the designs there 17 patterns that can be generated.

The standard repeating movements and operations to generate different patterns are (a) a translation alone, (with no rotation or reflection). (b) the rotation alone through an angle. (c) the reflection alone and (d) the combination of reflection and translation together. This is known as glide reflection.

These four combination types may be combined with one another on any of the lattices to produce complicated repetitive patterns. When the combination is done systematically, the result will be the total number of ways of reflecting a given motif in the plane. The lines over which the motif is translated or repeated are called reflection lines and glide lines.

Patterns can be blocked out in unit cells. A unit cell is that portion of a pattern which when repeated by the translations alone , develops the entire pattern. If a copy of the motif is developed the repeated movement of the motif at appropriate intervals in two directions will construct the pattern. The type of pattern will depend on the type of lattice used.

Other forms of tiling.

The first spiral tiling was discovered by Vonderberg (1936)

(figure available in print form)
We do not know all the different shapes of convex pentagons which can be used to tile a plane. These are called monohedral "spiral tiling".

These tilings and with the operation of translation develop many decorative spirals. If the spiral is cut in half and the other half translated affixed number of units it yields a tiling that is different from the original.

Lesson Plan I

Topic: Line and line segment

Objective/introductory statement: Student will discuss the concept of lines and line segments and will use these concepts to create designs. These can be used to repeat existing African designs, or to develop designs of their own.

Materials: Copies of African/Egyptian designs and ornaments, pencil, and straight edge.

Key Questions:

l. What are some of the major characteristics notable in the various African line designs?
2. How do these differ from culture to culture?

Background Information: Discussion on the readings on African wall designs. Many of the African designs were found decorating the mud walls of dwellings in places like Uganda, or carved on drums and wooden sculptures. These designs on the mud walls were executed by the women and could hold meanings that were embedded in their religion and culture.

Management Suggestions:

l. Students will work in groups reading the section and discussing the designs.
2. Students will be encouraged to brainstorm for ideas then complete and discuss their project with others in the group.

Procedure:

l. Discuss lines and line segments from the geometric perspective.
2. Introduce the symbols for lines and line segments.
3. Show evidence of lines in the buildings and shapes.
4. Discuss the use of line segments in the ornaments of other cultures (Egyptian).
5. Show and discuss use of lines in African wall decorations and ornaments.

Activities:

l. Students will complete their own designs.
2. Discussion and comparison with other students' work.
3. Display and then add work to students' portfolios.

Curriculum Coordinates:

(a) In art students can expand and develop their designs.
(b) Research the use of line designs in modern art.

Language Arts/History

(a) Students can research the use of line designs in different traditional cultures (for example Islamic cultures).
(b) Research the effects of Islamic culture on African tribes.

Lesson Plan II

Topic: Circular Designs

Objective/introductory statement: Student will be able to manipulate a pair of compass to create circular designs.

Materials: Pairs of compasses, paper, pencil, copies of African circular designs.

Key Questions:

l. What are some of the special features of African circular designs?
2. How can these designs be compared with circular designs of other cultures?

Background Information: Circular designs can be found in African ornaments. These designs can be found in other cultures notably that of the Hindus.

Procedure:

l. Have students study the circular designs of the Africans.
2. Give students practice using the pair of compasses by having them make concentric circles of various sizes.
3. Demonstrate the procedure by creating circular designs. Begin with the center design. Add the patterns inside. Add more circles and designs symmetrically. Fill in the open spaces. Shade to highlight special sections.

Activities:

l. Have students create their own circular designs.
2. Have students give a discussion on their designs.
3. Display individual work.

Curriculum Coordinates: Social Studies.

(a) Students can research the contribution of the Hindus to the development of the mandelas.
(b) Students can investigate the use of mandelas in the Hindu culture; medieval cultures, and the Indian cultures of the Americas.

Lesson Plan III

Topic: Knot Designs

Objective

(a) Student will be able to recognize knot designs in African art.

(b) Student will be able to make their own knot designs.

Materials: Paper, pencil, straight edge.

Introductory statement: Knot design is also found in African folk art. This design is found through many tribes as carvings or as wall paintings. It is said to represent the braided hair design. Knot designs are geometric designs that appear to weave or interlace like knots.

(figure available in print form)

Procedure:

l. Have students study examples of existing knot designs.
2. Discuss the procedures of creating knot designs.
3. Show the knot designs using a number of interlocking rings (using the pair of compass to construct the circles).
4. Have students brainstorm ways to create knots.

Activities:

1. Have students create their own designs, possibly one using the ring procedure, and another with a different procedure, for example using interlocking lines.

Curriculum Coordinates:

(a) Students can write a paper on the history and uses of knot designs.
(b) Identify instances in modern art where knot designs are used.

Lesson Plan IV

Topic:

l. Creating designs using the geometric shapes.
2. Combining these designs with tessellations.
3. Use repetitive patterns to create designs.

Objectives:

(a) Students will use geometric figures to create designs.
(b) Student will define and use the properties of tessellation to create their own designs.

Materials: Paper, pencil, straight edge.

Background Information: Students will have been studying the properties and names of the regular polygons. They will also have read some information on the use of geometric shapes in geometric designs. Students will also have discussed the concepts of tessellation and translation.

This lesson will be able to provide enrichment to a lesson after students have studied translations example tessellation reflection, and transformation. The purpose would be to provide students with a project using those concepts.

Procedure:

l. Discuss African patterns that contain geometric designs. Students could discuss the various shapes and the formations used to achieve the designs.
2. Discuss the use of tessellation and repetition in the design.
3. Have students select different shapes that would be suitable to produce similar designs.
4. Introduce students to other designs used for tessellations, notable the work of Escher and Voderberg.

Activities:

l. Students will complete their own designs, using tessellation with regular and non-regular polygons.
2. Students will research the artist M.C. Escher's work in creating designs by tessellation with nontraditional objects.
3. Students can explore designs using translation, rotation, demi-regular, pure tessellation, semi-pure tessellation, and reflection, to create designs.
4. Students can explore the use of the animals used for African ornaments and a combination of the different types of tessellations with regular polygons to create their own designs.
5. Students will be introduced to spiral tilings using non traditional polygons. These monohedral spirals developed by voderberg will be discussed (examples in the appendix). Students can experiment with using different polygons (ex 8—gons) to generate new ideas.
6. Discuss the ideas behind the development of patterns . Students can develop their own patterns from the motifs they designed, and using the coordinate systems introduced and the combination of transformations.

Curriculum coordinates.

Art. Students can use these ideas for spiral in developing patterns for fabric.

Research : The life and work , their contribution to mathematics of M.C Escher and Voderberg.

Conclusion

This unit can be used by the Social Studies or History teacher as an introduction to African traditional architecture and African art.

Many of the books I read had a wealth of information on African sculpture and mask making. The sources listed will provide a start to this field.

During the development of this unit the ideas for creating African designs were taught to one geometry class. Students produced individual projects.

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The text discusses the art of the people of Nubia.

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Excellent source for background information on the history of African art. Chapter 4 gives a brief but informative treatment of African architecture.

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This is a picture book. It contains 378 illustrations of African designs. Excellent source from which students can generate ideas.

(figures available in print form)