Mobile healthcare architecture in Africa: An analysis and design guide

by

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This is to certify that the master’s thesis of

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Signatures have been redacted for privacy
DEDICATION

This research and thesis is dedicated to Amma, Papa and Pradeep. Thanks to my major professor: Mikesch Muecke, committee members: Clare Cardinal-Pett and Ronald Myers and all other professors and architects who supported me. Thank you to all my friends and family who stood by me through my graduate education, here in the United States.
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ABSTRACT

Healthcare in Africa has changed over the years. The people and organizations that are responsible for Africa's recent developments range from large organizations like international communities, multinational companies and governments in Africa to smaller groups like the medical community, strong volunteering organizations and each individual's commitment to their community. In our portable, decentralized and global environment, we as architects, from across the planet, have a responsibility to the world community. The nomadic and rural population in Africa has priorities that are different from the rest of the world. The priorities in Africa do not lie in the sophistication seen in regular healthcare architecture, medical equipments and examinations. It is the accessibility to basic healthcare, awareness in the community, making the primary healthcare socially and culturally acceptable, encouraging community participation and catering to as many communities as possible across the continent; across each country.

The problem lies in basic healthcare available to people in Africa who live in areas that are difficult to access, including the nomadic communities. The simple solution is to use Africa's rich resources for materials and construction as well as the large army of voluntary labor that is available. However the final product with the healthcare facilities
needs to be taken to these people (in opposition to the people traveling long distances to these clinics) or the purpose will not be served. The options are numerous and so is the scope of such mobile structures. The design guide helps the architect with his pre-design research. It takes into consideration the requirements of this project and gives the architect an insight into four generic mobile systems. Each one of these systems has their own list of pros and cons, which the architect needs to prioritize and choose. Some examples of such combined prototypes conclude the design guide.
INTRODUCTION

Phrases that influence mobility of healthcare systems:

Kinetic structures
Dynamic components
Intelligence in design
Power of medical awareness
Speed of accessibility
Efficiency

A mobile way of living is familiar to Africa from pre-historic times. Africa’s nomadic communities moved for hunting purposes, for new areas for their cattle to graze: downhill to uphill and deserts to forests. The reason and the method in which these communities travel have changed over the years. But even today there are communities who follow this ancient way of living. Other familiarities with mobility in Africa consist of mobile houses and safari tents that are provided for tourists. These tents come in all sizes and shapes. They range from simple ‘camp style’ tents to luxurious settings.

With respect to healthcare, Africa has basic healthcare facilities in major cities. At the rural level there are facilities with basic infrastructure available. Thus it is almost logical that mobility and healthcare come together in Africa. As a solution, demountable structures could be hooked on to the services of the facility, or could
operate independently. The current mobile healthcare situation in Africa is extremely varied from make-do shipping containers to donated Landrover Defender vehicles.

The mobile healthcare situation all over the world varies from trailers and containers to aeromedical centers. In Africa, one has to take into consideration the vast variations in temperature, climate, topography and culture. The system needs to be sustainable, economical and aesthetic. Technology borrowed from NASA Space technology, military, ships and other portable building types may provide an answer. However how do we create that extra creative dimension and functionality for healthcare purposes only? What is that unique quality that makes it a successful healing system, which is in harmony with the community it serves? The biggest concern is to create prototypes of an efficient system.

Mobile healthcare systems in Africa need to tread lightly on the earth yet identify with the place and its people. This thesis is not about a perfect design for such a system. It's about a design guide: it encourages other architects to think about the details that go into such a system. My research has been organized into a workable design guide that allows architects to consider their options in a systematic and analytical way.
SCOPE OF THE PROJECT

Africa is a vast continent that is occupied by people who belong to a large number of communities, cultures, languages and traditions. Moreover, a wide range of geographical and climatic extremes exists across the continent. Africa has seen a lot development lately in the healthcare and architecture field, especially in South Africa. However, there are large areas that are occupied by rural inhabitants and nomadic communities that are not easily accessible. These areas do not even provide the basic needs of a community like a primary health center. Mobile systems appear to offer a practical solution in such a situation.

- The system can be mass-produced thus making it economical and available to as many countries in the continent as possible.
- A mobile system can cover a large area at a time during times of vaccination, general examination, emergencies and even healthcare awareness education.
- Basic, yet essential needs such as regular examinations for tuberculosis, pediatric examinations and vaccinations are not available. These can best be served with a mobile system.
- Nomadic communities can be accessed efficiently only by the use of mobile systems which move through air, water or land.
REQUIREMENTS OF THE PROJECT

The design competition: (Appendix)¹²

The competition organized by ‘Architecture for Humanity’ required the design of a mobile clinic in Africa for AIDS/HIV patients. The criteria and requirements for the project reflected the cultural, social and medical environment in Africa. The project is a precursor to the thesis. This competition brought forward various questions regarding mobile clinics and its architecture in Africa. The most difficult question to answer was the choice of a specific mobile system that caters to every requirement of the competition. A quest to answer such questions led to my thesis.

Analysis:

The analytical study involved a timeline that was tracked to understand the various possibilities, needs and priorities of mobility, cultural effects and healthcare trends in portable environments. It helps us appreciate innovations in the past, their prioritization methods and learn from their mistakes. A further observation of Africa gives the thesis a feel of the site, in this case, the entire continent.
The design template: (Appendix)

The next step is to find a way to assimilate all the information and classify the different kinds of mobile structures that may be used for healthcare purposes in Africa. The classification is broad and allows the architect to choose his or her particular system according to the program’s priorities. The template stimulates further research and interrogation when the architect chooses his or her system of choice. The template also makes the architect aware of the possibilities and limitations of each system. A design such as this with challenging requirements needs to look beyond conventional structures. Though the needs of the healthcare system are primary, the technology needs to be advanced and updated to ensure a sustainable and efficient mobile system.
A brief study of the history of mobile architecture in general and in healthcare is essential to track the successes and pitfalls of previous examples. This timeline is divided into four sections; each section deals provides an example during the particular time period as well as an analysis. The timeline starts with nomadic communities before the ice age and then covers temporary agricultural settlements. Healthcare architecture saw mobility mostly during the 19th century. Four possible sections in the timeline for mobile healthcare architecture:

**Prehistoric:**
- 2 million years ago
- 1.5 million years ago
- 150,000 years ago
- 10,000 years ago

**Traditional:**
- Nomadic communities in Africa
- Traditional: movable
- Traditional: portable
70 AD to Industrial revolution

1787

First World War

Industrial revolution

19th and 20th century

1917 - 1990
Prehistoric

200 million years ago:
Example: The primary tools used were simple chipped pebbles found in Olduvia Gorge, Tanzania and East Africa.
Description: Early hominids did not need shelter most of the time because of the tropical climate. They adapted to the surroundings.
Analysis: Caves were used occasionally, to hold the more vulnerable: babies, old people, and the weak. Possibly, one of the earliest ever spaces to hold the weak and sick.

1.5 million years ago:
Description: The first full-scale Ice Age occurred. The scarcity for food, forced humans to evolve into hunters and food gatherers. This was the first hint of their nomadic lifestyle. They started moving from Africa to Asia and Europe.
Analysis: The first instance where we can distinguish a permanent from a temporary lifestyle. This gave rise for the need of shelters.

150,000 years ago:
Example: Grotte du Lazart near Nice in France.
Description: Hunters or gatherers who moved in an annual cycle built the huts. It consisted of upright poles that were supported with the help
of stones. Animal hide was used for the tent membrane.
Analysis: These structures were demountable. They were usually built against a permanent support like the wall of a cave.

13,000 years to 10,000 years ago:
Examples: Excavations from Chinchihuapi Creek in Southern Chile and Pincevent in Seine Valley, North France.
Description: There was a mix of both permanent (huts) and temporary settlements. The temporary settlement was a tent with wooden poles and animal hide for covering. They were portable. It was occupied between mid-summer and mid-winter.

Figure 1. Sketch of Pincevent, Siene Valley, N. France

Analysis: Temporary settlements were still related to nomadic life though agriculture had started in its most primitive form. As far as healthcare is concerned, most spaces were 'modified' to accommodate
the sick and weak. The most important criterion would have been fast and easy availability of water and food; what we call 'services' today.

Inference: Prehistoric mobile architecture used locally available materials in the most efficient way possible with limited resources. They were built with an inherent understanding of the environment.

**Traditional**

**Nomadic communities in Africa:**

Example: Berber nomads, Zulu dwellings, herding communities of N. Africa

Description: The Zulu hut is considered the best traditional example for architectural efficiency, economic construction and proper use of local materials. Their migration can be due to influences in climate or because they are herding communities.

Analysis: The simplicity of the structures was often dismissed. But this comes from its function and the tribe that it houses. Though the objects carried with them were minimal, the structures themselves were not without comfort and beauty. Yet again, these structures reflect the land on which they are built.
Traditional movable structures:

Example: The Tipi, the tent and the yurt.

The Tipi:

Description: Communities of Native Americans who followed the herds existed between 12,000 to 6000 years ago. The Tipis were developed swiftly due to abrupt changes in their lifestyle. It consisted of a fixed set of main poles, subsidiary poles and sewn buffalo skin cover—all made by the women in the tribe. It was a simple, yet advanced system with 'smoke flaps' to avoid drafts and 'dew cloth' which was used for insulation and prevented condensation. The Tipi had a symbolic meaning, especially the shape. The circle was a powerful emblem for Native Americans.

Figure 2. A sketch of the Tipi
Analysis: Since it was transportable architecture, spaces were strictly allotted and organized. It was a simple and practical design that could cope with various environmental conditions. It is the only kind, even today, which is used for alternative lifestyle mobile homes. The ingeniousness of this system especially towards insulation and wind drafts is indirectly advantageous for healthcare purposes.

The Yurt (Turkish word for dwelling):
Description: The Yurt is the transportable dwelling used by communities from Iran to Mongolia (Asia). This is a relevant system to study since it is lightweight and is adaptable to both summer and winter conditions. It was easily transportable with a horse driven wagon and yet when it was set-up, it stood solid on the ground. It consists of strips of willow with swiveling joints that can be contracted. The roof consists of three main poles, held by two vertical poles before the rest of the framework is set in place. The circular wall and roof is held together with tension members. Felt is used for insulation.

Analysis: There are many architects today who learn from this structure. Its symbolism is important as it provides a sense of space; it can be dismantled and transported in half an hour by cattle, camels or horses, its plans work well since they are of in strict accordance yet functional and they can be quickly moved over short distances. Yurts are used even today by three quarters of the Mongol population since
they are cheap, efficient and transportable, especially for a daily wageworker.

Figure 3. Sketch of the Yurt: Construction and plan in Asia

Boat buildings:

Example: Entire cities in China and the Far East, houseboats in Kashmir, etc.

Description: Boats are one of the oldest vehicles used by man that changed into a space for living. They developed into floating cities like in China. In Kashmir, India, the boats were almost pieces of art.
Analysis: Though the boat has taught us a great deal about prefabrication and services, they can be used only in areas, which are close to a coast. It has many restraints as far as this project is concerned.

![Fig. 4. Boathouses in Srinagar, India](image)

**Wheeled vehicles:**

Examples: Scythians, Napoleon's campaign coach, gypsy caravan and traveling communities in Ireland.

Description: The early coaches (like the Scythians) were used for basic transportation but the dwelling 'came out of' these coaches. The wealthy like Cardinal Richelieu and Napoleon could afford a horse driven coach with extra facilities for comfort. The gypsies who originally lived in tents, later moved into caravans. They were experts in fabrication. The most advanced traditional wheeled vehicle may be from the travelers in Ireland who developed the timber dwellings These
had to accommodate large families in small spaces. They had a height of 1.2 meters, which needed to be stabilized by special props to prevent failure due to wind.

Analysis: These vehicles became a form of living rather than for a specialized purpose like healthcare. The beginnings of military hospitals can be seen here.

Traditional Mobile Systems teach us:

1. The importance of functionality.
2. The importance of a sense of space.
3. Use of sustainable materials.
4. Energy efficiency
5. Light weight construction
6. Innovations to adapt to the surroundings.
7. Symbolism and aesthetic value.
8. Space planning for the interior
70 A.D. to Industrial revolution

70 AD:
Removable tension roof made of canvas was seen in Colosseum, Rome. Several demountable theatres, mansions, platforms and booths were set up.

1400-1600:
1439: Changing scenes: theatre by Filippo Brunellischi
1520: Temporary banqueting and entertainment halls for Henry Tudor VIII in N. France.

1787: Samuel Wyatt designed twelve movable hospitals. They could be dismantled and re-erected within one hour. The main features were their interchangeability and dimensional coordination. It was the first time a mobile structure was used for a 'specific function' such as this.

1897-1911: Circus structures were made of framed and tensile structures. An example is Ville' Morgan, France.

First World War: Sears Roebuck and Company shipped mobile hospitals to the Red Cross. They were the first responsible for the design, manufacturing and mass production of components that went
into mobile units.

*The industrial revolution:* Invention of cast and wrought iron contributed to the 'light weight' nature of mobile units. They were also fire resistant. Buildings were componentized and prefabricated. Though they were meant to be permanent, their use as a temporary assembly was recognized later.

19\textsuperscript{th} to 20\textsuperscript{th} century\textsuperscript{1,2}

*Renkoi, Isambard kingdom, Brunel*

Description: This was one of the first mobile hospitals for the wounded. It was set up according to very astute principles.

Analysis: These principles can be seen in mobile healthcare conditions of today as well.

(1) Mobile clinics should be adaptable to any site condition (2) There must be flexibility according to the system's capacity and availability of services. (3) The construction should not only be portable but also economical.
1917: Nissen hospital hut

Description: Captain P. N. Nissen designed the Nissen Bow Hut. It was the first of its kind to use minimum material with large volume occupancy. The simple design was made up of a semi-circular roof with two ends made of the doors and windows. The primary material used was corrugated iron. Ventilators and roof lights were later developed.

![Figure 5. Construction of the Nissen Hospital Hut](image)

Analysis: The hut was extremely flexible—sometimes doubled for an entertainment center. The system was one of the first in mass production and prefabrication. The components were easy to build and assemble and thus the construction was fast and well coordinated.

1918: Weblee portable hut

Description: It was a mobile timber hut that was built during the First World War.
Analysis: Prefabrication such as this had scope for innovation and further reinventions. This structure needed a certain degree of skill during installation. Labor was required to attain stability 'during' construction.

1928: Dymaxion house

Description: The revolutionary Buckminster Fuller invented this unit. For the first time, architecture borrowed its components from varied technologies from different industries (such as aircraft, automobile etc.).

Analysis: The unit was economical and could be mass-produced. It was equipped with a fully self-sustained kitchen, bathroom and generator. It was air deliverable and could be drawn by a trailer.
1942: Wichita house

Description: This was termed the reinvention of the dwelling. This was a prototype of the Dymaxion Deployment Unit.

Analysis: Innovation in terms of systems inside the unit was seen. Some examples are cupboards on rollers, automatic natural ventilation and air-filtration and plumbed-in vacuum cleaning. All the above were fitted in a reusable stainless steel tube and were all lightweight.
1954: US Marine dome

Description: The geodesic dome was magnesium framed, Dacron-clad and air-transportable.

Analysis: Mobility differs from other professions. Fuller showed was that 'lightness' was important to architects as against engineers who built ships and automobiles. The dome was highly mobile. The larger the dome, the thinner the shell ('eggshell' concept). Minimum and light materials were used for the frames and the shell. The disadvantage is that it requires highly skilled labor (Keeping in mind the site- Africa).
1960: Atomedic Hospital

Description: Dr. Hugh C. Maquire first developed this hospital. It was an advanced medical center with built-in and movable surgical equipment, laboratory, X-Ray suite and furniture. The plan was radial with the outer ring consisting of patient units and the inner core consisting of services. The partitions were semi-rigid and movable. Toilets were like the ones in a Boeing 707 airliner. The building was made of metal that was assembled on a concrete slab. The services included an advanced HVAC system and everything else like the dishes and lab supplies were disposable.

Analysis: The hospital, though a step ahead of its time, was extremely expensive. It borrowed technology from mobile architecture that existed in mobile homes. It catered to the rural and suburban community.
1962: Pneumatic Portable Satellite Unit (PPSU)

Description: This is basically a bubble that was developed by Stanford University in 1962. It was light, portable and disposable. This was used to move patients with highly contagious diseases from their rooms to the diagnosis and testing areas.

Analysis: This was an ingenious method. Architects were getting more and more creative with not only the system, but also the materials used for mobility. This was a cost-effective system. The drawback was that the bubble was far from a soothing and healing environment, at this scale.
1966: U.S. Army inflatable hospital, Vietnam

Description: This was a vaulted, pneumatically inflatable hospital, which was held to the ground with numerous cables. The army named the project Operation MUST (Medical Unit, Self- contained and Transportable). The name speaks for itself, as far as mobility is concerned.

Analysis: The hospital was set up in a war zone and the pneumatic nature of the system was sometimes damaged by heavy mortar attack. The political situation in some of parts of Africa may also pose such problems. Otherwise, the hospital was one of a kind when it came to highly portable emergency systems for healthcare. MUST was a pioneer in pneumatic mobile healthcare systems.
1968: Prefabricated hospitals by Oxford Architects and International Professional Consortium for Health Services

Description: The units were manufactured in Britain and then shipped to Africa, Central and South America. This was a response to the high rates in infant mortality in these regions. The prefabricated hospitals varied in design. There were four types that varied in complexity. All materials were carefully chosen to avoid insect infestation and could be maintained and repaired with a simple screwdriver.

Analysis: This particular system took into consideration site conditions in these countries. They also kept in mind all the economical aspects that went into building them. The governments of these countries were in close collaboration with the architects. The mass produced prefabricated structures assisted in assembly with the help of unskilled labor.

1968: Cashion- Horie clinics, CA

Description: Three clinics of this kind were built in the US. They were prefabricated units that were shipped from the factory with all the fixed equipment in place. They were mostly one-story buildings, which were assembled from pre-finished transportable units.

Analysis: The best part about this system is the speed at which it can be set up on site. It requires half than usual time to be assembled and hooked up to the site utility lines. It was also a predecessor to a
number of such industrialized 'kit-of-parts' clinics like the ones manufactured by Marshall Erdman and Associates, WI.

1969: Prototype Patient Capsule (PPC)

Description: Architect and educator, William N. Breger, developed this capsule. This capsule could run along a service track, which also carried air-ventilation ducts, electricity and other plug-ins. The capsule contained everything from a TV, movable or foldable mattress to a centralized illumination system. Waste disposal and ventilation was borrowed from NASA space ship technology.

Analysis: This system was developed during the period of the 'mega-hospital'; it brought mobility within huge hospitals so that patients could go to the services and equipment. Nurses and technicians did not have to travel long distances across the hospital. But this also created
a danger of psychological side effects like claustrophobia. It was also not very cost effective. What can be learnt from this system is the way in which the services were developed. The capsule fed into the services from a single source, which also helped in its mobility.

Figure 14. Sketch of a PPC²

Late 1960s: Modular and open plan clinics:

Description: Texas A & M University- College of Architecture had created an ideal patient care environment in late 1960s. It is basically a modular prefabricated clinic prototype and the first one was built in the Presbyterian Hospital in Dallas. The module was a loft-like unit that could be fitted into the interstitial spaces that were then only in the experimental stage. They consisted of four parts: a raised paneled floor, a partition panel system, a perforated suspended- ceiling panel and a Plexiglas hygiene component. Clearance was given for waste
lines, electricity, vacuum lines, etc. All shelves were recessed and panels were stacked or notched.

Analysis: This led to the 'marketing' of such prefabricated clinics. They all had self-contained clinics. The plan as against, most mobile units, was extremely flexible due to open-plan configuration.

Figure 15. Open plan and modular community clinic


Description: The Erdman system was successful mainly because of its minimal use of materials and mass production of its parts. Simple innovations like a centerline frame for doors, storage of components such as plumbing systems and roof joists helped in cutting costs. Their buildings were usually constructed of brick veneer.
Analysis: These clinics were a major success and continue to be widely used today. Their economy, speed of construction, and mobility is advantageous. At the same time, they have the feel of permanence. Another successful firm that designed kit-of-parts clinics, even today were designed and manufactured by Mariana and Associates. The firm designed the system; the parts were manufactured in the factory; shipped to the destination and assembled on site.

Figure 16. Transportation of Prefabricated hospital by Mariani and Associates, 1978
AFRICA: INFLUENCES AND PRECEDENCE

It is important to study African influences, once the timeline is tracked. This gives us an insight into the culture, topography, geography and healthcare situations of Africa. It is extremely important for the design of a successful mobile system in the continent. The acceptance of such a system in the community depends on how well the system has adapted to its surroundings. The system also needs to exhibit structural stability for varied climatic and topographical conditions.

Diversity

Africa, the second largest continent in the world is very diverse. This diversity is articulated in its physical geography and climate; in its plurality of cultures, traditions, beliefs, values, religions, and artistic expressions; in its many modes of economic production, distribution, and consumption; in its diverse social and political structures and practices.

Barclays and Schneider Ross³, the leading consultants specializing in equality and diversity issues were promoting globalization in Africa. To quote, the companies that promoted this growth: "The reason why the companies who are members of the network are so passionate about their work on diversity is that they
understand that they can only create long term value by working sensitively with local, developing African talent and coming up with African solutions to African problems."

This suggests that diversity is advantageous to growth and development rather than a complication. An insight into the African lifestyles, politics and culture would help localize the field of healthcare architecture in Africa. A mobile healthcare system therefore needs to consider the range of diversity across the continent.

**Natural diversity in Africa**

Most of Africa is covered by desert or grassland; forest covers less than ten percent of the land. Vast areas of plains that have uniform vegetation and landscape dominate much of the continent. The climate of any region is mainly dependent on temperature and the amount and distribution of rainfall. Since most of Africa lies within the tropics or subtropics and has warm temperatures, its climates vary principally in the amount and seasonality of the precipitation they receive.

The variety of climatic and soil conditions that are present in Africa has produced a great diversity of plant species; each is well adapted to and characteristic of the particular region in which it is found.
Plants grow together in recognizable patterns, often with the same neighbors wherever they are found. Just as people live together in what is called a community, the plant and animal populations that live together in a particular environment are known as a community. Within each community, the basic needs of the individuals are met. The plants and animals of a community depend upon one another, and there are close relationships between organisms in the same community.

The different soil conditions of the region give rise to different nomadic lifestyles. The diversity gives rise to a variety of building materials and construction. Other than the mountain ranges in the north, the relief in the east is rather plain, broken by occasional uplands.

The role of the architect is to design the system that can adapt to these communities and the diverse environment. The mobile systems touches many types of ecosystems and needs to be sensitive to its sites and surroundings.

Spatial layouts and volumes seen in nomadic mobile habitats are influenced by the unlimited horizon and uninterrupted sightlines of the land. Wind is another factor that affects need for the structural strength of these habitats. The sturdiest and heaviest elements of these structures are on the windward side. The hottest regions in the continent have more than ten hours of intense sunshine per day. The
shade of an acacia tree is a symbol of relief to the nomadic people. As a result their mobile dwelling span and shape in such a way as to create maximum, long shadows. Even the interior of the dwelling is laid out to reflect the path of the sun through the day.

Cultural diversity in Africa:

Africa’s land area is slightly more than 11.5 million square miles, nearly three and a half times the size of the continental United States. Africa is made up of more than twenty unique nations with their own political institutions, leaders, ideologies and identities. Each African nation is multi-lingual, with Nigeria alone encompassing more than two
hundred and fifty different language groups. Africa thus has incredible complexity and richness in its landscapes and cultures.

**Transportation in Africa:**

Transportation in Africa faces various challenges. There are smooth coastlines with limited harbors, rapid rivers like the Nile, deserts that cover 40% of the continent and mountains with under developed roads. Nevertheless, Africa continues to gradually advance for it's bright future. With advanced technology, Africa is now able to improve its transportation routes through the use of airports, railroads, improved roadways and artificial harbors. Many changes to overcome these challenges have already taken place. Here are two examples: one showing the excess use of a transportation system: the Matatu and the second, the need for practical solutions like the bicycle.

**The Matatu:**

The most popular form of transport in Nairobi and other East African cities is called the matatu, a minibus with twelve to fifteen seats. Some matatus operate along fixed routes, while others wait at one spot until they are full and then take their passengers to their destinations. Matatus are especially useful in East Africa, as they can penetrate areas impassable for larger buses. In 1982 Nairobi, a city of 750,000 had 1,550 matatus carrying 66,000 passengers a day.
Although matatus have a reputation for speeding, they are still popular compared to decrepit public buses.

Figure 18. The colorful Matatu

The bicycle:

Figure 19. Bicycles in Africa

"Transportation, Bicycles and Development in Africa: Progression or Regression," by David Mozer⁸, argues that one issue that needs more attention in sub-Saharan Africa is mobility. In rural areas, farming is done on small plots, often a distance from where farmers live. Over
these distances loads are carried back and forth especially by women. Delivering services, such as agricultural extension, adult literacy and healthcare are also obstructed by a lack of mobility. In urban areas a large percentage of people live below the poverty level. They must travel to work, school, medical services and markets. In evaluating the issue of mobility, Mozer considers the role of the bicycle.

Mozer\textsuperscript{8} writes, "To the limited extent that bicycles have been introduced into the structure of transportation in Africa, women generally have been excluded from access to the benefits. Exceptions include Burkina Faso and the isolated city of Maroua, Cameroon. African tradition puts an inordinate burden on women as the primary haulers of fuel, water, food and babies, and guardians of the health care of children. Yet "tradition" seems to have extended to them the least benefits from new technologies, including the wheel and labor saving transport as basic as the bicycle."

\textbf{Nomadic Africa:}\textsuperscript{6} For centuries African peoples have traveled across the Sahara. Many trucks and camel caravans still come to market in Kano, Nigeria, where nomads sell their goods and stock up on supplies for the long trip home. For example the Tuareg salt caravan travels on one of the world's oldest trade routes. It is amazing how people and camels depend on each other in the desert. For example, the Tuareg family in
a goatskin tent near a desert pasture, barter for a camel saddle, a robe or an amulet at the Kurmi Market.

Le Corbusier used the tent for his studies with measure and modular design. Tents all over the world served as both vernacular places to live in as well as 'urban' tents used for military and political uses. In Africa, tents were a part of the nomadic history of the communities. Therefore its familiarity to the continent is important while considering the aesthetics and nature of the mobile clinic. They were symbolic to their lifestyle reflecting changes in topography, climate and even social structures. Nomadic Africa cannot exist without these means of mobile transport. Means of mobility like the camel are a symbol of power in sub-Saharan Africa. Especially interesting is that women are the architects of nomadic architecture in these communities.

The oldest evidence of tents were the prehistoric rock paintings in Tassil n’ Ajjer (Sahara). The plan and layout of these tents match the layouts of contemporary Tubu and Mahria tents.

One of the oldest tents called mapalia were made of reed with high peaked roofs that gave a look of solidarity. The unique feature was that they were used both as a mobile pastoral dwelling and as a fixed agricultural dwelling. Later, skin covered tents were developed. This presented a whole new building technology that used elasticity and rigidity of a structure. Initially, they were seen more as institutional
buildings rather than vernacular architecture. Today, they are seen as symbols of flight and modernism. African tents are not the same across the continent. Sometimes, they cannot even be classified as mobile and sedentary. The materials could be interweaving palm, animal hair and animal skin. Sometimes tamarind roots, reeds and acacia are also used. The structural performance for these varies a large extent.

Figure 20. Teknas Lansas nomadic tent

Above, front view of the Tekna Lansas tent showing its interior canopy in use at night. During daytime use, below, the canopy sides are rolled up.
Contemporary African tents

Rooftop tents

Rooftop tents were designed and produced initially in South Africa. The features that make them successful are their safety, durability and strength. The tent is well insulated and warm on a cold night. The rooftop tent can be easily and quickly folded up. They are made of hard polyethylene case. These tents are available with a shower cubicle that attaches to the overhanging tent base. These tents can be used for quick make-do shelters for doctors and technicians during long travels. They provide quick shelters without taking into consideration the site conditions. This is because the base of the tent is elevated from the ground. The roof of the vehicle needs to be flat, elevated and strong.
Safari tents:

Figure 22. A luxurious safari tent in Africa.

Safari tents are common to Africa where tourism is common. These tents are luxurious and have amenities ranging from jacuzzis to outdoor decks. They come with attached toilets, kitchenette's etc. Therefore the various services that may be used for healthcare purposes can be analyzed from this. The tent itself is rather permanent than mobile.
THE DESIGN GUIDE

The precedence studies have given us an idea about the history of mobile healthcare systems, culture and diversity in Africa. It has given us an overall idea about the need for such a system in the continent. The design guide is then created as a reference for architects from where they can 'start' their design development. The design guide created with Macromedia Flash helps them navigate through the various permutations and combinations of the choices available. The properties and features of each method of construction and materials are stated. Since this is a pre-design 'tool', the architect, using this as his template, explores each system in detail. This leads to the development of the schematics and the actual design.

When architects design systems like these there is a vast amount of information available to be considered. Researching such systems can be tedious and time consuming. When a design guide such as this is provided, the architect can make his choice and move to the stage he is best at- designing the system. The design guide thus stimulates the thoughts of architects to further their choice of interest.

The systems were inspired and developed after the design competition 'Mobile Clinic in Africa for AIDS/ HIV' organized by Architecture for Humanity (Appendix) \(^2\). The criteria for the design of such a clinic were:
The unit would transport and store medical equipments and furniture. It would house doctors and technicians. The clinic should be cost-effective. If possible it should be built using sustainable materials and construction techniques. Local labor can be used and the use of local materials should be considered. Topography and terrain of the widely diverse areas of Sub-Saharan Africa should be considered.

Although the unit will primarily be used for the prevention, testing and treatment of the HIV virus and associated infections, it must also be a place where healthcare professionals can teach and disseminate information. The ideal design will take into account the varying healthcare needs of the population and should be easily adapted to treat these AIDS/HIV and other diseases and conditions.

One of the major obstacles is the stigma surrounding the disease and this should be taken into strong consideration when designing. If a clinic arrives into a remote area for the first time, we need to think of how it will be received into the community.

After this design competition, the thesis was developed to assist architects, with the help of a design guide or template. The possibility and scope of mobile structures for healthcare purposes in Africa is largely due to the increased development in healthcare programs and vaccination initiatives. The challenge lies in the topography, cultural diversity and healthcare situation in the continent.
The classifications in this design guide are broad and further research would reveal detailed and complex mobile structural forms. Four systems of classification have been established for mobile healthcare services. They are retractable, pneumatic, tensile and modular structures. These systems are chosen for several factors. They are:

a. They can adapt themselves to the diversity in Africa.
b. The systems have a large scope to use sustainable and renewable resources.
c. Keeping in mind, long-term goals, they are economical.
d. Medical equipments and services can best be integrated into these systems.
e. Accessible to remote areas and interior villages. They can be carried by land, air or water.
f. The systems have the capacity to aesthetically create a healing environment for the patients.
g. They are 'mobile' and 'portable' structures that can be assembled quickly. Local labor may be used if and when necessary.
h. The classification is generic enough to stimulate post-design schematics by the architect.
1. Retractable structures\textsuperscript{13,14}

Properties:

The simplest definition for such a structure may be one that expands from a closed compact form to a designed bigger structure, which is capable of carrying loads, and is structurally stable. The deployable components can be masts, slabs, grids, straight bars, plate elements etc. The unique feature that separates retractable structures from others is that, recently, these have been designed for other than the final configuration. Ease of construction and the structure's shape and stability 'during' construction is also taken into consideration. Structures are mass-produced in the factory in the desired configuration and the members are easily assembled on site. The connections, design and assembly of these structures are expensive and need professional acumen. The stability and portability of these structures make up for this initial cost.

Types:

(a) One dimensional bars: pantographs

Pantographs are the basis of most retractable structures. Future developments and combinations of such structures have resulted in retractable structures. Each basic pantograph rod consists of three nodes. Two of these nodes are at the end of the rods. They are
connected to neighboring rods at their ends. They cross over at an intermediate point, which acts as a pivot. They can be packed into a compact bundle. The bundle does not have any stresses acting on them except their own weight. Before the 'snap-through' type was invented most rods needed locking devices such as cables and connections to hold them together. This is not a problem for small structures.

The basic principal is that all rods should radiate from an inner apical point. This point should have elements that are slightly longer than the rest. This increases its rigidity and self-supporting action. The more pivot connections you can add the more the structure is foldable. These systems can form the entire structure, the roof a
structure, a retractable column etc. The fabric that covers these structures should not have any link to the connections of the system to prevent tear. They are in tension when the structure is expanded and collapses into a small bundle when the structure is compact.

(b) Two dimensional stiff panels:

These are two-dimensional surface structures. They are essentially made up of triangular panels that fold into a flat, compact shape. One of the angles of the triangle has to be 90 degrees. The apex angles may be equal. Several such modules are joined together in a particular sequence. They may also be connected with hinges.

Figure 24. Sketch of basic forms and variations of retractable panels.
A further development of the 90 degrees module is the 120 degrees module. It has more appealing characteristics since the clear width and the apex angle increases. At the same time the number of hinges would have to increase.

By lifting restrictions of keeping the edges parallel and in a straight line other forms are introduced.

(c) Tensegrity structures: stiff rods and flexible cables

'Tensegrity' is coined from the word 'tensional integrity' by Buckminster Fuller. It suggests a strict segregation between tension and compression members. Therefore members and connections needed for tension can be eliminated. The result is a simple structure that minimizes massive components and is aesthetically not as intrusive. The simplest, most stable tensegrity structures consist of three poles and nine cables. A typical tripod consists of six tendons. The 'apex' tendons bind the struts together. These form a triangle. The other three tendons connect apex end of one end of the strut to the non-apex end of the other. This then continues in progression, each element containing apex tendon, inter-layer tendon and a strut. A repetition of such a structure can even create a complex geometric structure, a dome or a polyhedron.

Shelter Systems, for e.g., had developed a tensegrity structure that combined tensegrity and geodesic systems. They are tensegrity
because the poles are not connected but stand due to the tension caused by the fabric. Since, the cords of the structure follow the shortest line in an inscribed circle they follow the geodesic principles.

Figure 25. A tensigrity tripod and a basic tensigrity structure.
(d) Retractable roofs:

The difference between these and the previous deployable structures is that these roofs remain rigid even in their compact state.

![Image](image_url)

Figure 26. Sliding roof on a large span structure.

The main criteria for design are that they need to be safe and structurally stable during deployment and after deployment. They need to be structurally balanced in the open, semi-open and closed state. The covering will be subjected to motion. Therefore they need to be flexible. Time limit for closing a structure and the effort and labor required to do so must be taken into consideration. The structure basically consists of sections of cross segments that slide into one another. They are based on steel beams that support the outer flexible covering. They are arranged on wheels that slide on special rails. These segments slide with the help of synchronized motion. The systems can rotate in a radial, linear or in a different axis. These mechanics need to make sure that they permit thermal and structural movements and transmit horizontal dynamic movements by wind and seismic forces.
Advantages:

The speed of construction is the most important factor here. The structure can be assembled easily without complicated equipment or special skills. In its compact form, the structure is small in size and light. Therefore it can be stored easily and transported without the need for special trucks or vehicles. Reusability of these structures is quite high. The parts can be replaced easily due to mass-production. It has competitive overall costs compared to most deployable structures.

Disadvantages:

External stabilizing is a problem for most retractable structures. Temporary support, which is expensive, is required during assembly of larger spans. The connections for some structures may also prove expensive and complicated. Though research has provided us with various alternatives, compared to tensile and modular structures, these have limited configurations. The more complicated the configurations, the more structural calculations needed for the structure. Bowed and bent elements in the structural frame leads to buckling which in turn reduces its load bearing capacity.

Healthcare uses in Africa:

The most complex forms of one-dimensional bar can be used for small units. The entire structure can be deployable or the mobility can
be restricted to the roof structure. Retractable roofs and tensegrity structures may be used for relatively large structures. These structures are extremely effective for mobile healthcare purposes. This is because of the above-mentioned advantages. All services can be integrated within the system. The careful configuration of cables, rods, connectors and service lines can result in a successful portable system. Moreover the fact that the components can be mass-produced makes it feasible in Africa. Since these consider wind, thermal and seismic forces, a diverse topography like that of Africa’s can take advantage of retractable systems.

2. **Pneumatic Structures**¹⁴,¹⁵,¹⁶

*Properties:*

Precursors to the architectural use of pneumatic structures ranges from parachutes, rubber balloons, inflatable rings to learn swimming, large ‘air houses’, to indoor stadiums. Pneumatic structures developed quite independently of other conventional construction systems. The main difference between pneumatic structures and the conventional types are that permanent structures need to bring in suitable environmental conditions within the building, for thermal comfort, but the pneumatic structures are literally a bag with a manufactured environment. Therefore these systems are a membrane
that is stabilized by small pressure differentials created by applying environmental energy. In traditional structures, the structure determines the environment while in pneumatic structures the application of environmental energy produces structural stability.

In general this method of construction is called pressurized construction. In this method, there is control and stabilization by means of pressure differentials caused by uniform loading actions of air, gases, liquids etc.

Basic elements needed for this type of construction are the membrane, membrane supporting elements, anchorages and access. The membrane may be plastic films, coated fabric, woven metallic fabrics, metallic foils or strengthening foams. The supporting elements could be lightweight metal in hybrid systems. In fully pneumatic types support is usually with the help of a fan, by wind or by up thrust. Ballast or ground anchorages are used. Access is by a single door, revolving doors, air lock or air curtain.

Types:

Pneumatic structures can be broadly classified into two main categories: (i) Air stabilized construction and (ii) Air controlled construction. We will be looking at the former in detail. This is because the former is not yet well developed in the field of architecture. However they are used for hover crafts, pneumatic drills etc.
(i) Air stabilized construction:

The pressure differentials that support the structure induce tensile stresses to resist gravitational wind loads. Further calculations and analysis proves that there are two main factors influencing to the design of an air-stabilized system: the pressure differential should be high enough to prevent compressive membrane stresses, under all loading conditions. When all parts of the membrane are under tension, complete stability is achieved. Secondly, the membrane stress at any point of the structure must always be less than the permissible stress of the material.

(a) Air inflated Structure:

In this case, air is contained within the membrane that supports the structure. These can be any supporting structure such as columns, beams, walls, arches etc. The four factors important to this system of construction are the volume of space contained within the membrane, excess pressure differential exerted by air, the membrane material and the structural form. Modulus of elasticity is required in addition to the tensional strength of these materials. Larger volumes and higher pressures leads to greater spans but the materials need to be strong and reliable.
The basic essentials for these structures are the structural membrane, support for this membrane, anchorage to the ground and the means to access in and out of the pneumatic building.

The two types of inflated structures are inflated rib structures and inflated dual walled structures. Rib structures are made up of inflated ribs that support a weatherproof membrane in tension. The volumes of air in the ribs are quite small and allow small spanned structures.

![Figure 27. A pneumatic ribbed support for a small spanned tent.](image)

Inflated dual walled structures are those that have air contained between two membrane structures. They can span to large volumes. The volume is held together with the help of drop threads and diaphragm configurations.
(b) Air supported structure:

Figure 28. Inflated pneumatic structure.

This consists of a single membrane structure with a small pressure differential for support and stability. The internal building pressure should be slightly higher than the external pressure. Access in and out of the building is through a pressure differential. Uninterrupted air supply is necessary to replenish lost air. Unlike conventional structures that apply loads downwards, these structures cause uplift forces that need anchorage.

(c) Hybrid Structures:

Figure 29. A sophisticated hybrid structure.
A combination of both the above types is called Hybrid pneumatic structures. These structures have features from both that can be clearly distinguished but at the same time draw the benefits of both into one system. The spanning potential of air supported systems is achieved and the insulation properties of dual walled systems is adapted. Therefore this combined structural stability avoids collapse due to its failure. Though very few of these structures have been developed because of their sophistication, partial hybrid structures have played an important role in the building industry. They are combination of conventional building supports and pneumatic structures. For e.g. a lightweight metal frame to support the pneumatic membrane is used to create innumerable combinations.

**Advantages:**

Pneumatic structures are considered when one talks about 'instant' portable architecture or 'disposable architecture'. These structures are the new-age large span tents that do not need poles or supports. They are extremely flexible. The entire structure can be erected or dismantled easily and quickly. They are portable and mobile, as in, they can be deployed in a very efficient way. They are lightweight and have low bulk for easy packaging for handling and transportation.
The strength of these structures depends on their contained air volume, the internal air pressure, the structural form and materials. Air volumes and differentials make the structure stronger. Therefore large volumes, enclosed by the pneumatic structure, require small pressure differentials for air supported structures and vice versa for air inflated structures. Therefore larger spans are possible for air-inflated structures. There is no limit to the span a pneumatic structure can cover. It depends on various factors, the material of the structure being the most important.

If the external loads on the structure are uniform, then all the internal stresses will counter-act uniformly. Therefore no anchorage may be required in this case. Under heavy loads, like snow and wind, the interior is pressurized to support the additional loading.

**Disadvantages:**

A full understanding of such a structure is still under research and the design analysis and calculation need in-depth knowledge of its mechanisms. An incomplete analysis will lead to serious building (pneumatic) failures. Pneumatic structures are ‘alive’ and dynamic. The main problem misunderstanding distortion is not understood. It can be controlled in such a way that the stress concentrations are within allowable limits. Air replenishment is generally necessary even if the structure has no air-leaks. This is because materials may have some
degree of porosity. Temperature differentials cause expansion and contraction and affect low pressure structures. Therefore, depending on the size of the structure, continuous or periodic air replenishment is required. Uplift forces might need anchorage to stabilize the structure. Also, air leakages may become a common issue especially at entrance points and access areas. These need to be handled with care.

**Healthcare uses in Africa:**

The time taken to erect such structures is one of the important aspects for healthcare mobile structures. The larger the volume, the more time it takes. Smaller ribbed structures may be adequate for most mobile clinics.

If the external loads are not uniform, then the pressure differential needs to be very high to resist compressive stresses. This in turn leads to large span structures. Large spans and volumes allow flexible planning inside the structure. Thus we can achieve several different configurations for various clinical layouts within the structure. It can thus adapt to any given site in Africa. Flexibility also exists in three-dimension. Its volume can inflate or deflate to a required volume depending on the site on which the clinic sits.

The structure is extremely safe for medical purposes and otherwise. Structural failure in conventional buildings is usually sudden without any prior hints or warning. The loads falling within the building
are dangerous and heavy. In pneumatic structures, the failure leads to gradual deflation of the outer membrane. Any supporting structure like cables and rods are lightweight.

In clinics, more complex constructions can overcome the problem of thermal and acoustic insulation. Mechanical and electrical lines can be integrated with ease. It could have one utility element that would provide power to three or four medium sized clinics. Access doors can be air locked or could have air curtains.

In areas within Africa, where vandalism or military actions are dominant, these structures may be subjected to 'pop the bubble' vandals. This was also a major problem with the pneumatic MUST clinics in Vietnam, which were damaged due to bombings or gunshots around the site.

The major disadvantage for a pneumatic mobile clinic in Africa would be its high cost. But its long-term benefits may overcome this problem.
3. **Modular Structures**

**Properties:**

Modular structures are the 'oldest modern' of medical clinics that are well researched and most common. The modular forms have several components and each has an array of permutations and combinations. Modular structures are no longer unattractive. There are several modular structural configurations that can be transported by air, land or water. They could be specially designed shipping containers and even structural frames with support systems. The materials used also vary to a great degree. Usually a lightweight material like tubular steel or aluminum is used for frames. The frames may consist of roof sections, uprights and counter-bracing. The roof section can be the suspended variety, which carry the mechanical and support services. The floors could be 'floating floors' that could serve the same purpose. The walls, panels and openings could be made of lightweight eco-friendly material like fiberboard. Rooms could offer a wide range of window styles, ceiling heights and flooring options, with an array of wall covering possibilities.

All components are manufactured and produced in a factory. They have to be easily transported, easily constructed on site and durable while in use. Mass production of a prototype is thus easy when it is industrialized.
Types:

(a) Truck based Modular Clinics:

These may be diesel trucks equipped with raised intake and exhaust manifold for fording water. Some trucks break down to two sections for helicopter transport. Amenities may include built-in medical laboratory, bathroom, shower, kitchen, ultrasound, X-ray, electro surgical and other exam instrumentation. The HVAC could be in the form of an antimicrobial air purification system.

The trucks could be equipped with a generator or equipment to connect to a nearby pole. The truck can expand into an extra examination room or pharmacy when it arrives on site. Helicopter lift points are provided for air transportation.

Figure 30. The manufacture of a prefabricated modular system by Marshals.
(a) Trailer based modular clinics:

Trailer based clinics are similar to truck based. The only difference is that all the medical facilities are within this structure rather than being taken out of it.

![Figure 31. Mobile health clinics by MOEX.](image)

**Advantages:**

Modular structures can be modified to unique needs. For example modular sandwich panels can achieve sound isolation. Modular construction allows rooms to be moved, reconfigured or expanded, without high costs. HVAC systems can be integrated into the system. Reduced costs are seen because of mass production. Quick field assembly helps in reducing on-site construction time, noise and the
disruption of normal operations. Similarly relocation is simple and quick.

_Disadvantages:_

Design possibilities are limited, at least on the exterior. Though it has been proved for ages that it is an ideal mobile clinic, new innovative systems could take over.

_Healthcare uses in Africa:_

Most manufacturing is done off-site. Therefore noise and disruption are much less than in traditional construction. The structure is then connected to the host site for the provision of water, waste and sewage disposal and electricity supply. Panels can be made of composite panels for roofs, flooring and internal and external walls.

Amenities may include patient gurney with tie-down straps, ceiling-mounted IV track, catheter storage cabinet and wheelchair lift.

However, in Africa, these trucks and trailers may not be able to access interior areas. They may be used in areas that have direct access to the highways.
Properties:

Compared to conventional structures, gravity and rigidity are not the most important factors in tensile structures. In fact, the materials used in tensile structures are so light that their loads are almost never considered. A specific geometric form or 'surface shape' and a pattern of internal stresses called 'prestress pattern' are required. The geometry of tensile structures is therefore not random but follows strict geometry and structural analysis. Boundaries and support points need to be set, prestress pattern selected, and finally there is a three dimensional surface shape that must be in equilibrium at all points. This shape is derived from a mathematical process called form finding or shape generation.

Figure 32. Frei Otto’s basic four point structure.
There are two approaches to designing a tensile structure that is different from designing conventional structures. First, is by the simplest way of architectural design process—making models. The models are made with a stretch fabric, which has the closest feel of the actual structure. Secondly, is by mathematical means called iterative computation method. This is done in grids and the method is quite systematic and simple.

![Figure 33. Sketch of the formation of a basic tensile structure.](image)

After reaching prestress level, a stable structural system is attained. All upward curves resist wind velocity and downward curves resist snow loads. Four is the absolute minimum for the number of anchor points in a tensile structure. The anchor points thus create a dynamic structure as against a conventional structure where the stability is its maximum with three-point stability.

Structural fabrics used for these structures are made of a base material and a surface coating. The base could be polyester or
fiberglass. The coating could be polyvinyl chloride, Teflon or silicone. PVC is dirt resistant and is durable but may not last as long as Teflon. Even more durable is silicone. The rigid elements in the structure may be made of structural steel, aluminum, fiberglass, carbon and even lumber. Bridge strand cables are the strongest cables used to support and prestress tensile members. These have been adapted from bridge construction and have amazing load capacities. New cable materials are polypropylene, carbon, fiberglass and Kevlar.

Fire protection can be achieved by using the right materials and placing sprinklers. Tensile materials are usually less vulnerable to fire damage.

**Types:**

(a) Four point structures:

These are formed when two cable ends are stretched to transfer loads to the ground or the support and the other two ends are shortened and stressed. Alternatives of four point structures involve joining nodes and give scope for larger span structures.
Circular tensile structures evolved into radial tensile cables that we see today. In radial cable systems, at any node in the net the stresses are in the opposite directions and pull and against each other thus prestressing and stabilizing them. Radiating cable lines intersecting
with concentric stabilizing cables leads to a radial tensile configuration. These two lines are quite different from each other. The radial lines have just one node, while the hoops disappear towards the end of the structure. Therefore they are self-contained in one way.

**Advantages:**

![Figure 36. Interior of a framed tensile structure.](image)

Slender compression members tend to buckle with added loads. But it is quite the reverse for tensile members. Added loads increase the stress levels on members and make them tougher and stronger. These stresses need to be uniform. If not, a counter-balancing support cable is required to equalize lateral forces.

Tensile members are flexible and can be transported easily. Minimal structural members are required to hoist a system. They are as durable as conventional structures, if not more. This is keeping in mind that all the structural components are of high quality. They provide
flexible planning within its structure. Tension is the force used to pull the molecular structure of a material apart. It is the most efficient way to use a material because it utilizes the whole cross section at maximum efficiency; rather than just the material at the extremes of the cross sectional form, as in bending and compression loads.

![Figure 37. Tensile structure with radiating cables.](image)

It is untrue that the fabric is elastic in nature. If it were so, it would balloon under wind loads and settle under snow. A typical structural external fabric has a tensile strength of 10 tones per linear meter and will creep no more than a few percent after 20 years of extreme conditions.

**Disadvantages:**

Tear stress is the biggest problem in tensile fabrics. They start at an open edge and or at a hole in the fabric. The best way to protect this is to maintain continuity and hierarchy of strength and tension.
The structure can be assembled but needs complex calculations to design them for stability during and after installation. A degree of expertise is required while designing and constructing the structure. They rely on internal tensile forces to remain stable.

Great spans can be achieved by reinforcing the fabric with webbing or cables. Thermal values may limit its use but can be overcome with thermal lining and double skins at the cost of translucency.

**Healthcare uses in Africa:**

Aesthetically, a tensile structure blends with the topography of Africa because of its fluid form. The interiors also provide a dynamic yet healing environment for healing purposes. This structure needs to be designed, keeping in mind that it's used for healthcare purposes. For example, it can assemble on a skeletal frame structure that can be quickly assembled. The use of too many cables and stabilizing members can take too much time and labor. The key is to keep the structure simple and efficient. Care must be taken that all points on the tensile member are under stress. Prestress structures may not work because most of them are permanent like rigid Teflon fabrics. The structure can be designed for almost any condition. Heavier fabrics and more three-dimensional forms will cope with extreme wind and snow loads.
CONCLUSION

The next step for the architect is to move towards design development. There are hundreds of manufacturers who offer each component of the integrated mobile system. The key to a good design is to use the design guide as a tool to achieve various combinations of these mobile structures. Keeping in mind, each system’s properties, some possible combinations are:

- Pneumatic membrane with a retractable frame.
- Pneumatic structure with tension cables to anchor them.
- Modular structures set in retractable grids.
- Tensile structure on a modular retractable framework.

There are numerous such possibilities that open a whole new world of portable healthcare structures. Services, medical equipment and furniture can easily be integrated into these systems. They can be hooked on to the site and run through the structural members of the system. The other option is to use a strong mobile system that can carry the loads of water barrels, generators etc.

The end result is a well thought out and sensitive approach to the design of a mobile clinic that not only caters to the primary medical needs in Africa, but also provides a healing environment. Prototypes of such structures can finally be manufactured off-site, for mass-production.
APPENDIX: ACCOMPANYING CD-ROM AND OPERATING INSTRUCTIONS

The CD-Rom contains

a. DesignBoard.html. This is the image submitted for the competition organized by Mobile Clinic in Africa for AIDS/ HIV' organized by Architecture for Humanity.

b. DesignGuide.html. This is the file that contains the graphical explanation of the various generic mobile classifications.

System Requirements:

These files were designed to run on a PC, hard disk (5GB minimum) 32 MB free RAM, Pentium III processor, Windows 95/08/2000, Internet Explorer 4.0 or higher with Macromedia Flash 5.0 or higher plug-in, with a CD-ROM drive.
BIBLIOGRAPHY


