DESIGN, FABRICATION, PRODUCTION AND ERECTION OF ELEMENTS FOR A LOW COST HOUSING UNIT.

by

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I DECLARE THAT THE THESIS REPRESENTS MY OWN WORK.

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DEDICATION

The product of this research project is dedicated to:

my beautiful wife Nana

and

our wonderful kids Mulalo, Lutendo, Ehua and Adhieman.

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ABSTRACT

Housing is currently one of the most critical development areas in the Republic of South Africa (RSA). This developmental project forms part of a possible solution in the delivery of housing through mass production. The objective of this study is to establish a empathetic connection between modern geodesic construction and the traditional dome and to design an effective and efficient prefabricated dwelling unit suited to be easily built by semi-skilled persons. The success of this project will fulfill one of the major objectives of the RSA's Reconstruction and Development Programmes (RDP) - '*A better life for all*'.

The areas researched are the development of a design for a housing unit from a geodesic point of view and panels for the design, and a comparison between the western, the traditional dome and geodesic constructions with a view of further developing an acceptable geodesic design. The practical approach followed was that of constructing different geodesic shapes, with a view of coming up with a combination of designs or a suitable design. The housing unit was then tested to withstand loads by wind loading and by practically erecting the dwelling unit which is being monitored for durability of withstanding all kinds of weather at the place of establishment of the house.

The design of the panels which can be fabricated by semi-skilled people in small industries was a great challenge. The design has allowed for simple methods of manufacture and delivery in any particular environment or mass production from a factory. The target group for this particular design are the squatter camps, overcrowded townships and under developed rural areas. The materials chosen for the panels, have a proven record of success in their application with the South African Bureau of Standards (SABS) backing, acceptable durability and mechanical properties.

A dwelling unit which meets the criteria stipulated has been designed and a prototype of this unit can be seen at the Berea campus of Technikon Natal, Durban.

For effective delivery, the design needs to be well marketed to government and the private sector. The practical use of this housing units is unlimited as can be seen by the three unit creche facility built in Umlazi. The government being the sole vehicle to change, will be the major role player in the success of the project through it's RDP and the Department of Housing's incentives scheme. The private sector having sponsored the research project up to this stage, ideally can work with government to initiate efficient mass production of quality panels for the housing unit.

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NOTATION

Wind Loading Symbols

V_d = Design wind speed ($m.s^{-1}$)

V_z = Characteristic wind speed at height Z ($m.s^{-1}$)

V_o = Mean wind speed ($m.s^{-1}$)

Z = Height at which V_z is measured (m)

Z_0 = Reference height at which V_o is measured (m)

q_z = Free stream velocity pressure of wind at height z ($N.m^{-2}$)

C_p = Pressure coefficient

F = Total/Resultant drag force on building or element (N)

P_i = Internal nominal wind pressure on surface ($N.m^{-2}$)

P_e = External nominal wind pressure on surface ($N.m^{-2}$)

C_{pi} = Internal pressure coefficient

C_{pe} = External pressure coefficient

k_p = factor for converting wind speed into velocity pressure

= 0,5 air density ($Kg.m^{-2}$)

k_r = factor for adjusting V to other return periods

k_z = factor for converting regional wind speed into nominal wind speed allowing for the variation of wind speed with height, according to terrain category and class or size of building or element

A = Area of surface concerned, perpendicular to wind direction (m^2)

A_e = Projected or effective area of building or element (m^2)

w = the lesser horizontal dimension of a building (m)

b = the greater horizontal dimension of a building (m)

h = height of a building (m)

PART I
INTRODUCTION

1.1 Introduction

Before the democratic elections of 1994 in the Republic of South Africa, the violation of human rights, against the indigenous population was present and very common. For forty-eight years before these elections, the political situation excluded participation of the African population in developing the country. Because it was a white-only government, white supremacy and domination had been the norm and are still perceived as valid today by some whites. Legislation throughout those years protected and offered the best in terms of development to whites at the expense of blacks who had lower level citizenship.

"The paradox thus exists that in the most developed and prosperous country in Africa, not one of the black majority, who are some 83% of the population of South Africa, has a voice in selecting the members of the legislature that determines the supreme law of the land." (Carter and O'Meara 1979)

The beginning of the century came along with many changes in RSA, as a revolution in industrialisation took a wider spread. Many people, both black and white, moved away from the rural areas to the fast-growing cities, looking for jobs. Working opportunities mainly centred on the mines, and a lot of people, even from neighbouring countries, were employed to work under extremely bad conditions. Many of them lost their lives as safety regulations did not adequately cater for blacks. Mineworkers were housed in filthy hostels and not even allowed to go out except during holidays when they visited their rural homes (Lemon 1976). The question troubling most citizens is: how do we as South Africans close the housing gap? Fortunately, the new South African government is moving towards narrowing this gap by exhorting the financial institutions to lend more money for housing bonds to prospective buyers.

1.2 Discriminatory Policies

"In fact, influx control has so broken down that the real number of inhabitants was probably around 1,5 million, with hundreds of thousands of desperate job-seekers crowding anything from 6 to 25 into little three and four bedroom boxes of houses" (Johnson 1977)

The old government has created dramatic inequalities in income, wealth, employment opportunities and in the provision of social and economic infrastructure (education, housing, health, etc.). The apartheid system was based on the violent enforcement of white privilege through racial segregation, the denial of political and other rights, the Bantustan policy, job discrimination, unequal property and education rights and also the unequal access to houses, health and other social and economic services (Maylam 1989).

Blacks were considered only for labour jobs and therefore not allowed by legislation to participate in any training related to human resource management, science and engineering technologies. South Africa is now battling to make up for these human resources now so seriously lacking. From the Human Development Index (HDI), it is clearly indicated that black South Africans are still badly lagging, although the problem is dealt with by identifying literacy, life expectancy and income (HSRC 1995).

"Under the Reservation of Separate Amenities Act (1953) facilities may be reserved for persons of one race without provision being made for the other races, whether equal or otherwise." (Lemon 1976)

The legislation on housing blacks in the RSA was orchestrated in such a way that no black could own property. The land and premises which blacks occupied was owned by the government. The Group Areas Act allowed no blacks in white developed areas except if that black person was a labourer (Pampallis 1991, Maylam 1989). Cities and small towns were white territory; no blacks were allowed to stay overnight except for those who were there for purposes of work and approved by the authorities (de Bono 1991).

"The Group Areas Act (No.41 of 1950, amended and consolidated in No.77 of 1957) has had more far-reaching effects than any previous legislation on racial segregation...Implementation of the Act is the responsibility of the Group Areas Board and, subsequently, the Community Development Board" (Lemon 1976)

When the restrictions on home ownership for blacks were removed in urban townships during 1968, blacks could still not be granted free title hold to land. This made life very difficult for blacks because they were not even allowed to trade in the cities. Blacks were effectively silenced, as all who stood up for human rights were either arrested or simply eliminated. Worst of all, in terms of community spirit and physical hardships, blacks were faced with forced removals from their areas, which were earmarked for whites, to scheduled areas *('scheduled areas' constitute land set aside for Africans in terms of the Native Land Act of 1913).* (Lemon 1976)

The backlog on housing was incredible and was worsened by the low interest given to township development by the authorities at the time who allocated very little funds. The government in the late 1970s went on a spree of bribing homeland leaders into becoming 'independent' in their dream of maintaining white supremacy and control. Much money has been spent to woo black people back to their respective homelands in the hope that division among blacks themselves will prevail according to their ethnic groups (Davernport 1989). This led to four so-called independent homelands: Transkei, Bophuthatswana, Venda and Ciskei. Although the intention was to control the influx of blacks into urban areas, it helped improve the living conditions in these rural set-ups.

As very little or no housing was provided for the majority of the black families, for survival they had to remain closer to the cities and make ends meet with whatever was available in terms of providing food and shelter for themselves (Heard 1991). This led to the unlawful occupation of land and formation of settlements which we call squatter camps today. Blacks were excluded from the government of the day, and decisions on how they were to survive were taken without any consultation whatsoever (Carter & O'Meara 1979).

Resistance to these worsening situations was shown by strikes which were organised from as early as 1913, and the 1922 revolt in the mines, to 1990 when the President of the present RSA government (Government of National Unity (GNU)), Mr Nelson Mandela, and his colleagues were released from prison. The atrocities that continued led to much bloodshed and loss of lives.

The 1961 massacre which left 67 killed and 186 injured will not be forgotten to many who lost their loved ones. The same applies to the 1973 massacre and 1976 uprising (Johnson 1977) in protest against the change of the medium of instruction in all schools from Afrikaans into English (Mashabela 1986). The Boipatong massacre and many others will not be forgotten even though black people are working on healing the wounds through the Truth and Reconciliation Commission (TRC).

1.3 The present and future prospects of the RSA

The earlier removal of legislated oppressive racial laws was a good gesture which bolstered the new interim constitution to implement the speedy changes required for our economy to improve. The politics of yesterday, which centred on the protection of white supremacy, and the education system designed to undermine the capabilities of the black people have done much harm. "Apartheid did not just fail, it damaged each one of us, the oppressor and oppressed alike." (Sachs 1992). This is the time for reconciliation and for us to nurture what finally has been achieved after so many years of conflict, *the road to democracy (ANC 1994).*

Now the way forward is to address the situation by coming up with solutions that will help alleviate the housing shortage with as little delay as possible, which is why this particular project was started.

The government of the day is willing and committed to assist in the process of providing houses to the communities, a policy which emanated from the Botshabelo Housing Accord 1994 under the leadership of the late Minister of Housing, Joe Slovo. The all-inclusive talks which gave birth to the accord strengthened the Reconstruction and Development Programme for the housing sector. An all-inclusive Housing Policy, passed by Parliament, focusses on redressing the imbalance (ANC 1994). Monies for housing projects have been allocated, and work in most areas has already started.

1.4 Low-income Housing Policy in South Africa

As shown above, the housing problem in our country cannot be over-emphasized. Population growth is one of the major crises we face in South Africa, because lack of education and jobs have led to unacceptable differences in living standards. From a recent survey which was published in the *Sunday Times* of 5 January 1996, the housing backlog is estimated at an astonishing 2,5 million while the expected number of houses to be built during 1997 is a mere 330 000.

The shortage of housing versus population growth in the urban areas leads to overcrowding in hostels, townships and squatter camps. This situation exacerbates the crime rate we see in our townships and cities; because of poverty, everyone tries to find food to support their families and themselves in order to survive. Among those who are working, it is very rare to find a black couple earning more than R1500-00 combined income; even though we have achieved democracy, there is no money from the government coffers to alleviate such imbalance.

The effect of changes can be observed by a closer look at the new housing policy (ANC 1994) which has been formulated after thorough consultation with all affected parties, sealed by the Housing Accord, and passed by Parliament at the beginning of 1995. This has led the present government to allocate funds, using the following criteria:

- housing backlog in the province;
- performance in the delivery of houses;
- demography;
- income profile for the province.

The above has acted as the basis for the budget committee which divided the funds accordingly, the product of fruitful discussions which started in 1992 till the Botshabelo Housing Accord on 27 October 1994. The housing policy as indicated in the white paper from the government and passed in Parliament constitutes the following:

- stabilizing the housing environment;
- housing support;
- mobilising credit and savings;
- subsidies;
- institutional arrangements;
- land and services, and
- coordination of public funding and development activities.

There are many housing designs ranging from rectangular, round, conical and different shapes that house people all over the world. The advantages and disadvantages of these designs vary, according to what people want.

Prefabrication in the housing scenario allows for quick erection of houses, and from a mechanical point of view, it is the quickest means of delivery in mass production. Geodesic constructions as a form of dwelling having not been fully explored in the Republic of South Africa.

The larger population of South Africa in rural areas still live in spherical constructions which are geodesic in nature, e.g. the Zulu and Xhosa domes. The surface area covering a geodesic construction encloses a much larger volume as compared to rectangular structures (Kahn 1973).

***Figure 1**: Typical Zulu traditional huts (Indlu)*

There are several companies in the RSA involved in pre-fabricated housing modules, e.g. Pozzi Hut, Gemini Huts, Sagex, Mondev, Uniply (NBRI 1987). These companies are failing to deliver something substantial to the majority of those in need of housing because their designs have no inclination towards African tradition or culture, or indeed some synthesis of African and Western designs. They make only rectangular modular kits (Grobbelaar 1990). To this day in the RSA, only one typical geodesic housing unit has been built in Cape Town by a student of the University of Cape Town as part of his Master's degree (Waizenegger 1983).

Looking back at the early years of industrialisation in the RSA, there was a flow of people, black and white, into the urban areas looking for work. The unfortunate thing is that the local government of the time addressed mostly only the plight of white residents at the expense of blacks (Mashabela 1986). Most blacks were forced to provide shelter for themselves with whatever material was at hand. This led to a build-up of the so-called 'shanty towns' which we call 'squatter camps' today (Grobbelaar 1990). The situation was worsened because of the discriminatory laws which did not allow blacks to own a house or land (Maylam 1989, Davernport 1989).

Traditional African housing has been maintained in rural areas, utilizing materials and methods of high standard and quality, resulting in a typical form of round hut with conical

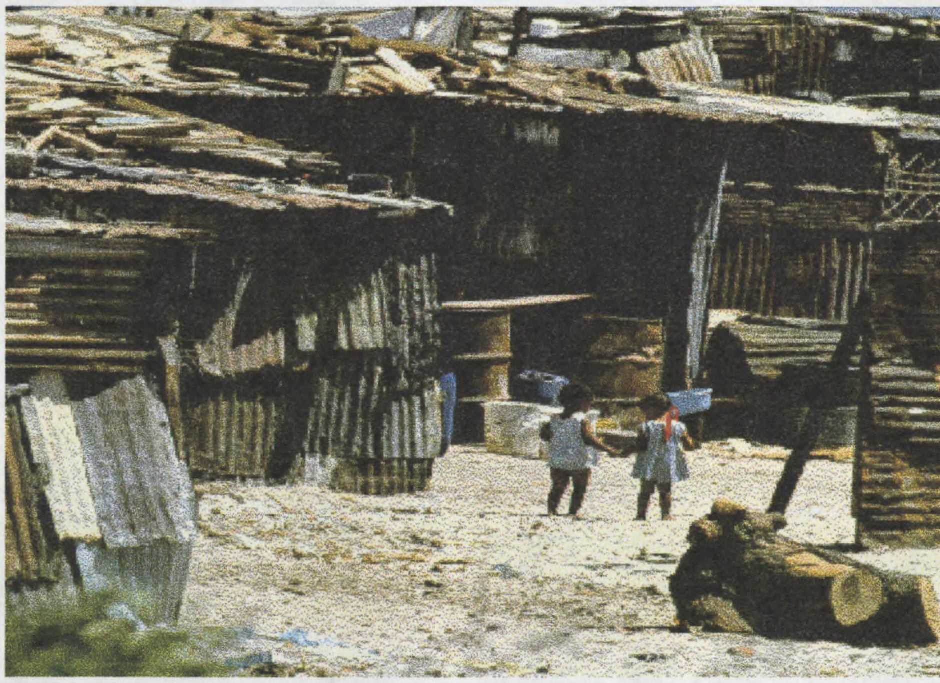


Figure 2:*An example of a typical squatter settlement: photograph; Cape Town*

roofing and also traditional spherical huts called 'indlu' (NBRI 1987). Housing development for whites in their western styles, brick and mortar rectangular walls and angled roofing with roofing tiles or sheets (Raeburn 1980), continued as usual with black labour and skills (Mashabela 1986). This has left black traditional housing at odds with modernisation trends, and no synthesis of the two was made (Raeburn 1980, Smith 1980).

The rapid increase in the poverty-stricken black population in urban areas is clearly indicated by the HSRC (1995) and poses severe problems in the affordability of housing. The necessary amenities and infrastructure received little attention. So little was achieved by way of provision of housing for the majority of black people (Pampallis 1991, Heard

1991). In the RSA, housing problems are acutely experienced by the largest sector of the population, blacks (De Klerk 1988, Davernport 1989).

This situation is the main motivation for this developmental research project. This has led in a natural way to thinking about the types of houses that have been designed and built by blacks (Hammond-Tooke 1993, Briggs 1991). Western building style and architecture have dominated most parts of the world, including the RSA (Schultz 1980).

Figure 3: *Typical western housing style as early as 1200 AD.*

1.5 Solutions to the problem so far

There has been a lot of input from all over ranging from individuals to both smaller and bigger industries. These indicate the degree of commitment, participation being outlined below. The lack of improvement and recognition of the designs of houses for indigenous Africans is acknowledged by this project.

1.5.1 Private sector and individuals

Tremendous progress in seeking solutions to the housing crisis has been made by various individuals and companies. Looking at available low-income houses, one finds a range from self-help designs to prefabricated standard panels for the different designs. These housing systems differ in design and materials. The author has come across many different companies who are now involved in the business of low-cost/affordable housing and will mention a few and what they offer.

1.5.1.1 Self-help designs

These are designs created by companies for individuals who will be supplied with materials to enable them to build the house themselves with the aid of manuals providing building instructions. They pay for materials only and end up with a standard house built by the normal brick-on-brick method.

Companies like Federated Timber (RSA) and the Concrete Masonry Association (RSA) have been involved in this self-help housing scheme. Gypsum Industries (RSA) has its partitioning Rhino-Drywall panels which are used in low-cost housing.

1.5.1.2 Pre-fabrication as a solution

Pre-fabrication and mass production are seen as the strongest tools and the fastest way of coping with the present demand for housing the needy. Pre-fabs range from the simple panels to the most sophisticated and expensive sandwich panels. These panels are of varying designs and materials cater for different applications and assemblage system.

(a) Erection by specific company

Companies have their own plans and customers choose the ones that suit their needs. A team from the chosen company goes and builds a foundation under the supervision of an inspector or foreman. After completion, trucks deliver the panels on site and the crew assembles them to build a house with the help of a crane, as some of these panels are heavy.

Companies undertaking this type of an operation include:

- Abkin's Housing Systems (Pty) Ltd (RSA);
- Speci-Home (RSA);
- Sagex (RSA), and
- Built Environment Support Group & Gumbou Manufacturing (RSA).

(b) Erection by the customer

A variety of plans are also designed by companies or individuals to allow people to choose what is most suitable for their needs. Standard panels are available for these designs, and instruction manuals are supplied to each purchaser. The purchaser can arrange his transport or the panels will be delivered to site, but he prepares the foundation and erects the house according to the manual. The following companies in the RSA are in this line of business:

- Fabricated Steel Manufacturing;
- Pozzi Building System;
- Zinki;

- Timbrik;
- Ezebilt; and
- Thesen Uniply.

1.5.2 Government

The previous government did very little over the past few years to address the housing crisis. Although housing projects were carried out in some sectors (about 38 000 houses built per year), it seemed as if little was being done because of the shortage of housing being experienced by black people in general (NBRI 1987).

The above has acted as the basis for the budget committee which divided the funds accordingly, a product of the fruitful discussions which took place between 1992 and the Botshabelo Housing Accord on 27 October 1994. The housing policy as indicated in the white paper from the government and passed in Parliament constitutes the following:

- **stabilizing the housing environment;**
- **housing support;**
- **mobilising credit and savings;**
- **subsidies;**
- **institutional arrangements;**
- **land and services, and**
- **coordination of public funding and development activities.**

There are records available for houses that were being erected for blacks, Indians and coloureds, indicating the quality and size of the dwelling, the lowest standards being for blacks; but surprisingly there are no records available for the white communities and houses that were being built for this sector. About 350 000 houses need to be erected per year for the next ten years to eliminate the backlog in housing.

The government of the day has so far introduced a subsidy scheme for the underprivileged to assist them to afford houses through the Reconstruction and Development Programme in conjunction with the Department of Housing. This is offered according to salary scales and calculated to a maximum of R15 000-00 for households earning less than R800-00 per month combined salary. Efforts are also being made by the present government to persuade housing financing schemes to lend monies to those who can repay, as the government cannot succeed alone without the private sector's involvement (Housing policy of RSA 1995).

South Africa has been divided into nine provinces since the democratically-elected government of national unity was established in April 1994. The Ministry of Housing announced the budget funds earmarked for housing during the 1995 financial year to be R1,8 billion for all nine provinces. The biggest share went to Gauteng (R437 million), second being KwaZulu-Natal with R351 million. The rest was shared accordingly among the provinces, with the Northern Cape receiving the smallest bite of R30 million.

The total allocation for housing stands at R2,92 billion of which about R2,8 billion is available for capital expenditure. Of this amount, R700 million is reserved for spending on infrastructure which will be allocated to the provinces once criteria for spending have been developed. For the remaining R2,22 billion, about R292 million is for the national expenditure which includes R220 million for the National Housing Finance Corporation, R50 million for the Housing Support Centres, R10 million for the National Housing Education Programme and R5 million for the National Housing and Services Information system.

The Housing Minister and her provincial housing MECs have reached an agreement on the allocation of budget funds based on demography, income profile, housing backlog and performance with regard to the delivery of housing. Between the elections of 1994 and the end of 1996, records from the Minister of Housing show that 362 000 subsidy applications were approved (*Sunday Times*, 5 January 1997).

The most recent survey on the delivery of services, water and electricity, and housing published in the *Sunday Times* (5 January 1997) shows that the estimated delivery for low-cost housing is 150 000 short for 1996. Therefore the implementation of this present project into a pilot project for delivery of houses can play a significant role in the future of the RSA.

1.6 Objectives of the study

- To establish an empathetic connection between modern geodesic construction and the traditional dome type housing for the indigenous peoples of South Africa.
- To design or recommend an effective and efficient prefabricated dwelling unit suited for erection by unqualified persons.

The contribution of this developmental research project is its design flexibility. This type of design makes a step forward in housing products of a geodesic nature. As Fuller pointed out, geodesic constructions are inherently strong and stable, while a minimum of material encloses a maximum volume (Macgregor 1981). This reduces material costs and weight, and minimises the rate of heat transmission (Popko 1968).

As regards this project, the first thing to do was to look at geodesic constructions which have already been built to find out if they are suitable to our environment at all (Sheppard *et al.* 1974). The second is to find a suitable design, with due regard to the history of geodesic constructions, recent developments and geodesic mathematics (Kenner 1976).

The requirements for the housing unit project were specified as follows:

- the ultimate design must be acceptable and appealing;
- the unit must be rigid and durable;
- the design is to be modular and extendable, to cater for future needs;
- the unit is to be perfectly sealed;
- it is to be demountable, with the possibility of being assembled again somewhere else, (reusability);
- the materials to be used in the construction must be freely available in the RSA;
- the unit must come with suitable sandwich panels that are mechanically sound and

cheap;

- the panels should preferably be lightweight; and
- the unit must be affordable, each not exceeding R500-00/sq metre as of June 1996.

The research will not include the following: plumbing work, drainage systems, electrical installations and internal decorations.

CHAPTER 2

GEODESICS

2.1 Introduction

If one looks at most of the major admired complexes, it is noticeable that if there is no dome or related spherical shape incorporated within the whole structure, it simply does not appeal to the majority of the people (Raeburn 1980, Rogers 1993). From this it can be learnt that anything geodesic is very attractive to many people, which is why many different designs will be emerging in the form of geodesic structures (Schultz 1980). In America, for instance, there are organizations researching on possible geodesic structures to this day, and one such organization was founded by RB Fuller himself (Kahn 1971, Kenner 1973).

2.2 Historical perspective of geodesic constructions

> "One symbol of original perfection is the circle. Allied to it is the sphere, the egg, and the rotundum- the 'round' of alchemy... Therefore the demiurge made the world in the shape of a sphere, giving it the figure which of all is the most perfect and the most equal to itself." (Sheppard *et al.* 1974)

The first recorded geodesic dome was seen in China's Summer Palace, Peking. There were other domes all over the world, but these were not divided into the smaller triangles which describe a geodesic structure (Kenner 1976). *An interesting factor is that nobody knows who invented geodesic domes*! But when dealing with geodesic structures, the first thing to look at is the basic polyhedra whose spherical versions forms the basis for all geometric development (Popko 1968).

Another way of looking at geodesics mathematically is described as follows:

"If we define the distance between two points p,q on the cylinder as the length of the shortest join (on the cylinder), then the cylinder becomes a finitely compact convex metric space" (Busemann 1955).

There are a number of theorems to prove the point that geodesics are real and two mathematicians, Finsler and Riemann, have played around with these and have come up with different theories in the geometry of geodesics which are explored by many others to conform with the changes in the new era (Busemann 1955, Shiohama 1984).

The primary purpose of this project is to establish connection between modern geodesic construction with the traditional dome so as to re-introduce it in a modern form. In modernisation this traditional housing dome, it is hoped that it will bring acceptance amongst the people in need of housing. The generic dome constructions have proved to be very strong in all weather conditions, by having provided shelter to so many people for a long time, using available materials (Hammond-Tooke 1993).

The secondary purpose of this developmental project is seeking to find a suitable geodesic design that is envisaged to form part of the solution to the real housing need through mass production. This can only be achieved through prefabrication.

Geodesic constructions began with the construction of domes and the first dome architecture is as shown below. This magnificent piece of work was designed by a Roman architect, Byzantium (Schultz 1980). Architect, Buckminster Fuller, initiated the analysis of geodesic constructions and incorporated his ideas and findings into innovative designs which he shared with students and interested parties around the world (Raelton 1955).

Figure 4: ***Santa Sophia***, *one of the first dome architectural engineering pieces as early as 532 AD.*

Nobody knows who built the first geodesic construction (Macgregor 1981). The development of geodesic constructions gained popularity when many individuals came together to build domes for themselves for all manner of purposes (Sheppard *et al.* 1974). These prompted dome construction enthusiasts into forming groups which are still existing today and available on the advanced technology in communications International Tele-Communications Network (INTERNET) using computers.

Subsequent studies of geodesics have brought about a complete spherical geodesic construction topic known as geodesic mathematics (Kenner 1976). The most important component of geodesic mathematics is spherical trigonometry and, as can be seen below, the 'subdivision' of spheres by great circles gives us a totally different picture, e.g. a complete sphere divided into triangles (Sheppard et al. 1974, Popko 1968).

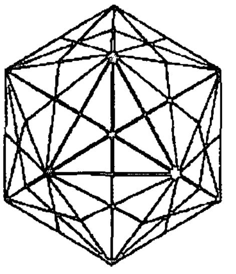


Figure 5: Fifteen great circles
An example of the 'subdivision' of a sphere: an icosahedron into triangles by the rotation of great circles from the mid-point.

Geodesic constructions are generic terms used for a huge range of geometrical shapes consisting, generally speaking, of planar shapes which are tangential to some hypothetical sphere, or ellipsoid (Popko 1968). These are normally called domes because of their spherical shape and orientation. We can find a relationship between the African traditional housing constructions and geodesic constructions; for example, Shaka's Kraal in Kwazulu-Natal, RSA (Hammond-Tooke 1993). There is also a connection between geodesic constructions and western construction styles, such as Church Square in Pretoria and the Johannesburg Supreme court, to mention but a few in the RSA (Briggs 1980).

2.3 The prototype

After considerable experimentation with cardboard and metal models, the design which was selected comprises a semi-geodesic octahedral housing unit. If a housing unit is to be designed as proposed, the possibility of mass production and delivery of prefabricated panels may become a reality. The ultimate aim is to unleash the entrepreneurial spirit of those for whom housing is a problem; just as these same people solved their rural and urban transportation problems, not waiting for central government to provide bus and train services.

It is envisaged that industries will fabricate the panels and supply them to the people in the form of a kit. In this way, the living conditions of the most disadvantaged people will be

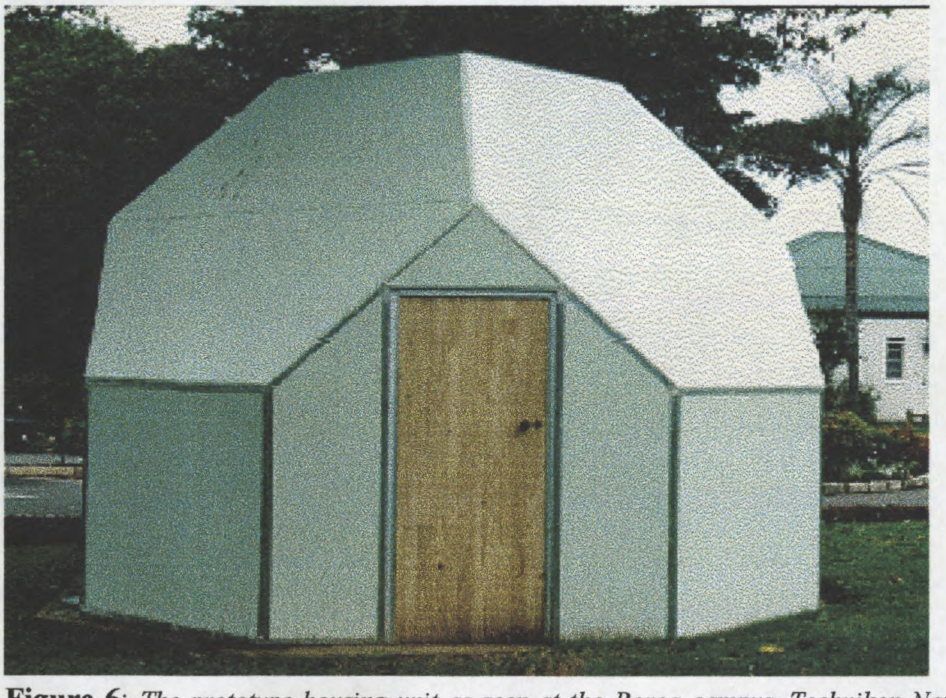


Figure 6: *The prototype housing unit as seen at the Berea campus, Technikon Natal, Durban, RSA*

improved by the provision of hygienic and comfortable homes, as envisaged in the government's Reconstruction and Development Projects (RDP 1994). The pride of black people will be restored as they themselves contribute towards the improvement of traditional housing styles (RSA Housing Policy 1996). As has been witnessed all over the world, especially in the USA, there is great potential in geodesic constructions (INTERNET Dome working group, Schultz 1980).

The objective of this report is to discuss the design and analysis of elements for the prototype housing unit. Implementation of the design and further research work aimed at solving the ever-growing problems will also be addressed, as well as possible solutions.

2.4 Geodesic domes

Geodesic structures have been around since the beginning of the century and the only person who realized them and looked at geodesics from within, 'breaking down' the sphere into triangles, is Richard Buckminster Fuller. He patented the method for constructing a spherical sphere by 'subdividing' it into triangles in 1951 (Kahn 1971, Kenner 1973). The interest in this was due to a simple reason: "The sphere encloses the greatest amount of space with the least amount of materials." (Kahn 1973).

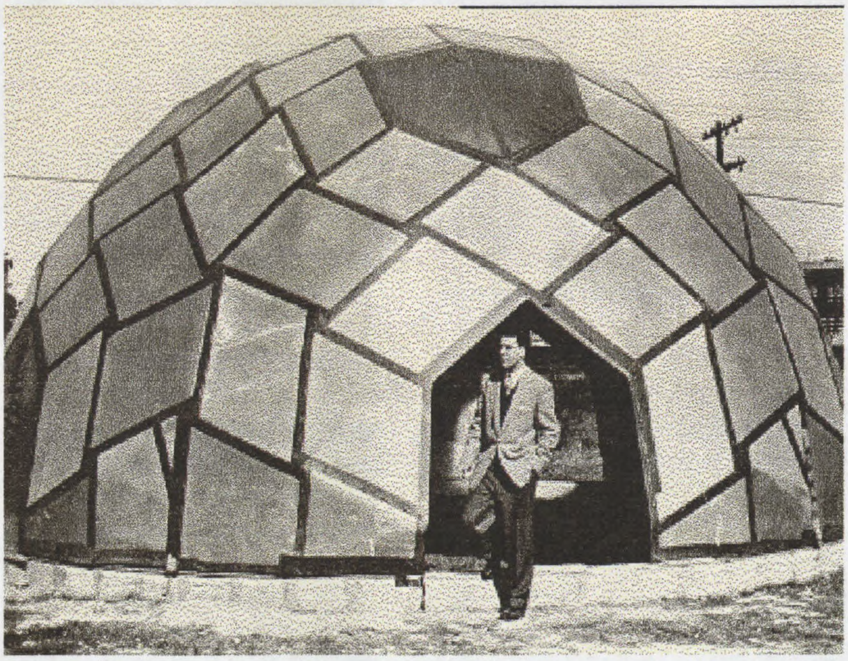


Figure 7 : *Mcgill University students' dome, School of Architecture, 1957, in a seminar with Buckminster Fuller.*

Geodesic construction arise naturally from the study of regular solids. There are five platonic solids found in nature which forms the basics of geodesic structures. They are the *Callimitra agnesae* - which is a tetrahedron, *Lithodubus geometricus* - cube, *Circoporus octahedrus* - octahedron, *Circorrhegma dodecahedra* - dodecahedron and *Circognia icosahedra* - icosahedron. These five platonic solids are related to the platonic polyhedra (Kenner 1973).

Many dome structures have been built around the world by different cultural groups using whatever materials they had at the time to provide themselves with shelter (Rogers 1993, Raeburn 1980). These structures were mostly spherical, cylindrical and conical but very strong and longer-lasting than anyone would imagine. Despite the changes sweeping the whole world involving the use of technologically-advanced materials, there are people who are still using their natural resources to build their houses, including spherically shaped structures (Kahn 1973).

Domes come in different designs and are as follows:

. ***Sun Domes*** - made of triangles on frames that bolt together to make the dome. The first one was a swimming pool cover and was published by Fuller through *Popular Science* in 1966. This was the only geodesic geometry available for dome builders at the time (Kahn 1971).

. ***Struts or Skin Domes*** - The framework is first put up through various vertex connectors and then a skin applied (Kahn 1971).

. ***Flange Panel Domes*** - skin and struts are one-piece, with skin flanged over to form strut. Assembly is done by either rivets or bolts as with the Sun Dome (Popko 1968).

. ***Monolithic Skin Domes*** - the skin of the dome is applied or sprayed in liquid form, and when solidified, makes a one-piece rigid skin (Sheppard *et al.* 1974).

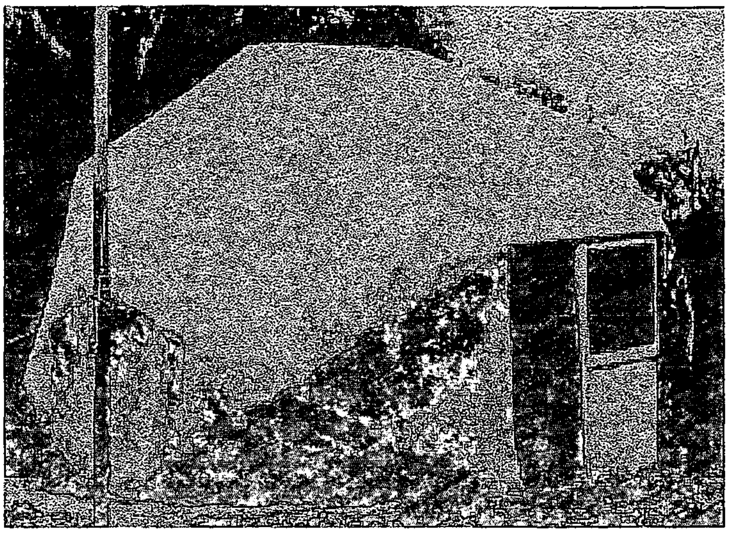


Figure 8 : *Concrete sprayed on triple layer corrugated cardboard covered in chicken wire by Michael Ben-Eli and Keith Critchlow, 1967.*

. ***Tent Domes*** - one-piece skin is either hung from the frame or draped over the frame. These types of domes are very useful for disaster areas where people have to be housed without delay. The framework can be connected quickly with any form of material suitable for cover in order to form temporary shelter.

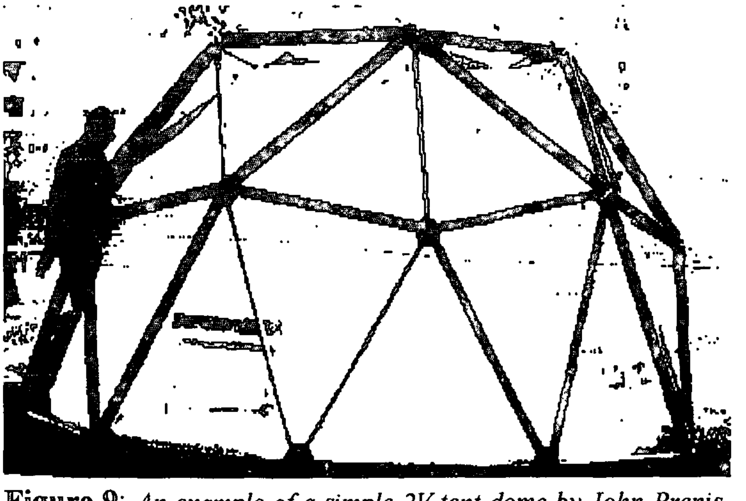


Figure 9: *An example of a simple 2V tent dome by John Prenis, 1967.*

2.5 Geodesic geometry

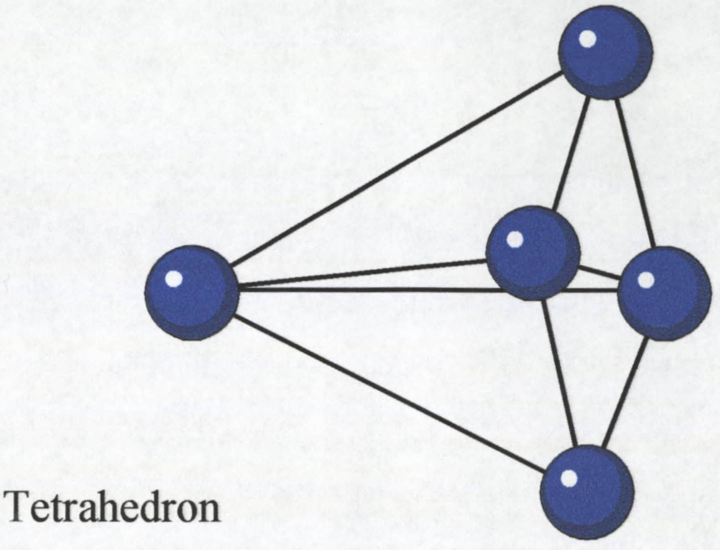
2.5.1 Introduction

At an early age young boys and girls make their own kites, but it is amazing that most of them couldn't realize that the kite was made stronger and could fly higher because of the triangles which are formed within the kite. The kite is a tetrahedron and one man by the name of Alexander Graham Bell explored the concept and strength of the kite to an extent where he built kites strong enough to carry a passenger (Kahn 1971).

Basic polyhedra, whose spherical versions form the basis for all geometric development, are the core divisional means of identifying geodesics. There are three families of polyhedra; namely: the platonic, Archimedean and Archimedean duals. The five platonic solids are the most basic, and we will discuss more about these because of their relevance in our project (Popko 1968).

2.5.2 The platonic solids

The tetrahedron, octahedron and icosahedron form the basis of the development of domes because of their subdivisions of triangular faces which are simple and stable. Domes have the symmetry of the three polyhedra above and also of their duals, but are not well related to the hexahedron and tetrahedron, although the hexahedron (cube) is the most common archetype for construction from among the platonic polyhedra (Waizenegger 1983).



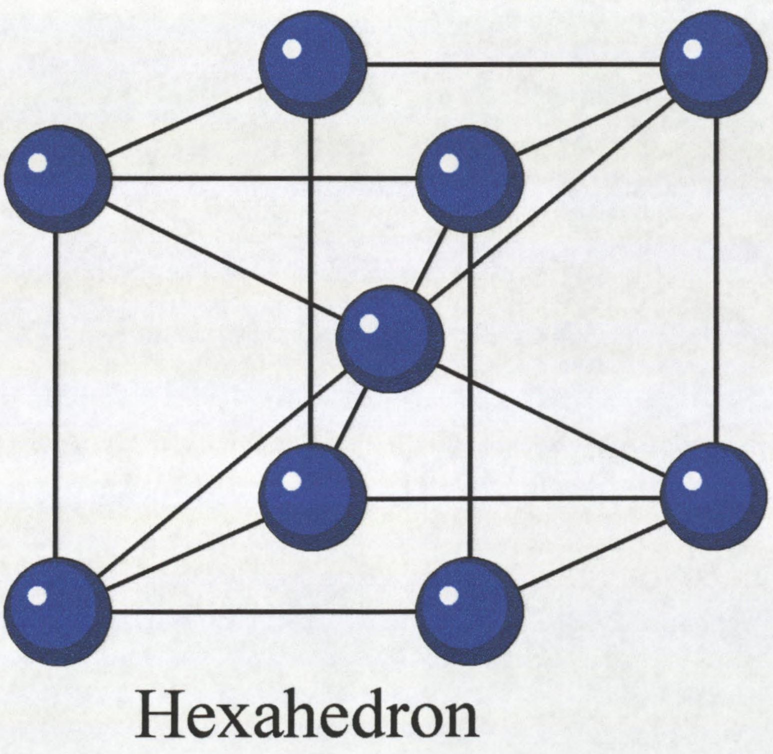


Figure 10

Octahedron

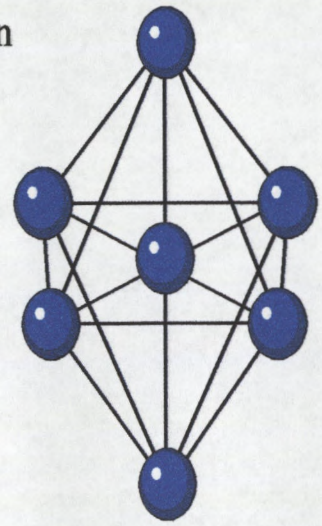
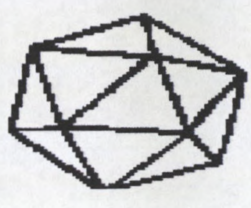


Figure 11

Icosahedron



Dodecahedron

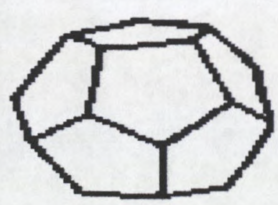


Figure 12 & 13

The table below shows the relationship between our five polyhedra in terms of the number of faces, edges and verteces. As can be seen from the table, the hexahedron and the octahedron have the same number of edges; therefore the number of their vertexes correspond to the faces of the other. The same applies to the dodecahedron and the icosahedron. This relationship is called *duality* (Kahn 1971)

Polyhedron	No. of Faces	No. of Edges	No. of Vertices
Tetrahedron	4	6	4
Hexahedron	6	12	8
Octahedron	8	12	6
Dodecahedron	12	30	20
Icosahedron	20	30	12

Table 2.1

Examples of duals

The hexahedron and the octahedron are therefore duals, as are the icosahedron and the dodecahedron. The tetrahedron is a dual of its own. The icosahedron is the one that closely resembles the sphere, and some who have built domes have started with the icosahedron.

2.5.3 Spherical Geometry

The first thing to be understood on the division of geodesic spheres is the face of the triangle and the subdivision thereof into smaller triangles which gives us the frequency breakdown of a particular face (Popko 1968). The face is composed of struts which come in different lengths, and the face is divided into triangles in the breakdown for the particular frequency of the dome. The angle made between the faces is called the face angle. From the sides of the faces which are struts or chord lengths, and knowing the central angle, the chord factors can be calculated (Sheppard *et al.* 1974). Chord factors are a set of constants for each strut length which can be used to calculate the diameter of the sphere being dealt with. Therefore, if we know the radius of a sphere, we can determine our strut lengths from the corresponding chord factors. This can be easily demonstrated by the diagrams below;

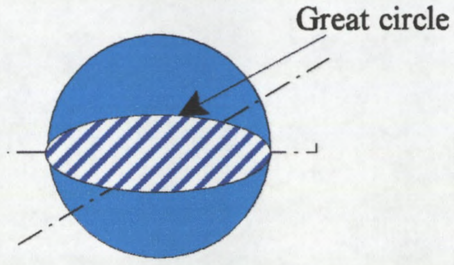
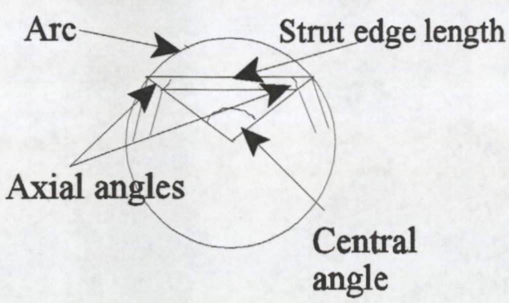


Figure 14 : Great Circle



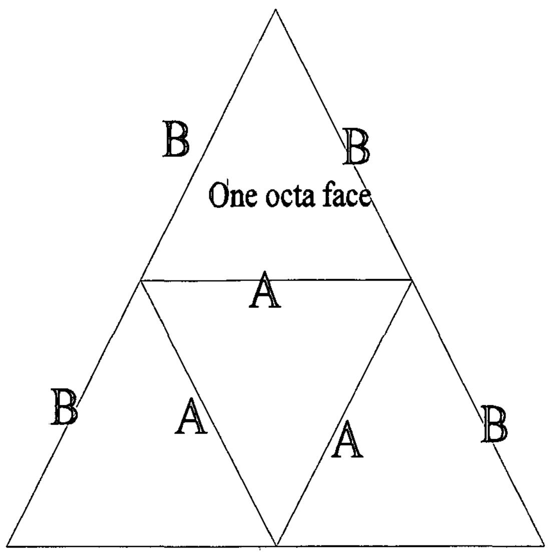


Figure 15 : *An example of a 2v octa alternate breakdown.*

Great circle, axial angles and edge length

Axial angles are the angles that the strut ends make with the centre of the sphere and are useful in hub design (Kahn 1973). To find these angles the following formula is used:

Axial angle = (180^0 - central angle) / 2

Dihedral angles are the angles subtended between the triangles, and their calculations are quite complex. Most of this is already calculated for you in designs that have already been dealt with.

This $2V$ frequency breakdown shows that the face triangle can be divided into a specific frequency. The above breakdown can further be made $4V$ frequency alternate breakdown by subdividing the triangle into half. These frequency breakdowns make it possible for any dome builder to be able to make the framework and panels as accurately as possible.

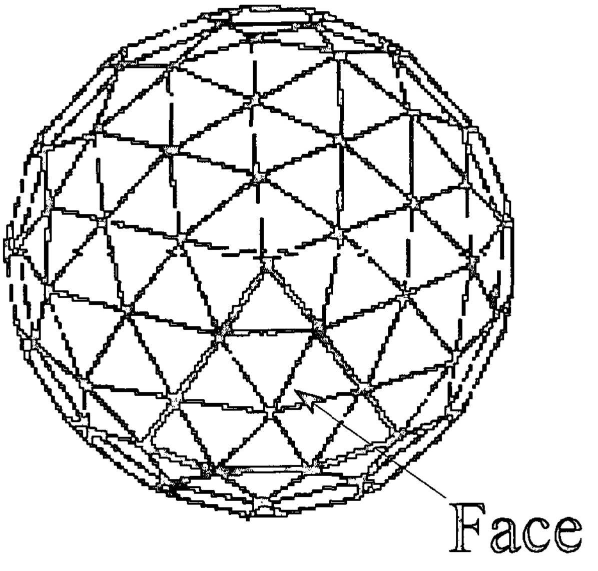


Figure 16

Fuller discovered first that there are thirty-one great circle planes produced by different rotations of the icosahedron. Looking at the diagrams below, it becomes clear why spherical structures are divided into triangles, because the great circles, on being rotated at different axes, cut one another to form triangles (Bauer 1971, Popko 1968).

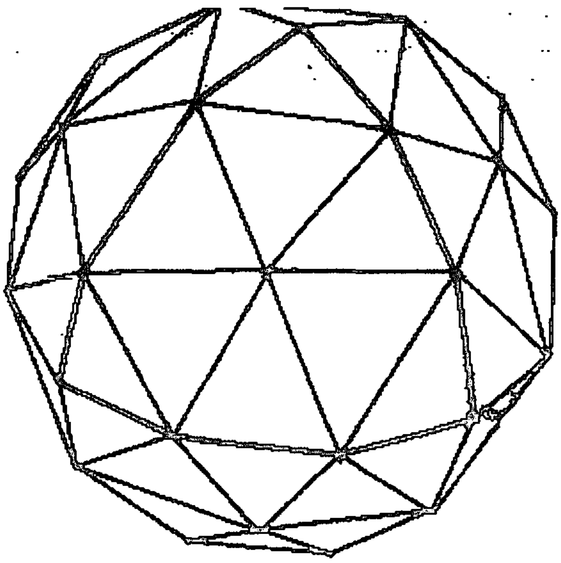


Figure 17

Typical icosahedron showing the subdivision into triangles.

Fuller further used spherical trigonometry to calculate the chord factors and angles of the spherical triangles which are made of arcs on the surface of a sphere. The angles of a spherical triangle are more than 180 degrees and not more than 540 degrees because of the three separate arcs which form the spherical triangle (Waizenegger 1983).

From the above it will be noticed that you can subdivide the sphere into triangles which can give all sorts of shapes and different orientation. Enthusiasts of geodesic domes and spheres can start right here and build on to create other kinds of structures. There is no limitation in the study of geodesics as they comprise a variety of shapes - there is no beginning and no end (Kahn 1973).

CHAPTER 3

3. GEODESIC HOUSING IN SOUTH AFRICA

3.1 History

As with the rest of the world, South Africans have successfully provided shelter for themselves by using materials and resources from their immediate vicinities (Briggs 1991). This is evidenced by the way in which Africans dealt with housing in their environments. Their structures were cylindrical, spherical and conical-shaped houses which lasted many decades without failing to provide warmth and security. Some of these early structures are still in use (Hammond-Tooke 1993). Although they look primitive to the eyes of many today, those houses had more meaning and life to them than one might imagine.

The idea of bringing them back into wider usage in a modern form may be supported by the design and manufacturing of prefabricated materials, for mass production. The study of platonic solids may well prove to be of great value in this process.

> "In all pre-industrial societies the shape of the villages, buildings, and artifacts represents a microcosm of the universe as they see it. Every building is a model of the structure of man and of the universe. We have lost this understanding; our life-styles are no longer in phase with natural rhythms. We don't know how, but domes may be relevant to a rediscovery." (Sheppard *et al.* 1974)

Richard Buckminster Fuller has done very well in coming up with a method of constructing a spherical surface by subdividing it into triangles and translating these geodesic principles into structures that can be built (Kenner 1973, Popko 1968).

The triangle being the only structural configuration which exhibits rigidity makes the geodesic dome the strongest, lightest and most efficient building of all systems. We did not have these in South Africa, but we had domes way back, even though they were not subdivided into triangles. So we had domes but not geodesic domes.

Fuller travelled all over the world visiting students from different universities, not forgetting his visit to the University of Natal in South Africa, where students at the time were involved in building a geodesic dome on campus. According to one ex-student at the time, it is clear that he had a wonderful experience, although their geodesic dome was not one of the best (Raelton 1955).

Large amounts of knowledge, mostly theoretical, have been generated in geodesics over the past 50 years. The USA presently leads in the development of low-cost geodesic houses, which they call *dome homes* (INTERNET 1995). There are at least twelve companies in the USA which specialize in dome homes, not all of which are fully geodesic.

Geodesic constructions is a generic term for a huge range of geometrical shapes consisting, generally, of planar panels which are tangential to some hypothetical sphere, or ellipsoid. An alternative definition of geodesic requires that the vertices of the construction meet at the spherical surface, and is basically the shortest distance between two points on a sphere (Macgregor 1981, Popko 1968, Kahn 1973).

As for Africans in the RSA, the Zulus and Xhosas are among those closest to achieving a truly spherical shape in their domes *(indlu)* (Waizenegger 1983).

The art and skill that go with the construction of the domes is quite exceptional and, as can be seen below, the meshing of framework members which allow themselves to be bent in circular forms is well constructed and netted to allow stability in the compressive and other directional stresses.

Although many blacks from the RSA could not read and write, they were perfectly capable of working out that the best shape to withstand a lot of external forces with ease, be durable enough to provide shelter for their families and give them enough space and

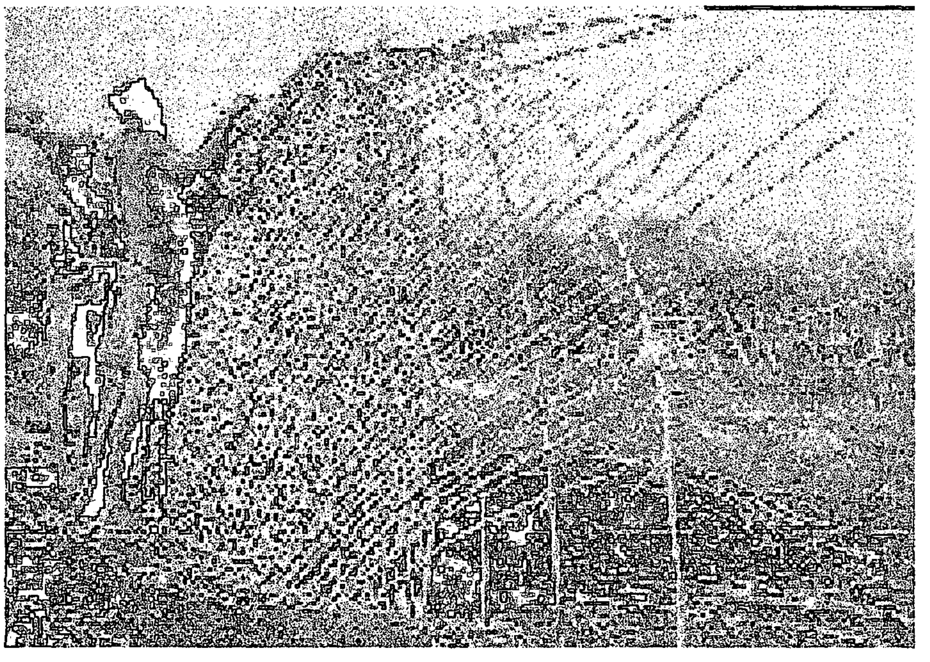


Figure 18: *The Zulu dome (indlu) under construction (KwaZulu-Natal)*

comfort, was the dome shape with its everlasting appeal.

3.2 Advances

Based on literature survey on geodesics in the RSA it has been found that only one ex-student has fully built a prototype dome of the icosa family to this day as part of the fulfilment for the requirements of his Master of Science Degree in Building Management at the University of Cape Town (Waizenegger 1983).

The title of his thesis is : "A techno-economic evaluation of the geodesic as a possible form of low-income house in Southern Africa".

In his analysis he has researched the theories of the breakdown in spherical geometry with basically the icosahedron and octahedron families. He built all the triangle framework and panelling for the icosahedron which is one type of a triangle that makes up the whole dome. This type of design is the closest you can get to a truly geodesic sphere (Kahn 1973). His prototype, as seen in the Botanic gardens in Cape Town, RSA, is as shown below (Waizenegger 1983).

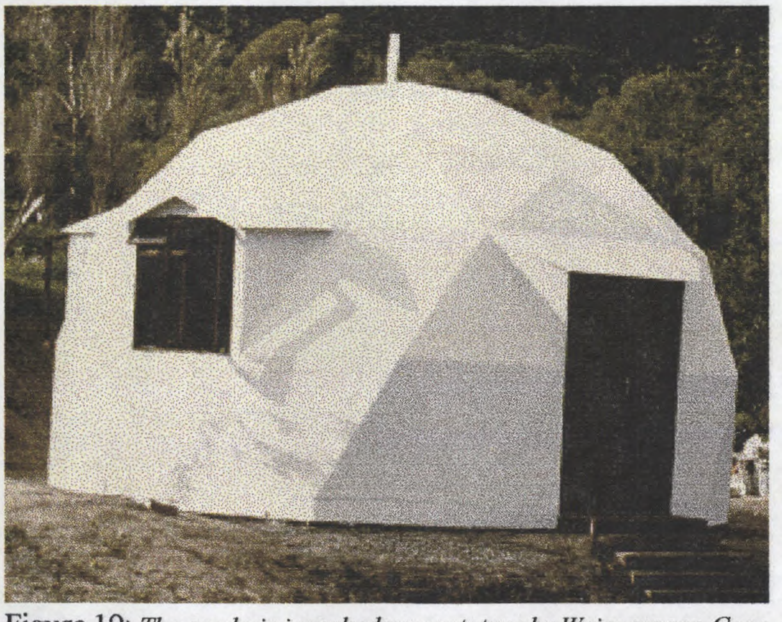


Figure 19: *The geodesic icosahedron prototype by Waizenegger, Cape Town, RSA.*

Recently (1996), there is one icosahedron geodesic structure under construction by the Natal Parks Board (NPA) in Mitchell Park (Morningside suburb), Durban, RSA.

The project carried out by Waizenegger (1983) was only to evaluate the geodesic icosahedron as a affordable form for low-income housing, a design that is known and has been built successfully world-wide (p16). In all geodesic constructions, the icosahedron is the beginners choice as it is the core design that Buckminister Fuller started to identify geodesics by subdividing the sphere. It is also the construction that is closest to a sphere (Kenner 1973, Kahn 1971, Popko 1968).

If the Waizenegger project was followed up and fully supported by companies and more units have been built, it will have by now brought an understanding amongst some communities in the RSA. The evaluation, has indicated that the geodesic construction is a viable option in terms of costs as a low-income housing option. The project was not pursued further to mass-produce for instance or marketed to the larger South African communities, although the parameters for the project were covered successfully (Waizenegger 1983).

There is a lot of interest in geodesic constructions in the RSA which only needs some stimulation by way of awareness programs in order to jumpstart some real activity in changing the way people house themselves. Previous research into geodesic constructions has not been linked to implementation.

However, this developmental project goes beyond the boundaries of researching the topic and engages in designing and implementing the design for community use and development. And this will not be the end of this project, for it is hoped that it will help stimulate other ideas around this design, and that other designs will be devised by others.

It should be noted, with respect, that geodesics are part of the African heritage, and that by way of this project the author is reinforcing and developing concepts that were there within the African culture, although they neither researched nor recorded in a way contemporary academic practices would understand or even acknowledge. The development of this research project will also be to acknowledge the role modernisation would play in preserving this cultural heritage while enhancing it with modern gadgets because it has been accepted that the world we aspire to live in, is indeed a modern one.

CHAPTER 4

DESIGN AND CONSTRUCTION OF THE PROTOTYPE

4.1 Introduction

After a lot of paper modelling, making different geodesic dome designs, the most acceptable and appealing shape found was the semi-geodesic one. This was so because this design conformed to the first criteria of extension, to which the designer was bound in the beginning of the project.

The final product and design are based on the octahedron which has the following useful characteristics :

- natural equator at all frequencies;
- vertical slicing line at all frequencies, allowing a half dome to be joined to a rectangular structure;
- simple generation of non-spherical contours;
- relatively simple computations;
- provision for square openings, either one at the zenith or by rotation;
- has right-angled triangles at its principal vertices; and
- equal edge length.

4.2 Design details

It is a 2V alternate truncated semi-geodesic housing unit which has the features based on our first requirements of the design, i.e. uniformity of components for ease of manufacture and extendability while not neglecting rigidity and the weatherproofing of the housing unit.

The design comprises three main shapes namely: *hexagons, pentagons and squares.* These can be divided into smaller triangles to satisfy the geodesic pattern for geodesic domes, although this is not easily visible at first sight. That route has not been followed because the approach is mostly based on mass pre-fabrication with jigs in an industrial environment, while minimising the number of component panels that can be joined together with ease.

The hexagon has been divided into two parts of half-hexagons and therefore to build one unit, as you require four hexagons, you must have eight half-hexagons. The pentagon is divided into a rectangle for the bottom part and a right-angled triangle for the top part, which also forms part of the window where required.

Four pentagons are required to complete one housing unit. The square has not been divided at all, and a total number of five square panels are required for one unit: four at the bottom part forming the wall, and one for the roof part of the unit. The top square which forms part of the roof is done differently in that it has to have one side elevated to allow water to run off easily when it rains. Drawings for the three polygons are as shown below:

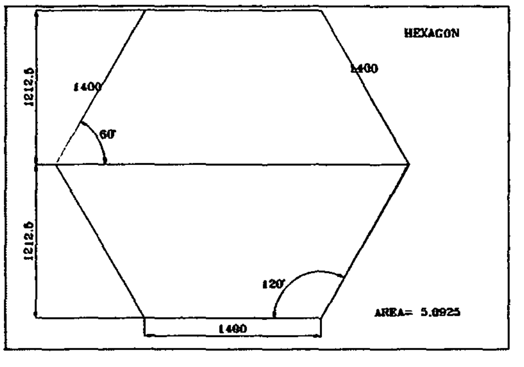


Figure 20: *Hexagon*

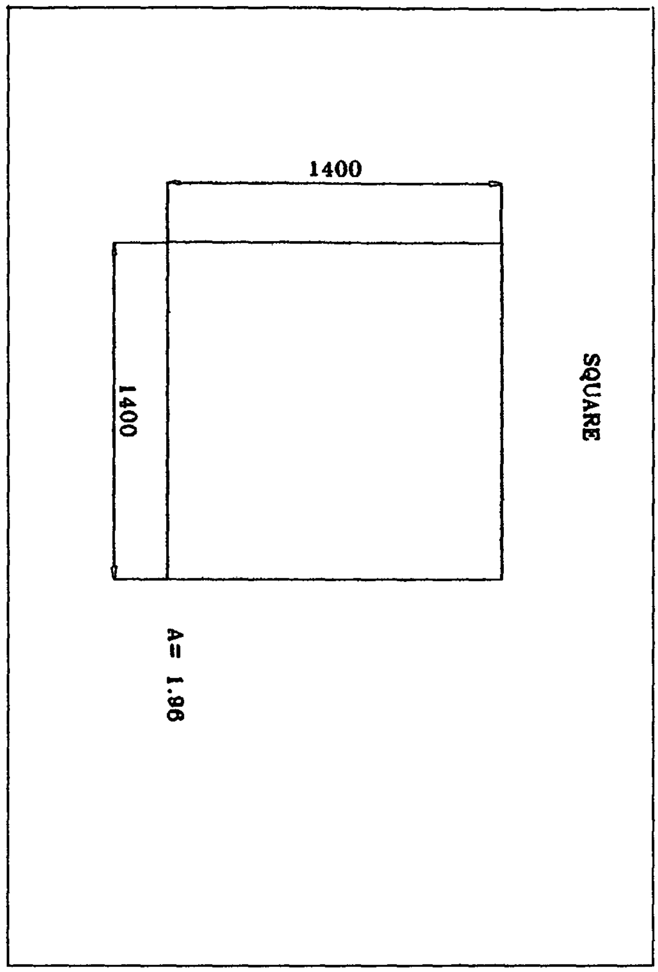


Figure 21: *Square*

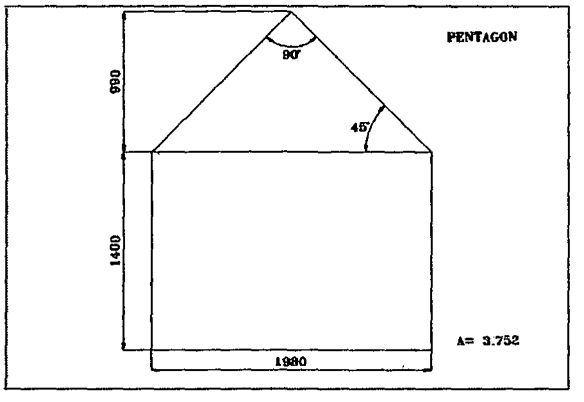


Figure 22: *Pentagon*

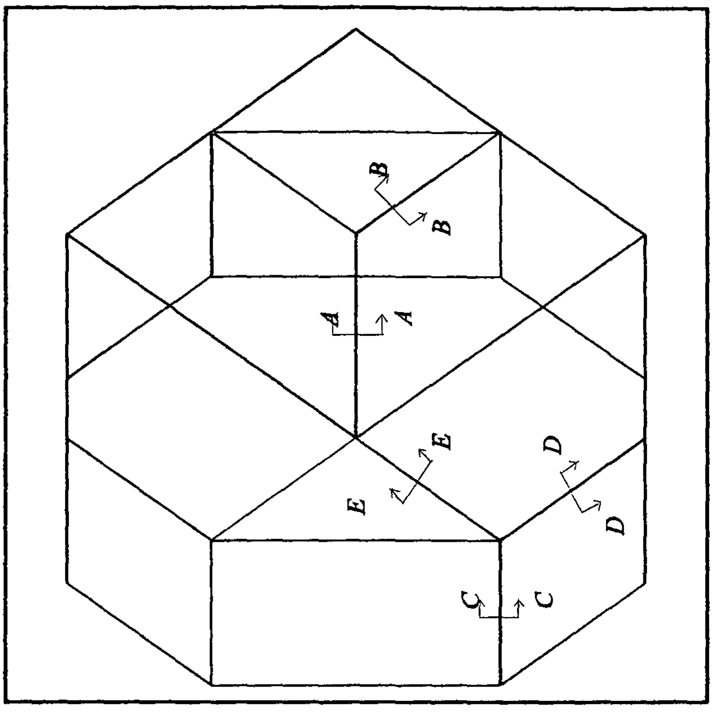


Figure 23: *3-D view of the framework of the housing unit.*

By joining the above components as indicated in the following paragraphs, we end up with the prototype. All illustrations pointed out in the following paragraphs are to be linked together with appendix 1 & 2 drawings and photographs of the prototype and models. Looking at the drawing of the housing unit in 3-D above , with the sections A, B, C, D & E, the coming together of the panels at their respective angles is clearly indicated. How these have been dealt with is indicated in the framework section below.

4.3 The foundation

The foundation can be prepared in any shape, whether circular, rectangular or octagonal, as long as it covers the floor area required for the dome. But for a saving to be made, it will be beneficial to make a foundation that will cover the floor area in the octagonal fashion. The foundation edges must be dug well to cover a depth of 200mm and width of 200mm (NBRI 1987), while a minimum of a 75 mm thick concrete surface bed with a 25 mm thick screed are to be maintained throughout. The mixing of the concrete, sand, cement and water is to be strictly according to the required specification (SABS 0161 - 1980). A drainage system for rain water, as there are no gables, will not be considered at this stage.

This will require measuring the area first and digging and preparing for the foundation. When concrete is being poured, there will be anchor bolts which need to cast 250mm into the foundation if required, and jigs in this instance will have to be prefabricated in accordance with the foundation drawings. This jigs will be made to assist in casting the anchor bolts accurately. Anchor bolts will come in an "L" shape and M8 in size.

A foundation can be done without the anchor bolts, and therefore holes will be drilled onto the foundation and the bottom squares and pentagons mounted onto the foundation. The second method has been used for the erection of the prototype.

Where required; for instance, with poor, closely-packed soil, it is recommended that BRC steel mesh be laid down to support the foundation, although the housing unit can be erected without a foundation, except for the clearing and levelling of the area, and this can therefore be done at a later stage.

This will give those who are unable to afford a foundation time to arrange funding, although it is not recommended. After the foundation is satisfactorily dry and intact, the squares and pentagons framework can be joined and bolted to the foundation. The foundation for the prototype on campus was laid down with the help of the Buildings and Maintenance division of Technikon Natal under the leadership of foreman and the supervision of the author. The quality of workmanship on the foundation for the prototype is available for inspection at Technikon Natal, Berea campus.

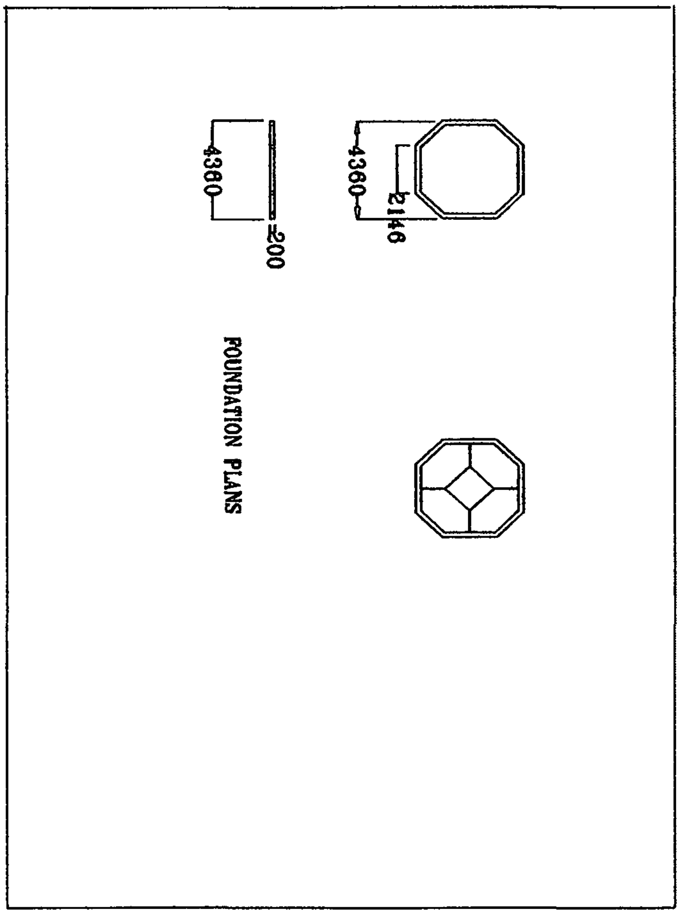


Figure 24: *Foundation plan*

4.4 The framework construction

4.4.1 Model joints and links design

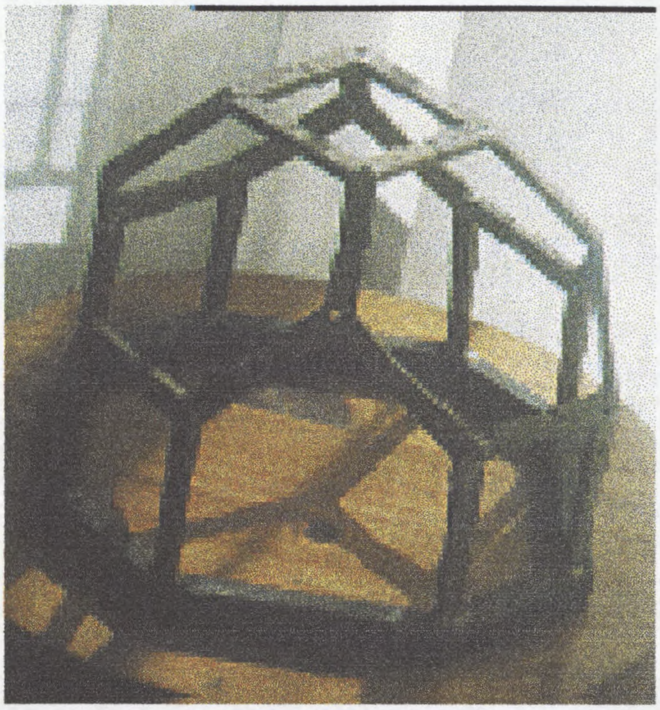


Figure 25: *Interlocking model made of brass square tubing hubs and struts*

The idea at first was to find a suitable framework which would comprise hubs (joints) and struts (links) connectable in such a way that they would lock easily. A smaller model was built by author using brass square tubing of two sizes that fitted well together and drilled holes for locking the links and hubs together (Kahn 1971). The model is as seen above.

Experience has shown that it would be very difficult, if not impossible, to mass-produce these hub joints using jigs and welding them accurately at the correct angles (Barry 1993). The jig for the model parts was also very difficult to make and therefore was going to cost more. The only other way possible for mass production would be to use casting, which was avoided at the time owing to the enormous amount of money required for the dies and the testing of the prototypes (Timmings 1992). It's a possibility that could have worked, but another concern was that this method would not meet one of the most important criteria, that of extension.

4.4.2 Model channel framework design

Having to make do with little funds, looking at alternatives, and after a lot of analysis, the final acceptable design was the method of dividing the dihedral angles in such a way that they share the same line of action using channel sections bent to the correct angles. Dihedral angles are angles between polyhedral faces of a polyhedron, i.e. internal angles between two faces that share the same edge. In this case when you look at the 3-D view drawing, the sections are there to help in differentiating the faces that come together at different dihedral angles.

There are four different dihedral angles between the faces that make up the housing unit in this particular design and they are as follows:

- **between the bottom square and the pentagon - 135 degrees**
- **between the bottom square and the hexagon - 144.74 degrees**
- **between the pentagon and the hexagon - 125.26 degrees**
- **between the hexagon and the hexagon - 109.48 degrees**
- **between the hexagon and top square - 125.26 degrees.**

These have been divided into two angles sharing the same line of action while the channels come bent in the half angle so that when they come together they actually form a unit as if they were one link. In other words the two channel sections end up making the required dihedral angle, in a way flushing together perfectly. It is interesting to note that in nature, most combinations of the atomic structures, like H_2O, have the internal angles between the hydrogen and oxygen atoms found to be 109^0. Most polymer atoms also share their atom combinations at 125 degrees as in the case of silicon and hydrogen (Askeland 1990)(Timings 1991).

This actually reinforces the fact that in this particular design, which falls under the category of *flange panel domes*, strong bonds between the framework and the faces of the panels will be achieved, which means a stronger and more stable structure has been found which can best serve the purpose for which it is meant. It further reinforces the arguments which have occurred with Fuller's theories against scientists, engineers and architects in his research and discoveries of geodesics (Kenner 1973).

'Nature has made things which we call natural, and everything else is 'man-made', ergo artificial. But what one learns in chemistry is that Nature wrote all the rule of structuring; man does not invent chemical structuring rules; he only discovers rules.' (Meller 1970).

The model which the author built based on the above principles is shown below:

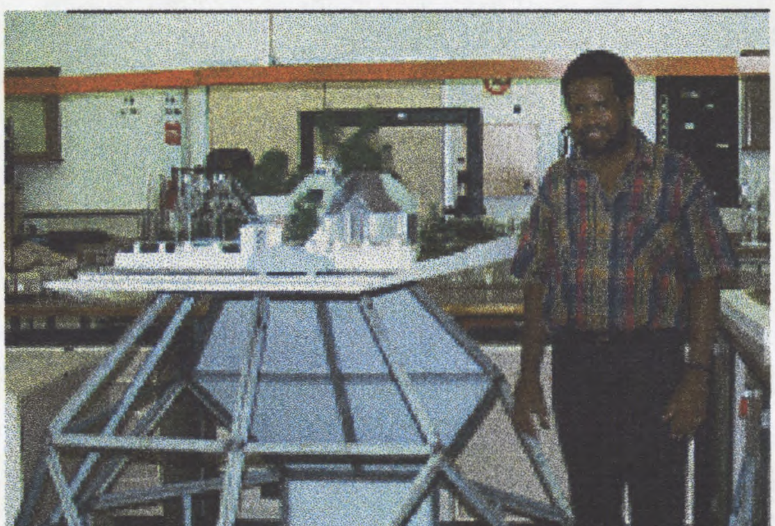


Figure 26: *One-third of the prototype which has gone missing at the Berea campus, Technikon Natal, Durban, RSA.*

The approach of building a model or unit in the manner of using channels lying in the same line of action while sharing the same dihedral angles is the author's own discovery in the geodesic field which, it is hoped will be used and applied in other fields and designs.

4.4.3 Paper model design variations

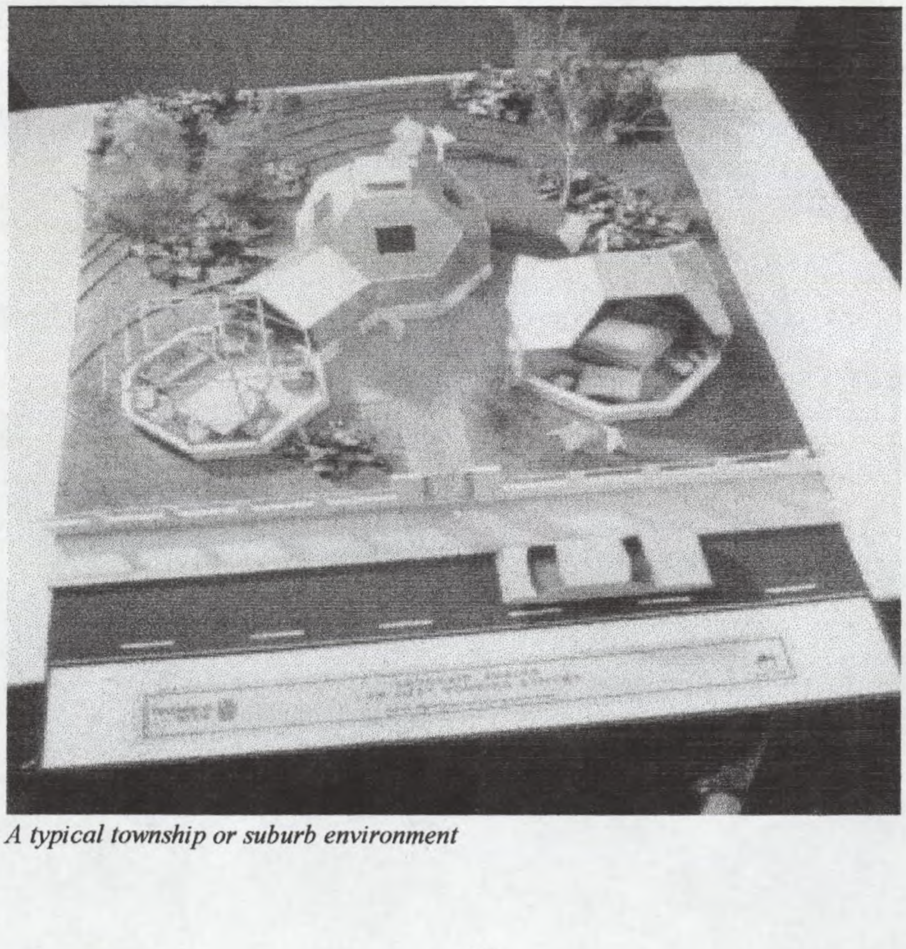
This is where it all started, cutting out the polygons and bringing them together and looking at the various designs. Various models indicating a few variations were built by the author. After proving that the chosen design is the right one and could be enhanced, the Department of Architecture at Technikon Natal was approached.

The first models made by the author were checked and verified under the geodesic theories and constructions possible. The interesting part of the chosen design was that it was unique on its own, and the idea of exploring on the basis of this very design was supported by Chris Kistrick, a computational geodesic expert from the USA.

Additional models were done with the help of fourth-year Architectural students to show the possibilities of other variations for this design. The author has worked with these students in two groups, and two excellent models which are shown below have been developed.

These was made possible by the author's supervisors who felt strongly that something remarkable could come out of the interaction and involvement of the Architectural students. The models are as shown above and below. These are just a few examples of possibilities of variations which would be suitable for the problems facing the RSA.

A typical village set-up



A typical township or suburb environment

The materials used for making the above models are hard white paper, model sticks, glue and other accessories (Latham & Brooks 1991, Rogers 1993). The whole process which is a very time-consuming exercise took about six afternoons to finish. A lot of interest and enthusiasm have been shown by the Architectural students, and they where delighted to be involved in the project and anxious to see the real prototype.

4.4.4 Chord factor for the design

As indicated earlier in the geodesics chapter, the edge length of the faces of a geodesic sphere or construction can easily be found if the chord factor and the radius of the particular design are known (Kenner 1976, Kahn 1971).

The chord factor (cf) is the number that when multiplied by the desired radius of a spherically approximating shape provides the length of edges of the faces. For the truncated octahedron there is only one chord factor and this is also seen from the fact that all the edges are of equal length (Macgregor 1981)(Popko 1968).

$$cf = 2 \sin (A / 2)$$

Where:

cf - chord factor

A - subtended angle of an edge

The chord factor for our truncated octahedron is:

$cf = 2 \sin (36.869) = \mathbf{0.63245}$

In this particular design it is known that the edge length is 1,4 m

Therefore the radius of the sphere enclosing the truncated octahedron is:

Radius = 1400mm / 0.63245

= 2213,61 mm

Therefore the diameter = 4427,22 mm

This is where the points of the edge lengths meet for this truncated octahedron on the part where it is fully geodesic and these points are in contact with the invisible sphere (Kahn 1971).

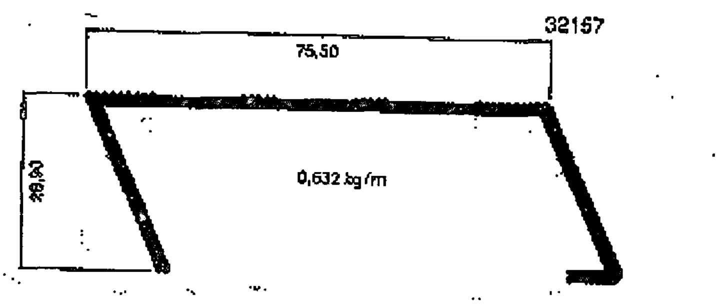
4.4.5 Framework for the prototype

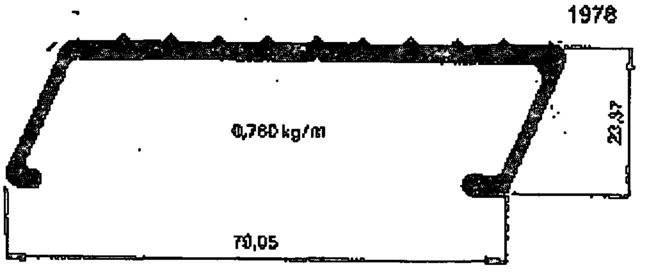
The hypothesis of dihedral angles with the use of mild steel on the model was proved correct as the mild steel could be bent to the correct angles. As aluminium was preferred for the prototype and chosen for reasons mentioned earlier, something that will work from the aluminium industry had to be found (Aluminium Profiles 1985).

The only way to find the channels made of aluminium is to extrude after going through making dies suitable, and this is a very costly exercise. The idea of a simpler design made of the channel-like sections which can be joined together using pieces of aluminium and crimping them together is a much more realistic and possible one. This method is being used in the manufacture of windows and doors and really works (Malan & Paterson 1985). This simplified version can be modified when starting to make dies for the mass production of extrusions at one of the aluminium producers like Huletts Aluminium in Pietermaritzburg, KwàZulu-Natal, RSA (Malan & Paterson 1989, 1992).

For this prototype, something was found from the Hulett Aluminium Products standard and non-standard profiles that will do nearly the same thing as above. The sections found to be usable in this instance are as follows:

- 32157
- 1978
- 16587





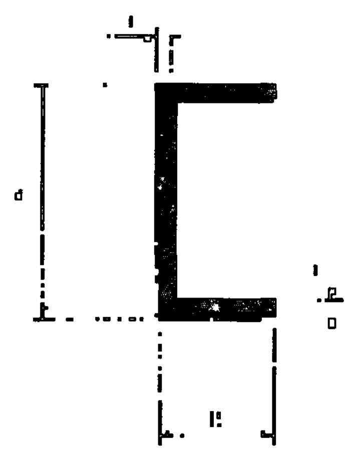


Figure 29: Normal channel section No 16587 - [80 * 35 * 2]
The configurations for the extrusions found from Hulett Aluminium.

Extrusion No 1978 was found to be very difficult to handle, and in the end the author resorted to using the other two sections on almost all the framework members of the prototype.

This was a sacrifice of a lot of small angles in between the framework members as extrusion 32157 has an angle of 63^0. In a situation like that, there is a slight difference of shortage or excess angle formed when two extrusions come together. The author hypothesised that the unit would come up even under these circumstances.

These extrusions are basically used in the ladder industry and are standard profiles. The three different types chosen were supplied and delivered by Huletts Aluminium from Pietermaritzburg, RSA. These were cut to specification, and the edge length that was used on the prototype is 1.4 m.

The profiles are at different angles as well as the mitre cuts, and this makes it a bit difficult and tricky to cut these sections. This is noticeable when you look at the section of the *proposed suitable* in extrusions as shown in appendix F with their different angles. Looking at the sections from the 3-D view we see the sections as follows:

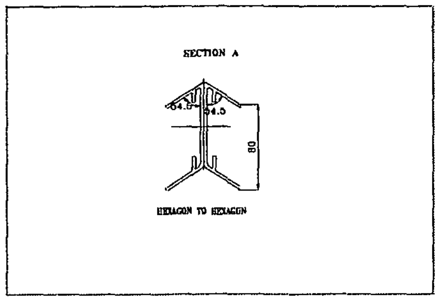


Figure 30

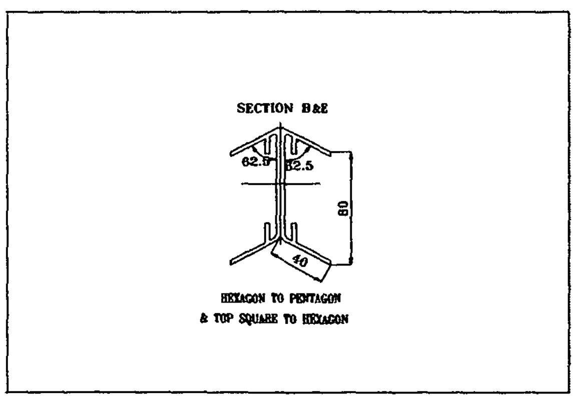


Figure 31

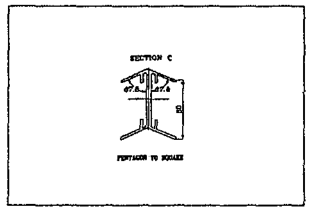
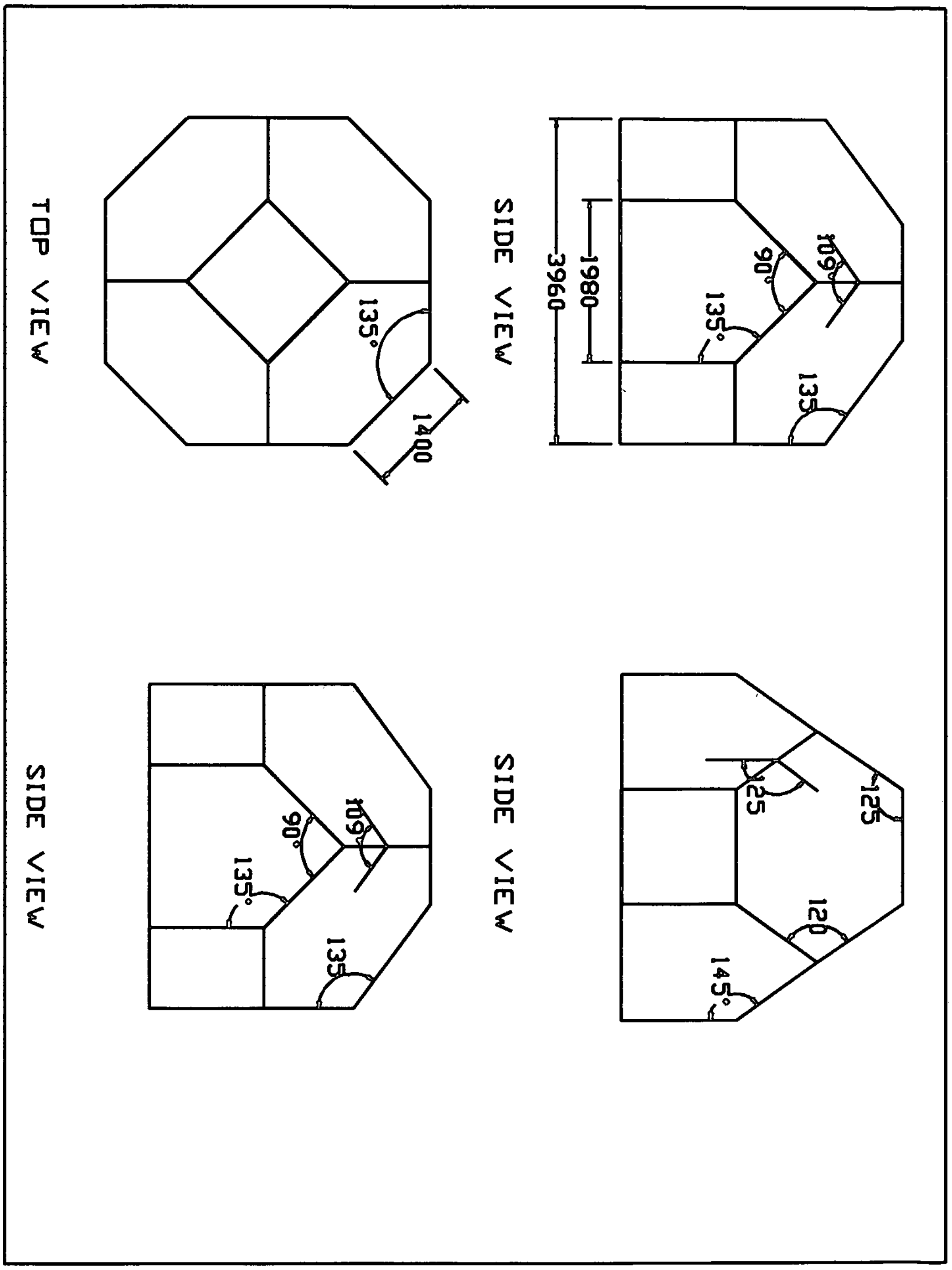


Figure 32


TOP VIEW
SIDE VIEW
SIDE VIEW
SIDE VIEW
3960
1980
1400
135°
109°
90°
135°
135
125
125
120
145°

The extrusions 32157 and 16587 were then welded by Aluweld cc. from Queensmead industrial area, as aluminium welding is a specialized field. This was done with the author's supervision, and the job was well done (Barry 1993)(Jorstad & Rasmussen). The welded framework was transported to the woodwork workshop at Technikon Natal Berea campus.

The panel part was then attached to the framework as explained in the panel section. Welding was done to specification and the framework assembly worked out almost perfectly (Porter 1991). Holes of 8 mm diameter are drilled at a distance of 100 mm from the corners and then at 240 mm intervals for all the 1,4 m edge length, this applies to all side lengths for the squares, hexagons and pentagons.

For hexagons, the half-hexagons normal channel section faces, holes of 8 mm diameter are drilled at 100 mm from the corners and then at 325 mm intervals. The above also applies to the normal channel sections of the top triangle part and bottom rectangle of the pentagon.

For panelling, the same pattern regarding the dimensions of holes to be drilled is followed, although this is done on the inside edge of the extrusions. Two jigs for the edge length and the pentagon width have been made for accuracy, easier handling and time-saving in the drilling of holes (Timings 1993).

These cut and drilled profiles are now ready to be joined and for this prototype, as mentioned earlier, welding has been used. The profiles are welded together so that the panels can now be attached to the framework. The panels are joined and bolted to the framework with a silicon sealant in between, and this satisfies the criterion for sealed, weatherproof panels (Parker 1967). The framework and the sandwich panel therefore make a complete panel to be sent on site for assembly.

4.5 The panels

4.5.1 Sandwich panel theory

At a certain stage in the evolution of technology there were particular requirements on the properties of panels in the aerodynamics field. The main factors really needed were strength with less weight. This led to the development of the honeycomb sandwich panels which are very strong but extremely light (Askeland 1990)(Brydson 1969).

Further development by other developers looking at sandwich panels from a different angle in terms of usage and applications has evolved since then in industries ranging from racing cars and housing, to mention but a couple of examples.

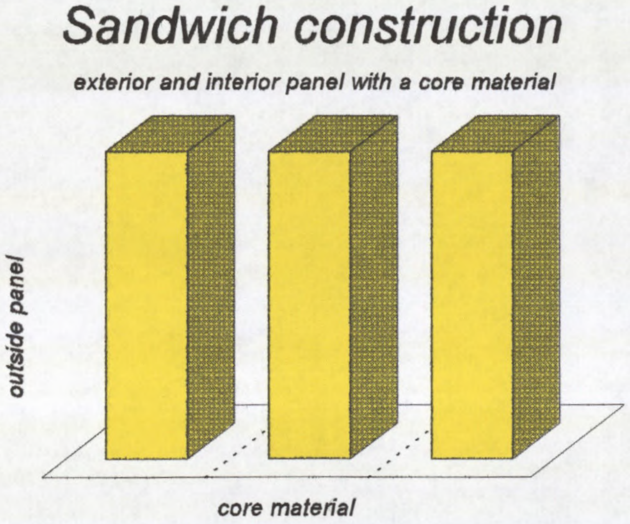


Figure 33: *Sandwich panel*

In other words, a sandwich panel will consist of two layers on the outside and inside, and another material in between the two layers. The idea is to have a strong product with less weight, which brings enormous savings in the cost of the product.

The sandwich panels vary in design. Manufacturing can start with self-adhesion between layers, high-powered compressive action involving big presses (Porter 1991), adhesives bonding, as well as injection moulding, to mention just a few examples (Timings 1992 &1993).

For the sandwich panels that were made, the method of adhesive bonding was used *(Materials Technology Vol 8 1993)*. In this method, the sandwich panels that were made for the prototype on campus differs from those that are already in production by other companies in the RSA.

The sandwich panels produced by other companies in the RSA are as follows:

(i) Glass reinforced concrete used by most companies in low-cost housing.

(ii) Ceramic tiles with honeycombed paper as a core by Wave Paper (RSA) for housing.

(iii) Sagex Ltd (RSA) product, expanded polystyrene as a core with GRC (glass reinforced concrete) also for housing.

(iv) Exterior CCA treated plywood produced by Uniply.(Pty) Ltd.(RSA).

The sandwich panels that have been fabricated for the prototype will be discussed in detail in the following section on material selection. From the above panels, the normal GRC panel was found not to be suitable for use on the prototype housing unit. The other panels were found to be suitable for the design of the housing panels with modifications done to suite the application.

The glass reinforced concrete panel comes in sizes of about 200mm width while the panels for the housing unit were to be less than 100mm width. These GRC panels have been in use for more than thirty years and some structures built in the late 1960's are still intact. The ceramic tiles with honeycombed paper panel has been in use for only two years and is a research product from Wave Paper, Pinetown (RSA).

The GRC from Sagex Ltd, Pinetown, Johannesburg and Cape Town (RSA), is their product developed in-house and has been applied in several houses for the past four years. The exterior CCA treated panels have been used extensively in the Eastern Cape (RSA) for the past six years. This product is manufactured in the Eastern Cape, East London (RSA).

From the above panels which are already in production by the respective manufacturers, the author was impressed by the Wave Paper (RSA) panel which has very interesting characteristics and is very strong. Unfortunately the author did not get the permission from Wavepaper (RSA) to use their panel in the prototype housing unit.

4.5.2 Material selection

In the selection of materials, there was considerable scrutiny to find something reasonably cheap and durable that could perform sufficiently well to meet the criterion for this housing unit. The following materials with their respective manufacturer have been chosen and used in the prototype after considering their characteristic mechanical and physical properties:

- Aluminium - Hulett Aluminium (Pty) Ltd (RSA).
- Fibreglass - Harvey's Fibreglass (RSA).
- Exterior CCA treated plywood - Thesen Uniply (Pty) Ltd (RSA).
- Expanded polystyrene - Sagex (Pty) Ltd (RSA).
- Structabord - Structa Industries (RSA).
- Polyurethane - Silicon Products (RSA).
- Gypsum board - Gypsum Industries (RSA).

The combinations that were looked at regarding the above materials for sandwich panels are as follows:

- exterior treated plywood on the outside layer - expanded polystyrene as the core - gypsum board for the interior layer (for the panels that were forming part of the wall, i.e. the bottom squares and pentagons) - four off;
- exterior treated plywood on the outside layer - structabord polyisocyanate foam as core with the polyethylene fibreglass facing - white aluminium foil strip as the interior layer. (for the panels that were forming part of the wall, i.e. the bottom squares and pentagons) - four off;
- 3 mm fibreglass for outside layer - structabord polyisocyanate foam as core with the polyethylene fibreglass facing - white aluminium foil strip as the interior layer (panels forming the roof, i.e. the hexagons) - four off.

The materials were brought together under pressure by a special glue, the RWL 428 A from Silicon Products, which is suitable for all the chosen materials. The adhesive is applied on both surfaces of materials and left for about 10 to 15 minutes and then brought together under pressure. Heavy flat boards from the workshop were used in the application of the required pressure until the sandwich panels were formed.

The process was a lengthy, time-consuming exercise, but at the end of the day was worth it. The panels that have been manufactured are still in a very good condition to date, and the anticipated durability for the housing unit has been achieved. The above choice of materials was done to find the most suitable panel for the unit from available and reasonably cheap materials. The strength of the combination of materials chosen, and the applicability of these combinations according to the criterion, have been proved a success by the prototype as seen on the Berea campus. Further research in this area is still required to enhance the design and the units to perform and look their best.

4.5.3 Thermal analysis

Thermal conductivity of a material determines its most sensitive characteristics and properties (American Society of Metals 1988, Schaffer, Saxena, Antolovich, Sanders & Warner 1995). Consideration is always taken from the natural perspective of weather. When it is too hot in buildings, the effects can be very detrimental and may cause sickness and even death. A table giving the characteristics of heat conduction is shown below:

Material	% Thermal efficiency	Coefficient of thermal conduction (W/m^2k)	Water absorption % per volume
Aluminium	>95	0.5	0
EPA- polystyrene	96.3	0.034	4
structabord	95.9	0.5 -0.85	Less than 4
plywood	-	0.38	12
fibreglass	96.8	0.65 - 1.00	0
gypsum board	-	0.65 - 1.00	>28
polyurethane	95	0.023	0,3

Table 4.1

From the selection of materials it will be noted that the thermal characteristics of these materials are good and acceptable. All the materials have been chosen in terms of the criteria laid down in the introductory chapter and the availability factor of products produced in the RSA. Thermal analysis plays an important role in determining the insulation capabilities of a material which is caused by its atomic arrangement (Askeland 1990, Schaffer *et al.* 1995).

4.5.4 Special panels

In this housing unit we have two special panels which are not produced in the same way in terms of the special cuts and mitre cuts for the extrusions and panel materials and special jigs.

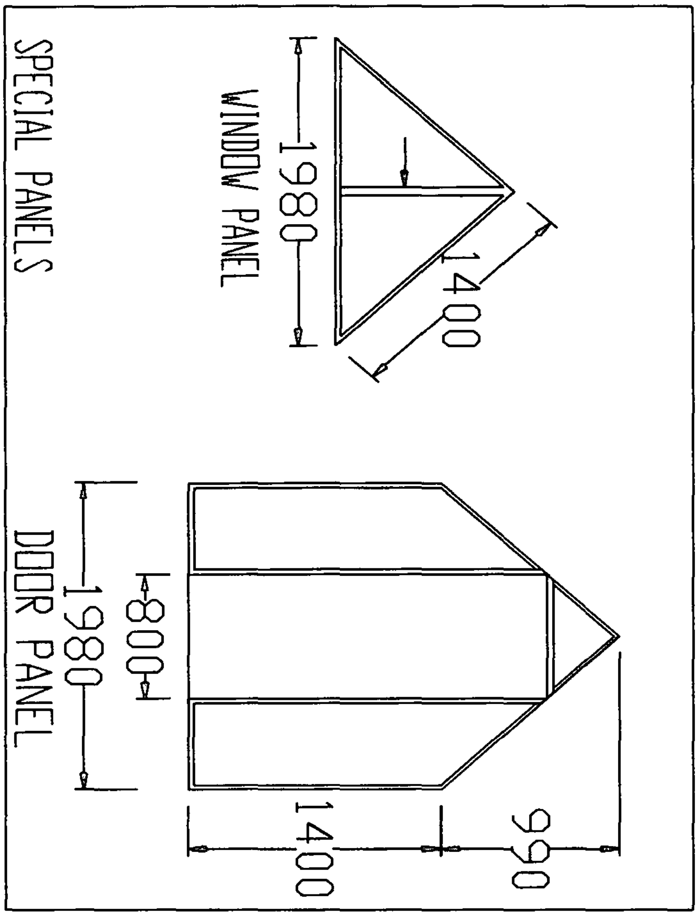


Figure 34: *Special panels*

The two panels are the triangular section of the pentagon which can be fabricated to accommodate a window or a triangular cover panel, and the complete pentagon fabricated to include an opening for a door (Porter 1991).

These two special panels can be distinguished by being called the door panel and the window panel and are as shown above.

(i) The window panel - This is the top part of the pentagon and is therefore the

triangular part. This was made separately.

- The woodwork workshop personnel assisted in making one window panel under the supervision of the author. It comes as a complete panel and what is required is to fix it onto the triangular framework opening left to complete the pentagon. On this window panels meranti wood was used as the framework and a 4mm glass was fitted to complete the panel.

- The other window panel was made of an aluminium framework by Aluminium Enterprises at their Springfield Park under the author's supervision. This was done free of charge after negotiating with the manager, who has shown interest in the project. Aluminum extrusions for making normal windows were used. The difficulty of not having a jig for this type of window especially for the mitre cuts and hinges was overcome by merely being patient. A 4mm glass was also used to complete the window panel.

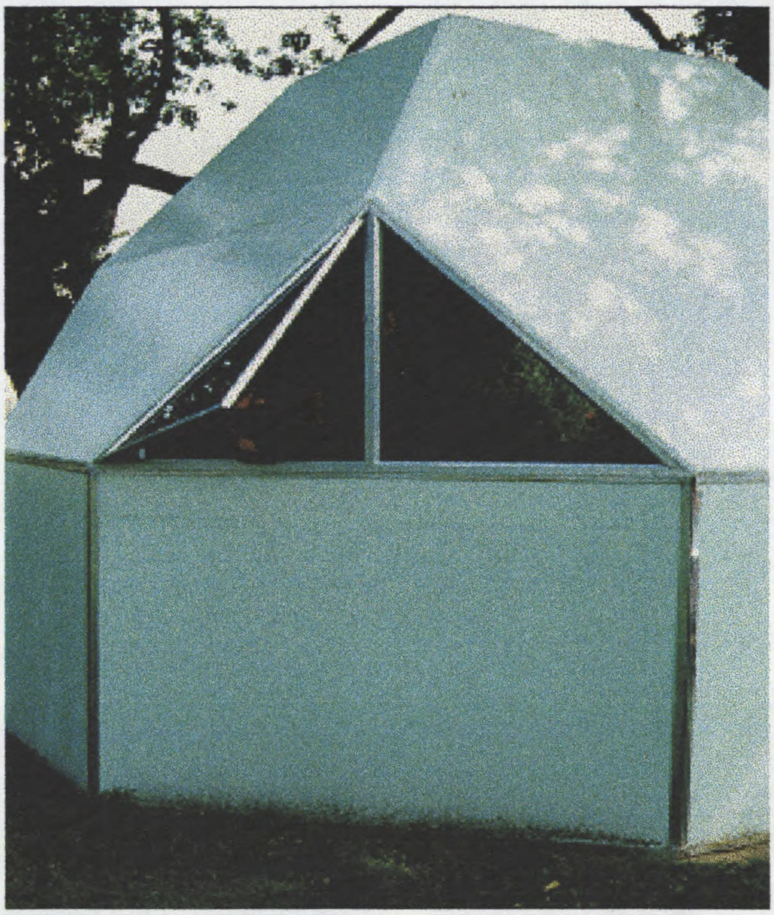


Figure 35: *Side showing the aluminium window*

(ii) The door panel

One of the pentagon sides is taken up by the door panel, and the framework is made of aluminium providing for a 800 * 2000 door for entrance. The framework of the pentagon with a door frame inserted has been welded together and then covering panels done in the workshop. The door frame panelling was made of aluminium extrusions for doors ordered from Pelikan Systems (Pelikan Catalogue).

4.6 The roof

A house is completed when it has a roof and that is why most people talk about having a roof over their heads, meaning: “I have a house to live in”. In this design there is also a roof , which completes the housing unit in a totally unique manner.

The roof is comprises four hexagons together with the top square. The hexagons have been divided into two halves in order to strengthen them. This led to the opportunity to take the point in the middle or the centre line of the hexagons when assembled as the *equator*. The division of this roof in such a manner appeals and makes it easier to assemble this way. Another important advantage is that the separating framework serves as a stiffener to ensure that deflection of the hexagon centre panels does not spring to the adjacent joints (Malan & Peterson 1992).

The half hexagons for the upper part of the roof together with the top square can be assembled together as a unit which can be called the "*hood*", because of its appeal. A much lighter material aluminium white-coated polyethylene is used as ceiling and an insulant for the hood which makes it even easier to handle when lifting it into place (Structabord Catalogue). Caution has been taken to avoid leaks on the joint of the hexagon to hexagon by letting the framework material come together perfectly and sealing with silicon. This was also done for the equator joint.

As indicated in the panel section, this roof part comprises the fibreglass on the outside with a polyethylene core and a white coated aluminium foil on the inside. The sealing between the fibreglass and the aluminium framework was done by applying a layer of silicon before they were reverted together. This type of sandwich panel is very light and strong with good thermal properties for insulation.

The top part of the roof (the top square) was completed by joining clear perspex from Maizey Plastics to the aluminium framework with a silicon layer in between for sealing. This was done only for the prototype. Why was perspex chosen? Because this unit was the first prototype into which people could walk, and this allowed them to appreciate its volume and potential. The most important factor to consider for the top panel is that it must be able to cover the adjoining sides of the hexagons coming in contact with the top square so as to avoid any leaks.

The roofing dream has been accomplished by the easy assembly as witnessed in the prototype. The roof is well sealed which also serves to fulfill the criteria of sealing all joints properly. '*PART IV*', which is the implementation stage, has seen the use of galvanised corrugated iron sheets for the roof part, which has a well-proven track record amongst the larger population.

4.7 Sealing the dome

One of the most important criteria for the housing unit was that it must be sealed. After the choice of materials, adhesives consultants from Genkem Ltd and Bob Larson Silicone cc were consulted to find the right adhesives.

The sealing of the housing unit has been considered between the sandwich panels and the framework as well as between the framework joints. This has been done to avoid any leaks that might occur due the changes in weather which involves temperature change, including rain and unexpected storms.

For the sandwich panels to meet the criterion of no leakage, a special glue, the RWL 428 A, from Bob Larson Silicone cc., which is suitable for all the chosen materials was used. The adhesive is applied on both surfaces of materials and left for about 10 to 15 minutes and then brought together under pressure.

Silicon has been used between the exterior treated plywood and aluminium framework and also between fibreglass and aluminium. Polyurethane has been used to seal all joints between the framework which required attention. The whole unit has been painted to give it a good finish with paint from Plascon (Pty) Ltd. The outside was painted with the Velvaglo cucumber colour, while on the inside a white PVA was used.

The prototype housing unit has been well sealed and has now survived three summers with heavy rains in the Kwazulu-Natal region. The unit is still looking good and solid.

4.8 Material Properties

4.8.1 Introduction

In this particular research we will discuss the material properties that have been taken into consideration and tested on the prototype. This will involve the framework which is made of aluminium and the panels which are made from plywood, expanded polystyrene, gypsum board, fibreglass and white coated polyethylene (structabord).

4.8.2 Aluminium alloy 6063 (T6)

For the framework, which carries the whole weight of the structure and has to withstand the outside forces imposed on the structure, the choice for such a material had to be done thoroughly (American Society of Metals 1979). After looking at all the possibilities, aluminium was the most suitable because of its numerous advantages over other materials. Cost, being one of the most important factors, was considered, while not losing site of quality (Malan & Paterson 1989).

Aluminium was chosen for the framework in this particular design because of its many advantages. They are as follows:

- High strength to mass ratio - tensile strength varies from 60 MPa to 580 MPa in alloys.
- Moderate modulus elasticity - as compared to that of steel, aluminium's Young's Modulus is a third that of steel.
- Excellent ductility - can easily be cast, rolled, extruded and forged according to the designer's specification.
- High and low temperature performance - can structurally withstand high

temperatures up to 260 C^0 and will not embrittle or fracture below freezing point.

- Resistance to atmospheric and chemical attack - it does not rust and can withstand chemicals with a pH value between 4,5 and 8,5.
- Durable finishes - a variety of coatings with a lifespan of over 25 years in the worst conditions by anodising, plating or painting.

This type of aluminium alloy is of the family of the 6xxx series and is composed of silicon and magnesium which makes it heat treatable. They are reasonably strong and have good formability, weldability, machinability and corrosion resistance (Malan & Paterson 1985).

Chemical composition and composition limits

Nominal composition: Aluminium - 98%
Magnesium - 0.7%
Silicon - 0.4%

Composition limits: 0.45- 0.90 Mg; 0.20- 0.60 Si
0.35 max. Fe; 0.10 max. Cu;
0.10 max. Mn; 0.10 max. Cr;
0.10 max. Zn; 0.10 max. Ti;
0.05 max. others (each); 0.15 max. others (total)

The rest of the chemical composition is aluminium.

Mechanical properties

Bending strength	: 96 MPa
Axial strength	: 87 MPa
Bearing strength	: 139 MPa
Tensile strength	: 241 MPa

Yield strength	: 214 MPa
Shear strength	: 52 MPa
Fatigue strength	: 69 MPa
Temper	: T6

Mass characteristics

Density	: 2.69 Mg/m^3

Thermal properties

Liquidus temperature	: 655 ^0C
Solidus temperature	: 615 ^0C

Fabrication characteristics

Annealing temperature	: 415 ^0C cooling at 28 /hour
Solution temperature	: 520 ^0C
Machining and welding	: good machinability and excellent weldability

4.8.3 Mechanical properties of the materials forming the panels

Of the materials chosen for the completion of the panel, meaning those panel materials forming part of the sandwich construction, these are already in use and are mass-produced under the governing laws of the RSA and comply with their respective SABS Codes.

- Plywood - it is a CCA (Copper Chrome Arsenite) treated plyood which has a permanent protection against ants, wood borer and dry rot. Also exterior protected against UV-rays. Interior is not waxed meaning it is odourless, lighter (7,3 $Kg.m^{-2}$) and non-sticky, and can therefore be painted. It is produced by Thesen Uniply Ltd who used it for their low-cost housing project (Uniply Catalogue)(Jennings 1995).

- Structabord - a rigid board consisting of polyisocyanate foam core insulant sandwiched between a polyethylene fibreglass facing and a layer of aluminium foil. It has exceptionally good heat and insulation properties. Can adhere to most materials and is one of the most effective if not the best insulator in the RSA for industrial and domestic applications. It is very light weighing only 1,25 $Kg.m^{-2}$ for the 25 mm thickness which has been used for the prototype unit (Strutabord Catalogue 1994).

- Polystyrene - easy to handle and not toxic as can be used for toys. Less density and strength but good insulator and reasonably cheap (Sagex Catalog)(Askeland 1990, Timings 1991).

- Gypsum board - very good for partitioning, but difficult to handle as it is brittle. Does not respond very well to moisture but fairly strong and very heavy (11$Kg.m^{-2}$) (Gypsum Industries Catalog).

- Fibreglass - very high strength coupled with resistance to all kinds of weather. Fair density, therefore lighter (2.3 $Kg.m^{-2}$ for 3mm thickness) and easy to handle. Fibreglass is considerably stronger because its' free from scratches and other surface defects (Timings 1991, Schaffer, Saxena, Antolovich, Sanders & Warner 1995). Can be produced easily if there is a mould (Brydson 1969, Timings 1991).

Their mechanical properties are as follows:

Material	Tensile strength (MPa)	Density ($Mg.m^{-3}$)	Modulus of Elasticity(GPa)
Plywood	35	0.35	8.3
Polystyrene	0.07	0.016	4.5
Structabord	1.92	0.0385	119
fibreglass	$2.5 - 4.6 * 10^3$	2,490	87 - 88

All the above materials have very high tensile strength, except for the expanded polystyrene as it was used as a core material in the construction of the panels as indicated earlier in the chapter. Their Young's Modulus is good considering the use, and their mass characteristics are acceptable as they were looked at from the perspective of being easily transportable.

4.9 Construction Methodology

From the first experience which has been reinforced by the implementation stage, after the fabrication of panels as explained in the early sections, a method of construction which is much easier has been identified as follows:

- First mark on the foundation where the framework of the bottom squares and pentagons is going to be located as can be seen from Appendix A-11, the inner line being the centre point where the framework is supposed to be mounted.

- Bring the squares and pentagons to their respective place and bolt them together. Anchor the panels onto the floor so that they cannot move, and avoid displacement. The special door panel must be placed in the correct position on one side of the pentagon. The panels will direct themselves towards each other in the correct way as they are bolted together.

- First construct the four hexagons from eight half hexagons according to the drawing specification. Construct the roof part by adding the four hexagons side "A" together by bolting all these sides, section "A-A". Add the top part of the roof which is a square, with the joining section being "B-B", and having an elevation to the side for water to run off. For the prototype, which had an aluminium framework, the top part of the roof could be carried only by four powerful men and laid on top of the squares which is section "D-D", to complete the unit. For the implementation units, which had steel framework, about eight men where required to pick up the roof section.
- The window special panels can now be fitted with ease. They are now bolted onto the bottom part of the roof which is actually the bottom part of the hexagons,

namely section “E-E”. The housing unit is now complete.

- The construction of the housing unit, as can be seen from the above explanation, does not require a skilled person. The production of the panels requires only one semi-skilled person who can read a drawing and weld. If jigs are fabricated and provided, an additional unskilled or semi-skilled person would be required to lend a hand in the cutting and fabrication of the panels. Therefore the mass production of these units can be done in even small industries by training the semi-skilled. Mass production can also be achieved in a manufacturing plant as an alternative in future.

CHAPTER 5

WIND LOADING THEORY

5.1 Introduction

The changes in temperature that occur on the earth's surface are caused by heating and cooling by the sun. This causes large-scale air turbulence, and therefore air flows from areas of high to low atmospheric pressure. The earth's rotation on the other hand brings about frictional drag at ground level and the geography with its buildings causes further turbulence. This is just one definition of the wind, but we need to consider the effects of the wind on our structures.

Many structures have been destroyed by intermittent gusting winds. Apart from damage, there may be loss of lives. This is why man using whatever material is at hand has had to design his accommodation in such a way as to avoid such disasters. Although technology did not develop early in African societies, their designs were very strong and could withstand the worst situations. With population growth throughout the world increasing every day, this situation leads to a build-up of shanty houses which are inadequate to withstand wind loads.

Most developed countries have control bodies to regulate the housing scenario, and the same applies to the RSA. The building codes of practice in South Africa consider wind loads an integral part of the design and construction of buildings in this country. These is due to the fact that any structure must be able to withstand the loads imposed on it by the wind which is capable of high pressures which result in huge forces operating on buildings. These come on horizontally and also vertically onto buildings and therefore the shape of the building is of importance in determining the internal and external pressures in relation to the wind flow.

The prediction of maximum wind speed which gives us the magnitudes of the pressures that the structure will come across is an unknown factor as it is very difficult indeed to know the real facts of the weather, as we can see from meteorology. The collection of data is an ongoing process. As nature is very unpredictable at times, the assumptions made can only be substantiated by references to the Weather Bureau stations in all areas across the RSA, which has been subdivided according to terrain categories according to their weather conditions in relation to natural gust wind that occurs in that particular category. The most reliable estimates are from the maximum gust velocity recorded once in different Terrain Categories in, say, 50 years at a height of 10 metres as shown on the table below:

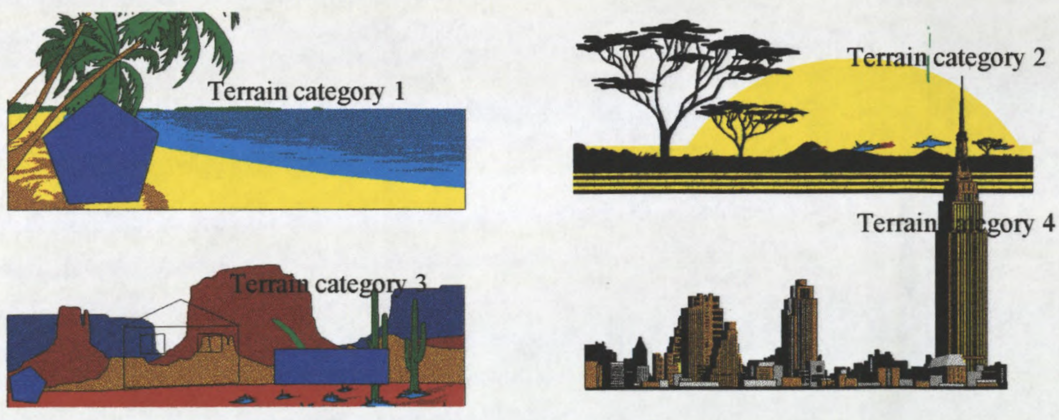
Terrain categories as shown above:

1. *No obstructions, open land or sea.*

2. *Widely spaced obstructions, airfields, outskirts of towns and suburbs and farms.*

3. *Closely spaced obstructions, substantially developed areas.*

4. *Huge, tall closely-spaced obstructions, large cities.*



In order to be able to determine the maximum stress, first find the maximum value of the mean wind speed. Therefore consider this structure as a *stiff* one where wind pressure is proportional to the square of the velocity . The trace of structural deflection is similar to the velocity trace with peaks in deflection and velocity occurring simultaneously. This is a quasi-static behaviour as both load and response vary with time and the mechanism of response is the same as that of static load.

Assuming that this housing unit is quasi-static, the deflection and stress at any point will be the same as if instantaneously the mean wind load has been applied as a static load. It follows that the resulting peak stress can be calculated from a static load. COSMOS calculations and analysis has proved the design a success (Koumatarakis 1994, Voss 1994).

There are many considerations in the structural integrity of a building, and this will be outlined below:

- Degree of safety of the structure - failure of one load-bearing member must not cause failure by collapsing of the building. This can be minimised by design and, in this particular design, the structure will not collapse under these circumstances.

- Structure to withstand horizontal forces - wind loading for this design, these forces can be shared between the elements depending on the stiffness and strength of the structure.

- Traditional structures - they possess an adequate degree of structural integrity and this design is both very close to traditional structure and very modern, with the use of reliable materials. It will be shown in the following sections that this structure has an adequate degree of structural integrity although it is a new and unusual form of construction.

As can be rationalized from the above, the most important section to cover and prove the integrity of the structure is by wind loading. Therefore the focus in the calculations will be mainly on proving the building's structural integrity. The shape that is being dealt with is unique and therefore most of the material for calculations that will be used will have been proved on normal structures. The necessary allowances for unforeseen circumstances will be given the attention they deserve.

The calculations done in the following section are to prove according to the South African Standard Code of Practice for *The general procedure and loadings to be adopted in the design of buildings* (SABS Code 0160 - 1989 as amended 1990) that the housing unit conforms to the standards as set out and will withstand the pressure forces due to wind loading without failure.

5.2 Design Wind Speed

In order to determine the instantaneous mean velocity, the variation in mean wind speed with height is a necessary tool as can be noticed in the formulae below. This contributes to the estimation of the design wind speed. Wind loading calculations are relevant only to extreme wind conditions and it is a known fact that the mean velocity is influenced by the temperature gradient and ground roughness. The simple formulae for finding velocity, external and internal nominal wind pressures are as follows:

$$V_z = k_r * k_z * V \qquad \text{......................(5.1)}$$

$$P_e = k_p (V\, k_r\, k_z)^2\, C_{pe} \qquad \text{......................(5.2)}$$

$P_i = k_p\,(V\,k_r k_z)^2\,C_{pi}$ ....(5.3)

and the force on the building is given by

$F = \Sigma\,(P_e + P_i)\,A$ .... (5.4)

or

$F = C_f q_z A_e$ .... (5.5)

but

$q = k_p\,(V\,k_r\,k_z)^2$ .... (5.6)

therefore

$P_{e\,or\,I} = q\,C_{pe\,or\,pi}$ .... (5.7)

where

V_z = nominal wind speed at a reference height Z

V = regional basic wind (gust) speed, according to the regional location, for a 50 year return period at height 10 m in Terrain Category 2 ($m.s^{-1}$)

Z = height of anemometer measuring V (standard height is 10 m)

P_e = external nominal wind pressure on surface ($N.m^{-2}$)

P_i = internal nominal wind pressure on surface ($N.m^{-2}$)

q_z = free stream velocity pressure (Pa)

k_p = factor for converting wind speed into velocity pressure

= half the air density ($Kg.m^{-2}$)

k_r = factor for adjusting V to other return periods

k_z = factor for converting regional wind speed into nominal wind speed allowing for the variation of wind speed with height, according to terrain category and class or size of building

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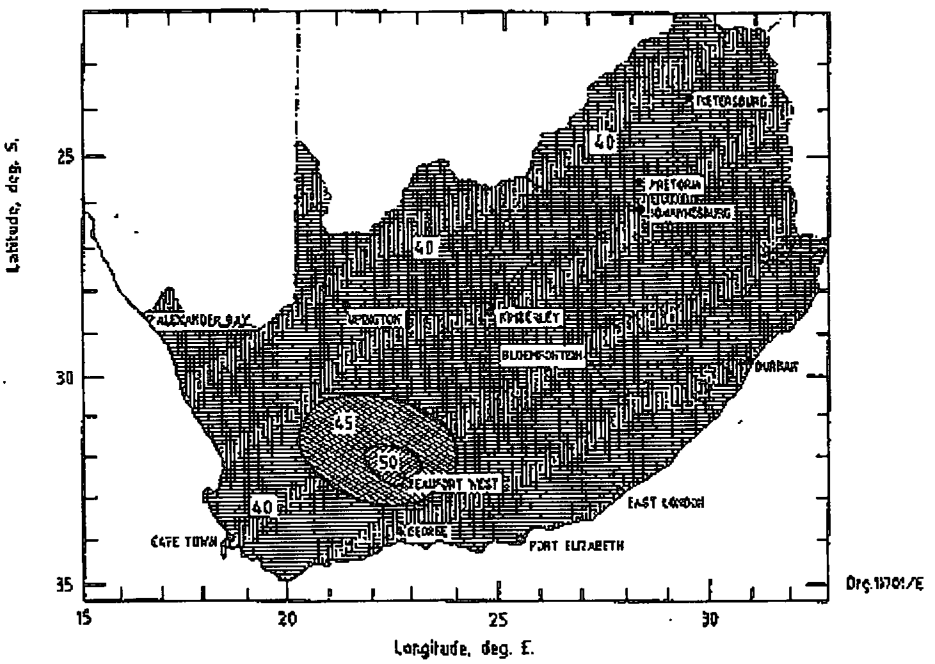

Fig. 3 - Regional Basic Wind Speed V, m/s (Isopleths of 3 Second Gust Speeds at 10 m Height in Terrain of Category 2, Estimated to be Exceeded on Average Only Once in 50 Years)

Table 5.1

The regional basic wind speed V is determined according to its geographical location. Table 5.1 above shows a map with values for V for a 50 year mean return period within the RSA. This has been collected and analysed by the Weather Bureau throughout the RSA wherever there are weather stations. The mean return period for this housing unit will be considered as 25 years as indicated in the nature of building or element table, (SABS 0160- 1989 as amended 1990), considered as a building that will not be hazardous to the lives of people and property in case of failure.

From the above table, the area of KwaZulu-Natal shows that the maximum recorded regional wind speed, which is the regional basic wind speed V, is 40 m.s^{-1}.

Values for k_p for a range of altitude above sea level are as follows:

Site altitude above sea level (m)	k_p (k_p is half the density of air in Kg.m^{-2})
0	0,60
500	0,56
1000	0,53
1500	0,50
2000	0,47

Table 5.2

Looking at the front section of the housing unit, as seen from appendix B1, the variation of characteristic wind speed with terrain , height and class of structure for this housing unit is as follows:

Height Z (m)	Wind speed multiplier k_z *Terrain Category 2* *Class of building A*
up to 5	0,94

Table 5.3

from equation 5.1 it follows that;

V_z = 40 m.s^{-1}* 0,99 * 0,94

= **37,224 m.s^{-1} per reference height Z(m)**

= **37,224 m.s^{-1} per m**

and from equation 5.6 ;

$$q_z = 0{,}53 \text{ Kg.m}^{-2} * (37{,}224 \text{ m.s}^{-1})^2/\text{m}$$

$$= \mathbf{734{,}38 \text{ Kg.m}^{-1}.\text{s}^{-2}}$$

$$= \mathbf{734{,}38 \text{ Pa}}$$

*Assuming the worst possible combination of having a negative external pressure coefficient and a positive internal pressure coefficient, the shape coefficient of **2,0** is used.* Therefore :

$$q_z = 2{,}0 * 734{,}38 \text{ Pa}$$

$$= \mathbf{1468{,}76 \text{ Pa}}$$

This becomes the design wind load for the housing unit.

5.3 Wind pressure force calculations for the housing unit

The faces in our configuration which are directly opposed to the wind flow, and therefore external wind pressures, are the vertically exposed squares and pentagons. While there are external pressures in the housing unit, internal pressures balance out this or contribute to the wreckage of the building. Therefore it must be established whether this particular housing unit will be able to withstand these forces. The effects of the pressure forces will be dealt with in these two orientations. They are:

. the pentagon face; and

. the square face.

To get our pressure forces, equation 5.7 will be used:

$$P_{e\ or\ I} = q * C_{pe\ or\ pi}$$

External pressure coefficients (C_{pe}) will be determined and found using the following ratios:

$Ratio = \dfrac{h}{w}$ (height to width ratio)

and also $Ratio = \dfrac{b}{w}$ (breadth to width ratio)

First calculate the ratios and then from the results of the ratios it will be seen that the corresponding values of external pressure coefficient are found.

For the pentagon face;

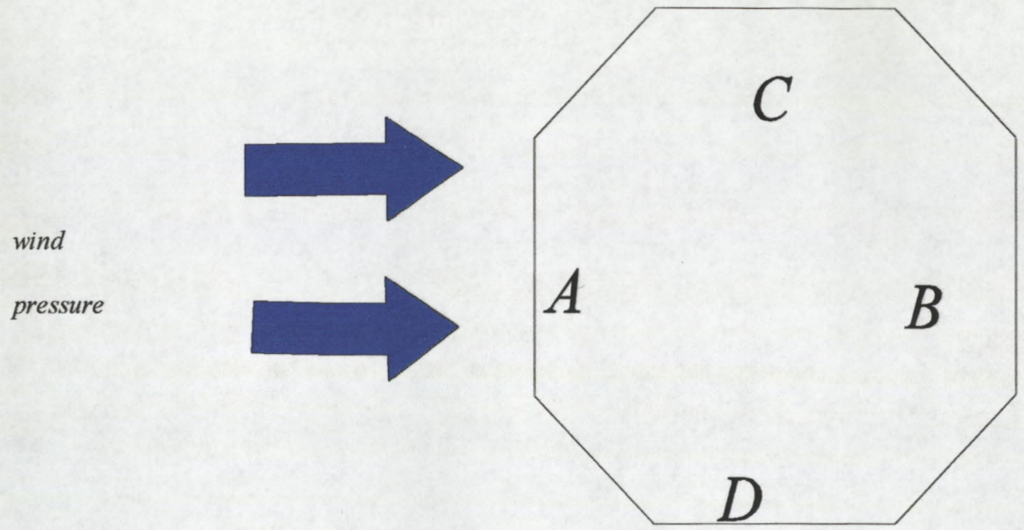

Figure 36 **:***Plan view indicating the wind direction perpendicular to the pentagon face (1.98m width)*

The height of the structure h = 1.4m + 2.424m * sin 54.74

= **3.379m**

The height of the square = **1.4m**

Length of the hexagon across (i.e. where it touches the top square and the bottom square)

= **2.424m**

Angle of the hexagon to the horizontal= **54.74 degrees**

Therefore the Ratio = height/width

= 3,379/3,96

= **0.853**

Also Ratio = width/length

= 3,96/3,96

= 1

Using these ratios, values for C_{pe} can be read from appendix D2.

The external pressure coefficients as read from appendix D2 with reference to the 1.98m pentagon face are:

Surface	Impact	Suction
A	0.7	
B		-0.25
C		-0.6
D		-0.6

Therefore from equation 5,7:

P_e = 0,7 * 1468,76 Pa

= **1028,13 N.m^{-2}**

and

P_i = -0,6 * 1468,76 Pa

= **-881,25 N.m^{-2}**

From equation 5.4;

A = 0,5 * 1,98m *0,99m + 1,98m * 1,4m

$= \quad 0{,}9801\text{m}^2 + 2{,}772\text{m}^2$

$= \quad \mathbf{3{,}752\ m^2}$

$F \quad = \quad (1028{,}13\ \text{N.m}^{-2} + 881{,}25\ \text{N.m}^{-2}) * 3{,}752\ \text{m}^2$

$= \quad 1909{,}38\ \text{N.m}^{-2} * 3{,}752\ \text{m}^2$

$= \quad \mathbf{7164{,}19\ N}$

This is the force on the pentagon face.

For the square face;

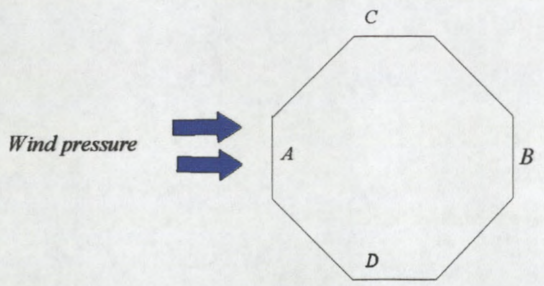

Figure 37 :*Plan view indicating the wind direction perpendicular to the square face (width 1,4 m)*

The ratios are found to be:

$$\text{Ratio} = h/w = 3{,}379/4{,}2 = \mathbf{0{,}8045}$$

also

$$\text{Ratio} = w/l = 4{,}2/4{,}2 = \mathbf{1}$$

Using these ratios we find the C_{pe}'s from appendix 12.4 as follows:

Surface	A	B	C	D
Impact	0.7			
Suction		-0.25	-0.6	-0.6

Table 5.4

Therefore from equation 5.7, still P_e & P_i are:

P_e = **1028,13 N.m^{-2}**

P_i = **-881,25 N.m^{-2}**

From equation 5.4;

A = 1,4m *1,4m

= **1,96 m^2**

Therefore from equation 5.6:

F = 1909,38 N.m^{-2} * 1,96 m^2

= **3742,39 N**

This is the force due to wind loading under normal circumstances on the square.

From the mechanical properties of the materials chosen for the housing unit only the framework material which is aluminium and the plywood for the bottom panels will be considered and are enough to prove their integrity in this building.

The ultimate load, which when applied to the members of the aluminium framework will fail, can be calculated from the tensile strength. For the worst condition this will be taken as acting at a point first of an area of 0,1 * 0,1.

Ultimate Tensile Strength = Breaking Force / Area

$241 * 10^6$ Pa = F / 0,01 m^2

therefore:

F = **2410 kN**

which is higher than the expected force due to wind and other factors.

If, for instance, we chose to take the route of taking the breaking force as uniformly distributed, as is the case when the complete panel is fixed together aluminium and plywood, the breaking force will be much larger considering the materials. The tensile strength for plywood is 35 Mpa and therefore when considering a small portion of 0,01 m^2, on its own plywood will survive because the breaking force will be:

F = **350 kN**

That is why shanty buildings made of plywood are lasting so long in squatter camps. The author has examined many of these shanty structures, including some that have lasted more than ten years.

From the above comparison it is clear that the integrity of this housing unit will conform to the SABS 0160 (As amended 1990) Code of Practice for *The general procedures and loadings in the design of buildings.*

PART IV

CHAPTER 6

FINDINGS

6.1 Introduction

The main objective behind this project after achieving the successful design is to deliver the housing units by mass production of panels to the masses who are in need of housing. That is why it has been looked at from the view of prefabrication in industry which allows for mass production of the panels and faster delivery.

As companies like Hulett Aluminium (Pietermaritzburg) and Alusaf (Richards Bay) have shown interest during the model stages of the design, a follow-up via a report on the progress to date has been compiled and sent to these companies. Response is still being awaited in this regard.

The government Minister of Housing has received a copy and has responded positively by referring the author to the contacts in Local Government for further support for the project.

NGOs (non-governmental organisations) dealing with the communities have been contacted with regard to the further development of the project in the communities and have been very positive. The author, through the NGOs' efforts, has been invited to attend several meetings relating to developments on housing in KwaZulu-Natal.

Technikon Mangosuthu, the institution where the author was employed, has allocated R2000 - 00 for the promotion of the project. Contacts with various organisations that are interested in the housing sector are being established by the author wherever possible.

One of the very few people who gave way to the first implementation project is the Reverent Dr S Khumalo from the Presbyterian Church in Umlazi 'V' section. The implementation of this project will focus on the development of three units which were built for the above church in their Umlazi church yard and are to be used as a creche facility.

6.2 Comparative analysis of results

The relationship between the traditional dome can be easily identified with the likes of the church people who decided to have a similar structure for their creche facility. The comments made about the housing unit's round shape appeal endorses the hypothesis made at the beginning of the project. There are many shapes of housing units to chose from, especially the normal western square shape, but the choice for the creche was the housing unit design.

The method followed of researching and studying geodesic constructions as opposed to the box shape western constructions, designing of the unit and panels, selection of materials and wind load testing, have proved a success as all criteria set at the beginning of the project have been met.

The choice of a geodesic design has also proved to be strong by being able to stand all sorts of loading and wind loading. It is cool inside when it's hot and warm when it's cold. The volume to surface area is almost the same as that of a traditional dome, whilst the normal box shape uses more materials with less volume. Therefore if panels for the housing unit are mass produced, it will cost less materials to build these units.

Preference of aluminium for use on the framework of the panels has not been ruled out where steel has been used. This will require further research with AFSA, Hulett Aluminium, Alusaf and all other interested parties to come up with the necessary extruded sections for the panels. The design is reasonably aesthetic and very strong and durable. The relationship and recognition of the dome, improvement in terms of coming up with a different design of the same family that works has been met. These assumptions have been fulfilled practically by this project.

The prototype has already withstood three summers of heavy rains and the creche has already withstood two summers of heavy rains.

6.3 Project marketing

The use of these channel sections has proved the above theory to be correct as one-third of the prototype model came out perfectly. Although coming up with this model was not the easiest thing, the people who saw it, were interested to see the real prototype.

The presentation to the managers from the aluminium industry has proved to be a success as most of them showed interest in the project. These was done at the Principal's office, Techinkon Natal, Berea campus, in early 1994.

These led to support in the aluminium industry from Alusaf, Huletts Aluminium, and the Aluminum Federation of South Africa. Alusaf supported the Technikon's research to the tune of R50 000-00. Huletts Aluminium in Pietermaritzburg offered the extrusions which were used to build the prototype on campus. They also gave the author a week's orientation in the manufacture and production of aluminium at their Pietermaritzburg branch. The Aluminium Federation of South Africa offered a three-day course on the possibilities of aluminium fabrication and processing at their headquarters in Isando near Johannesburg.

The model which has been used for the above presentation has disappeared from Technikon Natal, Berea campus.

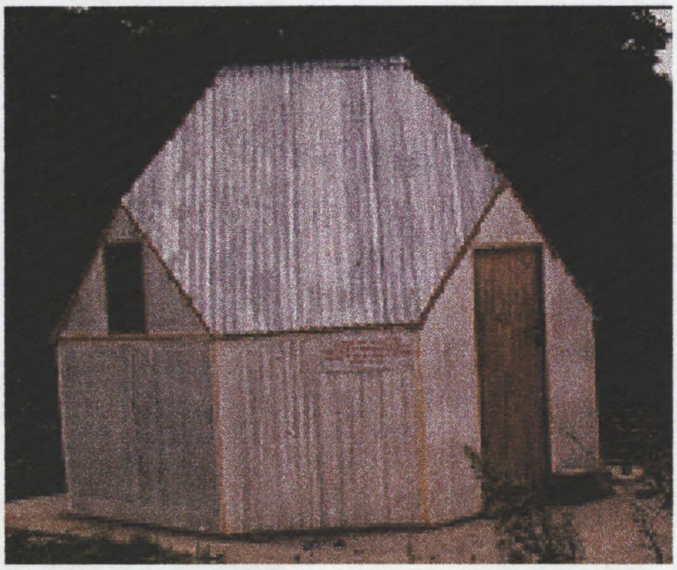

Figure 38 : *Unit built as part of the implementation of the project - Presbyterian Church (Umlazi 1996)*

6.4 The first unit for implementation

The order for three units was made by the church group after they had a look at the prototype on campus. They were very excited about the design and were looking at modifying containers for their creche facility. Although their funding was not finalised at that stage, the Reverent Dr Khumalo did not hesitate to give the go-ahead to start producing the panels.

Mild steel, used by the author in the first model, was the only possible way to go as it could be bent to the required angles for the right profiles. Although this was not galvanised, it has been painted with an aluminium paint to prevent rust.

The specification for the roof was chosen by the church, and they wanted galvanised corrugated sheets as a standard on their units. Plywood was used for the bottom panels, and this first unit was covered inside with the Rhino board as an interior panel. Polyurethane was used as an all-over seal for this first unit. The second and third unit did not require any polyurethane.

Riggings were used to cover the joints where the hexagons meet. The interesting part of the fabrication of panels was on the hexagons; although they are divided into halves, the corrugated iron was attached to form the complete hexagon and then trimmed as required. An allowance has also been made to avoid having running water come into contact with the plywood on the bottom panels by extending the corrugated roof by about 200 mm on all sides of the hexagons, coming together except where two units join each other. All the other panels have been done in the same way on their respective jigs.

The project was successful, and it is envisaged that more funding will be raised to erect more of these units all over KwaZulu-Natal for the purposes of the church's creche facilities. This is one of the ways in which the church contributes to its respective communities.

The three units for the creche facility have been completed and have met the requirements of the end-users and complies with the criteria set out for the design. The three units for a creche facility are as shown in appendix B-6.

There are a few individuals who have placed orders for these housing units although most of them cannot afford the cash price to subsidise the author for materials. The selling price, in terms of December 1996 costs for each unit is R6 250 - 00. This covers the expenditure for materials and special services for bending the channels sections to specification.

Negotiations will be undertaken with financing institutions for individuals who want to own these housing units.

For significant implementation to take place, all stakeholders will be contacted for funding a full-scale mass production of panels to be achieved in an industrial environment. At present the author has requested an open space at the church in Umlazi to work on, with the few tools at hand, to fabricate panels on a small scale until things start to pick up.

CHAPTER 7

CONCLUSIONS

7.1 Housing unit performance.

So far the prototype that is on Berea campus of Technikon Natal has shown few or no structural problems while the panels, because of their various forms, are responding differently. We have experienced a lot of rain in the Kwazulu-Natal region during the past few months when the housing unit was in place, but the resistance shown by this unit so far is incredible and satisfies our criteria for stability and resistance to all weather conditions.

The plywood - expanded polystyrene - gypsum board panels have shown a lot of degradation, because the gypsum board has absorbed a little water, which indicates that the gypsum board will not be considered in future as we may encounter problems. They are heavy, and this creates handling problems as exposure of these panels to rain will have detrimental effects.

The plywood - polyethylene - white coated aluminium strip panels are still intact and looking good. Considering the tensile strength of polyethylene combined with that of plywood, we have excellent strength while the weight is reasonable. This type of panels are suitable for all the bottom panels for the housing unit.

Fibreglass - polyethylene - white coated aluminium strip panels are also in good shape on the prototype. Their strength to weight ratio is enormous and as they form part of the *hood* above our *equator,* their lightness is a major advantage in the assembly of the housing unit. Only four people were required to lift the whole roof into place. With the unit well-sealed with silicon, the performance of these panels is convincingly very good.

the country, the more improvements there will be in the quality of the housing unit and the design itself.

It is envisaged that after several housing units have been put in place in the surrounding townships and squatter camps, there will be a need for more units to play a role in the improvement of the lives of those in need. This is indicated by the various responses shown by the people who have seen the prototype so far.

There are many things still to be looked at in terms of the housing unit, and just a few will be mentioned. The exploration will start from simple things like the conversion factors in the materials and the impacts thereof. This can be witnessed at the first implementation stage when the church requested the corrugated iron on the roof. Other possibilities exist, and a few are as follows:

As mentioned earlier, the framework alone can be used and a tarpaulin hung over that to form shelter, or raw materials available to the particular community can be used individually to the satisfaction of the owner. Perhaps concrete poles for the bottom frame can be pre-manufactured and panels thereof and the roof part fastened to the other panels.

Another possibility is to look at improving our sandwich panels for mass production and consider those already in use from different suppliers; for instance the wavepaper sandwich panel. Although the author has approached Mondev regarding the possibility of using their wavepaper sandwich panel, the response was not positive at all, and this is the case not only with this company. The answer might be to come up with a competitive sandwich panel which can be achieved if the necessary equipment is available.

7.2 Conclusion.

This developmental research project was indeed a success and may be suitable for the South African environment. The design was tested in realistic conditions, did not show any signs of quick deterioration. The possible mass production of panels for this housing unit will make this housing units to be reasonably priced.

This housing unit give more space inside with a possibility of even a little upstairs for a bed or compartment. This extra volume as compared to a normal box shape give the housing unit comfort because it's cool when hot and warm when it's cold outside.

The housing unit serves it's purpose from a person who can only afford one unit to someone who can have as many units as possible to complete a whole house because of the extendability and flexibility of the design. It's applications are also limitless as it can be used for all other uses in the housing and other sectors. This goal of coming up with a design and a way of fabricating and erecting the design has now become the starting point for the delivery stages to our needy communities. This will involve marketing of this product to the end users and entrepreneurs who are interested.

Efforts will now be directed at forming links with the government and private sector for viability. The main focus will be on the RDP funds as the project has great potential for being part of the solution in their wet core endeavour delivery system. This system allows the end user to build a foundation with, say, one room and toilet and bath as a start and then to add on the rooms as and these can be afforded. This system is in line with the vision of this project as can be seen in appendix C-11, indicating the possibilities.

There will be an extensive investigation regarding setting up a production line where entrepreneurs will be trained in the fabrication, installation and maintenance of these housing units.

Research will also focus on the developments and reports from end users on the performance of the units. The SABS (South African Bureau of Standards) will be approached in assessing the building according to their standards for the award of the Agreement Certificate, which the author believes is in accordance with their standards. Therefore the issuing of the certificate in this regard will be processed when the setting of an industrial fabrication line gets under way. This will assure consumers that quality will take priority in all aspects. The NBRI will also be approached to acknowledge the new design on the market.

7.3 Recommendation for further work

The price of extrusion dies, for the mass production of the framework profiles, is still an issue to be discussed with Hulett Aluminium in Pietermaritzburg. Further research in finding the correctly designed dies and accompanying extrusions has to be done in conjunction with industry.

The next move is to locate two or more structures in the townships and, if possible, in the informal settlements. Because of the viability of this project, various partners will be approached for further development of this design. There is an interest in producing an optimal framework, i.e profile elements to be clamped together at joints. A further exploration will be to look at various sandwich panels in which the core can be anything from hot water piping to photo-sensitive panels.

From the implementation project, a lot has been learnt regarding the short falls of the prototype, and corrections have been done. The more these housing units are built around the country, the more improvements there will be in the quality of the housing unit and the design itself.

It is envisaged that after several housing units have been put in place in the surrounding townships and squatter camps, there will be a need for more units to play a role in the improvement of the lives of those in need. This is indicated by the various responses shown by the people who have seen the prototype so far.

There are many things still to be looked at in terms of the housing unit, and just a few will be mentioned. The exploration will start from simple things like the conversion factors in the materials and the impacts thereof. This can be witnessed at the first implementation stage when the church requested the corrugated iron on the roof. Other possibilities exist, and a few are as follows:

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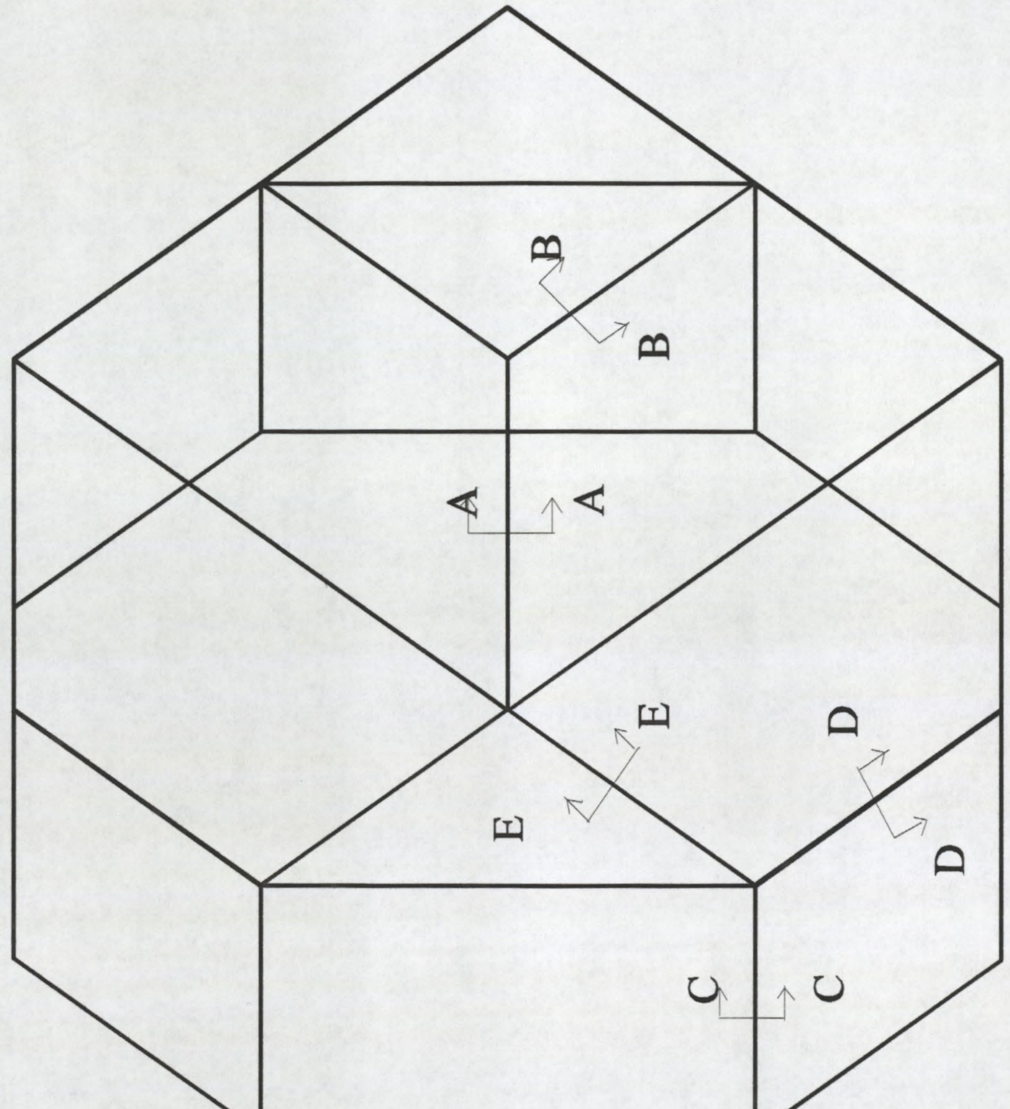
Note:

Most of the information gathered was also found by consultation with a lot of people, professionals and academics who showed interest in the project.

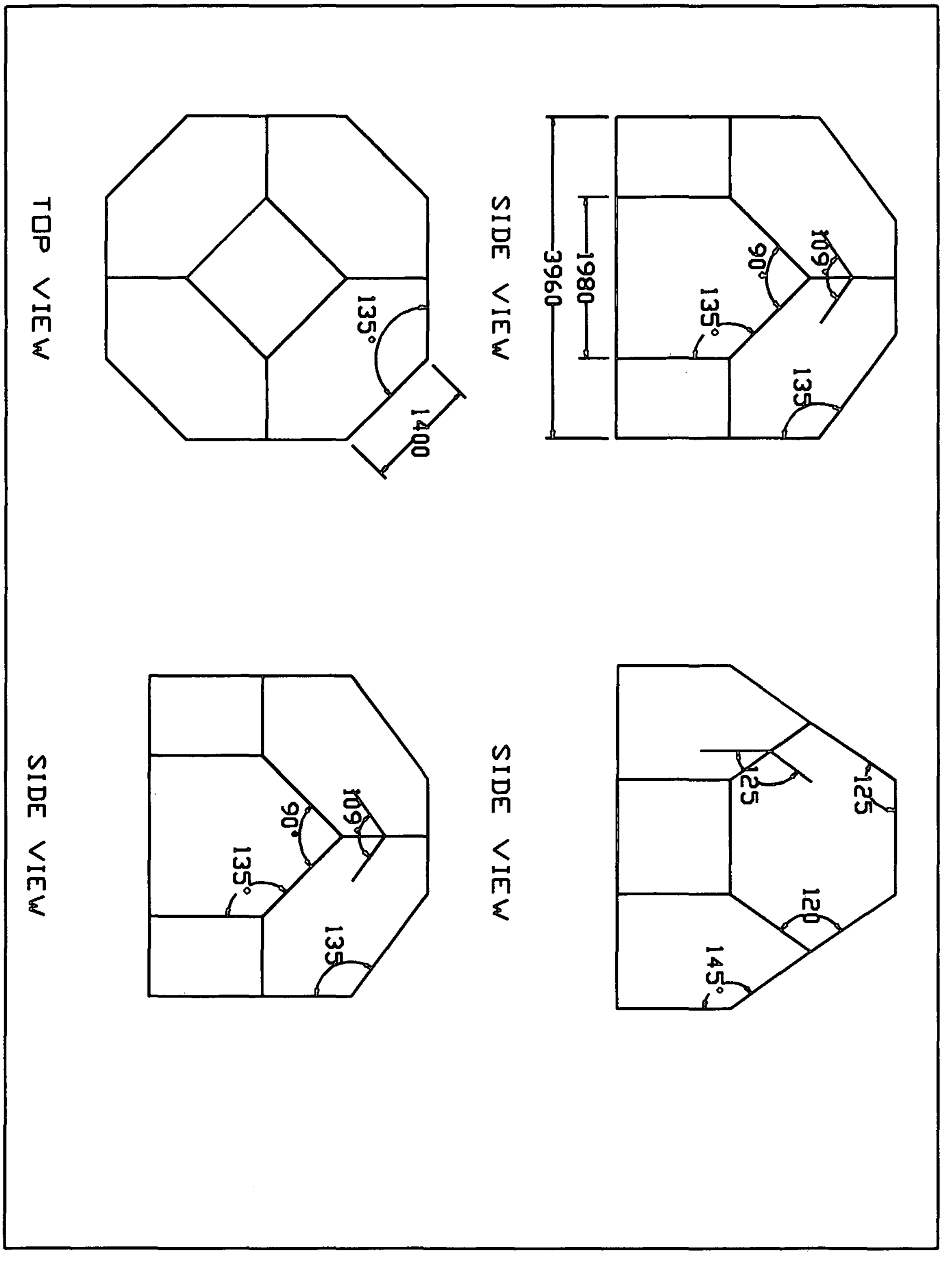
APPENDICES

APPENDIX A-1



3-D VIEW

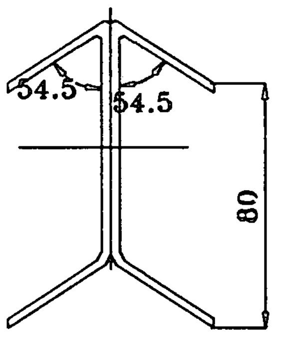
APPENDIX A-2



TOP VIEW
135°
1400
SIDE VIEW
3960
1980
90°
109°
135°
135
SIDE VIEW
90°
109°
135°
135
SIDE VIEW
125
125
120
145°

APPENDIX A-3

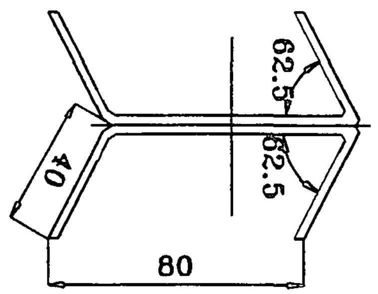
SECTION A



HEXAGON TO HEXAGON

APPENDIX A-4

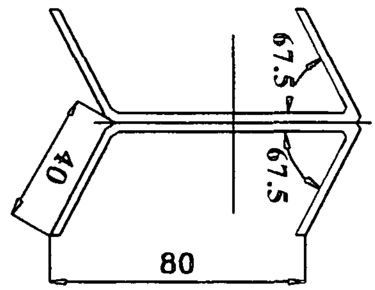
SECTION B&E



HEXAGON TO PENTAGON
& TOP SQUARE TO HEXAGON

APPENDIX A-5

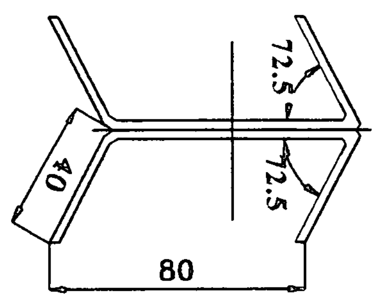
SECTION C



PENTAGON TO SQUARE

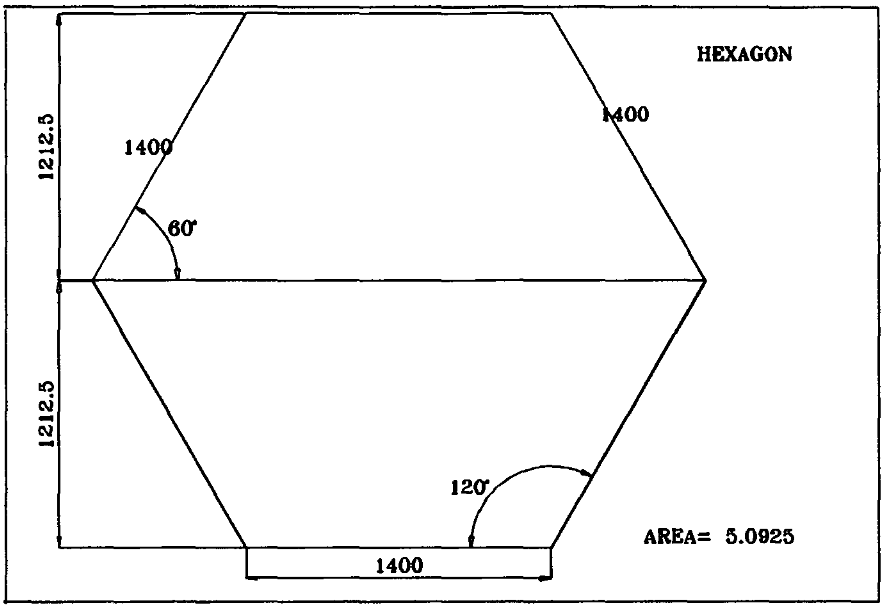
APPENDIX A-6

SECTION D



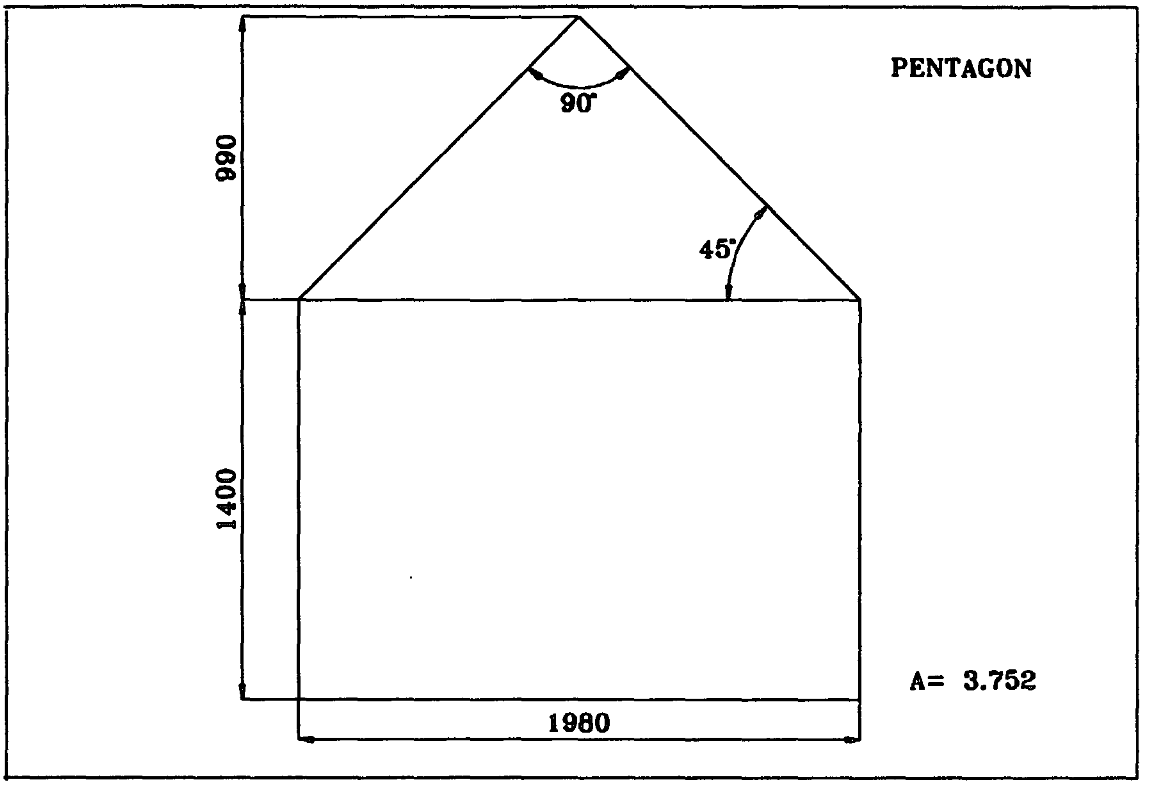
HEXAGON TO BOTTOM SQUARE

APPENDIX A-7



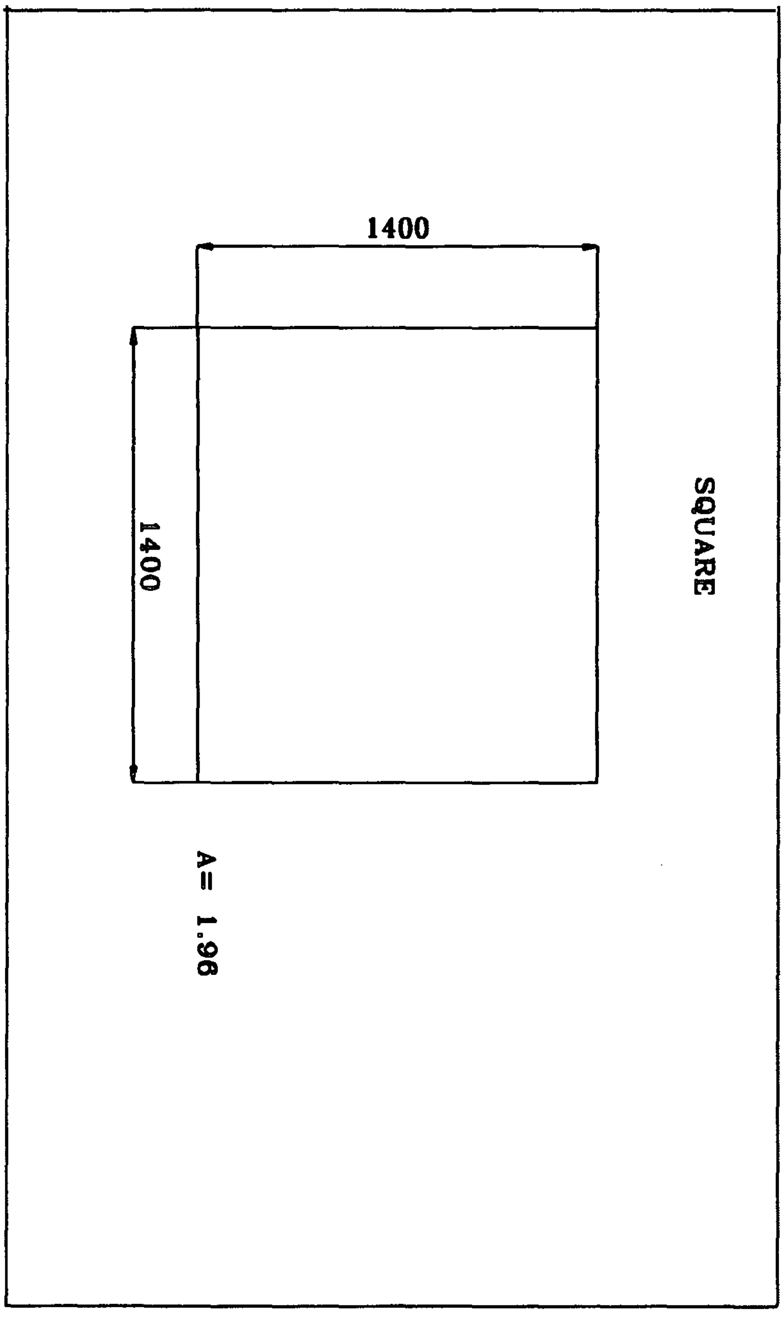
Hexagon

APPENDIX A-8



Pentagon

<u>**APPENDIX A-9**</u>



Square

APPENDIX A-10

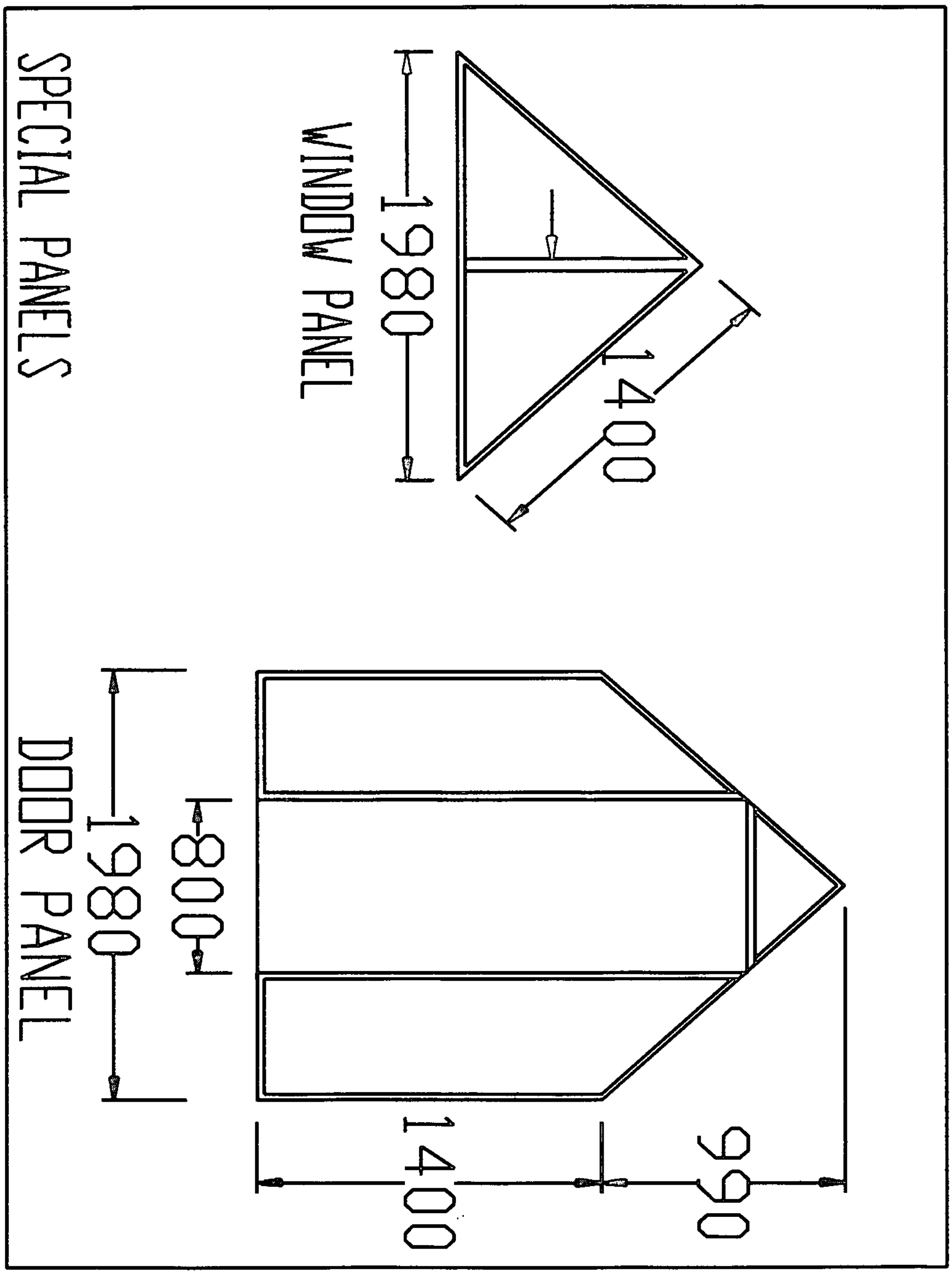
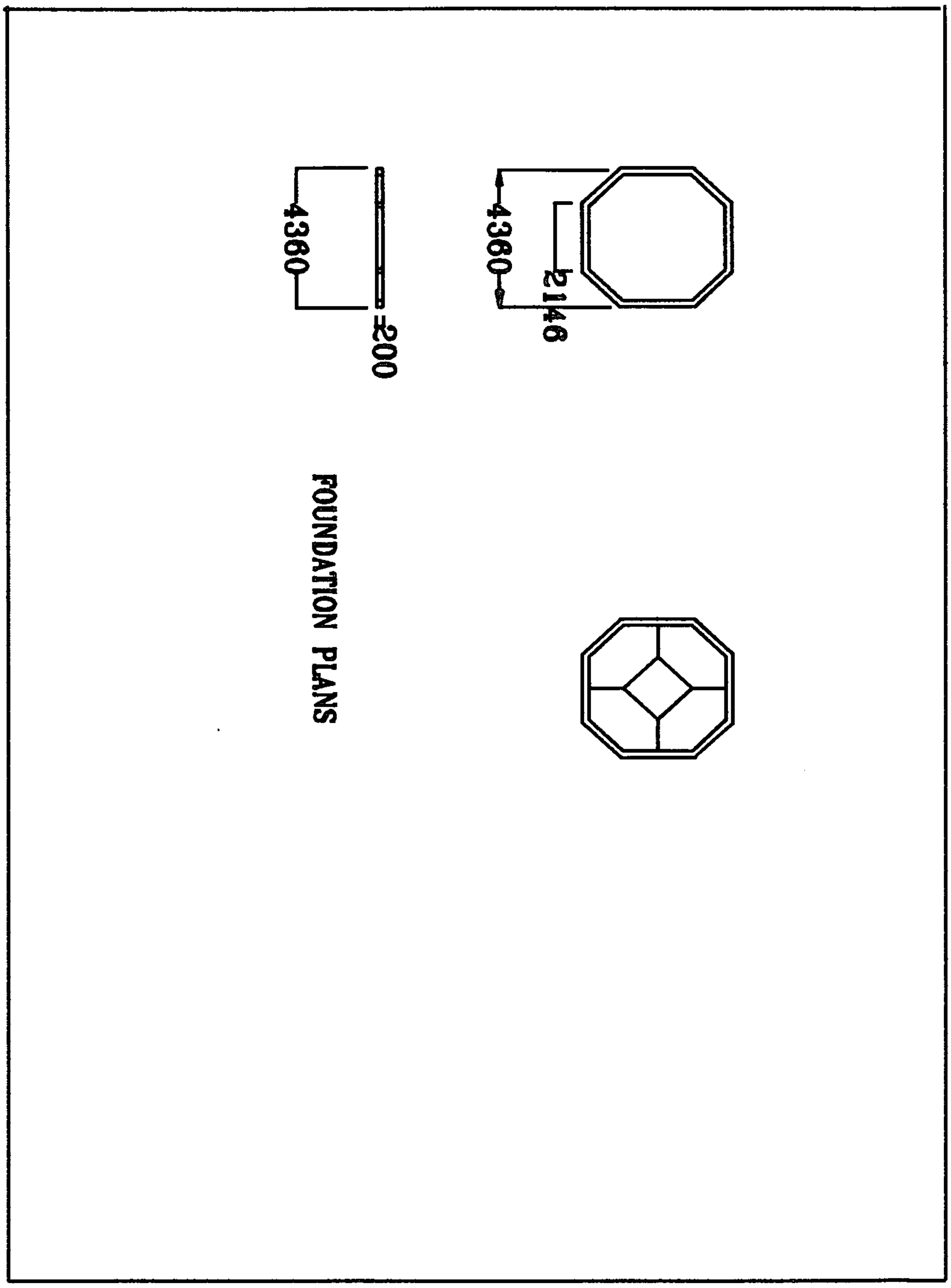


Figure 34: *Special panels*

APPENDIX A-11

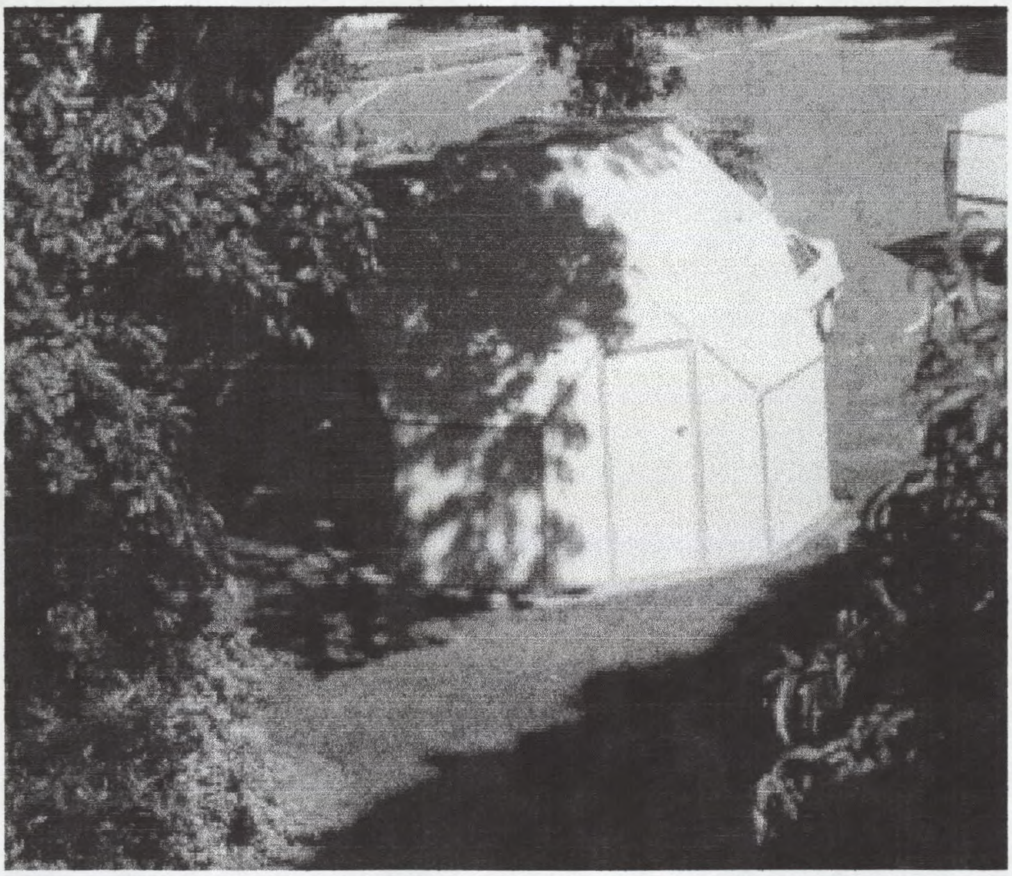


Foundation plan

APPENDIX B-1

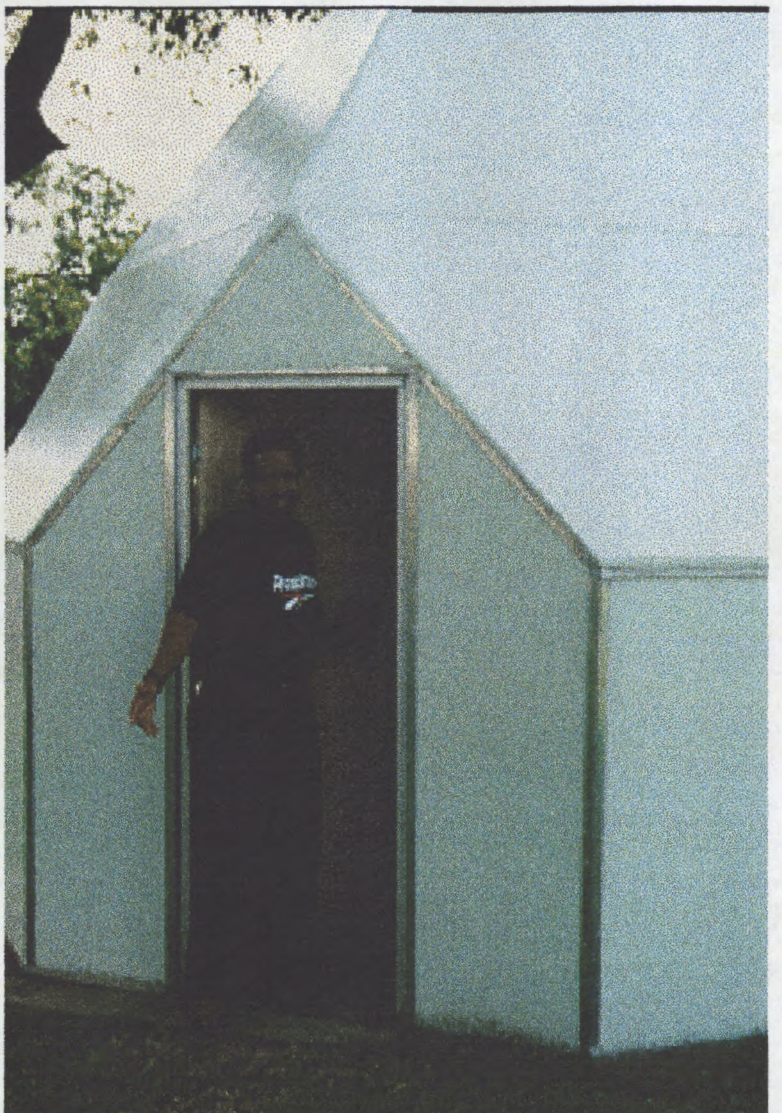
The prototype housing unit as seen at the Berea campus, Technikon Natal, Durban, RSA

APPENDIX B-2



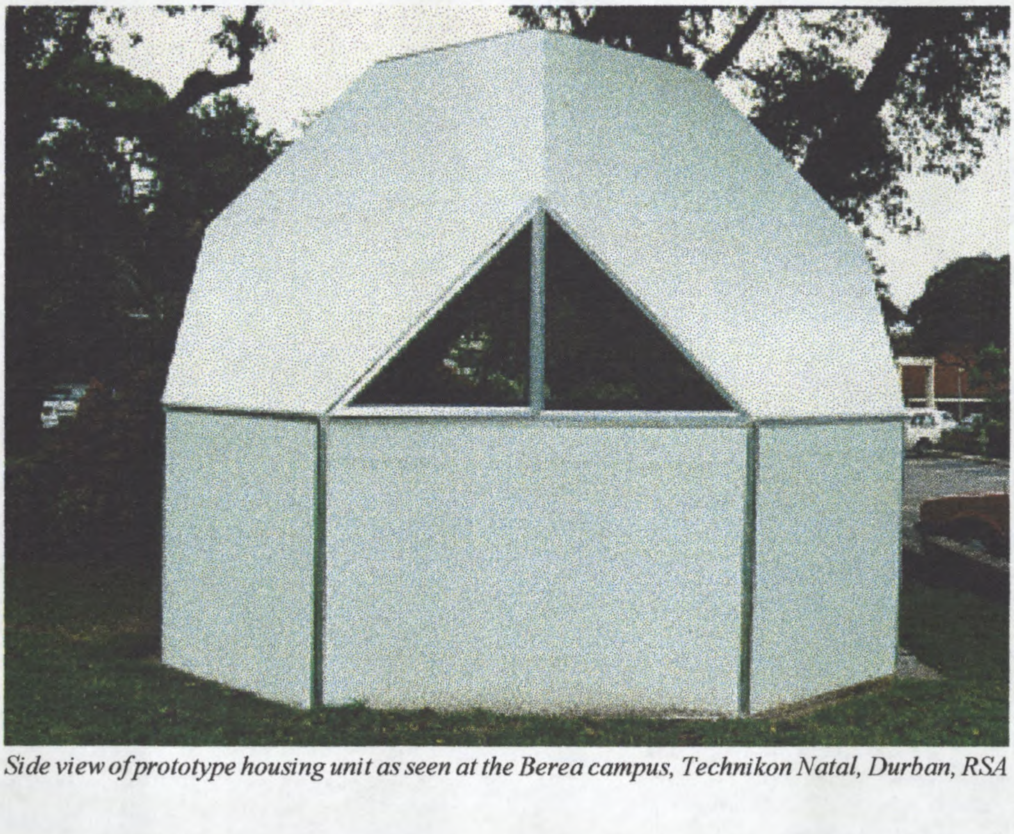
The prototype housing unit as seen at the Berea campus, Technikon Natal, Durban, RSA

APPENDIX B-3



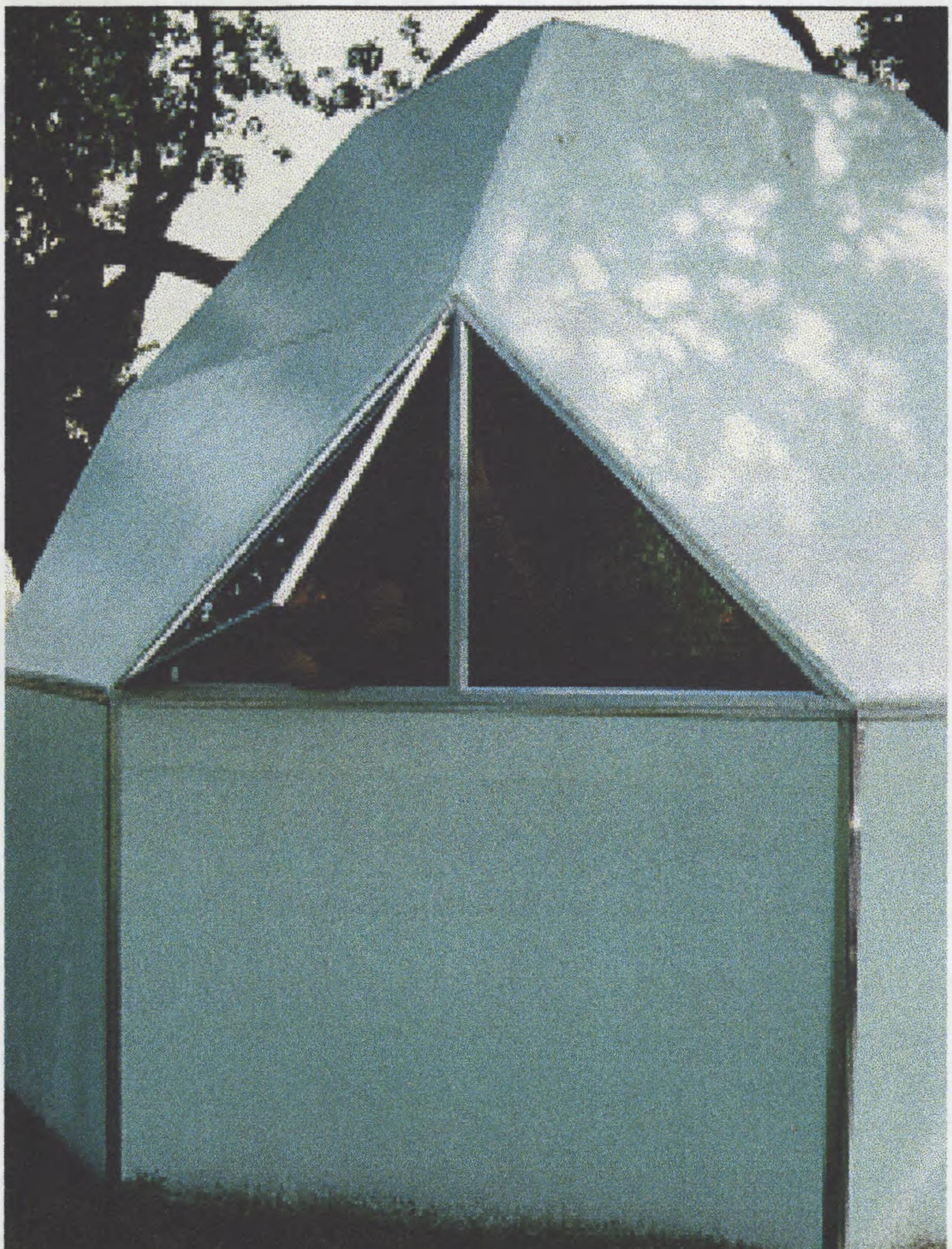
The prototype housing unit as seen at the Berea campus, Technikon Natal, Durban, RSA

APPENDIX B-4



Side view of prototype housing unit as seen at the Berea campus, Technikon Natal, Durban, RSA

APPENDIX B-5

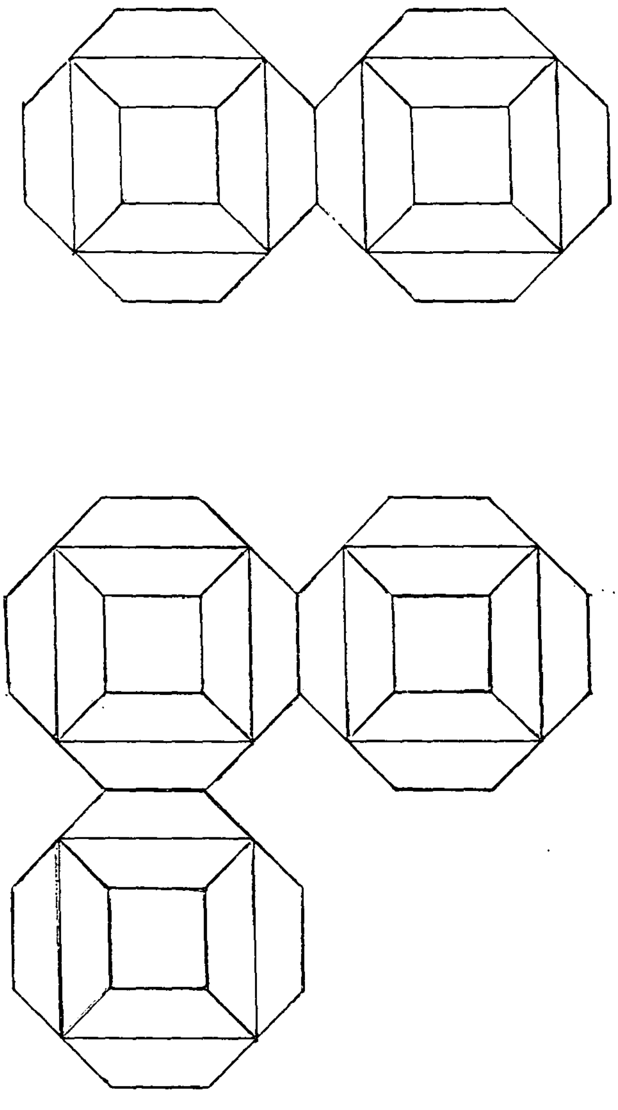


Side showing the aluminium window

APPENDIX B-6

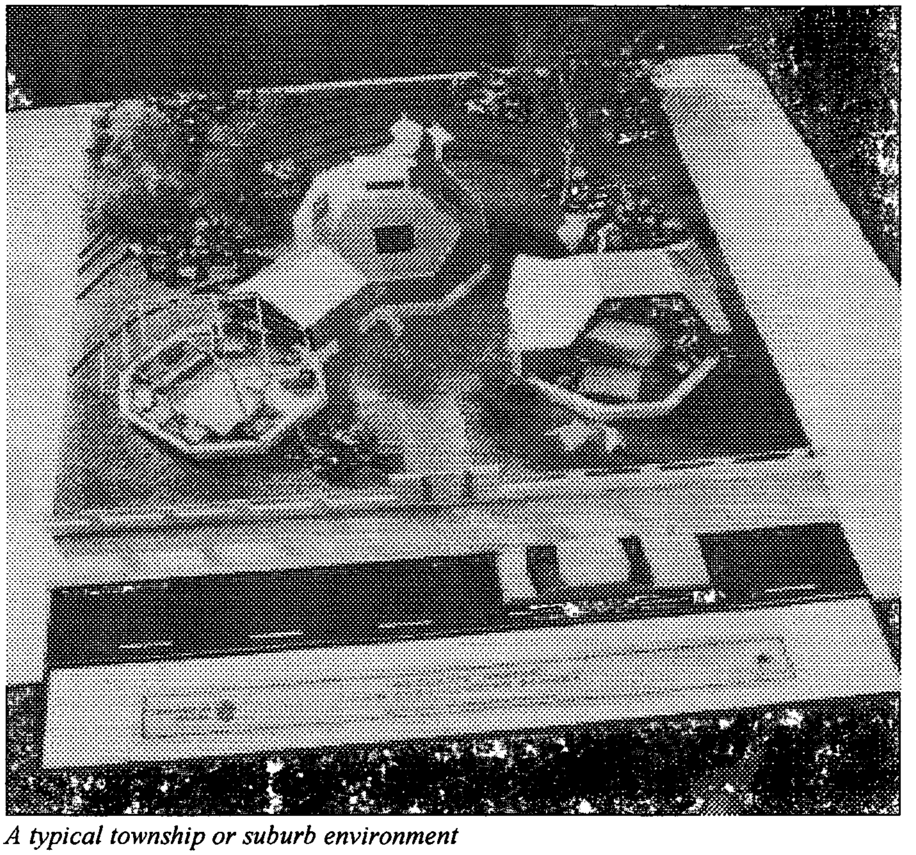
Unit built as part of the imlementation of the project - Presbyterian church (Umlazi 1996)

APPENDIX C1



Plan of the framework showing some possibilities

APPENDIX C-2

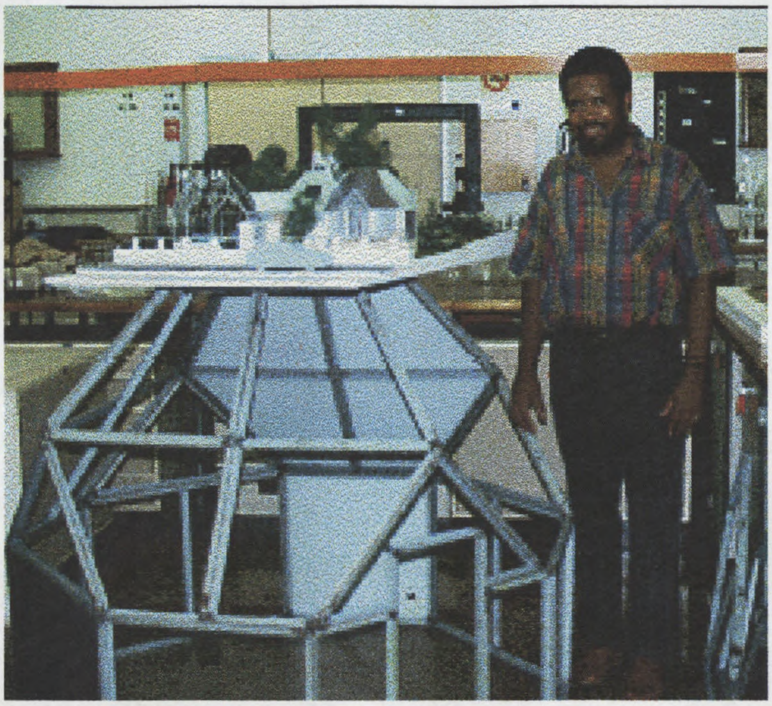


A typical township or suburb environment

APPENDIX C-3

A typical village set-up

APPENDIX C-4



One-third of the prototype which has disappeared at the Berea campus.

APPENDIX D-1

TABLE 5 - VARIATION OF CHARACTERISTIC WIND SPEED WITH TERRAIN, HEIGHT AND CLASS OF STRUCTURE

1	2	3	4	5	6	7	8	9	10	11	12	13
	Wind speed multiplier* k_z											
	Terrain Category 1			Terrain Category 2			Terrain Category 3			Terrain Category 4		
Height z, m	Class of building or element+											
	A	B	C	A	B	C	A	B	C	A	B	C
Up to 5	1,03	1,02	1,00	0,56	0,92	0,89	0,67	0,64	0,60	0,65	0,67	0,57
10	1,09	1,08	1,05	1,03	0,98	0,95	0,74	0,71	0,68	0,65	0,62	0,57
15	1,12	1,11	[illegible]	[illegible]	1,02	0,99	0,81	0,78	0,76	0,65	0,62	0,57
20	1,14	1,13	1,11	1,07	1,05	1,02	0,86	0,83	0,81	0,65	0,62	0,57
50	1,22	1,21	1,20	1,16	1,15	1,13	1,00	0,98	0,96	0,86	0,84	0,80
100	1,28	1,27	1,27	1,23	1,22	1,21	1,11	1,10	1,08	1,00	0,98	0,95
150	1,32	1,31	1,31	1,28	1,27	1,26	1,18	1,17	1,16	1,08	1,06	1,04
200	1,34	1,34	1,34	1,30	1,31	1,30	1,23	1,23	1,22	1,15	1,13	1,11
250	1,36	1,26	1,36	1,32	1,34	1,34	1,27	1,27	1,26	1,20	1,19	1,17
300	1,36	1,36	1,36	1,35	1,36	1,36	1,31	1,31	1,31	1,24	1,23	1,23
350	[illegible]	1,36	1,36	1,35	1,36	1,36	1,34	1,34	1,34	1,27	1,27	1,27
400	1,36	1,36	1,36	1,35	1,36	1,36	1,36	1,36	1,36	1,31	1,31	1,31
450	1,36	1,35	1,36	1,36	1,36	1,36	1,36	1,35	1,36	1,33	1,33	1,33
500	1,36	1,35	1,36	1,36	1,36	1,36	1,35	1,36	1,36	1,36	1,36	1,36
Above 500	1,36	1,35	1,36	1,36	1,36	1,36	1,36	1,36	1,36	1,35	1,36	1,36

* The wind speed multipliers for heights exceeding the height of the obstructions producing the surface roughness (reference plane height), but less than the gradient height are based on the variation of gust speeds with height, determined by the formula

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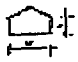
APPENDIX D-2

TABLE 7 - EXTERNAL PRESSURE COEFFICIENT C_{pe} FOR PITCHED ROOFS OF RECTANGULAR CLAD BUILDINGS

1	2	3	4	5	6	7	8	9	10
Building height ratio	Roof angle, degrees	Average C_{pe} for surface				Local C_{pe}			
		Wind angle θ = 0°		Wind angle θ = 90°					
		EF	GH	EG	FH				
	0	-0,8	-0,4	-0,8	-0,4	-2,0	-2,0	-2,0	-
	5	-0,9	-0,4	-0,8	-0,4	-1,4	-1,2	-1,2	-1,0
	10	-1,2	-0,4	-0,8	-0,6	-1,6	-1,4		-1,2
	15	-0,6	-0,4	-0,8	-0,6	-1,2			-1,2
	20	-0,5	-0,4	-0,7	-0,6	-1,0			-1,2
	30	0,0	-0,4	-0,7	-0,6	-0,8			-1,1
	40	+0,3	-0,5	-0,7	-0,5				-1,1
$h/w \leq \frac{1}{2}$	50	+0,3	-0,5	-0,7	-0,6				-1,1
	60	+0,7	-0,6	-0,7	-0,6				-1,1
	0	-0,8	-0,5	-1,0	-0,6	-2,0	-2,0	-2,0	-
	5	-0,5	-0,5	-0,9	-0,6	-2,0	-2,0	-1,5	-1,0
	10	-1,2	-0,5	-0,8	-0,6	-2,0	-2,0	-1,5	-1,2
	15	-0,9	-0,5	-0,8	-0,5	-1,8	-1,8	-1,5	-1,1
$h/w = 1$	20	-0,5	-0,5	-0,8	-0,6	-1,5	-1,5	-1,5	-1,0
	30	-0,1	-0,5	-0,8	-0,8	-1,0			-1,0
	40	+0,2	-0,5	-0,8	-0,8				
	50	+0,4	-0,5	-0,8	-0,8				
	60	+0,6	-0,5	-0,8	-0,8				
	0	-0,8	-0,6	-0,9	-0,7	-2,0	-2,0	-2,0	-
	5	-0,9	-0,6	-0,8	-0,8	-2,0	-2,0	-1,5	-1,0
	10	-1,1	-0,6	-0,8	-0,8	-2,0	-2,0	-1,5	-1,2
	15	-0,9	-0,6	-0,8	-0,8	-1,8	-1,8	-0,5	-1,2
$h/w = 2$	20	-0,7	-0,6	-0,8	-0,8	-1,5	-1,5	-0,5	-1,2
	30	-0,3	-0,5	-0,8	-0,7	-1,5			
	40	0,0	-0,5	-0,6	-0,7	-1,0			
	50	+0,3	-0,5	-0,8	-0,7				
	60	+0,5	-0,5	-0,8	-0,7				
	0	-0,7	-0,6	-0,9	-0,7	-2,0	-2,0	-2,0	-
	5	-0,8	-0,6	-0,8	-0,8	-2,0	-2,0	-1,5	-1,5
	10	-0,8	-0,6	-0,8	-0,8	-2,0	-2,0	-1,5	-0,2
	15	-0,5	-0,6	-0,8	-0,8	-1,8	-1,8	-1,5	-1,2
$h/w = 3$	20	-1,0	-0,6	-0,8	-0,8	-1,6	-1,5	-1,5	-1,2
	30	-0,5	-0,5	-0,8	-0,7	-1,5			
	40	-0,1	-0,5	-0,8	-0,7	-1,0			
	50	+0,3	-0,5	-0,8	-0,7				
	60	+0,5	-0,5	-0,8	-0,7				
	0	-0,7	-0,8	-0,9	-0,7	-2,0	-2,0	-2,0	-
	5	-0,7	-0,8	-0,8	-0,8	-2,0	-2,0	-1,5	-1,0
	10	-0,7	-0,6	-0,8	-0,8	-2,0	-2,0	-1,5	-1,2
	15	-0,8	-0,6	-0,8	-0,6	-1,8	-1,8	-1,5	-1,2
$4 \leq h/w \leq 6$	20	-0,8	-0,6	-0,8	-0,8	-1,6	-1,5	-1,5	-1,2
	30	-1,0	-0,5	-0,8	-0,7	-1,5			
	40	-0,2	-0,5	-0,8	-0,7	-1,0			
	50	+0,3	-0,5	-0,8	-0,7				
	60	+0,5	-0,5	-0,6	-0,7				

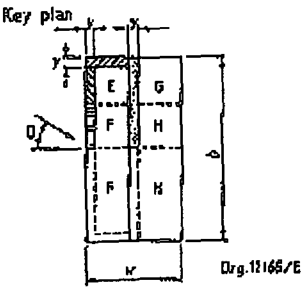
NOTE

a) h is the height to eaves or parapet and w is the lesser horizontal dimension of a building.

b) Take the pressure coefficient on the underside of any roof overhang as that on the adjoining wall surface. Where no local coefficients are given, the overall coefficients apply.

c) Use the value of q_z applicable at ridge height.

Key plan



$y = h$ or $0,15\ w$, whichever is the lesser

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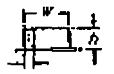
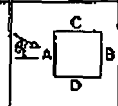
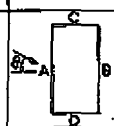
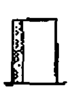
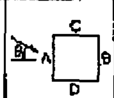
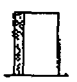
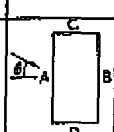
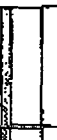
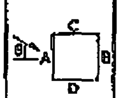
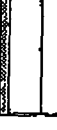
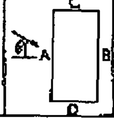
APPENDIX D-3

TABLE 6 - EXTERNAL PRESSURE COEFFICIENT C_{pe} FOR THE WALLS OF RECTANGULAR CLAD BUILDINGS

1	2	3	4	5	6	7	8	9	10
Building height ratio	Building plan ratio	Elevation	Plan	Wind angle θ, degrees	Average C_{pe} for surface				Local C_{pe}
					A	B	C	D	
$\frac{h}{w} \leq \frac{1}{2}$	$1 < \frac{b}{w} \leq \frac{3}{2}$	 0,15 w or h, whichever is the lesser		0 90	+0,7 -0,5	-0,2 -0,5	-0,5 +0,7	-0,5 -0,2	} -0,8
	$\frac{3}{2} < \frac{b}{w} \leq 4$			0 90	+0,7 -0,5	-0,25 -0,5	-0,6 +0,7	-0,6 -0,1	} -1,0
$\frac{1}{2} < \frac{h}{w} \leq \frac{3}{2}$	$1 < \frac{b}{w} \leq \frac{3}{2}$			0 90	+0,7 -0,6	-0,25 -0,6	-0,6 +0,7	0,6 -0,25	} -1,1
	$\frac{3}{2} < \frac{b}{w} < 4$			0 90	+0,7 -0,5	-0,3 -0,5	-0,7 +0,7	-0,7 -0,1	} -1,1
$\frac{3}{2} < \frac{h}{w} < 6$	$1 < \frac{b}{w} \leq \frac{3}{2}$			0 90	+0,8 -0,8	-0,25 -0,8	-0,8 +0,8	-0,8 -0,25	} -1,2
	$\frac{3}{2} < \frac{b}{w} < 4$			0 90	+0,7 -0,5	-0,4 -0,5	-0,7 +0,8	-0,7 -0,1	} -1,2

NOTE

a) h is the height to eaves or parapet, b is the greater horizontal dimension of a building, and w is the lesser horizontal dimension of a building.

b) Use the following values of q_z:

For windward walls: q_z applicable at top of wall or as a function of height in accordance with wind speed variation as given in 5.5.2.6(c);

for leeward and side walls: q_z applicable at top of wall.

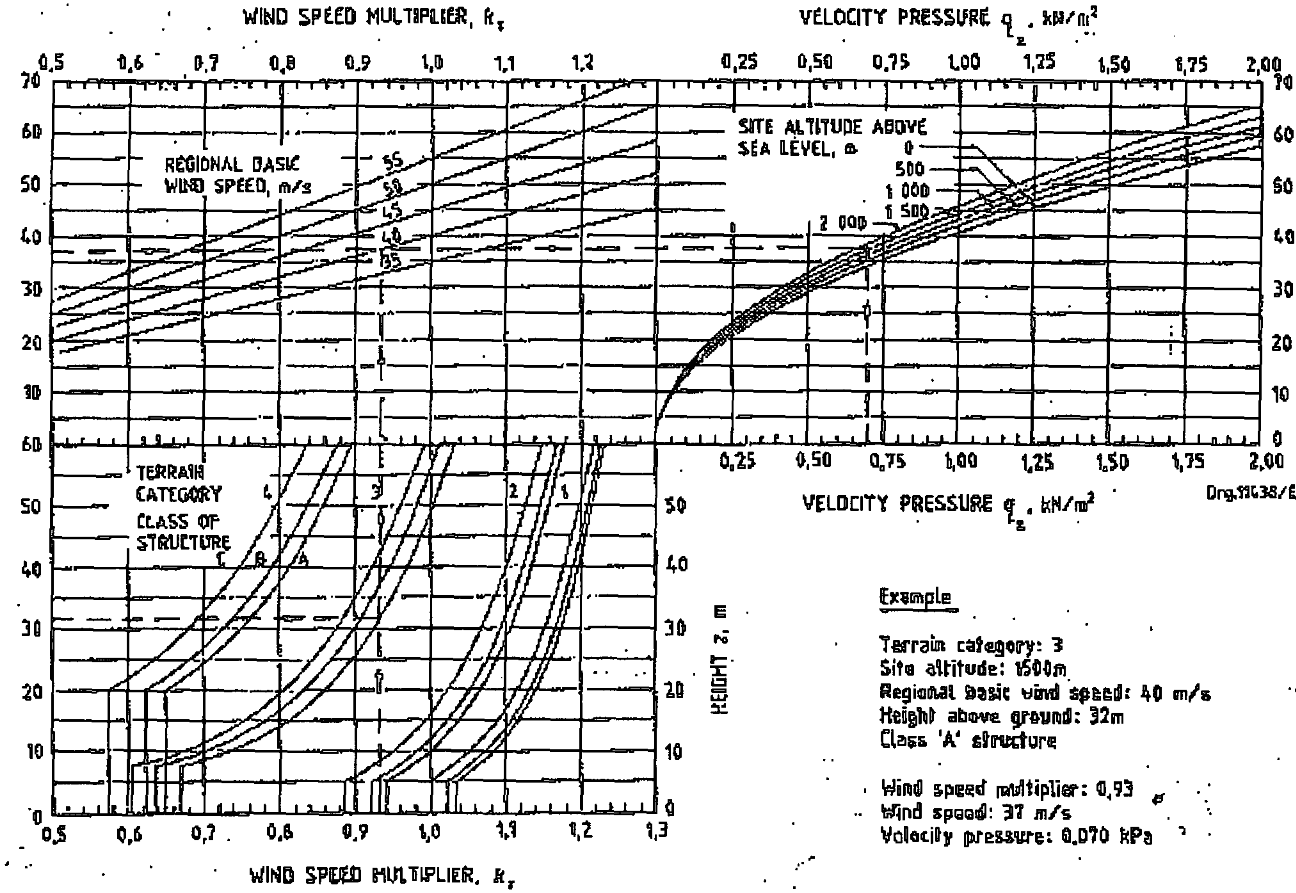


Fig. D-6 – Graph for Velocity Pressure, q_z

APPENDIX E

Cost analysis for the prototype housing unit excluding labour and foundation as at January 1996			
Material	Quantity	Price/unit (Rands)	Total amount (Rands)
Aluminium : 16587 32157	60m length 78m length	15.72 13.60	943.20 982.80
PLYWOOD (2.440*1.220)	08 sheets	88.08	704.64
Fibreglass (2.400*1.200)	08 sheets	72.15	577.20
Structabord (2.440*1.220)	08 sheets	100.91	807.28
Expanded polystyrene (2.440*1.220)	08 sheets	65.73	525.84
Gypsum board (2.440*1.220)	08 sheets	44.74	357.92
SUB-TOTAL			**4898.88**
Other expenses			
Stainless steel bolt and nuts	200	0.10	20.00
Anchor bolts	16	4.50	72.00
Rivets	200	8.00/100	16.00
Adhesives and Sealants: Silicon RWL 428 Polyurethane	 06 20*l* 04	 15.95 202.00/200*l* 19.95	 95.70 202.00 79.80
Aluminium welding	all framework joints	-	903.00
SUB-TOTAL			**1388.50**
TOTAL			**6287.38**