Konke Mazwai

Dissertation in fulfillment of the BSc (Eng) in Mechanical Engineering

Submitted July 2011

Supervisor: Prof. R. Knutsen

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ACKNOWLEDGEMENTS

I would like to thank Prof. R. Knutsen for technical guidance in the project. I also appreciate the assistance of Ms Barbara Schmid from the UCT Knowledge Partnership Project.

I would like to further thank my mother Ms T. Mazwai, my brother and sister, Sivile Mbekeni and Nyameka Dyakalashe.

PROJECT PROPOSAL

Title: Low cost fencing material for pre-school in low-income area

Supervisor: Prof. R. Knutsen

The project, which has been proposed by the UCT Knowledge Partnership Pilot Project, is aimed at providing assistance to an under-privileged community in the Western Cape. Fencing material is required for the play area of a pre-school to meet the following criteria: safe for children, inexpensive, preferably eco friendly, not valuable i.e. no metal otherwise it gets stolen, it must be strong, it must not block visibility, it must not be easy to remove but simple to erect.

The following options are not suitable: anything containing metal as it gets stolen. Wood gets taken for fuel. Brick and shrubs block visibility and provides an option for hiding criminal activity.

Searches into the potential use of recycled plastics reveal that this has not been explored as fencing material.

ABSTRACT

This project has been proposed by the UCT Knowledge Partnership Project. This institution is aimed at providing assistance to under-privileged communities in the Western Cape. A pre-school fence material which is low cost is to be investigated. The following criterions were set to be met for the material:

- The material is to have no fuel usage value such as wood, which can be burnt for space heating
- The material is to have no scrap metal value such as steel and wire fencing material as this easily gets stolen.
- The material is not to block visibility which harbors criminal activity in the area. Fences such as concrete slabs and brick block visibility.

The materials considered in this project are:

- Various plastic polymer materials
- Plastic Lumber composite material
- Recycled Plastic
- Rubber reinforced concrete

Plastic lumber and recycled plastic HDPE were considered for use in the fence material. After considering the available fence components and loading on the fence, 100 x 100 mm cross section plastic lumber and recycled plastic section were chosen to be used.

The fence design was based on existing patents which were modified. A design showing the meter of the fence was designed and is shown in the document.

MEMORANDUM OF UNDERSTANDING

Between

University of Cape Town through UCT Knowledge Co-op

(UCT)

And

New World Foundation, located at Grindal Avenue, Lavender Hill, Cape Town

(NWF)

(Hereinafter collectively referred to as the "**Parties**" and individually as the "**Party**")

1. Nature of the Collaboration

The collaboration foreseen in this agreement is not intended in a way that implies the creation of a legal partnership, joint venture or any other kind of legal entity between UCT and NWF.

The student, Konke Mazwai, will develop a design for a fence for a pre-school play area according to the needs of NWF. No guarantee is offered that this project will meet all specifications fully, but it will include advice on areas that need further work.

2. Roles of both Parties

Within this project, both partners will work within the Memorandum of Understanding (MoU) established for the project.

UCT will support the student in its collaboration with NWF.

The student will meet regularly with designated staff of NWF to brief them on progress and share intermediary deliverables. The student's academic project will be supervised by Professor Rob Knutsen from the Mechanical Engineering department.

The Parties undertake to cooperate to allow the timely submission, examination, publication and defence of any dissertation or thesis for a degree.

3. Duration

This MoU will commence on 1 March 2011, notwithstanding the date of signature of this MoU, and shall end on 31 May 2011, unless otherwise terminated in accordance with the provisions of this MoU.

4. Consideration

It is specifically agreed between the Parties that the student will be re-imbursed by UCT for travel expenses and any development costs over and above R 1 500 (one thousand five hundred rand).

5. Intellectual Property

Each party shall retain all rights to existing intellectual property owned by it at the commencement of the collaborative project arising under this MOU.

The rights to any Intellectual Property created by the student during the course of the project period shall be vested in UCT.

It is specifically agreed that NWF shall be allowed to use the design for their own internal purposes or to set up a small community project.

The Parties shall not be entitled to use the other Party's trademarks, logos, or corporate marks for purposes of the intended collaboration without the other Party's written consent.

6. Confidentiality

Neither party nor their respective employees, consultants or agents shall disclose, use or make public, any information or material acquired or produced in connection with, or by the performance of, this MOU, other than in the performance of their respective obligations under this MOU, or as required by law, without the prior written approval of the other party, which must not be unreasonably withheld.

The parties intend that the provisions of this clause shall be binding on them and shall survive the termination or expiration of this MOU.

THUS DONE AND SIGNED AT MOWBRAY ON THIS _____ DAY OF APRIL 2011.

As witnesses:

1. ________________________

2. ________________________

____

For and on behalf of the University of Cape Town

THUS DONE AND SIGNED AT _____________________ ON THIS _____ DAY OF APRIL 2011.

As witnesses:

1. ________________________

2. ________________________ ________________________________

For and on behalf of NWF

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1. INTRODUCTION

1.1. Project Background

This project involves the selection of a low cost fencing material for a pre-school in a low income area. It has been proposed by the UCT Knowledge Partnership Pilot Project. The Pilot Project is aimed at providing assistance to under-privileged communities in the Western Cape. The pre-school is situated in Lavender Hill, Muizenburg. The pre-school is operated by the New World Foundation (NWF). The NWF has advised that conventional fencing materials that have been used in the past have been vandalized and/or stolen by community members. The NWF members noticed that wooden lumber has been stolen for its fuel value while steel fences have been stolen for recycling. In addition to the problems faced with wood and steel, concrete and brick fences that have been installed in the area have proved to harbor criminal activity. The pre-school's main aim is to educate children in the area in an environment that is mentally stimulating. The fencing material which is to be installed in the playground of the pre-school should contribute to this environment.

1.2. Project Objectives and Criterion

The fence should be safe for children. As the fence is to be erected in a pre-school, it should be safe for children to play around it. If possible the fence itself should contribute to the mental stimulation of the children. Color and interesting shapes would be advantage in the fence overall design.

The fence should have no domestically usable fuel value. Materials such as wood are not to be used as they have a fuel value which can be used in the households. Low-income communities tend to use wood for space heating even when electricity is available. (1)

The fence should have no material value. Common engineering materials such as steel and aluminum have a recycle value. The scrap metal industry provides an easy entry for low income members.

Materials that block visibility such as brick and concrete cannot be considered as they have the potential to harbor criminal activity around them. In a study conducted in Mitchells Plain it was found that 37.6% of high school learners involved in drug/substance abuse consistently carry a knife. Of the same sample of high school learners involved in the study 34.4% have perpetrated theft and 22.6% have damaged property (2). The study further concluded that the prevalence of substance abuse of adolescents in Mitchells Plain is high relative to national and international figures.

The fence material should be low-cost and the material itself should be preferably recycled. As an outcome to the development of the fence, the creation of an economically sustainable market that provides employment would be an advantage.

1.3. Plan of Development

The contents of this repot shall begin with a literature review. The literature review shall start its focus on the materials that can be considered for use in the as a fence. The extensive analysis of the material properties shall be performed and modifications to these materials shall be considered.

A design report which is based on current fence designs will be drawn up. The fence designs will be considered from patents and existing designs depending on the material. The design report will also look at the loading dynamics of the fence.

Conclusions will be made on the literature review and a fence material will be chosen. The design report will assist in selecting the material and suggesting possible modifications to it.

1.4. Limitations of the Project Scope

The project scope as highlighted by the UCT Knowledge pilot project involves the design of a low cost fence and fence material for a pre-school. The memorandum of agreement attached in appendix C gives the overall responsibilities of the student. A prototype of the fence will not be installed in the preschool as part of the project.

1.5. Pre-School Pictures

Below are images of the school. The images include a panoramic view of the preschool in which the fence will be installed (it covers a 200deg view angle) and pictures of the exterior which show the fence which is to be replaced.

Figure 1: New World Foundation Preschool Panoramic View

Figure 2: Preschool Building exterior with playground

2. LITERATURE REVIEW

2.1. Virgin and Recycled Plastics

A plastic can be defined as a material, that when deformed, maintains its new shape. It is a form of synthetic polymer (3). Plastics are divided into two groups; thermoplastics and thermosets. Thermoplastic refers to a plastic that flows or is moldable when heat is applied to it. In addition, thermoplastics can be remolded when heated. Thermosets refer to plastics for which the "polymerization process is finished in a hot press where the plastic is liquefied under pressure" (4). It should be noted that thermoset plastics cannot be remolded.

2.1.1. Plastics Properties and Structure Overview

The mechanical properties of plastics are not as definitive as the mechanical properties of metals. Plastics unlike metals have minimal quantitative properties. Design calculations based on plastic properties cannot simply be taken from a generalized plastic data information sheet or property tables (5) (4). The behavior of plastic in the long term is still not well known. Some of the challenges that are faced with plastics include the fact that plastics are susceptible to creep (or cold flow) behavior when used over long periods of times and that plastics have local variations in their microstructure.

It is noticed that the microstructure of plastics has organized crystallized regions and non-crystallized (amorphous) regions. The consequence of these inconsistencies is that regions that have crystallized deform at higher stresses than amorphous regions. Plastic materials are also influenced by the temperature of the application. The deformation of plastics varies according to temperature. The critical factors that to be need heavily considered when designing with plastics are creep, time and stress. Additional factors that influence the selection of a plastic material are humidity, chemical exposure, radiation and biological agents (6). Below is a figure representing a semi-crystalline structure (5).

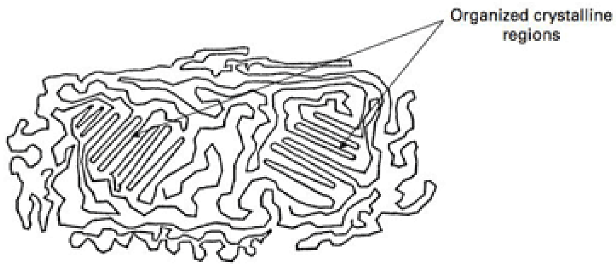

Figure 3: Semi Crystallized Structure

2.1.2. Virgin Plastics

Virgin Plastics are plastics which have not been recycled. There are several plastics available. The plastics which will be focused on for the purposes of this document are the plastics which can be recycled at a later stage. The properties of most virgin plastic materials are given in the form of a range as plastics properties vary.

2.1.2.1. PET

PET is a thermoplastic resin and is a linear synthetic polymer. It is commonly used in food and beverage containers. PET is formed via the esterification of dimethyl Terephthalate with ethylene glycol which is later followed by condensation. PET like most plastics exists in an amorphous state and a semi crystalline state. It can also be found in glass fiber reinforced states which show higher increased strength, modulus of elasticity and creep resistance. PET can also be available in flame retardant grades.

PET has the following functional properties (Reference):

- It has high stiffness, hardness and strength
- It has good toughness even at low temperatures
- It has good creep resistance
- It has low friction and high abrasion resistance

- It is capable of high dimensional stability
- It is capable of application temperature ranging from -40°C to 100°C
- It has low water absorption
- At room temperature PET is resistant to water, dilute acids, neutral and acidic salts, alcohol, ethers, oils, fats, percholated, aromated, aromatic and aliphatic hydrocarbons.
- PET is resistant to stress cracking, hot air and weathering.

Processing and Manufacturing PET is commonly via blow molding. There are applications where extrusion is used as a form of processing such as glass clear film.

Table 1: Mechanical Properties of PET polymer (7)

Mechanical Property	Value (Unit)
Coefficient of Frication	0.2 – 0.4
Izod Impact Strength	13 – 35 (J/m)
Poisson’s Ratio	0.37 – 0.44(oriented)
Tensile Modulus	2 – 4 (GPa)
Tensile Strength	19 MPa

2.1.2.2. POLYETHYLENE (8)

Polyethylene belongs to a family of polyolefines that are semi crystalline thermoplastics. It consists of branched linear macromolecules. Polyethylene has good chemical resistance, high toughness and high tensile strength. The biggest advantage in polyethylene is the low cost relative to the other plastics. Polyethylene can be produced by low-pressure and high-pressure polymerization. Low-pressure polymerization produces highly branched macromolecules, known as Low-Density Polyethylene. The low-pressure polymerization occurs at approximately atmospheric pressure with the assistance of a catalyst. The result of the low-pressure polymerization is High-Density Polyethylene.

Below is a table showing the fundamental differences between High-Density Polyethylene (HDPE) and Low-Density Ethylene (LDPE).

Table 2: Properties of HDPE and LDPE

Properties	LDPE	HDPE
Degree of crystallisation (%)	40-50	60-80
Modulus (MPa)	130	1000
Density (g/cm^3)	0.915-0.94	0.94-0.965
Crystalline melting zone (°C)	105-110	130-135
Chemical resistance	Good	Better

Polyethylene has the properties mentioned below:

- It has a relatively low density
- PE has a high toughness
- PE has been found to be operational in temperatures of between -50°C to 90°C
- It can be easily fabricated
- It has low water absorption
- It is resistant to acids, alkalis, salt solutions, water, alcohol, oil and petrol.

It should be noted that ultra violet radiation causes brittleness in the PE. This can be prevented by the addition of an additive, 2-2.5% well dispersed carbon black.

Table 3: Mechanical Properties of LDPE and HDPE

Properties	LDPE	HDPE
Density (g/cm^3)	0.92	0.955
Stress at Yield (MPa)	8 - 10	20 - 30
Elongation at yield (%)	20	12
Impact strength (mJ/mm^2)	No Break	No Break
Notched impact strength (Mj/mm^2)	No Break	No Break
Ball indentation hardness (N/mm^2)	20	50
Modulus of elasticity (MPa)	200	1000
Service Temperature Long term (°C)	60 - 75	70 - 80
Service Temperature Short term (°C)	80 -90	90-105

HDPE and LDPE can be processed via the same methods although the process pressures and temperatures differ. Blow is a table representing the process methods of polyethylene.

Table 4: Processing Methods of HDPE and LDPE

Processing Method	Melt Temperature (°C)		Mould/die Temperatures (°C)		Melt Pressure (bar)	
	LDPE	HDPE	LDPE	HDPE	LDPE	HDPE
Injection Moulding	160 - 260	200 - 280	30 - 70	50 - 70	400 - 800	600-120
Extrusion	150	180 - 200	150	180 - 200	100 - 150	150-250
Film Extrusion	140	180 - 250	140	180 - 250	100 - 200	150-200
Blow Moulding	140	160 - 190	140	160 - 190	100 - 150	100-200

2.1.2.3. PVC (9)

Polyvinyl Chloride is a popular thermoplastic material. It is a polymer which is made up of the vinyl chloride monomer. PVC is manufactured by means of mass, suspension or emulsion polymerization. It is an amorphous thermoplastic with an approximately 5% degree of crystallinity. PVC is supplied as a powder and additives such as plasticizers, impact modifiers, fillers and pigments make it more processable.

Different types of PVC are produced by the varying method of polymerization. Mass polymerization produces very pure PVC which when manufactured results in high quality products. Mass polymerized PVC is commonly written as non-standard PVC-M. Suspension polymerization produces a less purer product than mass polymerization as it contains protective colloids used in manufacturing. This is the most commonly used manufacturing method for polymerizing PVC. Suspension PVC is commonly referred to as PVC-S. PVC can be Emulsion polymerized. This includes the use of an emulsifier which makes processing easier. Products of emulsion polymerization are commonly known as PVC-E. Below is a table showing the properties of suspension polymerized PVC (PVC-S).

Table 5: Properties of PVC (10)

Properties	Suspension PVC
Particle size (µm)	60 to 250
Bulk Density	0.40 – 0.065
Mineral Residues (%)	<0.1
General Properties	Good Mechanical and chemical properties

PVC has the following functional properties

- PVC has a high mechanical strength
- It is resistant to alcohols, acids and petrol
- Various kinds of PVC can be manufactured to have weathering resistance
- PVC can be flame retardant with the addition of an additive

Table 6: Mechanical Properties of PVC

Properties	Value
Tensile Strength	44.75 MPa
Notched Impact Strength	2.0 – 45 kj/mm^2
Thermal Coefficient of Expansion	$80x10^{-6}$
Maximum Continued Use Temperature	60°C
Density	1.38 g/cm^3

PVC can be processed via injection moulding. This is where it is melted, injected and moulded. The melt temperature ranges from 180°C to 210°C. Injection pressures during the injection moulding range from 400 to 1200 bar. The mould temperatures are typically between 20°C and 50°C. In addition to injection moulding, a similar processing technique of blow moulding can be applied to produce PVC. Blow moulding requires similar melt temperatures as injection moulding.

Extrusion is also a common form of processing PVC. The melt temperature required for extrusion is slightly less than that of injection moulding. Further processing methods include calendering, where thin sheets of PVC are produced.

2.1.2.4. Polypropylene (11)

Polypropylene is a semi-crystalline polymer. It can be processed as a homopolymer or a copolymer with 50% or more aliphatic olefins. Homopolymer polypropylene is known as PP-H, while polypropylene with a random copolymer is abbreviated as PP-R. PP has the following functional properties:

- It has a low density
- It has a high stiffness, hardness and strength

- It is also resistant to weak inorganic acids and alcohols

Table 7: Mechanical Properties of PP

Properties	PP-H	PP-R
Density (g/cm^3)	0.91	0.91
Tensile Strength (MPa)	35	30
Elongation at yield (%)	14	15
Impact strength (mJ/mm^2)	5 - No Break	No Break
Notched impact strength (Mj/mm^2)	4	15
Ball indentation hardness (N/mm^2)	65 -80	60 -65
Modulus of elasticity (MPa)	1400	1200
Service Temperature Long term (°C)	100	100
Service Temperature Short term (°C)	140	140

2.1.2.5. Polystyrene (12)

Polystyrene is an amorphous thermoplastic. It can be polymerized by mass, suspension or emulsion. It has the following functional properties:

- It has a high hardness
- PS has a high dimensional stability
- PS has a high stiffness and high tensile strength
- It is thermally stable at up to 80°C

- It has low water absorption
- It can be processed in flame retardant grades

Polystyrene can be easily processed by means of extrusion, injection moulding and blow moulding. The PS melt has good flow properties and thus is easy to process.

Table 8: Mechanical Properties of Polystyrene (13)

Mechanical Property	Value (Unit)
Specific Gravity	1.1
Tensile Strength	35.3 – 45.1 (MPa)
Elongation at Break	2.6 – 12 %
Flexural Modulus	1.7 – 2.7 (MPa)

2.1.2.6. Final Comparisons

The table below shows the final comparisons of the plastic materials. The tensile strength and the modulus of elasticity are focused on in more detail than the other mechanical properties.

Table 9: Properties of Plastic Polymers

Polymer Type	Tensile Strength (MPa)	Modulus of Elasticity (GPa)
PET	19	2 – 4
LDPE	8 - 10	0.2
HDPE	20 - 30	1
PVC	44.75	[redacted]
PP	30 - 35	1.2 – 1.4
PS	35 – 45.1	[redacted]

These are the other properties of polymers that are to be considered. A less intensive materials properties table can be extracted from *www.matweb.com* . This is a materials reference website. Below is a materials property table from this website. All the data represented in the literature review thus far has by all means attempted to obtain data from South African sources.

Table 10: Mechanical Properties of Polymers: Table extract from www.matweb.com (14)

Polymer Type	Ultimate Tensile Strength (MPa)	Elongation (%)	Tensile Modulus (GPa)
ABS	40	30	2.3
ABS + 30% Glass Fibre	60	2	9
Acetal Copolymer	60	45	2.7
Acetal Copolymer + Glass Fibre	110	3	9.5
Acrylic	70	5	3.2
Nylon 6	70	90	1.8
Polyamide-Imide	110	6	4.5
Polycarbonate	70	100	2.6
Polyethylene, HDPE	15	500	0.8
Polyethylene Terephthalate (PET)	55	125	2.7
Polyamide	85	7	2.5
Polyamide + Glass Fibre	150	2	12
Polypropylene	40	100	1.9
Polystyrene	40	7	3

2.1.3. Recycled Plastics

2.1.3.1. Plastic Recycling Process

Recycled plastic refers to plastic derived from processes after user consumption. It is commonly collected from municipal solid waste. There are several categories of recycled plastics. They are arranged according to a specific code that relates them to their specific type of polymer. North America has a code for plastic types which simply separates polymers numerically from 1-7. The plastics federation of South Africa (PFSA) has adopted the same standard. The table below shows what number relates to which type of polymer (15).

Table 11: Feed Stock Plastic Categories

NUMBER	POLYMER
1	Polyethylene Terephthalate (PET)
2	High Density Polyethylene (HDPE)
3	Polyvinyl Chloride (PVC)
4	Low Density Polyethylene (LDPE)
5	Polypropylene (PP)
6	Polystyrene (PS)
7	refers to other plastic types

It should be noted that t he more common categories for recycle plastic feed stock are category 2-6.

"Plastics are a diverse group of chemically complex compounds, whose use has grown explosively, so that they now present a growing disposal problem." Recycling of plastic has proven to reduce landfill masses (16). The typical process of recycling plastic is described in the figure below (16).

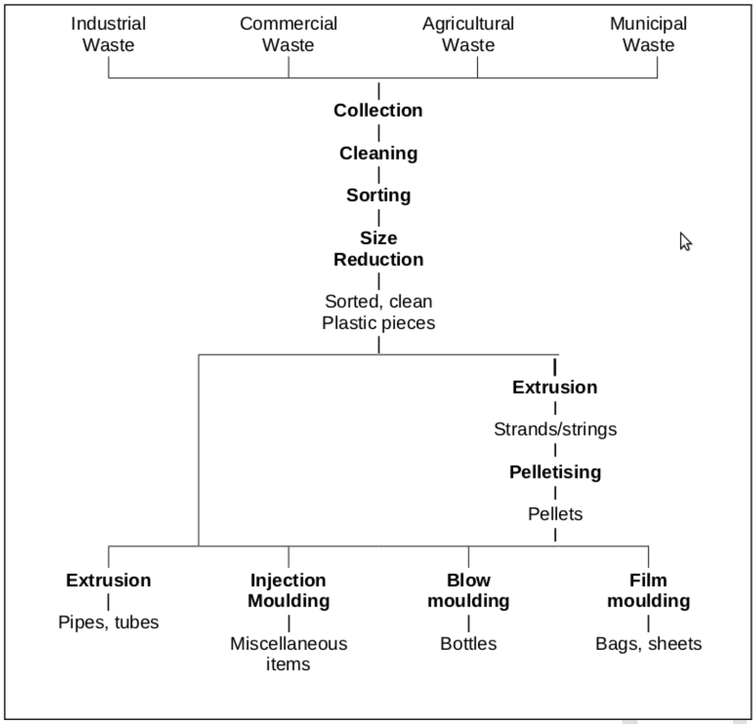

Figure 4: Plastic Recycling Process

As the diagram above explains, the material is first collected. There are various methods of collecting the plastic for recycling and it can be collected in different settings. Plastic can be collected in settings such as those described in the study by Arena, Mastelle and Perugini[1]. The settings are categorized as:

a) Semi-rural, where the collection area is approximately 667sqkm and a population density is approximately 193 people /km^2

b) Urban, where the collection area is smaller at 283sqkm and the population density is 1040 people/km^2

c) Super-Urban where the population density is 7418 people /km^2 and the collection area is 181sqkm.

Plastic can be collected via several methods. These methods include the options below:

a) House to house collection of all waste, house collection of unsorted plastic only and house to house collection of specific plastic products

[1] This is an Italian study which takes into account the collection of plastic in semi-rural, urban and super-urban regions of Italy.

b) Collection from a central point in a neighborhood
c) Purchasing plastic from scavengers on a municipal dump
d) Scavenging plastic from a municipal dump

After collection the material is cleaned, sorted and size reduced. It is either sorted by color, plastic type (thermoplastic or thermoset) or by product. The size reduction of the plastic can be performed by a shredder to produce irregular chips or by agglomeration. Agglomeration produces fine chips which can be fed into the hopper of an extruder (17) (16).

2.1.3.2. Life Cycle Assessment of Recycled Plastic

The wide spread use of plastic materials in industrial and engineering applications has had its advantages and disadvantages. The biggest disadvantage is the environmental cost of waste disposal. Work by Arena, Mastelle and Perugini show the environmental and energy savings inherent in recycled plastics. In this study the life cycle assessment of recycled PET and PE plastic is investigated. Factors such as sorting, transport and reprocessing were considered (18).

In the life cycle assessment of recycled plastic, every step of the recycling process will be analysed. The data analysed is from three different plastic recyclers in North and South Italy. The results of their energy consumption are averaged.

- The energy consumed during the **collection** phase is due to transport. It was found that the energy consumption per weight unit of collected plastic is 0.32MJ/kg.
- Several plastic waste management facilities use **compaction** stations in part of their recycling process. The average energy consumed by the compaction stations is 0.9MJ/kg.
- The **sorting** of plastics is a 58% efficient process. For every 1.73kg of plastic collected only 1kg of PET will be recovered. 0.11MJ of diesel and 0.16MJ of electricity are consumed per kg of plastic sorted.
- The energy consumed in the **reprocessing** of PET is 1MJ/kg for electrical energy and 2.5MJ/kg for methane energy.

Below is the process flow diagram for PET and PE recycled plastic. The diagram also shows the waste in mass (kg) of plastic for the processes involved. The total energy consumption for recycled PET and PE is 7.97MJ/kg and 20.70MJ/kg respectively.

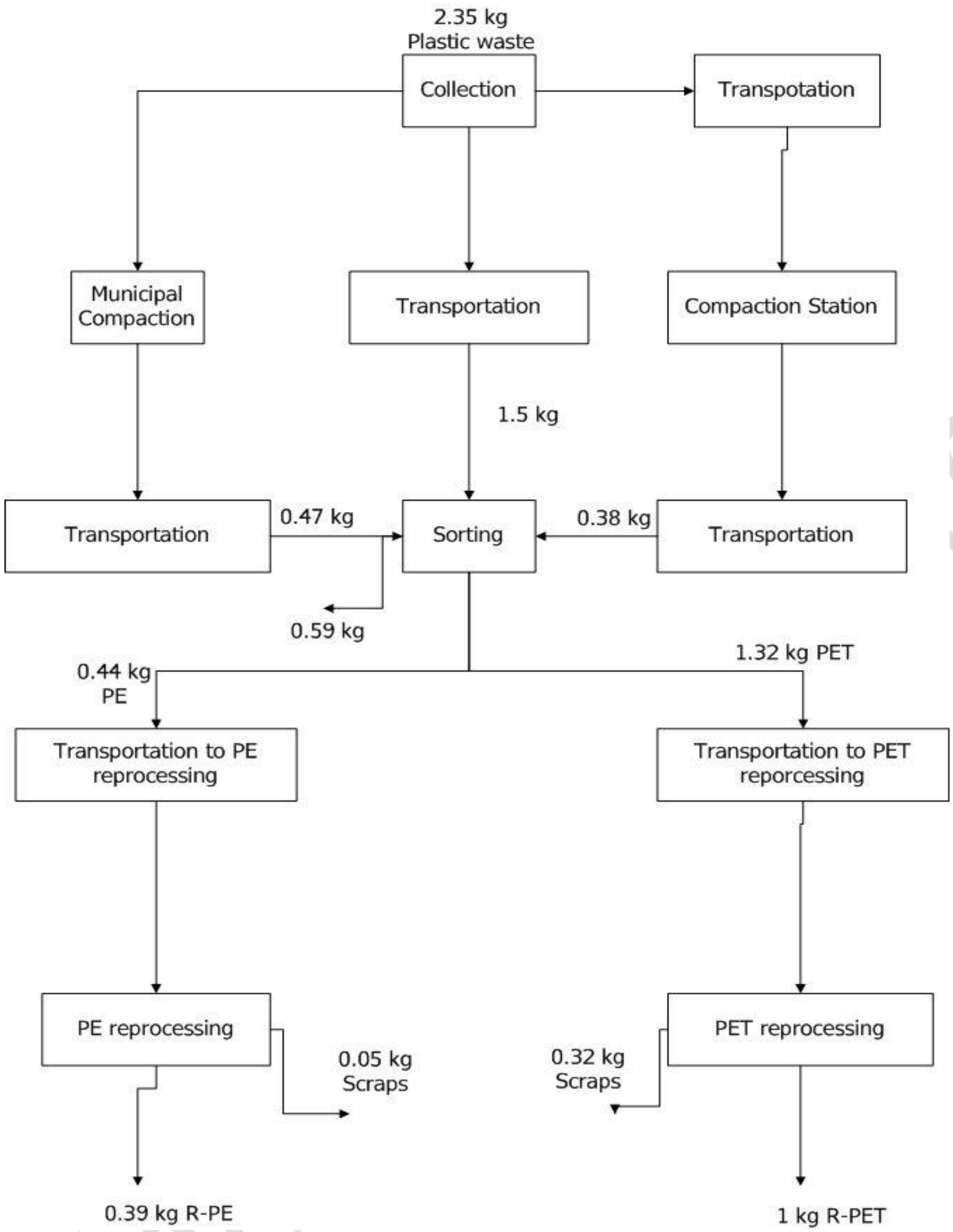

Figure 5: Recycled Plastic Flow Diagram

Recycled plastics are found to be useful as two broad products. The first product functions as a resin substitute. This is where the same polymeric product is made by substituting recycled resin for virgin material, in part or holistically. This can be done to a good degree of product quality and consistency. The second product functions as a material substitute. Examples of the second kind of recycled plastic product are recycled plastic being used instead of metal, wood or concrete (15). The second product will be the focus of the recycled plastics investigated for this report. This is because the pre-school fence was previously constructed from wood, metal and concrete.

2.1.3.3. Recycled Plastic Properties

The properties of the recycled plastic products are dependent upon the amount of virgin plastic resin and recycled plastic that exists as a percentage in the material. The amount of recrystallization that occurs in the material at the time of curing also plays an equal role in the virgin and recycled plastics alike in determining the mechanical properties.

PET (19)

Below is a material test on PET, it shows the percentage of recycled and virgin PET polymer in the material.

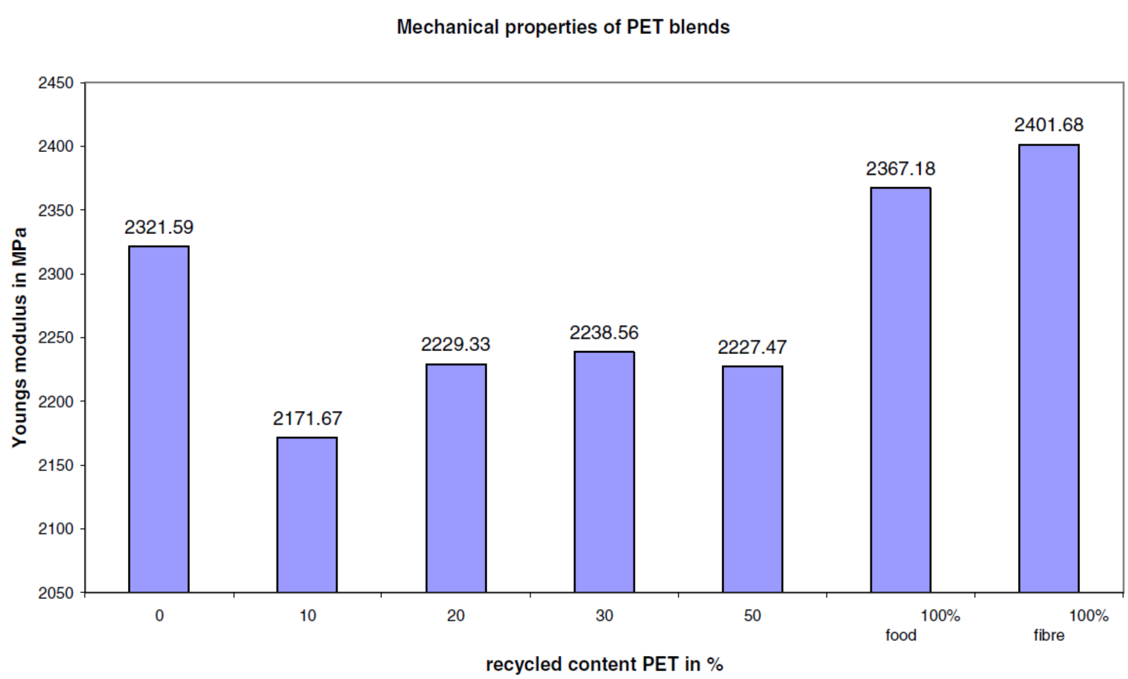

Figure 6: Young's Modulus of Recycled PET

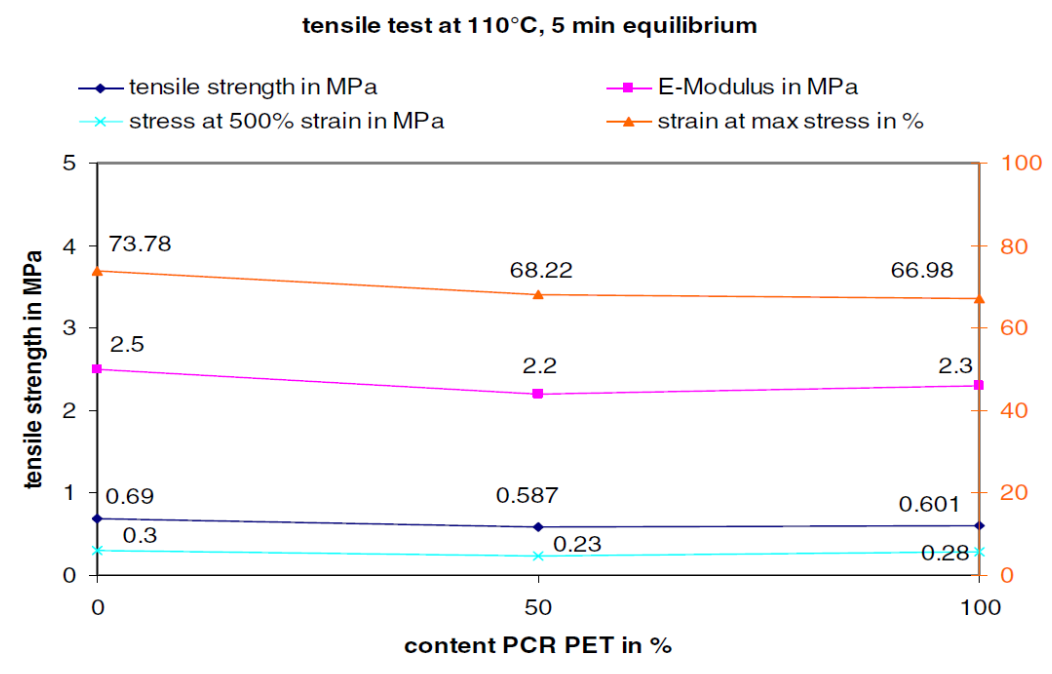

Figure 7: Tensile strength of recycled PET

Below is a table summarizing the results above

Table 12: Properties of rPET

Polymer Composition	Young's Modulus	Yield Strength	Yield Strain
0-100% rPET	2.1 – 2.3GPa	0.69 – 0.601MPa	67 – 73 %

POLYPROPYLENE (20)

Below are the properties of Polypropylene when it was recycled and modified with the addition of additives. The experiment where the results were obtained aimed to test the effectiveness of additives in recycled polypropylene. Post consumer waste polypropylene was used and no virgin polymer was added.

Table 13: Properties of rPP at 60°C

Polymer Composition	Young's Modulus	Yield Stress	Yield Strain
PP + s	320 – 590 (MPa)	13.6 – 14.5 (MPa)	9.9 – 13.5%

HIGH DENSITY AND LOW DENSITY POLYTHYLENE (21)

The properties of recycled LDPE and HDPE were taken from an experiment that tested the properties of recycled polyethylene with wood flour particles of 300 – 500 µm. The properties that are shown in the table below are from 300µm diameter wood flour composite polymer. The abbreviation $30SD_c$ was given to represent the addition of 300µm

Table 14: Properties of Recycled Polyethylene

Polymer composition	Young's Modulus(GPa)	Tensile strength (MPa)	Strain (%)
RPE + $30SD_c$	0.3	6.5	8
LDPE + $30SD_c$	0.316	7	11

POLYVYNIL CHLORIDE (22)

The table below shows the properties of recycled PVC. The PVC was collected in pellet form from a private company which recycled credit cards.

Table 15: Properties of Recycled Polyvinyl Chloride

Polymer composition	Young's Modulus (GPa)	Tensile Strength (MPa)	Strain (%)
R-PVC (100%)	1.83	32.16	4.18

2.1.3.4. Recycled Plastic Vs Virgin Plastic Properties

Below is a Table of collected information comparing the recycled and virgin plastics that could be used for the fence material.

Table 16: Recycled Plastics and Virgin Plastics Comparison

Plastic	Recycled Polymer (Tensile strength)	Virgin Polymer (Tensile strength)
PET	19	0.69
HDPE	20 – 30	6.5
LDPE	10	7
PP	30 - 35	13.6 – 14.5
PVC	45	32.16
PS	35 - 45	[redacted]

2.2. Plastic Lumber

Plastic Lumber is a composite material that is composed mainly of recycled plastic waste and wood fibers. The plastics/polymers are commonly High Density Polyethylene (HDPE), Low Density Polyethylene (LDPE) or Polyethylene (PP). These are polyolefins and commonly act as an adhesive for the wood fibers and other additives that make up the plastic lumber. Additives that are commonly added to plastic lumber are UV stabilizers, foaming agents and pigments (23). Plastic Lumber has been used in a variety of applications such as marine piling, pier and dock surfaces, fences and park benches (23). Even though previous research in plastic lumber has allowed it to be used in various applications, its structural properties are still not well understood. Furthermore the use of plastic lumber in structural applications is not authorized in common building codes (24).

2.2.1. Plastic Lumber ASTM & ISO Standards

The process for standardizing plastic lumber began in July 1993. The ASTM subcommittee D20.20.01 on Manufacturing Recycled Plastic Lumber & Shapes was formed to develop the needed test methods and specifications for plastic lumber materials (15).

The properties of the plastic lumber vary from different suppliers. This is due to the fact that there are no universal standards for the **production** of plastic lumber. In the event where a standard similar to that of steel were to be developed for plastic lumber, “most companies [would] not have adequate quality control programs to ensure that their products meet minimum standards” (24). There are however, guidelines available should one be willing to test plastic lumber. These guidelines to test plastic lumber were developed from the ASTM D20.20.01 committee. It should be noted that data representing the properties of plastic lumber in section 2.2.22 Engineering Properties was derived from the guidelines from the ASTM D20.20.01. Parts of this guideline are neither final nor official and should not be mistaken for a universal testing standard for all plastic lumber products.

The development of plastic lumber properties has proved more complex than the development of properties of more common engineering materials such as wood, metal and concrete. Plastic Lumber is non-homogenous. The cross-section of a plastic lumber beam is non-uniform along its length. The method of developing standards for plastic lumber was approached in an application specific manner. As plastic lumber is used in several applications such as decking boards, joists, marine fender piles and pallets, each of these applications require their own specification (15). The reason for the application specific standard is because of the large expected performance range of these applications. The residential decking board application promised the most significant market and was one of the first application specific standards to be developed. This standard is ASTM D6662, Standard Specification for Polyolefin Based Plastic Lumber Decking Boards (15). This is the standard which will be used in determining plastic lumber properties for the fencing material.

2.2.2. Engineering Properties

The engineering properties of plastic lumber which will be discussed in this section will include the results from an experimental study and experiments performed according to the ASTM D20.20.01 committee guidelines. The experimental study (23) was performed on a pier constructed for the use of loading and unloading of passengers aboard a boat. Plastic lumber samples were taken from the pier construction at different stages of the year after a certain period of being in use. The removed samples were replaced with identical lumbar profiles. The experiment performed according the ASTM D20.20.01 committee guidelines takes plastic lumber profiles and tests them for structural properties at low temperatures (simulating winter) and high temperatures (simulating summer). The table below shows the ideal testing standard by which the engineering properties from the ASTM D20.20.01 committee experiment should be received. The burden of structural change and property upgrading to implement these tests is on the plastic lumber companies. Other ASTM test methods are used where the below mentioned tests cannot be implemented.

Table 17: ASTM Testing Standards Relating Specifically to Plastic Lumber Materials

ASTM STANDARD	TEST DESCRIPTION
D6108	Standard Test Methods for Compressive Properties of Plastic Lumber and Shapes
D6109	Standard Test Methods for Flexural Properties of Unreinforced and Reinforced Plastic Lumber
D6111	Standard Test Methods for Bulk Density and Specific Gravity of Plastic Lumber and Shape
D6112	Standard Test Method for Compressive and Flexural Creep and Creep-Rupture of Plastic Lumber and Shapes
D6117	Standard Test Methods for Mechanical Fasteners in Plastic Lumber and Shape
D6341	Standard Test Methods for Determination of the Linear Coefficient of Thermal Expansion of Plastic Lumber and Plastic Lumber Shapes Between -30°F & 140°F
D6435	Standard Test Methods for Determination of Properties & Plastic Lumber Shapes

Table 18: Origin of Derived Properties

	PIER DOCK CONSTRUCTION STUDY (23)	ASTM 20.20.01 COMMITEE GUIDELINES (24)
DENSITY		X
DIMENSIONAL ANALYSIS	X	X
DUROMETER HARDNESS	X	
COMPRESSION MODULUS	X	X
COMPRESSIVE STRENGTH	X	X
BENDING (FLEXTURE) MODULUS	X	X
BENDING (FLEXTURE) STRENGTH		X

2.2.2.1. Density

The density of the plastic lumber as determined by the ASTM D792 ranges from 989kg/cm^3 - 1023kg/cm^3. The average density was found to be 1009kg/cm^3 (24). The average density will be used in calculations relating to weight and mass of plastic lumber used in the fence.

2.2.2.2. Dimensional Analysis (23)

This property is an indication of the stability of the material's dimensions. In an experimental study of plastic lumber used in pier construction such as the figure below, dimensions of the material's length, width and length were taken. Samples of the plastic lumber profiles measured to 1.2m length.

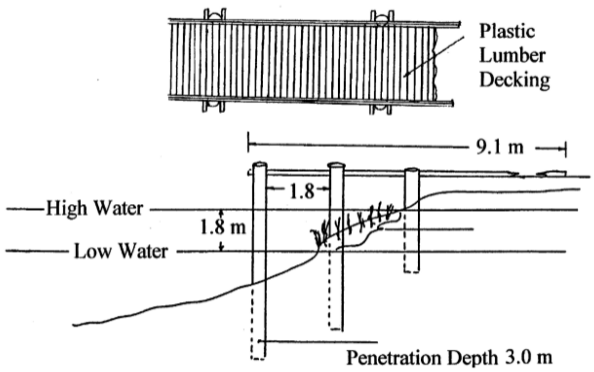

Figure 8: Decking Construction using Plastic Lumber and CCA Treated Wooden Lumber

The results of the plastic lumber dimensional stability experiment in this application showed that the plastic lumber remained within the manufacturers[2] claims (23). The results showed that the 1.2m plastic lumber sample was within 1.6mm – 3.2mm of its length.

2.2.2.3. Durometer Hardness (23)

The results of the durometer hardness tests show that the surface hardness of the plastic lumber is 60 ± 2on the Shore 'D' scale. The exposed cross sectional durometer hardness showed to be 30±2 on the shore 'D' scale. The more important property about the surface hardness of the plastic lumber is that is did not change over the 24 month period the tests were conducted.

2.2.2.4. Compression Modulus and Strength

The compression modulus of the plastic lumber samples was found to be 192MPa in-plane axis and 24MPa in the cross-sectional axis. Over the 24 month period of the experiment the compression moduli of the in-plane and cross-sectional axis were greater at 417MPa and 48MPa respectively. It was suspected the increase in the compression modulus was due to an increase in the moisture content of the plastic lumber (23). This increase in the compression modulus will not be assumed in the fence design as there could be other variables in that could have contributed to these readings.

The average compressive strength according to the ASTM D695[3] guided tests was found to be 37.3 MPa at low temperatures[4] and 16.8 MPa at high temperatures[5]. The compressive modulus was found to be

[2] Trimax Plastic lumber profiles were used
[3] Test method for the compressive properties of rigid plastics

22.5 GPa in low temperature while it was 5.76 GPa at high temperature. The large variation in the compression modulus is due to the different applications. Due to the large variety of applications and property demands for plastic lumber the process for standardization starts at recognizing the application. Standards for this application are then created. Since the pier dock experiment and the ASTM D6662 (plastic lumber for decking boards) are different applications the properties will have large variations.

2.2.2.5. Flexure Strength and Modulus (24)

The flexure tests were performed according to the ASTM D790[6]. The results of the low temperature flexure strength were found to be an average of 37.7 MPa and the average of the flexure strength at high temperatures was 12.0 MPa. The flexure modulus at high and low temperatures averaged 5.52 GPa and 1.03 GPa respectively.

2.2.2.6. Bending Modulus

The bending modulus according to the pier dock experiment found that the bending modulus was an average of 1400MPa in the in-plane axis. This property like the compression modulus, varied over the 24 month period. The figure below shows a plot of the in-plane and cross sectional axis bending modulus. The lower graph is the in-plane axis while the higher positioned plot is the cross sectional axis. The solid block shows the in-plane values while the solid circle shows the cross-sectional values.

[4] Average -23.3°C
[5] Average 40.6°C
[6] Test methods for flexural properties of un-reinforced and reinforced plastics and electrical insulating materials

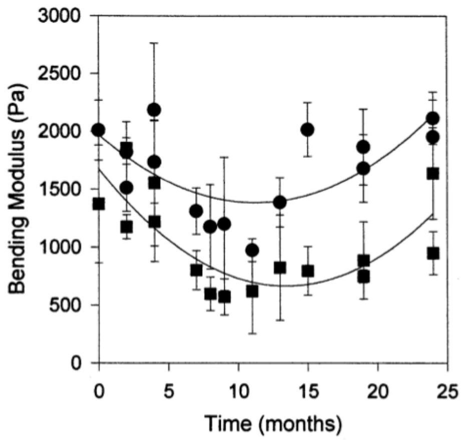

Figure 9: Bending Modulus of Plastic lumber in Pier Dock Experiment

Table 19: Final Properties of Plastic Lumber

Mechanical Property	Value (Unit)
Density	989 – 1023 kg/m^3
Compression strength	16.8 – 37.3MPa
Compression Modulus	0.417GPa
Bending Modulus	1.03 – 5.2GPa
Bending Strength	12 – 37.7MPa

2.3. Concrete and Brick

Concrete is the most widely used man-made material in the world. It is mainly composed of Portland cement, fly ash, water, chemical additives and aggregate. The fly ash is a byproduct from coal-fired powered plants while the aggregate is consistent of fine sand and coarse gravel. The concrete mixture can be considered a composite material. The properties of cement and water alone provide a brittle material, while the addition of aggregates creates a less brittle construction material. Fences can be constructed from concrete.

The process by which the mixture is combined is a hydrolysis process. The process by which the concrete mixture hardens is termed curing. The curing process is vital to the material's performance over time. The wet, "plastic", flowing mixture is initially weak and over time hardens and gains strength. Over a three week period, 90% of the strength has been obtained.

2.3.1. Structural Properties

The properties of the concrete are determined by the proportion of each composition (e.g. water, fly ash, cement) that has been added. Another factor that influences the properties of concrete is the additives. Rubber chips from car tires have some promise as additives that increase the toughness of the concrete (25). The results of a study[7] involving the use of rubber chips instead of coarse aggregate are shown in the table below.

Table 20: Properties of Concrete with Rubber Chips as Aggregate

Volume of Rubber Chips Aggregate (%)	Compressive strength (MPa)	Flexural Strength (MPa)
0	31.9	3.8
25	19.6	3.5
50	13.8	3.1
75	9.9	2.8
100	7.5	2.4

[7] 100mm diameter, 200mm height, cured for 28 days samples for compressive strength and 100X100X350mm for flexural strength.

It can be noticed that the greater the percentage of rubber chips in the concrete the less the compressive and flexural strength. The advantage of rubber chips only comes from the increased toughness. Below is a graph plotting the load vs. strain for both the compressive strength test and the bending test.

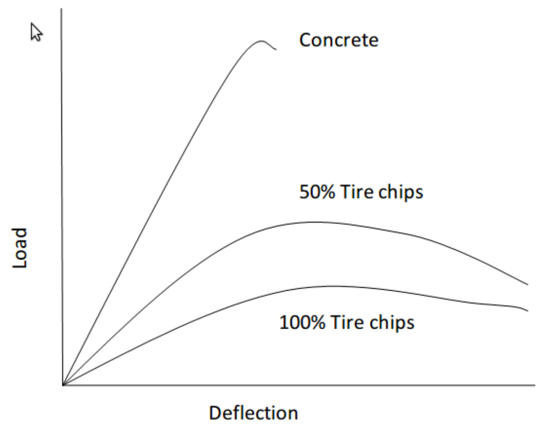

Figure 10: Load vs. Deflection Graph of Compressive Test

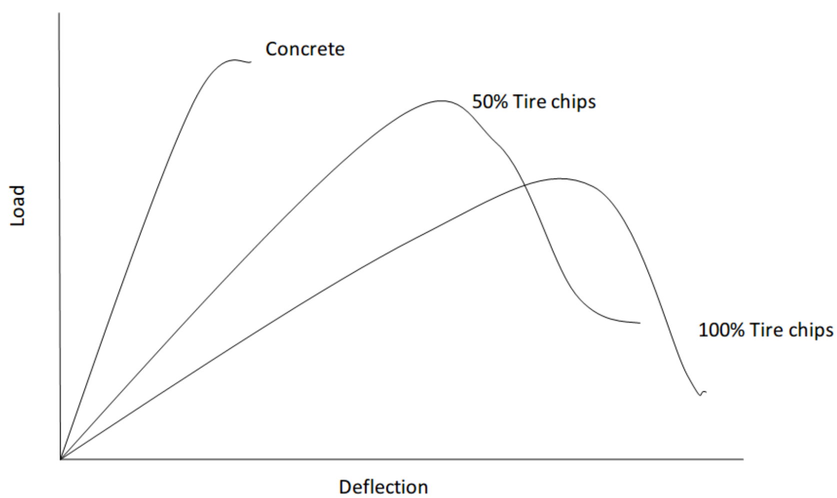

Figure 11: Load vs. Deflection Graph of Bending Test

The catastrophic failure of concrete can be avoided in low load applications such as those that are non-structural. It can be avoided by the addition of recycled tire chips that could be added instead of coarse aggregate. In an application where vandalism can be a critical factor which one should design against, the tough material is ideal.

3. FENCE DESIGN REPORT

This section deals with the design of the fence that will be installed in the preschool. The focus of the design report will be on the load analysis and the associated cost of production.

The wind loading on the fence will try to determine the main the uniformly Distributed Load (U.D.L) that the fence will experience. In addition to the wind loading several other loading factors are considered. This is the human loading on the fence.

The cost of the fence will be determined per meter of installation. Other materials that were not discussed in the literature review of the material will be considered only to compare prices and the viability of the materials checked in the literature review.

3.1. Wind Loading on Fence (26)

The speed of the wind causes a load on the fence structures. The document by Krishna et al. gives equations for wind loads on buildings and structures.

A gust of wind averaged over a short period of time (approximately 3 seconds) on a 10m height above ground level is termed V_b. This wind speed simulates the wind speed at 10m above the ground level. Considering that the fence is not 10m tall an adjustment factor to accurately determine the wind velocity at its height is required. This is the design velocity. A design wind speed termed V_z can be formulated from the gust wind speed at any height z.

$$V_z = k_1 k_2 k_3 k_4$$

Where k_1 represents the probability factor (or risk coefficient) which can be determined with the assistance of the table below

Table 21: Probability/ Risk Factor for Wind Loading k_1

Class of Structure	Mean Probable design life of structure in years	k_1 factor for Basic Wind Speed (m/s) of					
		33	39	44	47	50	55
All general buildings and structures	50	1.0	1.0	1.0	1.0	1.0	1.0
Temporary Sheds, structures such as those used during construction operations structures during construction stages and boundary stages	5	0.82	0.76	0.73	0.71	0.70	0.67
Buildings and Structures presenting a low degree of hazard to life and property in the event of failure, such as farm buildings other than residential buildings	25	0.94	0.92	0.91	0.90	0.90	0.89
Important buildings and structures such as hospitals, communication buildings, towers and power plant structures.	100	1.05	1.06	1.07	1.07	1.08	1.08

In the equation above the term k_2 represents the terrain roughness and height factor. This factor can be determined by the table below.

Table 22: Terrain roughness and Height Factor k_2

Height (m)	Terrain Category 1	Terrain Category 2	Terrain Category 3	Terrain Category 4
10	1.05	1.00	0.91	0.80

In the table above the terrain categories are defined according the criteria below:

- Category 1 is an open terrain with a few or no obstructions and in which the average height of any object surrounding the structure is less than 1.5m.
- Category 2 is an open terrain with well scattered obstruction having a height of generally between 1.5m and 10m.
- Category 3 is a terrain with numerous closely spaced obstructions having the size of building structures up to 10m in height with or without isolated tall structures.
- Category 4 is a terrain with numerous large closely spaced obstructions.

From the design Velocity at a height z, we can the wind pressure at height z which is represented by the equation below.

$$P_z = 0.6V_z^2$$

Where 0.6 is constant derived from $\frac{1}{2}\rho = 0.6$, the density of air is 1.2kg/m^3.

The wind speed in the Cape Area can be estimated using the Gumbel analysis. This method yields more accurate results for the speed maxima for a longer return period.

Over a 10 year period the wind speed gust can be taken as 25.6m/s (26) (27).

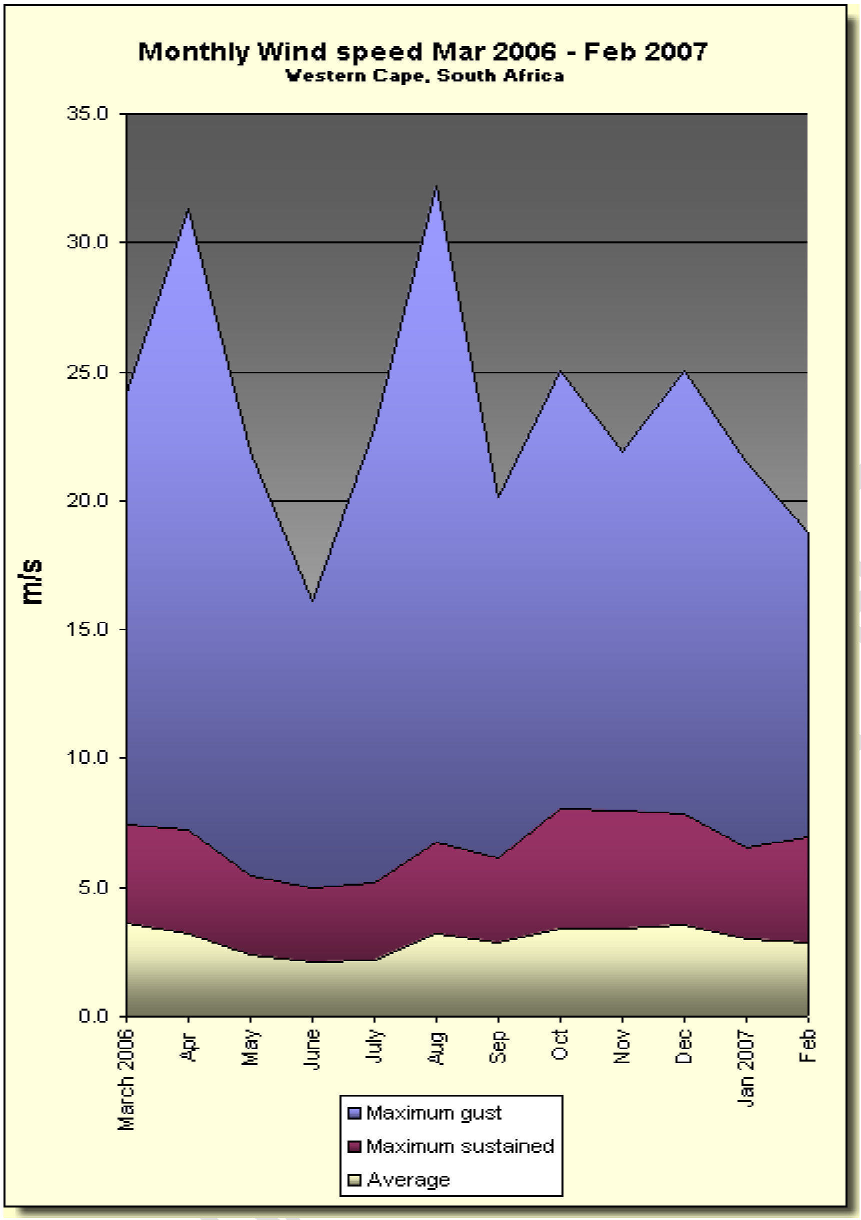

Figure 12: Wind Speed Western Cape

Below is a table from the catalogue . The catalogue gives the available sizes for various recycled plastics and plastic lumbers.

Table 23: Data for Plastic Lumber Products and U.D.L. at Maximum Wind Speed

Moment of Inertia Plastic Lumber				Wind Loading						
b	d	d^3	(bd^3)/12	Length (L)	Design (L)	Face Area A	Force Load	UDL	Price	
(mm)	(mm)	mm^3	mm^4	(mm)	(mm)	(L x d) mm^2	A x Pd (N)	N/mm	£	R
75	50	125000	781250.00	2500	1600	120000	4213.62	2.63	11.25	135
140	100	1000000	11666666.67	2500	1600	224000	7865.42	4.92	38.7	464.4
300	50	125000	3125000.00	1800	1600	480000	16854.48	10.53	34.26	411.12
43	43	79507	284900.08	1800	1600	68800	2415.81	1.51	5.09	61.08
53	53	148877	657540.08	1800	1600	84800	2977.62	1.86	6.92	83.04
70	70	343000	2000833.33	2000	1600	112000	3932.71	2.46	12.46	149.52
80	80	512000	3413333.33	2500	1600	128000	4494.53	2.81	6.79	81.48
80	80	512000	3413333.33	2500	1600	128000	4494.53	2.81	9.58	114.96
60	20	8000	40000.00	2000	1600	96000	3370.90	2.11	6.69	80.28
100	30	27000	225000.00	3000	1600	160000	5618.16	3.51	11.8	141.6
70	40	64000	373333.33	2500	1600	112000	3932.71	2.46	10.1	121.2
120	40	64000	640000.00	2000	1600	192000	6741.79	4.21	19.38	232.56
100	100	1000000	8333333.33	2150	1600	160000	5618.16	3.51	25.11	301.32

Table 24: Moment of Inertia for Recycled Plastic and U.D.L. at Maximum Speed

Moment of Inertia Recycled Plastic Bollards and Waymarkers													
b	d	d^3	(bd^3)/12	D	D^4	(πD^4)/64	Length (L)	Design (L)	Effective Area A	Force Load	UDL	Price	
(mm)	(mm)	(mm)^3	(mm)^4	(mm)	(mm)^4	(mm)^4	(mm)	(mm)	(L x d) mm^2	A x Pd (N)	N/m	£	R
				100	100000000	4908739	1500	1400	140000	4915.96	3.51	38	456
				125	244140625	11984225	1500	1400	175000	6144.95	4.39	45	540
75	75	3.2E+07	197753906				1340	1200	90000	3160.26	2.63	13.84	166
100	100	1E+08	833333333				1600	1400	140000	4915.96	3.51	20.56	247
150	150	5.1E+08	6.328E+09				1600	1400	210000	7373.94	5.27	43.94	527
				65	17850625	876240.5	1500	1400	91000	3195.374	2.28	7.46	89.5
				75	31640625	1553156	1800	1400	105000	3686.97	2.63	10.87	130
				95	81450625	3998198	2000	1400	133000	4670.162	3.34	19.37	232

The force calculations in for the wind loading above was calculated using the values in the table below. The design length is the length of the fence to be installed in the pre-school.

Table 25: Wind Loading Calculations at Maximum Wind Speed

Vb(m/s)=	25.5	Pz(Pa)=	390.15
Vz(m/s)=	20.91	Pd(Pa)=	351.135
k1=	0.82	kd=	0.9
k2=	1	ka=	1
k3=	1		
k4=	1		

K_d is the wind directional factor. For circles the wind direction factor is 1 and the factor for triangles and rectangular objects is 0.9.

K_a is the Area averaging factor. In an area of less than $10km^2$ the factor is 1 and for an area of between $10km^2$ and $25km^2$ is 0.9.

The above data is to determine the uniformly distributed load that is caused by the wind. These calculations are taken at the highest wind speed (3s gust).

3.2. Human loading on Fence

The Free body diagram(FBD) below simulates the human loading that will be dealt with by the calculations. The first FBD shows a person jumping on the fence while the second FBD shows a person pushing the fence. The assumption is made that the loading on the fence is 80kg*9.81m/s^2. This is the approximate weight of an adult person.

3.3. Total Loading and Selection

The total loading and the information from the literature review gives us an idea of the fence dimension that will be needed to provide a stable fence. The graph below shows stress experienced by the plastic lumber sections (which are available as recycled plastic) plotted against the wind speed. The human loading is taken as a constant and the variable can be considered to be wind speed. When looking at the recycled materials plastic materials, only the PVC has a stress above 30MPa[8]. While the plastic lumber properties which were determined under ASTM standard showed maximum flexure strength of 37.7MPa. It is expected for the properties of plastic lumber to be very similar to those of the recycled plastic as the plastic resin that is used in the plastic lumber is from recycled plastic. From the graph below a 100 x 100 mm cross section piece will be used to build the plastic lumber or recycled plastic fence. The rest of the decision will be based on cost.

[8] This can vary from supplier to supplier

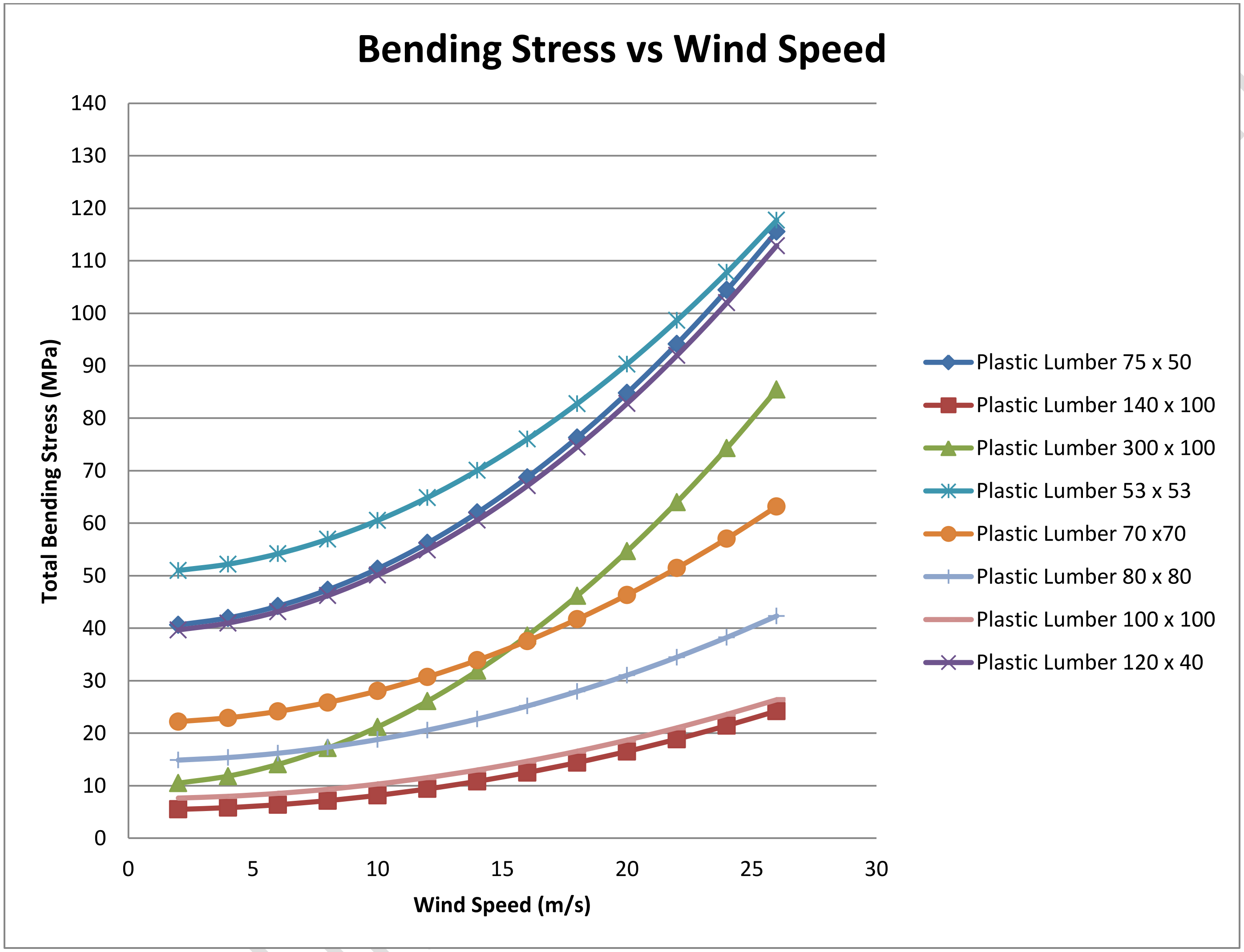

Figure 13: Behavior of Various Plastic Lumber Profiles under Wind Loading

Patent Search Review

The patent search looks a wide variety of fence designs that can be taken as a starting point for the design of the fence for the pre-school.

3.3.1. PATENT 1

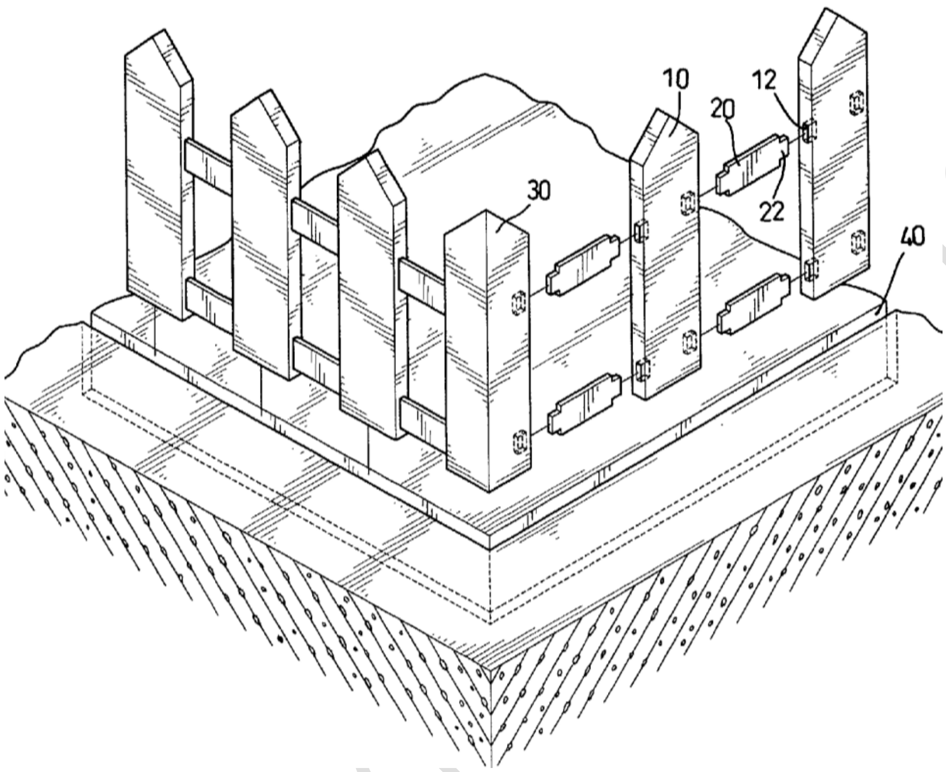

Figure 14: Patent of a simple fence design (29)

The above fence design can be easily assembled and installed. The disadvantage to this design is the ease by which it can be disassembled or dismantled and stolen.

Other forms of connecting the fence are shown below

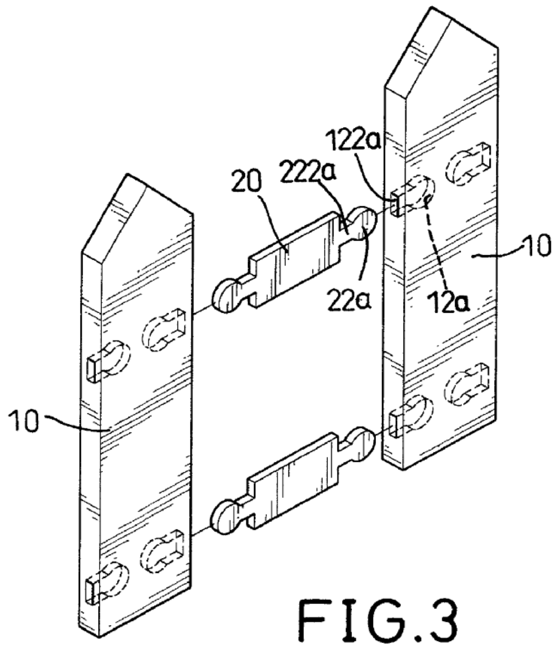

FIG.3

Figure 15: Fence connection method 2 (29)

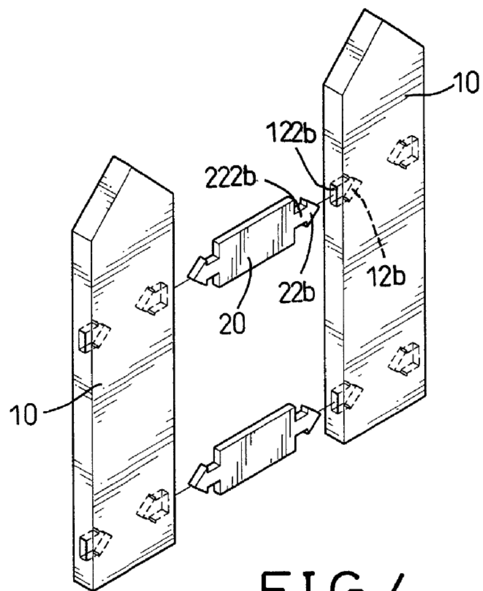

FIG.4

Figure 16: Fence connection Method 3 (29)

3.3.2. PATENT 2 (30)

The patent below shows a fence which can be assembled by connecting the individual component halves into one piece. This is a simple clip on design and has the advantage of a material saving as it is hollow. This could result in lesser fence material cost.

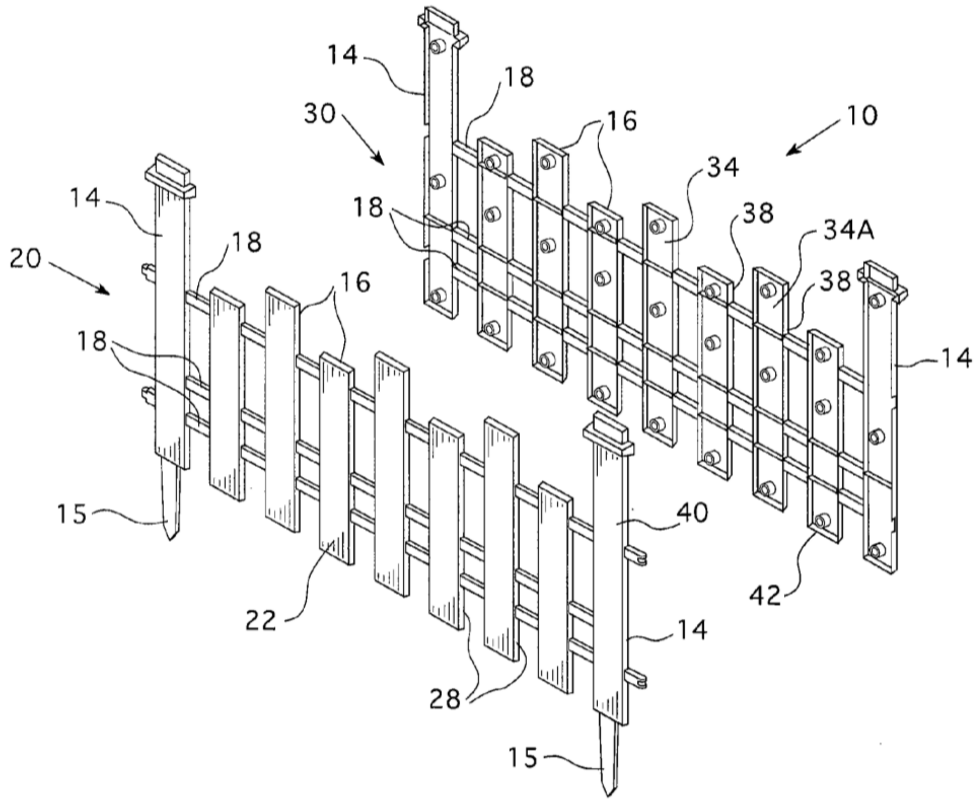

Figure 17: Patent of fence design

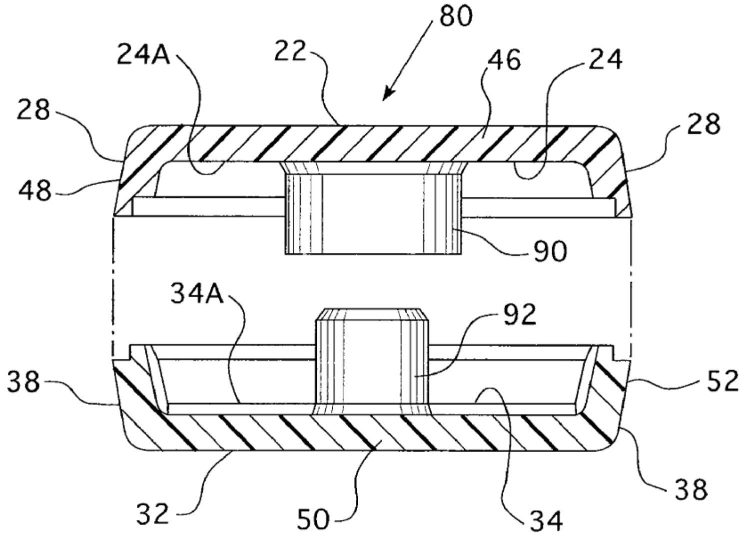

FIG. 2

Figure 18: Detailed Connection View

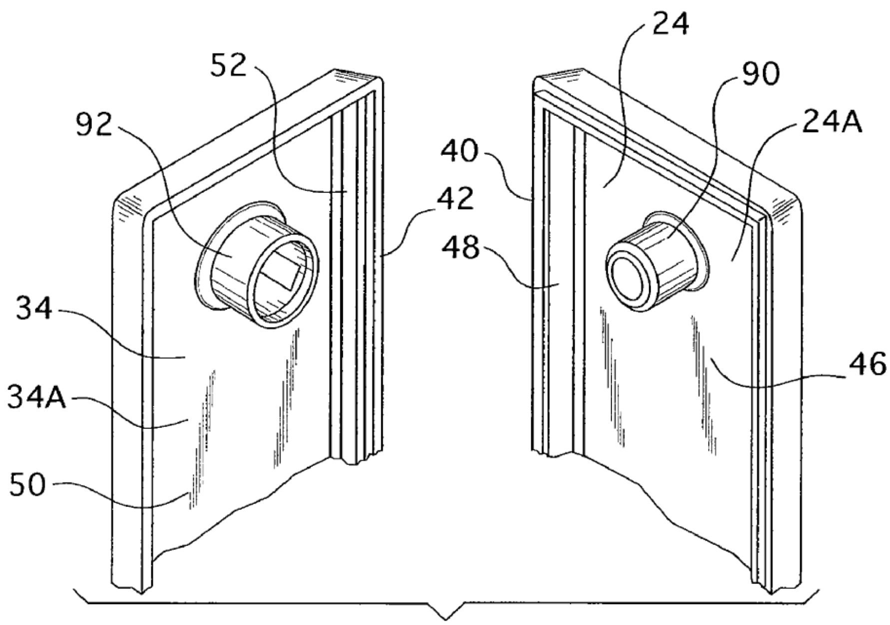

Figure 19: Connection of the component halves

3.3.3. PATENT 3

Below is a patent showing a fence with components that are tightly assembled together. The disadvantage of this fence is that it blocks visibility. As one of the requirements of the pre-school fence was to reduce the criminal activity by increasing visibility of the fence area, this fence would have to be modified to resemble patent 1.

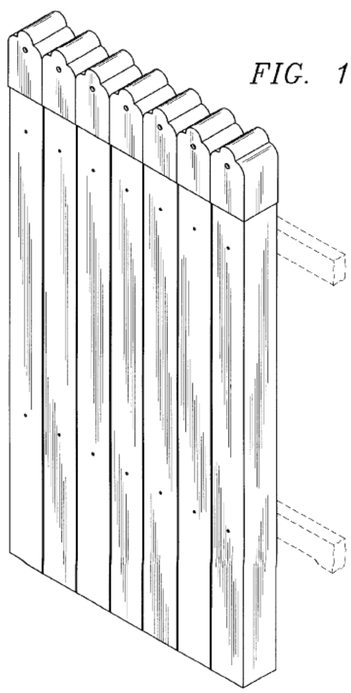

Figure 20: Tightly assembled plastic fence

A patent similar to that of patent 1 and patent 3 are going to be used as a starting point for the fence design. The design of the fence can be seen in the image below. This fence shows the meter sample of the fence.

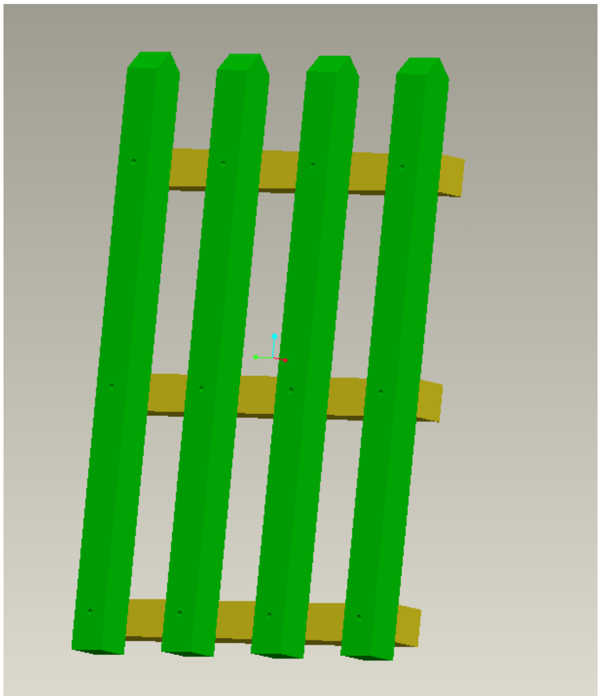

Figure 21: Fence design 1m

4. MATERIAL COST

This section deals with the cost of the materials that will be used in the fence.

For every meter of the fence that is used the following material products will be used:

7 x (100 x 100) sample components

12 x M16 bolts and nut set

Component	Cost per Unit	Total Cost
7 x (100 x 100)	301.32	R2109.24
12 x (M16) bolts	R10	R120
[redacted]		R2229.24

The cost of the fence can also be reduced by increasing the number of longitudinal components. For the 20m length required for the fence in the pre-school it would cost an excess of R22 290.

5. CONCLUSION

The fence material that is to be selected for the fencing material is HDPE. It is easily available in South Africa from the suppliers in Appendix B. If the material is to be selected from a recycled plastic or plastic based composite then plastic lumber similar to that used in benches can be used. It has good tensile strength and additives can be used to retard flammability, reduce creep and add color.

The material can be processed via extrusion.

The wind loading calculation and human loading calculations show that the section can be a 100x100mm. It would survive heavy extreme loading conditions if it is produced from the materials above.

The patent search proved to provide similar simple designs of fences. The chosen patent to base the design upon was the Patent 1.

The cost of the 1m fence is calculated to be an excess of 2000zar. The total for the 20m perimeter of the play area is 44 500zar. These prices were based on the material being exported due to the inconsistency of South African manufactures' prices and properties.

BIBLIOGRAPHY

1. *Household fuelwood use in small electrified town of the Makana District, Eastern Cape, South Africa.* **Shackleton, Gambiza and Jones.** 2007, Journal of Energy in Southern Africa, pp. 4-10.

2. *The Prevalence of Substance use and its Associations amongst Students attending High School in Mitchells Plain, Cape Town.* **Hamdulay, AK and Mash, R.** 2011, S Afr Fam Pract, pp. 83-90.

3. **Silberberg, Martin.** *Chemistry, The Molecular Nature of Matter and Change.* New York : McGraw-Hill Higher Education, 2003.

4. **Budynas, R and Nisbett, K.** *Shigley's Mechanical Engineering Design.* New York : McGraw Hill Higher Education, 2008.

5. **Sepe, Micheal.** [Online] [Cited: 16 March 2011.]

6. *Effects of Changing Enviroments on Microstructure of HDPE Polymer.* **Bal, S, et al.** 2007, Journal of Minerals and Material Characterization and Engineering, pp. 1-16.

7. **Technologies, Phoenix.** Phoenix Technologies. *Phoenix Tecnologies.* [Online] [Cited: 10 May 2011.] http://www.phoenixtechnologies.net/why/PET%20Properties%202008.pdf.

8. **Africa, Plastic Federation of South.** Plastic Federation of South Africa/PE. [Online] Plastics Federation of South Africa. [Cited: 10 April 2011.] http://www.plasticsinfo.co.za/PE-HD.asp.

9. **Africa, Plastics Federation of South.** Plastics Federation of South Africa PVC. *Plastics Federation of South Africa PVC.* [Online] Plastics Federation of South Africa PVC. [Cited: 11 April 2011.] http://www.plasticsinfo.co.za/PVC.asp.

10. —. http://www.plasticsinfo.co.za/PET.asp. *http://www.plasticsinfo.co.za.* [Online] March 2011. [Cited: 25 March 2011.] http://www.plasticsinfo.co.za/PET.asp.

11. Plastics Federation of South Africa. *Plastics Federation of South Africa PP.* [Online] Plastics Federation of South Africa PP. [Cited: 10 April 2011.] http://www.plasticsinfo.co.za/PVC.asp.

12. Plastics Federation of South Africa. *Plastics Federation of South Africa PS.* [Online] Plastics Federation of South Africa PS. [Cited: 10 April 2011.] http://www.plasticsinfo.co.za/PS.asp.

13. *Chemical Resistance Evaluation of Polystyrene/Polypropylene Blends: Effect of Blend Compositions and SEBS Content.* **Samsudin, Sani Amril, et al.** 1, Johor, Malaysia : Malaysian Polymer Journal, 2006, Vol. 1.

14. **Matweb.** Typical Tensile Strength of Polymers. *Matweb.* [Online] Matweb. [Cited: 10 May 2011.] http://www.matweb.com/reference/tensilestrength.aspx.

15. *From Waste Plastics to Markets for Plastic Lumber Bridges.* **Krishnaswamy, P and Lampo, R.** Recycled Plastic Lumber Standards.

16. **Practical Action, The Schumacher Centre for Technology and Development.** Recycling Plastics. *Practical action.* [Online] [Cited: 1 April 2011.] www.practicalaction.org.

17. Netplastmak. *www.netplasmak.com.* [Online] [Cited: 30 March 2011.] www.netplasmak.com/en/agglomeration.

18. *Life Cycle Assesment of a Plastic Packaging Recycling System.* **Arena, Umberto, Mastellone, Maria and Perugini, Floriana.** 2003, International Journal LCA, pp. 92 - 98.

19. *Thermal and Mechanical properties of recycled PET and its blends.* **Pattabiraman, Parthasarathy, Sbarski, Igor and Spurling, Tom.** Melbourne : ANTEC, 2005, Vol. 3225.

20. *Modification of mechanical properties of recycled polypropylene.* **Brachet, P, et al.** Trondheim : Waste Management Journal, 2008, Vol. 28.

21. *Mechanical Properties of Recycled Polyethylene Ecocomposites Filled With Natural Organic Fillers.* **La Mantia, F and Morreale, M.** Palermo : Polymer Engineering and Science (Wiley), 2006.

22. *Mechanical Properties of Recycled PVC Blends with Styrenic Polymers.* **Garcia, D, et al.** Valencia : Journal of Applied Polymer Science, 2005, Vol. 101.

23. *Long-term Engineering Properties of Recycled Plastic Lumber used in Pier Construction.* **Breslin, T, Senturk, U and Berndt, C.** 1998, Resources, Conservation and Recycling, pp. 243-258.

24. *Structural Properties of Recycled Plastic/Sawdust Lumber Decking Planks.* **Carrol, D, et al.** 2001, Resources Conservation and Recycled, pp. 241-251.

25. *The Use of Rubber Particles in Concrete to Replace Mineral Aggregates.* **Toutani, H.** 1996, Cement and Concrete Composites, pp. 135-139.

26. **Krishna, Prem, Krishen, Kumar and Bhandari, N.** *Wind Loads on Buildings and Structures-Proposed Draft and Commentary.* Roorkee : Department of Civil Engineering Indian Institute of Technology Roorkee, 2004.

27. *Estimation of Extreme Wind Speeds in the Mixed Strong Wind Climate of South Africa.* **Kruger, A.** Pretoria : s.n., 2010.

28. **cape, Wind Power western.** Wind Power western cape. *Wind Power western cape.* [Online] Wind Power western cape. [Cited: 2 May 2011.] http://windpower.org.za/westerncape/westerncape.html.

29. **Tsao, Hsien-Yang.** *Plastic Fence Assembly. US2002/0109132* United States of America, 15 August 2002.

30. **Cook, John.** *Plastic Fence. US 2009/0230371* Pittsburgh, 17 September 2009.

APPENDIX A

- Ethics Form
- Impact of Technology Form

APPENDIX B