UNIVERSITY OF NAIROBI

DEPARTMENT OF CIVIL AND CONSTRUCTION ENGINEERING

To investigate the extent of use of expanded polystyrene panels for building construction in Kenya

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Abstract

Kenya is currently facing a housing deficit due to an increasing middle class and a slow rate of construction of houses. Some of the reasons causing this deficit are the high cost of construction, long time taken to finish projects due to unpredictable weather conditions, varying workmanship on site and unexpected hiking of material costs. Introduction of new building technology, that uses expanded polystyrene panels, has led to reduction of the time and costs spent in construction of houses while producing housing products with innovative, modern and green credentials. This method of housing was officially approved by the Kenyan government in 2004 and has brought higher output capacity enabling realization of important projects.

This project sought to investigate the extent of use of the expanded polystyrene panels for construction in Kenya and assessed the strength of expanded polystyrene wall and slab panels. It also compared the time and cost incurred when constructing using the expanded polystyrene panels and conventional methods using machine cut masonry stone, and how this method of construction conserves the environment. The study approaches that were used are questionnaires, site visits and photography, interviews, desktop studies and minor lab tests to ascertain the information received about the strength of the expanded polystyrene panels. .

It was concluded that the use of the expanded polystyrene panels for construction in Kenya is yet to gain momentum. The study proved that expanded polystyrene wall and slab panels are strong enough to be used for construction of walls and floor slabs in buildings and conserves the environment. A time saving of 50% and cost saving of 30% though labor, transport and hiring of construction equipment and formwork, are being achieved.

Dedication

This piece of work is dedicated to my dear parents, brothers and sisters who have always believed in me and encouraged me through my education. Thank you for your unrivaled support and prayer throughout.

Most thanks to The Almighty God who has abided with me through the ups and downs and enabled me to achieve victory.

Acknowledgement

Special thanks to my supervisor Eng. Mrs. Monicah Gathoni Wokabi for her continuous and un-ending informed advice. Your effort at providing advice to me is greatly valued.

To Nicholas and Muchina of the concrete Lab University of Nairobi, your support and guidance was of great value.

To Lillian Kageni who was my partner in researching about expanded polystyrene in Kenya, may you have success in your project and career.

To all my classmates and friends whose company and team spirit enriched my stay at the university, may God bless you all. You will be missed.

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1.0 Introduction

1.1Background information

Real estate and housing projects have faced challenges during the construction stage, for example, adverse weather conditions which could not be predicted, varying workmanship on site and unexpected hiking of material costs. Sourcing of materials from different locations and suppliers also leads to uncertainty of the time required for a building project to finish. The construction industry has continuously embraced the introduction of new technology which makes buildings stronger, construction methods faster, more cost effective and environmentally friendly. This has led to reduction of in-situ construction; for example, wall and roof panels can be made under factory settings and assembled on site.

The first record of a prefabricated house was in 1837, where a prefab house called the Manning Portable was advertised, having being built by Henry Manning, a London architect, builder, carpenter, and entrepreneur (Postcards 2009). In 1855 during the Crimean War, Florence Nightingale asked for a prefabricated hospital to be built and delivered to Dardanelles for assembly. A one thousand patient hospital was built with innovations in ventilation, sanitation and flushing toilets (Aganto 2013).

Construction of prefabricated houses using expanded polystyrene panels gained popularity during the Second World War, because of the high demand by military staff, especially in America and Britain. Furthermore, many houses were destroyed during the same period so prefabricated housing was a quicker and affordable way of making quality homes for the many who were left homeless. By late 1940, more than 160,000 prefab homes made of expanded polystyrene had been built with the biggest recorded estate of the same being in Liverpool England, where more than a thousand units had been constructed (Postcards 2009). At present, expanded polystyrene houses are now associated with innovative, modern and green credentials. This is because it is easier incorporating environmentally friendly materials in such houses since the structures are built in parts.

1.2 Introduction to study

Use of expanded polystyrene panel introduces a factory aspect in the construction of reinforced concrete buildings. This industrial system entails production of a panel of wavy/undulated shape of polystyrene which is covered on either side with electro welded zinc coated square mesh. There are 33 connectors of the square mesh per m^2 to form a three dimensional hyper static reinforcement steel. There are two kinds of polystyrene panels, single and double. A single panel has a polystyrene sheet sandwiched between welded wire mesh on either side while a double panel is made of two single panels which are joined with an intermediate cavity. A building can go up to four floors with a single panel and fifteen floors in double panel. Assembly of the finished panels is done on site. A single operator can lift and place the panels at their respective design positions creating labor savings compared to traditional construction techniques which requires several workers to put up a wall using masonry stone and plaster.

It is easier, cheaper and faster to construct a building using expanded polystyrene panels. The polystyrene core is associated with desirable properties such as fire resistance and sound proofing. The finished structure is earthquake and storm resistant with possession of superior strength. The versatility and flexibility of design of the expanded polystyrene panels make it user friendly too during construction. Smaller values of factors of safety are included in the structural design of such buildings since factory settings under which the panels are made ensure standard panels are produced for use in construction. Original design specifications such as size, strength and behavior of structural members are therefore easily achieved.

1.3 Problem statement

Developing countries especially those in Africa, such as Kenya, are facing the challenge of a growing middle class with greater demand for housing facilities. Faster and more affordable methods of construction are being sought after now more than ever before. Increased innovation aimed at reducing the cost of construction, and creating affordable housing, is being integrated into methods of building and construction. This has led to introduction of factory settings in the construction process which reduces the negative aspects of in-situ construction such as theft, unreliable supply of labor, unpredictable weather conditions, unprecedented fluctuations in prices of materials and plenty of energy consumption. For example, transporting the various construction materials to the site usually leads to a large carbon footprint through CO_2 emissions.

Introduction of a factory aspect to the construction industry reduces the impact of the challenges above while still meeting building standards and saving on construction costs.

1.4 Objectives of the study

- To investigate the extent of use of the expanded polystyrene panels for construction in Kenya
- To assess the strength of expanded polystyrene wall and slab panels
- To compare the time and cost incurred when constructing using expanded polystyrene panels and conventional methods using machine cut masonry stone
- To investigate how use of the expanded polystyrene panels for construction conserves the environment

1.5 Methodology

The study approach used was tailor made to achieve the objectives of the field study project. To investigate the extent of use of expanded polystyrene panels in the construction industry in Kenya, the following methods were used

- ➢ Questionnaires
- ➢ Site visits and photography
- ➢ Interviews
- ➢ Desktop studies
- ➢ Minor lab tests to assess the strength of expanded polystyrene wall and slab panels

The various stakeholders in the industry who were involved in this process included those using expanded polystyrene panels for construction and others who are yet to start using it.

These stakeholders were

- Engineers using expanded polystyrene panels for building
- Contractors using the expanded polystyrene panels for building
- Homeowners and members of the public living in houses built using expanded polystyrene panels
- Engineers, architects and contractors not yet using expanded polystyrene panels of building

- Home owners, real estate developers and members of the public yet to use expanded polystyrene panels for building

Significance of the research

This research shows that more need to be done to spread the use of expanded polystyrene in Kenya. This method of construction reflects innovation in the construction industry that aims at reducing the time and cost of construction. All the stakeholders in this industry such as engineers, contractors, architects, real estate developers, members of the public and the government each have a role in enabling this method of construction to gain momentum in the country so as to reduce the prevalent housing deficit.

Limitations of the research

This research was limited by the scope of respondents covered by the questionnaires and the credibility of their responses. Small sample size of some units of analysis prevented discovery of significant relationships from the data since a larger sample size to ensure a representative distribution of the population. Lack of available or reliable data also limited the scope of our research since there is limited documentation on expanded polystyrene panels. Inadequate collection of data was also another factor limiting our research. It was discovered later that if some questions were included in the questionnaires, a more elaborate research would have been achieved.

Chapter 2

2 Literature review

2.1 General

Use of prefabricated elements such as expanded polystyrene panels introduces a factory setting in the building construction industry. This leads to stronger and more effective structures and reduces the time and labor spent in construction. Introduction of factory setting also allows development of quality surveillance systems to monitor and ensure that quality standard products are used in construction. This allows professionals in the construction industry to focus on developing good architecture and better designs having mitigated some of the shortcomings of in-situ construction.

2.2 Introduction to construction with expanded polystyrene panels

One of the ways use of prefabricated elements in construction has been implemented is through production of panels of wavy/undulated shape of expanded polystyrene, covered on either side with electro welded zinc coated square wire mesh, for walling and flooring buildings. These panels can be used to form vertical structural walls, horizontal structural elements, cladding elements and internal walls. 33 connectors of the square mesh per m^2 are used to form a three dimensional hyper static reinforcement steel. The panels are completed on site by spraying with shotcrete for walls using single panel (as shown in plate 2-1 and 2-2 below) or pouring concrete for double panel walls and slab and stair panels (Schnell 2014). Shotcrete is a mixture of cement, quarry chippings and sand in the ratio of 1:1.5:3 respectively

Plate 2- 1: Wall panels set up and process of spraying with shotcrete (Schnell 2014).

Plate 2- 2: Finished structure made of expanded polystyrene panels (Schnell 2014).

2.2.1 Expanded polystyrene

Expanded polystyrene is tough and rigid close-celled foam, normally white in color. It is manufactured from pre-expanded polystyrene beads as shown in plate 2-3 below.

Plate 2- 3: Pre-expanded polystyrene beads (Foam technology (2013)

Polystyrene is a synthetic polymer made from the styrene, a monomer and a liquid petrochemical. It is clear, brittle and hard with a low melting point. In addition, it is a poor barrier to water vapor and oxygen and is transparent naturally. Polystyrene is probably the most widely polymer in the world with applications such as for protective packaging, smoke detectors for houses, test tubes, lids, trays, bottles, tumblers and disposable cutlery. Being a thermoplastic polymer, polystyrene is a solid at room temperature and looks like glass. It flows when heated over 100 degrees Celsius and becomes hard again when cooled (Dow chemical company 2014). This behavior of polystyrene is exploited for purposes of extrusion, vacuum forming and molding since it can be cast at a fine detail into molds. Polystyrene is extruded or molded into extruded polystyrene foam, expanded polystyrene foam, copolymers and oriented polystyrene.

2.2.1.1 History on use of expanded polystyrene in construction

Polystyrene was discovered by Eduard Simon in 1839 as a close-celled foam that was able to resists moisture and had superior insulating properties and buoyancy (Dow chemical company 2014). It started being manufactured on a larger scale around 1931 by a company called I. G. Farben, in Ludwigshafen, Germany. The company wanted to test if polystyrene could be used to replace die-cast zinc that was used in many applications to prevent corrosion and wear resistance (Styron 2014). Expanded polystyrene started being used widely as a construction material during and after the Second World War in America and Britain because of the high demand for housing by military staff. Furthermore, many houses were destroyed in the same period; therefore, prefabricated housing was a quicker and affordable way of making quality homes for the many that were left homeless.

Expanded polystyrene is also used in road construction and is referred to as geofoam in such applications. The primary function of geofoam is to provide a lightweight void to fill below a highway, bridge approach, embankment or parking lot. Expanded polystyrene geofoam also minimizes settlement on underground utilities. Geofoam is also used in much broader applications, the major ones being as lightweight fill, green roof fill, compressible inclusions, thermal insulation, and (when appropriately formed) drainage. Slope stabilization is the use of geofoam in order to reduce the mass and gravitational force in an area that may be subject to failure, such as a landslide (Koerner 1990) such as the area shown in plate 4 below.

Plate 2- 4: Use of polystyrene as geofoam to stabilize slopes (Koerner 1990)

Expanded polystyrene started being used on a larger scale in the building industry in earthquake prone areas such as California, as an affordable and optimal solution to reduce the effects of such an epidemic. Since then, this technology has a spread in the world to countries such as Canada, Australia, Italy, South Africa and now Kenya. Expanded polystyrene was first used in Kenya in 2004 after government approval. Panels were imported from South Africa and Dubai for construction of houses in areas such as Muthaiga, Rongai, Kitengela and Balozi estate where residential houses and apartments were built. Government projects on the same are being done at State House Nairobi, Ruai and more projects for building hostels for universities are underway. Kenya started producing expanded polystyrene panels in November 2013 under a government parastatal , the National Housing Corporation (NHC), which has a factory in Mavoko, that produces self-extinguishing expanded polystyrene panels.

2.2.1.2 Process of manufacturing expanded polystyrene panels

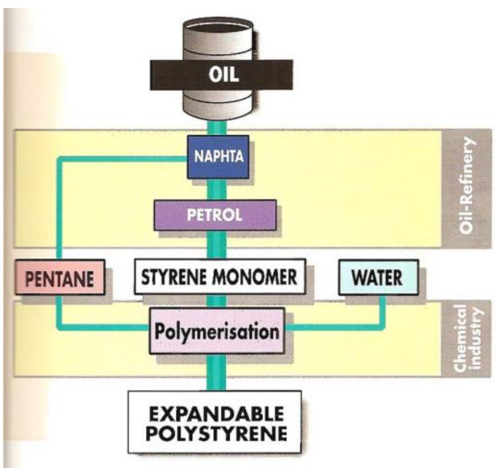

Figure 2- 1: Process of manufacturing expanded polystyrene (Barnesplastic 2014).

Expanded polystyrene is made from the polymerization process where the monomer, styrene, a derivative of oil, combines to form the polymer polystyrene as shown in figure 2-1 above. A hydrocarbon of low boiling point is impregnated in the polystyrene. The most commonly used hydrocarbon is pentane gas, which is not hazardous to the environment or the human health. This result is translucent spherical beads of polystyrene whose diameter ranges from 0.5 to 1.3mm as shown in plate 2-5 below (Barnesplastic 2014).

Plate 2- 5: Expanded polystyrene beads (Barnesplastic 2014).

Factories that manufacture expanded polystyrene units do not have remaining solid waste at the end of the production process. All cut-offs or waste are recycled into the production process making the process environmental friendly.

Processing of polystyrene beads into expanded polystyrene molds occurs in three stages as shown in figure 2-2 below.

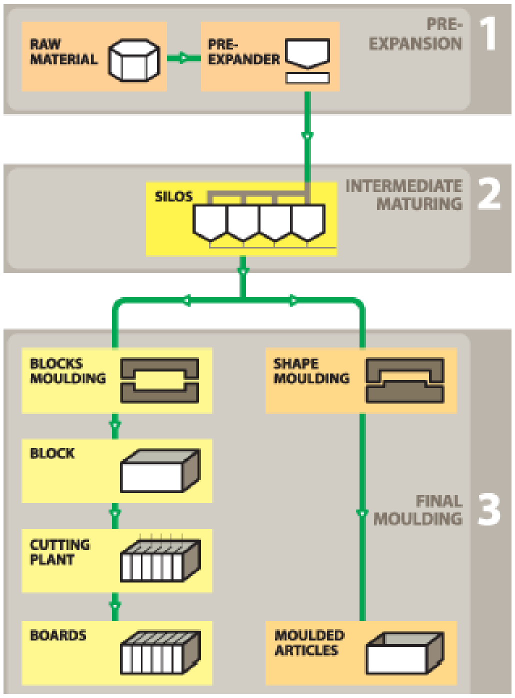

Figure 2- 2: Conversion of polystyrene into moulds (Barnesplastic 2014).

The first stage called **pre-expanding** entails heating the beads using steam at a temperature of approximately one hundred degrees Celsius. The pentane expands in the process as it is being released from the beads causing them to swell more than fifty times their original size as shown in plate 2-6 below. After attaining the required size, the expanded beads are dried in a bed dryer removing all condensed steam moisture from their surface (Dow chemical company 2014).

Raw material beads → Pre-expanded beads

→

Plate 2- 6: Expansion of polystyrene beads (Dow chemical company 2014).

The second stage is referred to as **intermediate maturing**; the expanded polystyrene beads are blown into mesh bags or large open silos for the aging process as shown in plate 2-7 below. After cooling, the expanded beads can form a vacuum in their interior since they become impervious to air. This vacuum is equalized to atmospheric pressure for two days in order to inhibit implosion or collapse of the beads. This allows the beads to be filled again with air enabling the expanded polystyrene to increase in size and achieve more mechanical elasticity.

Plate 2- 7: Silos and other machinery used for manufacture of polystyrene (National Housing Corporation)

When the desired density of the beads is achieved, the pre-expanded beads are taken through the final molding process where they are steamed further and compressed in rectangular molds. The resulting rectangular blocks are cut into panels and shaped accordingly. They can also be molded into other shapes according to their intended use.

2.2.1.3 Properties of expanded polystyrene

Expanded polystyrene is among the most important plastic materials, with more than 30 years of application in various functions. This is because expanded polystyrene has a unique combination of characteristics such as its lightweight, good thermal insulation, strong absorption of shock, high compressive strength and good moisture resistance. Expanded polystyrene is used in the construction industry due to the following benefits.

Relative lightweight

A single panel with a size of 1.2 by 3m for building a wall can be carried by a single operator. Compared with the traditional prefabricated structure, the panels are light weight with their variable weight approximately between 4 and 15 Kg/m^2. This feature enables an easy handling of the panels in all phases, from the production to the final erection of the building (National Housing Corporation 2013).

Improved strength compared to ordinary masonry wall

Walls made using expanded polystyrene panels are composite structures. The bond between the galvanized wire mesh reinforcement and shotcrete (or concrete for floor slab panels) makes the wall to be more capable of resisting applied flexural loads as if they were an integral section. The wire mesh is also connected across the panel assisting on transfer longitudinal shear. In addition, expanded polystyrene panels have a high strength to weight ratio.

It offers good thermal insulation and fire resistance

Expanded polystyrene panels have been used in the construction industry to mostly solve problems concerning the thermal insulation. Additives can be added to expanded polystyrene to give it "self-extinguishing" characteristics and ability to withstand heat or fire for a long period before combustion. The amount of aggregates in concrete or mortar determine the duration of time to resist fire, the more the aggregates, the greater the ability to resist fire. Shotcrete has more aggregates than mortar since the former has quarry chippings in addition to cement and sand.

It does not react with water

Expanded polystyrene does not react with water neither is water absorbed along the walls of the closed cells in the polystyrene foam as compared to masonry stone which can absorb water and become bulky over time in a wet environment. This can lead to damp conditions in buildings causing paint and plaster to peel off from the walls.

It is sound proof

The loss of sound transmission of a wall is related to the unit mass of the surface to its stiffness, and its intrinsic damping. An insulation to sound is created in shotcrete walls made using expanded polystyrene. The insulating ability of walls that are hollow or filled with a material with similar behavior to that of air is usually greater than that of a one layered structure whose weight and thickness is twice the former hollow or filled wall.

Earthquake and storm resistant

When hurricanes howl, flying debris is the greatest danger to property and people. Concrete walls such as expanded polystyrene walls covered with shotcrete do not generate flying debris during hurricanes and tornadoes. Buildings made of concrete are much more storm-resistant than buildings made of wood and steel. Most homes in North America and Asia, which are storm-prone areas, are now making concrete walls and are using alternative materials to wood and steel such as expanded polystyrene (Jackie Craven 2013).

2.2.1.4 Types of expanded polystyrene panels

Single panels

A single panel constitutes expanded polystyrene foam, galvanized steel mesh and structural plaster as shown in plate 2-8 below. The expanded polystyrene sheet has a width of 1.2 meters and a density of 10-15 $Kg/m^{3.}$ The expanded polystyrene foam used is self-extinguishing and has a thickness ranging between 40-100mm. The more load bearing a wall is, the more the thickness required in order for it to handle eccentric loads. The galvanized steel mesh used can handle tensile stress up to 700 $N/mm^{2.}$ Total width of the mesh is 1235mm. 19 longitudinal wires are used which have a diameter of 2.5 to 3mm. the longitudinal wires step 80mm from each other while transversal wires with the same diameter range have a 75mm step from each other. Connectors are used to make the steel mesh framework and the expanded polystyrene foam to be a monolithic structure. These connectors have a step of 150 mm from each other. Shotcrete is sprayed on either side of the single panel to a thickness of 35mm on either side. The standard size of a single panel is 3m in length and 1.2m in breadth. These panels are utilized as bearing structures for buildings up to 3 or 4 floors. Single panels can also be used to create partitions and for floors with a short span (National Housing Corporation 2013).

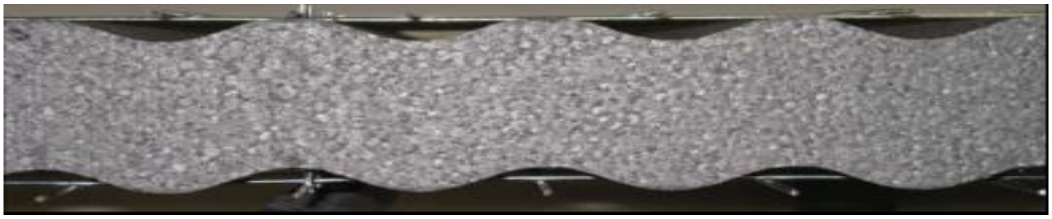

Plate 2- 8: Wavy undulated cross section of polystyrene (National Housing Corporation 2013)

There are various types of single panels. Some are suitable as bearing walls, others vary with parameters such as the polystyrene density, the thickness and steel wire diameters which can change in accordance to the requirements requested according to their purpose as shown in figure 2-3 below. For example, partition walls, sound-proofing devices, closing devices or thermal insulation devices.

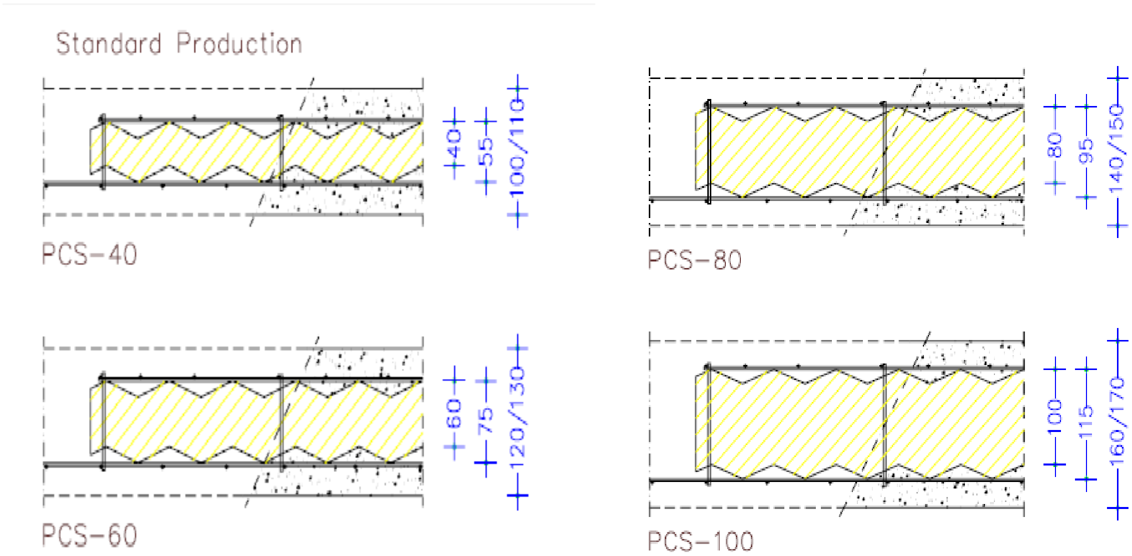

Figure 2- 3: Variations in the thickness of expanded polystyrene foam (Wong 2013).

Single panel evolution

The single panel evolution can be used as a bearing wall for special constructions where resistance is needed. Transversal wires are provided on the mesh to give an out-distance between the mesh and polystyrene sheet. This leads to more concrete cover with the mesh being completely covered by the concrete.

Double panels

A double panel is composed of two single panels which have an internal and external mesh as shown in plate 2-9 below. The mesh and panels are assembled with connectors to form a strong monolithic structure. Concrete is thereafter poured "in-situ" in the gap between the two panels. The two outer sides of the panel are finished by spraying with shotcrete and then plaster. The thickness of the core is determined on the basis of the structural requirements of the building to be constructed. The double panel can be used to construct a building of 10-15 floors (National Housing Corporation 2013).

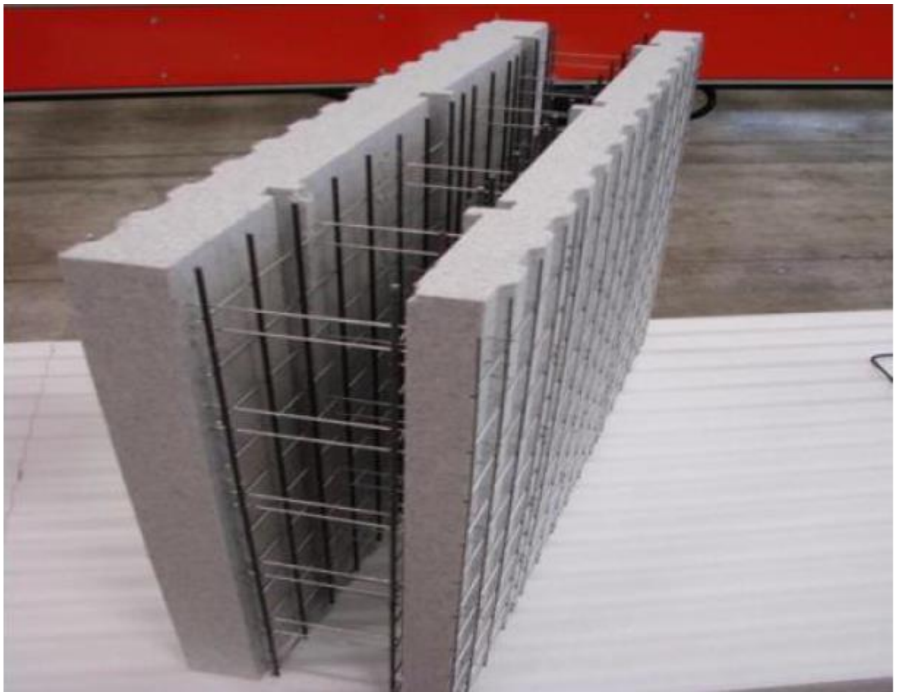

Plate 2- 9: Double panel (National Housing Corporation 2013)

Floor panel

Floor panels are used as floor slabs and for roofing too as shown in plate 2-10 below. The panels vary in thickness according to the span of the slab or roof. The floor panel is ribbed and gives it desirable properties of a ribbed slab such as

- Less amount of reinforcement required
- Used for longer floor spans
- Less amount of concrete cover is required
- Less formwork for support is required

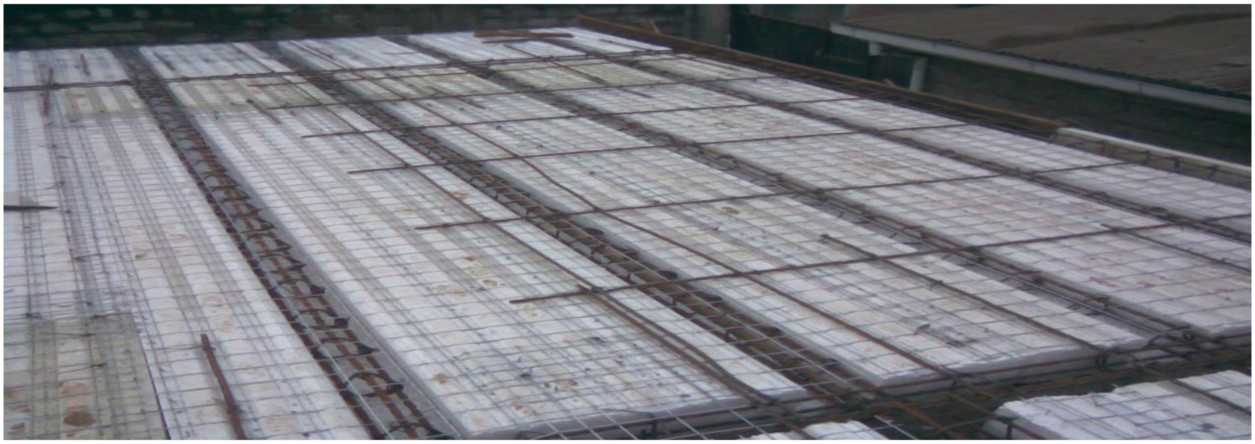

Plate 2- 10: Floor panel (National Housing Corporation 2013)

The floor panel has a rib in the middle where a beam made of 3 Y-12 bars are used and bound using R-8 links to form a triangular shape that spans along the panel length as shown in plate 2-10 above.

2.2.2 Material requirements

2.2.2.1 Shotcrete

This is used as the cover for single or double wall panels, which can either be structural elements of the building or used for partitioning. Cement, quarry chippings and sand are mixed in the ratio of 1:1.5:3 respectively. A water cement ratio of 0.55 is used to realize a workable mix. Quarry chippings of 6mm size are used allowing the use of a turbo pump to spray the shotcrete on the wall panels. Shotcrete is applied to a thickness of 17-20mm. The operator should ensure that the wire mesh is well integrated into the shotcrete before applying plaster. The wavy shape of the polystyrene foam creates small micro-columns in the structural panel elements. Shotcrete is micro-corrugated into small micro-columns which are spread over some length (National Housing Corporation 2013).

2.2.2.2 Concrete

The ratio of concrete mix used as the cover for the floor slab is 1:2:4, being the ratio of cement to sand to ballast (20mm). The concrete is corrugated to make a cover of 40mm for the slab (National Housing Corporation 2013).

2.2.2.3 Wire Mesh Reinforcement

14 gauge galvanized steel wire mesh is used as reinforcement for the prefabricated panel elements. Cold drawn and galvanized metallic wire with low carbon content, stress tension up to 700 N/mm² and a constant diameter of 30 mm is used. The low carbon content (less than 0.10%) enables the wire to be welded in the factory when making the meshes. The galvanized wire mesh provides an active protection to the metallic wires from rust as opposed to only having insufficient protection that is provided by the covering concrete (National Housing Corporation 2013).

2.2.3 Casting methods

A 3-phase power pump is used to spray shotcrete on the structure. Manual application is also possible especially since shotcrete with a water cement ratio of 0.55 has good workability (National Housing Corporation 2013).

Tools required for construction

1. Concrete batching plant (in the case pre-mix concrete is not available) of adequate capacity for the casting programs;
2. Means of lifting such as a crane or a pulley for the positioning/moving of the materials and other general tools and for the casting of concrete;
3. System for the spraying application of the concrete to cover the panels' surface (a concrete pump or air compressor can be used). It can be applied manually too by hand similar to how one applies plaster on a wall
4. Scaffold and service ladders
5. Reliable supports and aluminum bars. Clips and supports for roofing panels.
6. Manual tools like guns, shears, clips and portable heat generator to make the necessary spaces for the sanitary and electrical implants in the expanded polystyrene panels.

In summary, the expanded polystyrene walls requires two different types of concrete:

1. Concrete for the casting of the floor slab, stairs and double panel center nucleus for buildings of more than four floor levels. The concrete used here is composed of cement, sand and gravel in a ratio of 1:2:4 respectively.

2. Shotcrete for the surface covering of the single, double or roof panel. The shotcrete consists of cement, sand and quarry chippings in the ratio 1:2:3 for class 20 and 1:1.5:3 for class 25 concrete.

More attention is paid when preparing shotcrete with particular aim of having sufficient workability to allow use of manual tools or turbo pumps to spray on the expanded polystyrene wall. That way, the shotcrete can easily be compacted around the galvanized wire mesh reinforcement enabling a strong bond between the shotcrete and wire mesh reinforcement. Care must however be taken to avoid excess water in the shotcrete therefore preventing superficial dehydrations that could arise because of adverse climatic conditions. Shotcrete is the first application on the expanded polystyrene panel to a thickness of 17-20 mm, thereafter mortar is applied to a thickness of 15mm. This makes the expanded polystyrene wall to have an overall thickness of 115-120mm for panels whose thickness is 80mm (National Housing Corporation 2013).

2.3 Factors to consider when commencing construction on site using expanded polystyrene

- How to anchor the panels

It is prudent to first foresee how to anchor the panels on the foundation in terms of placement of rebars of a certain number, length and diameter as shown in plate 2-11 below. This is done according to the calculated stress at the base of the panel. Rebars used are 6-8mm in diameter for intervals of 30-40cm (Emedue 2011).

Plate 2- 11: How to anchor panels (Emedue 2011)

- Storing on the construction site

An area inside the site that is covered can be designated for depositing panels when the manufacturer delivers. The panels must be laid down carefully on a flat strong surface so that they can be vertically stacked. The panels should not be placed directly on the ground since when they get dirty, one may experience problems with plaster adhesion. The panels should be protected from rain or any other liquids, and also from exposure to sunlight for long periods. This prevents the polystyrene from changing appearance. Binding the panels makes sure that they are not accidentally moved by the wind.

- Identifying the panel elements to be utilized in construction

Panels should be identified according to how they fit into the building plan that indicates various alignments, elevations as well as the layout of floor s shown in figure 2-4 below.

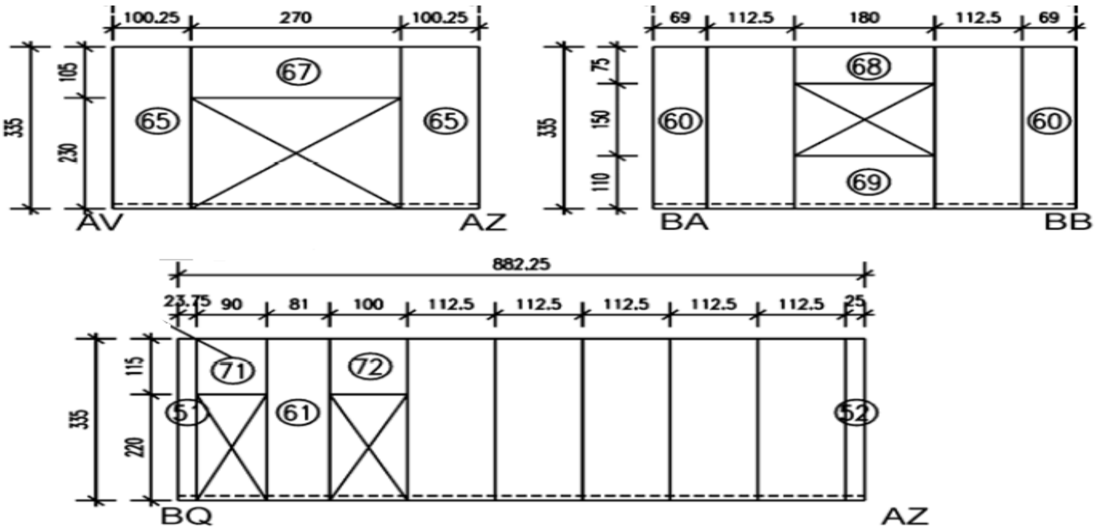

Figure 2- 4: Identification of panels for assembly (Emedue 2011).

- Assembling of the panels

Expanded polystyrene panels are anchored to the foundation bars using pliers and steel wires. In order to ensure continuity among the components, panels are equipped with an overlapping mesh wing on both sides to enable the operators to join adjacent panels. To achieve proper heat insulation, no empty spaces should be left between the joints of connected panels. Assembling of doors and balconies should be done carefully to ensure there are no openings that expose the panels.

2.4 Step by step procedure to follow in construction

1. Anchoring of rebars to the foundation
2. Assembling the panels
3. Alignment and plumb setting out of panels
4. Installation of plumbing and electric system
5. Installation of the floor panel
6. Application of shotcrete

1. Anchoring of rebars to the foundation

The panels are placed over a reinforced concrete foundation slab or strip foundation beam. The size and characteristics of the foundations should be determined by specific structural calculations, based on the geotechnical analysis of the site. The rebars can be placed in two ways

- Placing the rebars before casting the concrete

Plate 2- 12: Placement of rebars (Schnell 2014).

- Placing the rebars after casting the concrete. This is usually done by drilling holes in the foundation as shown in plates 2-13 and 2-14 below.

Plate 2- 13: Measurement for drilling holes (Schnell 2014).

Plate 2- 14: Drilled holes in the foundation (Schnell 2014).

2. Assembling of the panels

Assembling can be started from a corner and proceed along both sides with attention being paid to maintain perpendicularity. One can proceed to complete one single room to the next as shown in figure 2-5 below.

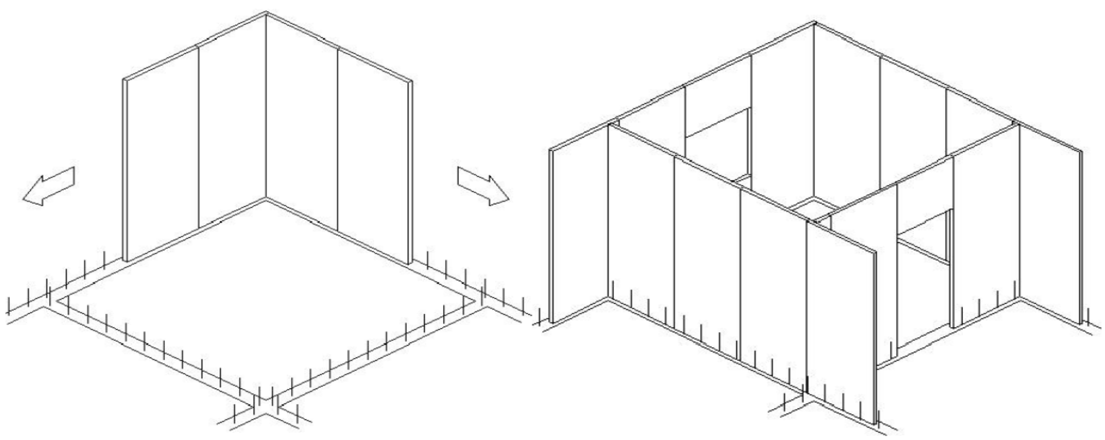

Figure 2- 5: Alignment of panels (Operators handbook 2011).

Mounting of the wall panels follows the designed foundation profile so that they can be connected, by means of tying, to the anchor steel bars prepared for this cause. The panels are light in weight thus a single operator can easily lift one leading to savings in time. They are connected to each other along the overlap line of the nets on both sides with the fastening of metallic wires or with metallic clips and placing in function the reinforcing wire too (Operators handbook 2011).

3. **Alignment and plumb setting out of panels**

The alignment and final leveling of the vertical walls are done during the assembly/installation with specific supporting framework capable to guarantee the stability of the work during successive work phases. After placement of the panels, the perfect linearity and verticality of the walls is checked and ensured. (National Housing Corporation)

4. **Preparation of plumbing and electric system**

The placing of the flexible tubes and accessories for the electrical implants and the rigid tubes for the sanitary implants is made after complete assembly of the panels and before casting of concrete. A hot air gun or torch is used to create channels in the polystyrene for the placement of switch boxes, electrical conduits, cables or pipes. In the case of rigid tubes, the cutting of the wired net can be done, and successively restored by overlapping and fixing a reinforcing wire mesh in the interested zone.

5. **Installation of the floor panel**

Once the floor panels are put in position, they are supported using framework and wooden rafters in order to limit the deformation of the panel under load. In the case of a multiple floors building, the sequence of the phases must be repeated floor by floor checking that the weight of the elements below will take place only after the adequate curing of the structural concrete castings. When casting a subsequent roof panel, it is recommended to maintain all the floor supporting devices in position until completion of the task. This way, weight is transferred directly on to the ground in case of heavy accidental load.

6. **Application of shotcrete**

Application of shotcrete is done on both sides of the single or double panel till a thickness of 17-20mm is achieved. After about 30 minutes, mortar of 15mm thickness is applied. Quarry chippings make shotcrete to have coarse surface which assist the mortar to stick. For double panels, it is favorable to do first the casting of the central nucleus, guaranteeing definite stability to the walls themselves. Proper curing should be done after in order to prevent possible superficial defects. Thereafter finishing work is done which includes placing doors and windows, painting walls, and any other electrical implants (Operators handbook 2011).

Chapter 3

3 Methodology

It is important that citizens of a country get an opportunity to express their opinion on the viability of a method of construction that the government proposes will alleviate the housing deficit. Stakeholders in the building industry such as engineers, architects, contractors and other consultants should be able to voice their concerns on the feasibility of the same. The following study approaches were used to achieve this

- Questionnaires
- Site visits and photography
- Interviews
- Desktop studies
- Minor lab tests to ascertain the information received about the strength of expanded polystyrene panels

3.1 Questionnaires

Questionnaires were used to get more output from stakeholders in the industry already using the expanded polystyrene panels for building. The questionnaires targeted

- Stakeholders in the construction industry who have been using this method of building in Kenya
- Stakeholders in the construction industry yet to start using this method of building in Kenya

Below is a summary of questionnaires for stakeholders in the construction industry who have been using this method of building in Kenya. The full questionnaires are at the appendices section of this report.

3.1.1 Questionnaire for engineers using expanded polystyrene panels for building

The questionnaire for engineers who are using expanded polystyrene panels for building sought to find out the reason(s) why they shifted from using ordinary masonry stone to expanded polystyrene panels for building construction. It also enquired about the properties of shotcrete, the ratio used to make it and why it was chosen. The engineers were also to explain which was stronger between a wall made using expanded polystyrene and one using masonry stone. The number of floors that can be built using the polystyrene panels was also inquired, and also modes of failure and defects that can be expected after construction and how to prevent them from happening.

3.1.2 Questionnaire for engineers, contractors not actively using expanded polystyrene panels for building

The questionnaire sought information from engineers and contractors in government and private sector who had varied years of experience in the construction sector. It checked their awareness of the use of expanded polystyrene in building and whether they believed that this way of building could reduce the housing deficit in the country and at the same time reduce the time and cost of construction. It also sought their opinion whether the government done enough to increase awareness of this mode of construction and suggestions on how it could do so.

3.1.3 Questionnaire for home owners / real estate developers not yet using expanded polystyrene panels for building

This questionnaire sought information from home owners, landlords, real estate developer and agents. They were asked the sizes of their homes and apartments of their concern and if they had tried other forms of construction materials. In addition, the questionnaire inquired whether expanded polystyrene was one of the construction materials they had worked with in the past and if they achieved their purpose for choosing it. For those who had heard about expanded polystyrene panels, the questionnaire inquired how they had heard about it and whether they believed it was affordable and had the ability to save on construction time and cost. The respondents were also allowed to give suggestions on other ways this way of building could reach the public more effectively.

3.1.4 Questionnaire for members of the public not yet using expanded polystyrene panels for building

Questionnaires in this category targeted respondents from different age brackets from 15 to 60 years of age who had varying levels of education. They were asked which construction materials they you aware of when it comes to building construction from among stone, mud, timber, expanded polystyrene, bamboo, bricks and galvanized iron sheets (mabati). Those who had heard about use of expanded polystyrene panels indicated how they found out about it and their opinion about houses made using the same. They were also asked if they would support the government if it passed a policy for government projects to be done using expanded polystyrene panels.

3.1.5 Questionnaire for home owners / real estate developers using expanded polystyrene panels for construction

Questionnaires were also issued to home owners and real estate developers who had used the expanded polystyrene panels for building in Rongai, Balozi estate, Muthaiga and Ruai. The questionnaire sought to find out if these respondents achieved their purpose when they chose to build using expanded polystyrene panels and whether they were comfortable with the need of this method to have the bulk of the money required for construction ready when starting to build.

3.2 Site visit and photography

Site visit and photography were also used to capture on-going construction projects using expanded polystyrene panels for building construction. Places that were visited are the National Housing factory at Mavoko, the Ruai police station and Balozi estate. Data on the history of expanded polystyrene, the manufacturing process, properties of the material and different product outputs used in construction was found out. In addition, the research covered other construction materials used in the expanded polystyrene method of building, their mix ratios and the steps to follow in construction using the same.

3.3 Interviews

Several interviews were conducted during site visits in order to accomplish our research project objectives. Among those interviewed were home owners living in houses made using expanded polystyrene, National Housing Corporation officials and staff, their officers at the factory producing expanded polystyrene panels at their factory at Mavoko, the lead contractor in the sites using expanded polystyrene panels, clerk of works at the site and other laborers and lab technicians at the Kenya Bureau of Standards. Interviews with the home owners sought to find out how they felt living in a house made using expanded polystyrene as compared to one made of masonry stone. The National Housing Corporation officials and staff interviews sought to know the history and process of manufacturing expanded polystyrene panels and costs involved in the process. The interviews with contractors and clerks of works at construction sites using the same revealed the challenges that one may face when building using expanded polystyrene panels. Interviews with lab technicians at the Kenya Bureau of Standards sought to understand the strength characteristics of expanded polystyrene panels that they gave (reflected under chapter 4 strength assessment)

3.4 Minor lab tests to assess the strength of expanded polystyrene wall and slab panels

Compressive and flexural tests were carried out on the wall panels. The size of the samples was governed by the machine capacity and availability at the factory which provided us with samples for testing.

3.4.1 Determination of the structural characteristics of expanded polystyrene wall panels

Apparatus and materials

1. Pozzolanic cement
2. River sand
3. Quarry chippings
4. Water
5. Weighing machine
6. Spade
7. Trowel
8. Curing tank
9. Mould oil

10. White wash
11. Blackboard timber and nails
12. compression test machine
13. Flexural test machine

Both the compressive and flexural tests were performed with the same sample size of 800mm*280mm*80mm. An all-round shotcrete cover of 35mm was adopted for the two wall samples.

Procedure

1. The formwork for casting the wall samples was prepared by joining the blackboard in appropriate sizes to form a rectangular mould. The size of the mould was 870mm*320mm*150mm which allowed a 35 mm shotcrete cover on either side of the prefabricated wall panels.
2. 13.64 kgs of cement, 20.46 kg of quarry chippings and 40.9 kg of sand were weighed separately and mixed together till a homogeneous mix was obtained. This formed a shotcrete mix of a cement, quarry chippings and sand ratio of 1: 1.5: 3.
3. The materials were then poured into the mixer and 6 liters of water were added to the mix to form a water cement ratio of 45%.
4. The mixer was switched on and the mixing done for 6 minutes
5. Mould oil was then applied on the interior part of the rectangular moulds so that the shotcrete did not stick on the faces of the mould.
6. Shotcrete was then poured to a thickness of 35mm into the mould and thereafter the wall specimen was inserted and made firm inside the mould, using binding wire, leaving space for a 35mm shotcrete cover on all sides and on top.
7. Shotcrete was then poured inside the mould and the vibrating table was used to facilitate compaction.
8. The sample was then left to set for 24 hrs in a cool and dry environment.
9. After 24 hours, the samples were removed from their formworks and dipped in water for curing. The process of curing was done for 28 days.

3.4.2 Determination of the structural characteristics of expanded polystyrene slab panels

Apparatus and materials

1. Pozzolanic cement
2. River sand
3. Ballast
4. Water
5. Weighing machine
6. Spade
7. Trowel
8. Curing tank
9. Mould oil
10. White wash
11. Blackboard timber and nails
12. compression test machine

Both the compressive and flexural tests had the same sample size of 650mm*450mm*150mm. An all-round shotcrete cover of 40 mm was adopted for the two slab samples

Procedure

1. The formwork for casting the slab samples was prepared by joining the blackboard in appropriate sizes to form a rectangular mould. The size of the mould was 730mm*530mm*230mm which allowed a 40 mm shotcrete cover on either side of the prefabricated wall panels.
2. 12. 56 kg of cement, 25.10 kg of sand and 50.16 kg of sand were weighed separately and mixed together till a homogeneous mix was obtained. This formed a concrete mix of a cement, sand and ballast in a ratio of 1: 2: 4.
3. The materials were then poured into the mixer and 6 liters of water were added to the mix to form a water cement ratio of 45%
4. The mixer was switched on and the mixing done for 6 minutes
5. Mould oil was then applied on the interior part of the rectangular moulds so that the concrete did not stick on the faces of the mould.

6. Concrete was then poured to a thickness of 40 mm into the mould and thereafter the slab specimen was inserted and made firm inside the mould, using binding wire, leaving space for a 40 mm concrete cover on all sides and on top.
7. Concrete was then poured inside the mould and the vibrating table was used to facilitate compaction.
8. The sample was then left to dry for 24 hrs in a cool and dry environment.
9. After 24 hours, the samples were removed from their formwork and dipped into water for curing. The process of curing was done for 28 days.

3.4.3 Workability Determination

Workability is the characteristic of concrete that prevents segregation when it is being mixed or transported. It also gives a good cohesion to for the constituents of concrete when it is being poured into formwork. Workability can be determined by the **Slump method,** which is used for all concretes which have aggregates with a maximum size of 120 mm.

This method is not recommended for concretes with low workability.

The slump method measures the degree of settling of fresh concrete under its proper weight.

Equipment required

- One tronconic vessel made of galvanized sheet of 2 mm thick, such as presented in figure 3-1 below provided with a prolongation;

- A steel rod (ϕ=16 mm, l = 600 mm) with rounded ends;

- One metallic line (l = 600 mm), a trowel;

- A scaled line (l = 500 mm).

The following procedure is used

- The tronconic vessel is filled with concrete in three successive layers, each layer corresponding to one third of the vessel's height;

- In each layer 25 stitches by use of the metallic rod are done; the rod must gently penetrate the anterior layer of concrete (for superior layer the prolongation is added to the vessel (Handojo 2009).

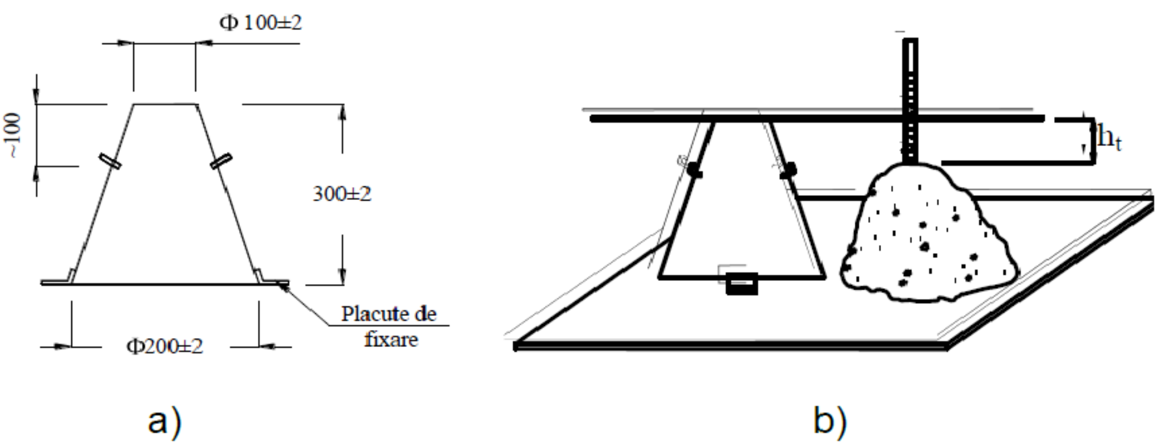

Figure 3- 1: Equipment used for slump test (Handojo 2009).

- the prolongation is taken away and the surface of concrete is leveled using the metallic line; during the filling and compaction, the tronconic vessel is fixed to the plane surface on which it was placed; this is done by help of fixing plates;

- the tronconic vessel is raised vertically in 5-10 seconds, without making any lateral movements or spins; all these operations must not exceed 150 seconds;

- The difference (ht) between the tronconic vessel's height and the most raised point of fresh slumped concrete is measured such as shown in plate 18 below.

The value **ht** expresses the concrete slump. The result is considered the arithmetical mean of two determinations done at a time interval of maximum 10 minutes (Handojo 2009).

Plate 3- 1: Measurement of amount of slump

Chapter 4

4 RESULTS AND ANALYSIS

4.1 Extent of spread of construction using expanded polystyrene panels in Kenya

The extent of spread of use expanded polystyrene panels in construction was analyzed through evaluation of data obtained from questionnaires filled by various stakeholders in the industry. Outlined below are the responses of the questionnaires which are in the appendices section of this report.

4.1.1 Data analysis from questionnaire for engineers and contractors using expanded polystyrene panels

Table 4-1 below summarizes information obtained from the questionnaire for engineers and contractors using expanded polystyrene panels.

Table 4- 1: Response of engineers and contractors using expanded polystyrene panels

Question	Response
Number of engineers who were respondents	6
Number of contractors who were respondents	8
Reason for shift to using expanded polystyrene panels	➢ Better structural performance compared to ordinary stone walls. ➢ Ease of construction using expanded polystyrene than using ordinary masonry stone. ➢ New government research and policy through bills e.g the New Building Code
Why shotcrete was chosen	➢ Better bond strength compared to

	normal mortar. ➢ Improved workability since it is fluid in nature with a 0.55% water cement ratio.
Shotcrete ratio used	Cement, sand and quarry chipping ratio of 1:2:4 for a building using class 20 concrete and a ratio of 1:1.5:3 for class 25 concrete.
Additives added to shotcrete	Admixtures that improve the workability of shotcrete
Thickness of shotcrete used	20 mm
Thickness of plaster used	15 mm
Thickness of expanded polystyrene foam is used in Kenya	80 mm
Total thickness of expanded polystyrene wall	150 mm
Number of floor levels that that can be built using single expanded polystyrene panels	4
Number of floor levels that that can be built using double expanded polystyrene panels	15

Additional information obtained from engineers and contractors through questionnaires are outlined below. The respondents stated that they shifted from using ordinary masonry stone to expanded polystyrene for building construction since the latter is a composite material with properties that give walls better structural performance compared to ordinary stone walls. Another reason is because it is easier to construct using expanded polystyrene than using ordinary masonry stone. New government research has also revealed that construction using alternative materials such as expanded polystyrene reduces construction time and cost as prescribed by the New Building code which is discussed in detail under chapter 5 of this research. Shotcrete performs as a concrete plaster. It has a relatively high cement content making it stronger for use on vertical elements. In addition, it has a better bond strength compared to normal mortar and is fluid in nature. Shotcrete has a good workability because it uses a 0.55%

water cement ratio. A ratio of 1:2:4 for cement, sand and quarry chipping is used for building using class 20 concrete and a ratio of 1:1.5:3 for class 25 concrete. Sand used should be 0.425mm in diameter while the quarry dust should be 6 mm in diameter (National Housing Corporation). Portland cement is used as the binder for the mix. The size of quarry chippings of 6 mm allows the shotcrete to be more workable compared to normal concrete. It also allows use of a pump to spray the shotcrete on expanded polystyrene panel without damage to the machine. Use of a pump to spray wall panels made of expanded polystyrene is one of the factors that make this method faster than the common practice of using masonry stone, mortar and plaster. Quarry dust also improves the strength of shotcrete too. Additives that can be added to shotcrete are admixtures that improve the workability of shotcrete so that it can be sprayed more easily and allow better compaction on the expanded polystyrene panels. Other admixtures that can be used are those that increase the speed at which shotcrete sets. Walls made using expanded polystyrene panels are stronger than those made using ordinary masonry stone since

- The walls are made up of more number of composite materials.
- The shotcrete behaves like a plaster concrete
- The galvanized wire mesh welded into the expanded polystyrene mesh spreads the stresses evenly throughout the wall panel surface.

The most common thickness of expanded polystyrene foam in Kenya is 80mm. The thickness of the expanded polystyrene foam differs according to the purpose it was intended for. For construction of outer structural walls, 80 or 100 mm is used since it allows the wall to handle more eccentric loads. This form of construction conforms to Euro code and UBC (Uniform Building Codes) building standards for Canada and America. Defects that can be expected from buildings made using expanded polystyrene panels are cracking along zones where the panels are connected next to each other. This can occur if insufficient overlapping wiremesh is used. Cracking in expanded polystyrene wall panels sprayed with shotcrete can be prevented using overlapping galvanized wire mesh at the points where panels are connected to each other, to increase the bond between the wire mesh and shotcrete and hinder development of cracks along the vertical axis for vertical walls. U-mesh kind of wiremesh are used for the panels around door and window frames so that all open points in the building are sealed to avoid zones of weaknesses developing at that point. The National Housing factory at Mavoko is currently producing expanded polystyrene walls that are 80mm thick and below. Production of thicker foam for example, 100mm or 120mm thick, improves the ability of vertical walls to handle eccentric loads and thus prevents buckling of such members. Increasing of the diameter of galvanized wire mesh increases the ability of the wall to handle shear loading.

Additional questions to and responses from contractors are covered in table 4-2 below

Table 4- 2: Further responses by contractors

Question	**Responses**
What sparked the interest to start using expanded polystyrene panels for building?	No other contractors had started using it yet it is a cheap, faster and modern way of building that conserves the environment
Reasons why most contractors chose to use expanded polystyrene panels for building	➢ Simplicity in construction ➢ Versatility and flexibility of expanded polystyrene panels. It can be used as structural walls, partitioning, making floor slabs swimming pool construction and underground car parks. ➢ Requires less number of skilled laborers on the site ➢ Less construction time is incurred compared to using masonry stone ➢ It is an environmentally friendly way of building with optimum use of materials from recycled waste products. ➢ Cost effective solution to reducing the housing deficit in the country ➢ Safer in construction with less noise dust on the site

	➢ Increase in the quality of construction due to introduction of factory setting ➢ Reduction of construction waste

The biggest initial challenge that contractors faced when starting to use expanded polystyrene panels in construction was acceptance of use of the same. They also faced a challenge of convincing stakeholders in the construction industry that houses made with expanded polystyrene panels had a long life span and were durable. So far they have overcome the challenges above. The current challenge they face as contractors using the expanded polystyrene panels is reluctance by architects to acceptance this mode of construction. This form of construction takes a shorter time in project completion and one can easily fabricate the panels at the factory to suit different building shapes and designs. These two aspects reduce an architect's expected remuneration in terms of site visit and consultation fees. If architects were to broadly embrace this idea and help to develop it further, Kenya can reduce her housing deficit and lead to more professional input which would improve the building construction industry.

4.1.2 Data analysis from questionnaire for engineers, architects, contractors not yet actively using expanded polystyrene panels

Table 4-3 below covers responses obtained from engineers, architects, contractors not yet actively using expanded polystyrene panels

Table 4- 3: Responses from engineers, architects, contractors not yet actively using expanded polystyrene panels

Question	Response
Number of respondents in this category	15
years of participation in the construction sector	45% had 15-30 years of experience while 65 % had 10-15 years of experience in the sector
Awareness of the use of expanded polystyrene in building	60% of the respondents were aware

Question	Response
Belief that this way of building could reduce the housing deficit in the country	60% of the respondents agreed that it could
Could this way of building reduce the time and cost of construction	80% agreed it could

Engineers and architects, contractors and quantity surveyors who were working in government, private sector, non-governmental organizations and consultancy firms were some of the respondents in this questionnaire. 60% of them had heard of this mode of construction that is being advocated by the government through the T.V, newspapers and social media. They were also aware that it could highly reduce the time and cost spent in construction projects and agreed that the initiative could reduce the housing deficit in the country. Most of them criticized the government for not having done enough to increase awareness of this mode of building in the construction industry. Some of the suggestions they gave for this to happen were

- More showcasing through the media (TV, newspapers and construction journals) on constructions in the country that are using expanded polystyrene project
- Organization of trainings and seminars on the same through bodies such as E.B.K, I.E.K, A.A.K, N.C.A. Professionals in these bodies such as engineers, architects and contractors to cold be invited to visit sites done using expanded polystyrene panels in Kenya and worldwide.
- Inclusion of alternative methods of construction such as the expanded polystyrene panels in the education curriculum for students doing civil engineering in Kenyan universities and colleges.

4.1.3 Data analysis from questionnaire for home owners / real estate developers not yet using expanded polystyrene panels for construction

An assessment of the awareness of home owners and real estate developers about this mode of construction was covered in table 4-4 below

Table 4- 4: Assessment of awareness of home owners and real estate developers

Number of respondents in the category interviewed	17
Percentage of respondents who were aware of this way of building	40%
Percentage of respondents who were not aware of this way of building	60%

Other stakeholders in the industry who were interviewed were home owners, landlords, real estate developers and agents who had not yet started using expanded polystyrene panels of housing. 60% of those interviewed had not yet heard of expanded polystyrene panels used for building. Some had used other materials for construction such as gypsum, block boards and fiber and were able to achieve better design and reduced cost for some of the applications. Those who had heard of how expanded polystyrene could be used in building construction stated they could consider using it as a construction material if the savings on time and cost were achievable. However, they complained that information on this mode of housing was not readily available. The main aspect of expanded polystyrene that caught the eye of most of the respondents was the reduction in time and cost of construction. On the query whether it was feasible for homeowners or real estate developers to have the bulk of the money when starting to build using the expanded polystyrene panels, 65% of the respondents said it was feasible if adequate planning was done prior to commencement of the project. Therefore, the project would not be affected much by radical changes in market dynamics such as cost of labor or construction materials. 35% of the respondents stated it was not feasible since it is not easy to get the bulk of the money for construction in advance and financial institution such as banks usually give out money for such projects in stages. Generally, homeowners and developers welcomed the idea of alternative construction using expanded polystyrene panels. They however felt more needed to be done to sensitize stakeholders in the building industry using avenues such as housing expos television shows, newspapers, construction journals and social media.

4.1.4 Data analysis from questionnaire for members of the public not yet using expanded polystyrene panels for construction

Table 4-5 below outlines the awareness of different members of the public about use of expanded polystyrene panels for building.

Table 4- 5: Awareness of different members of the public about expanded polystyrene

Number of respondents in this category	20
Level of education	70% had finished degree level 20% had reached KCSE level 10% had were below KCSE level of education
Number who were aware of use expanded polystyrene panels	10%

Members of the public who were interviewed and those who filled in questionnaires were between 20 to 60 years of age. Most of those we interviewed had reached diploma level in their education with only 2 having reached KCSE level. 90% of them had not heard about this new method of building using expanded polystyrene panels. They were used to the common ways using masonry stone, bricks, timber, mud, bamboo and galvanized iron sheets. After explaining to them how the expanded polystyrene panels can be used and the potential savings in building cost and time that could be achieved, they got more interested in the subject matter. All of the respondents agreed that they would support the government if it passed a policy to use expanded polystyrene panels on a larger scale in the country. 70% stated that they would consider using it for building their homes if it was as effective as it was said to be in terms of time and cost savings. All of the respondents stated that the government needed to do more to sensitize the public on this mode of construction through avenues such as housing expos television shows, newspapers, construction journals and social media.

4.1.5 Data analysis from questionnaire for home owners / real estate developers using expanded polystyrene panels for construction

Table 4- 6: Statistics of responses from home owners and real estate developers

Number of respondents in this category	8
Areas of residence of the respondents	Rongai, Balozi estate, Muthaiga and Ruai
Percentage who achieved their intended purpose of building using expanded polystyrene	95%
Percentage who felt the requirement to have the bulk of the money when starting construction was feasible	80%

Most of the respondents used this form of construction since they were informed of its positive attributes such as

- Reduced construction time
- Reduced construction cost
- Ease of designing house features that crate uniqueness and aesthetic
- Sound proofing ability of walls made using expanded polystyrene.

95% of these home owners and developers stated they had achieved their intention when they chose to use the expanded polystyrene panels for building. In addition, they did not feel any different living in their house as compared to a masonry house. In fact they felt that the houses made using expanded polystyrene panels were stronger. For example, they had to use steel nails to hang pictures or put up structures on the wall. This is because the shotcrete cover on expanded polystyrene walls acts like a plaster concrete. Some of the noticeable defects that some home owners had seen are hairline cracks on the walls. They had not been so big to raise alarm but they appeared where there were joints and around openings of doors and windows.

80% of the respondents in this category stated that it was feasible for them to construct with the bulk of the money being required in the initial stages of construction. This is because they had arranged their finances accordingly to make sure the material and construction requirements were catered for in the short duration of the project.

Most of the respondents in this category found out about this method of construction through friends and contractors who had prior knowledge about it. However, just like other members of the public, this category of respondents complained that they are not able to access information about expanded polystyrene easily when they wanted it. They felt that more needed to be done to sensitize stakeholders in the building industry using avenues such as housing expos television shows, newspapers, construction journals and social media.

4.2 Data analysis from interviews

Among those interviewed were home owners living in houses made using expanded polystyrene, National Housing Corporation officials and staff, their officers at the factory producing expanded polystyrene panels, the lead contractors in the sites using expanded polystyrene panels, clerk of works at the sites and other laborers. Lab technicians at the Kenya Bureau of Standards also helped in comprehension of the strength of the expanded polystyrene panels which they had tested which is reflected in the strength assessment of the panels in this chapter (chapter 4).

Home owners living in houses made using expanded polystyrene panels stated that they felt increased privacy due to the sound proofing of the walls. A mother mentioned that her baby slept soundly despite of heavy traffic passing by her neighborhood at Balozi estate. The main contractor who has won tenders to build using expanded polystyrene panels called Nasca was resourceful in giving information on this method of building. National Housing Corporation officials and staff informed us about the process of manufacturing expanded polystyrene panels and the factors that contributed to the cost of the panels which are outlined under this chapter under cost analysis.

Officials at the Ministry of Lands, Housing and National Development stated that the government approved use of this mode of construction in the country in 2004 after a visit by the cabinet secretary in charge of housing then to several countries to seek a way of reducing the housing deficit in the country. Italy was chosen as the country that would mentor Kenya in starting this process. Building and consultancy firms from Italy partnered with the National Housing Corporation to bring this to effect. Currently there is a silent government policy to build

30% of government projects using the expanded polystyrene panels for building. However in future, the government intends to do more than 80% of its construction projects using expanded polystyrene panels (National Housing Corporation 2013).

4.3 Desktop studies

Desktop studies revealed structural defects that arise in structures built using expanded polystyrene panels such as shrinkage cracks.

4.3.1 Shrinkage Cracks

Shotcrete is made of cement, sand and quarry chippings ratio having a ratio of 1:1.5:3. It uses a high water cement ratio of 55% which gives it better workability and enables ease of compaction on the sides of the wall panels. Floor slabs made using expanded polystyrene use a cement, sand, ballast ratio of 1:2:4 which use a water cement ratio of around 50% to enable adequate compaction in the slab. Space is taken up by the water and making the slab a certain size. The slab then gets a bit smaller as it starts losing moisture as it is curing. Stress is created on the concrete slab due to shrinking and rigidity of concrete. The concrete shrinks drags across its granular subgrade as it shrinks. This creates an impediment to free movement leading to stress which can pull the slab apart literally. The hardened concrete slab will crack when the stress becomes too great, in an effort to relieve tension, as shown in plate 4-1 below. Shrinkage cracks occur in a few hours, especially in hot weather, after the slab has been poured and finished (Handojo 2009).

Plate 4- 1: Shrinkage cracks (Handojo 2009).

Shrinkage can become more if the shotcrete or concrete used is too wet. The reason for this is because the additional water takes up more space, which pushes the solid ingredients in the mix farther apart from each other. After the excess water leaves the slab, the solid particles are left with larger voids between them. These empty spaces weaken the concrete making it more prone to cracking. Two common problems found in concrete installation are plastic shrinkage cracking and dry shrinkage cracking.

4.3.1.1 Plastic Shrinkage Cracking

Plastic shrinkage cracks occur when the evaporation of moisture at the surface of the concrete is greater than the availability of rising bleed water to replenish the surface moisture. Incase concrete has not yet achieved enough tensile strength when plastic shrinkage occurs, the volume change (shrinkage) at the surface will cause cracking. Often, plastic shrinkage cracks in expanded polystyrene houses are barely visible and only a hairline in width. Plastic shrinkage cracking occurs when the concrete is in the plastic state, which is within the first 24 hours after the cement begins to hydrate. In addition, plastic shrinkage cracks are usually spaced 1 to 3 feet apart, and are generally parallel to one another (Handojo 2009).

How to solve plastic shrinkage cracking

- **Admixtures**

Water reducers, retarders, and super plasticizers are concrete admixtures, which aid in slowing the setting rate of the concrete while reducing the water content in a mixture and retaining the flowing properties of a concrete mixture. Admixtures can modify the properties of concrete or mortar leading to savings on mechanical energy used in the process by making them more workable by hand.

- Water reducing admixtures (WRA)

The use of water reducing admixtures is defined as Type A in ASTM C 494. These admixtures alter the fresh properties of concrete by decreasing the amount of water used by 5% to 12% while maintaining a certain consistency levels. In addition, these admixtures may retard or accelerate the initial setting time of concrete (Handojo 2009).

- Super-plasticizers (High Range Water reducer)

Super-plasticizer admixtures aid in reduction of the amount of water by 12% to 30% while at the same time maintaining workability and consistency levels. This can produce flowing concrete which has high strength suitable for use in inaccessible areas for heavily reinforced structures. The initial setting time can be retarded or accelerated within an hour according to its chemical reaction (Handojo 2009). The use of super-plasticizers does not significantly affect surface tension of water or entrain a significant amount of air. The main disadvantage of super-plasticizer usage is incompatibility of cement and super-plasticizers and loss of workability due to rapid slump loss.

- **Additions of reinforcement using synthetic fibers, rebar or reinforcing wire mesh**

The presence of reinforcement can determine if a crack will remain hairline in nature or separate to become wider and unsightly. Concrete on both sides of a crack can be kept on the same horizontal plane using steel reinforcement. This means that one side doesn't heave or settle more than the other, which could cause a tripping hazard. In houses made using expanded polystyrene panels, cracking can be prevented by adequate use of overlapping galvanized wire mesh at the points where panels are connected to each other to increase the bond between the wire mesh and shotcrete and hinder development of cracks along the vertical axis for vertical walls as shown in plate 4-2 below. U-mesh kind of wire mesh are used for the panels around door and window frames so that all open points in the building are sealed to avoid zones of weaknesses developing at that point.

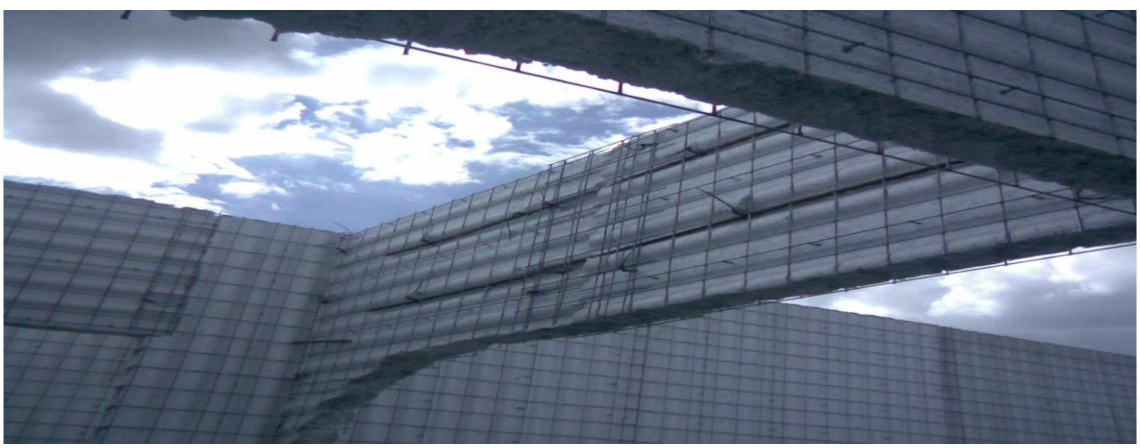

Plate 4- 2: Additions of reinforcement

- **Control joints**

Control joints, commonly referred to as expansion joints, are incorporated into the floor slab in order to combat random shrinkage cracks. These are grooves that are sawed into the slab or tooled into fresh concrete as soon as the concrete reaches its initial set. Control joints create a weakness, leading to cracking in the joint rather than randomly across the slab when the concrete shrinks. Crack control joint should be ¼ as deep as the slab is thick in order to be effective. These joints should be placed as soon as possible after the concrete is poured on the floor slab panels in order to reduce the chances of early random cracking. If the control joint is not deep enough, the concrete can crack near it instead of in it. Crack control joints should be evenly spaced and placed at all slab penetrations and re-entrant corners (Texas Department 2006).

- **Proper curing** can often, but not always, prevent plastic shrinkage cracking by delaying the evaporation of bleed water.
- **Possible Construction Changes that can reduce plastic shrinkage**

1. Protection of the shoctrete/concrete from adverse weather conditions.

2. Erecting wind screens or using a water fog mist around the panels

3. Provision of additional personnel to accelerate the finishing and curing operations.

4. Proper use evaporation retardants, especially when finishing operations are lagging behind.

4.3.1.2 **Drying Shrinkage Cracking**

Concrete is usually mixed with more water than is needed to adequately hydrate the cement. The remaining water which is referred to as the water of convenience evaporates, which causes the concrete to shrink. Restraint to shrinkage provided by the subgrade, reinforcement, or another part of the structure causes tensile stresses to develop in the hardened concrete. In many situations, drying shrinkage cracking is inevitable as shown in plate 4-3 below (Texas Department 2006).

Plate 4- 3: Drying shrinkage cracks (Texas Department 2006).

Therefore, contraction (control) joints are routinely placed in concrete to predetermine the location of drying shrinkage cracks.

Preventing Drying Shrinkage Cracking

• **Possible Concrete Changes** (if allowed by specification and approved by the engineer)

1. Reduction of the total water in the mix, either using chemical admixture or combined aggregate gradation

2. Reducing the amount of paste (cement + water) in the mix.

3. Minimizing use of poorly graded fine aggregates.

• **Possible Design and Construction Changes**

1. Designing of adequate and appropriate contraction and construction joints.

2. Employment of a design that minimizes restraint of the concrete, such as the use of a bond breaker.

3. Sawing of contraction joints to the proper depth

4. Provision of good curing to allow concrete to gain sufficient tensile strength before significant shrinking forces develop.

4.4 Assessment of the strength of expanded polystyrene wall and slab panels

The New Building Code advocates that professionals in the industry should shift their mindset to building materials that are centered on material performance instead of materials specification as is the norm. Expanded polystyrene panels are a composite material made of wavy undulated panels of polystyrene that are reinforced with welded galvanized wire mesh on either side. They are used to make structural and partitioning walls, roof panels, floor slabs and staircases. The walls are covered using shotcrete which is a form of plaster concrete. It has a relatively high cement content making it strong. Shotcrete was chosen as a cover since it has a better bond strength compared to normal mortar. It is also fluid in nature and has good workability which enables the use of a pump to spray it on walls.

4.3.1 Reason for use of quarry chippings in shotcrete

Quarry chippings improve the strength of performance of shotcrete. Quarry chippings were chosen as the course aggregate for shotcrete since

- They give it properties of concrete meanwhile it is used as an improved wall plaster.
- The size of quarry chippings allows it to be more workable compared to normal concrete
- It allows shotcrete to be sprayed using a pump without possible damage to the pump

Normal aggregate size is usually 20mm in size for use on floor slabs or foundation or 10mm if used for foot paths or thins sections. The size of quarry chipping of 6 mm allows the use of a turbo pump to spray shotcrete which is not possible with larger sizes of coarse aggregate.

The flexural design of expanded polystyrene panels is similar to that of solid panels that have the same cross-sectional thickness. Both sides of the panel are connected in such a way that both resist applied flexural loads as if they were an integral section, making them to be fully composite panels as shown in figure 4-1 below. The galvanized wire mesh are connected on either side by 33 connectors of the square mesh per m^2 to form a three dimensional hyper static reinforcement steel. The connectors transfer the required longitudinal shear so that the bending stress distribution on the cross section of the panel is as shown below.

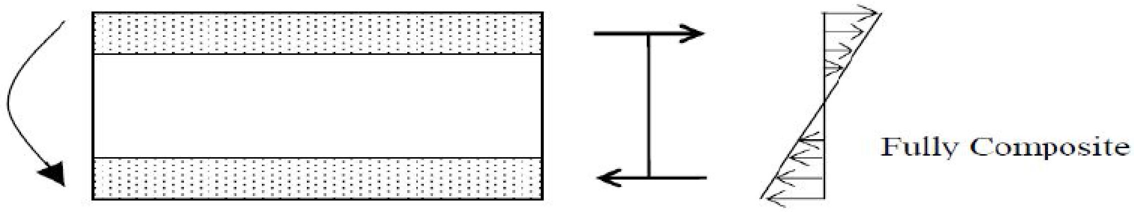

Figure 4- 1: Behavior of a fully composite panel (Emedue 2011)

4.3.2 Laboratory tests obtained from National Housing Corporation performed by the Kenya Bureau of standards

The Kenya Bureau of standards tested wall and slab samples of the made using expanded polystyrene panels. Compressive and flexural strengths were obtained for wall panels and flexural strengths for the floor panel from the Kenya National Bureau of Standards. The compressive strength of wall panels made using shotcrete was given as 4.563 N/mm^2. The wall panel failed under a flexural load of 47 KN. The flexural strength obtained for the floor panel was 65 KN.

This shows that walls made using expanded polystyrene panels and shotcrete are slightly weaker than the masonry wall made of mortar and plaster which usually record a compressive test of 5 N/mm^2 and above. The flexural strength obtained for the floor panel was 65 KN which it is stronger compared to normal slabs which have a flexural strength greater than 25 KN. This means that the expanded polystyrene panels are capable of being used for construction.

Lab tests at the University of Nairobi were done to confirm the above results as shown in plates 4-4, 4-5 and 4-6 below. A compressive strength of 4.143 N/mm^2 and flexural strength of 54 KN were obtained for the wall panel. The flexural strength obtained for the floor panel was 68 KN. These tests confirmed that the results obtained for the concreted expanded polystyrene wall and slab panels were correct. The margin of error could be attributed to unevenness of shotcrete or concrete cover on either side of the panel during compaction.

Plate 4- 4: Wall panel under flexural loading

Plate 4- 5: Flexural load setup of expanded polystyrene wall panel

Plate 4- 6: Expanded polystyrene wall panel intact after failure under compression load

Plate 4- 7: Failure of wall panel under compressive load

The flexural test revealed that the panel failed at the point where the load was acting only, leaving other parts of the panel intact as shown in plate 4-5 above. The expanded polystyrene core was still intact as shown in plates 4-6 and 4-7 for both the slab and wall panels. This shows that buildings made using the expanded polystyrene panels would have fewer cases of injured occupants in case of earthquakes or other strong vibrations since the walls remain intact. The high flexural strength of 65 KN shows that floors would not easily crush in on the occupants during such epidemics too.

4.4 Cost analysis of building using expanded polystyrene panels

The main savings in cost when building using the expanded polystyrene are achieved through reduced transport, labor and running and maintenance costs. The following costs involved in construction were analyzed

- Material costs
- Labor costs
- Transport costs
- Running and maintenance costs
- Opportunity costs

4.4.1 Material cost

Two tables were used to compare the cost of materials required to construct a three bedroom house 12.6m by 6.9 m using the conventional method and using expanded polystyrene panels. The conventional method of building in this case refers to the common practice of using of machine cut masonry stone, mortar and plaster for walling and concrete for floor slabs. The expanded polystyrene method uses prefabricated polystyrene wall and floor panels for building. The three bedroom apartment shown below was used for this comparison. For ease of analysis, the apartment was assumed to be the first floor of a four story block with a beam depth of 450 mm. The following notes below were used to compute the material costs of the building.

Notes

Masonry stone building

Perimeter of house   67,560mm

Density of cement   1440 kg/m^3

Density of sand   2650 kg/m^3

Density of ballast 1750 kg/m^3

Volume of mortar used for walling – 5.270 m^3 (cement sand ratio 1:3)

Volume of mortar for plastering – 6.080 m^3 (cement sand ratio 1:3)

Depth of reinforced slab of 450 mm (for a building with 4 floors)

Building made using expanded polystyrene panels

Panel area (1.2m by 3m) = 3.6 m^2

Cost of a wall panel per m^2 = 5600/3.6 = 1,555.55

Volume of shotcrete for plastering = 4.0536 m^3 (cement, quarry chippings, sand ratio 1:1.5:3)

Volume of concrete = 7.496 m^3 (cement, sand, ballast ratio 1:2:4)

Using conventional method

Table 4- 7: Cost of constructing a 3 bedroom house using masonry stone

ACTIVITY	ITEM	QUANTITY	PRICE (Kshs)	AMOUNT (Kshs)
WALLING An area of 202.68m^2	Sand	10.474 tons	@ 2,175	22,780.95
	Cement	37.94 bags of 50 kg	@ 850	32,249
	Building stones	1740	@ 20	34,800

	Whoop iron	17	@ 2,600	44,200
PLASTERING An area of 202.68m^2 with plaster 30mm thick	Cement	58.37 bags	@ 850	49,614.50
	Sand	10.742 tons	@ 2,175	23,363.85
FLOOR SLAB	Reinforced concrete slab with a cement, sand ballast ratio of 1:2:4	45.21 m^3	11,400/m^3	515,421.36
Total Cost				722,429.66

Using expanded polystyrene panels

Table 4- 8: Cost of constructing a 3 bedroom house using expanded polystyrene panels

ACTIVITY	ITEM	QUANTITY	PRICE (Kshs)	AMOUNT (Kshs)
Walling using panel and shotcrete An area of 202.68m^2 with 20 mm shotcrete	Expanded polystyrene wall panel	202.68 m^2	1555.55/m^2	315,278.87
	Cement	25.94 bags	850/bag	22,049
	Quarry chippings	2.230	789/tons	1,759.47

	Sand	7.162 tons	2,175/tons	15,577.35
Plaster An area of 202.68m^2 with 15 mm plaster	Cement	29.18 bags	850/bag	24,803
	Sand	5.317 tons	2,175/ton	11,681.93
Reinforced slab with concrete ratio 1:2:4	Floor panel	26 panels	10,400	270,400
	Cement	30.84 bags	850/bag	26,214
	Sand	5.676 tons	2,175/ton	12,345.30
	Ballast	4.283 m^3	2927/m^3	12,536.34
	Y12 bars	78	850	66,300
	R8 links @ 200 spacing	832 ft	10/ft	8,320
Total cost				787,265.26

On comparison of tables 4-7 and 4-8 above, the material cost when using the expanded polystyrene panels is more than cost of the same when using the conventional method. The former has a material cost of Kshs. 787,265.26 which is more than Kshs. 722,429.66 achieved through the conventional method of building. This can be attributed to the high price of the wall and slab panels. The current price of wall panel in Kenya is Kshs. 1555.55/m^2 while it should range between Kshs. 680-700 per panel if bought directly from suppliers outside Kenya. This would mean that the cost of construction using the expanded polystyrene method has the potential of reducing significantly.

Some of the causes of the high cost of construction using expanded polystyrene are

- The National Housing Corporation acting like a monopoly thus maintaining high price of panels
- High cost of importing and assembling the panels in Kenya.

4.4.2 How use of expanded polystyrene panels reduces the cost of construction

4.4.2.1 Savings in renting or purchasing of formwork to be used

Less amount of formwork is used when building with expanded polystyrene panels. The arrangement of floor panels allows for a less number of supporting pillars of timber or metal to be used to support the slab during concreting as shown in plate 4-8 below. In addition, this method uses less concrete in its floor slab due to the expanded polystyrene filler, therefore it has less weight. House made using expanded polystyrene panels have no columns but ring beams, therefore, no formwork is required to support columns as is the case when using the conventional method of construction.

Plate 4- 8: Supporting formwork for expanded polystyrene floor panels (Emedue 2011)

4.4.2.2 Savings in labor cost and time

Use of expanded polystyrene panels in building reduces the labor cost significantly. For example, between 7-9 workers are required at any one time to build the three bedroom apartment above within 30-40 days. Using the conventional method of using masonry stone for walling, it would take more number of workers (about 15-18) to build the same house within a similar time frame. Furthermore the contractor would feel time constrained since there are more tasks involved in the conventional method using masonry stone, for example

- Laying and setting up the formwork
- Stone setting and laying while placing mortar in between layers of stone
- Plastering the wall using mortar
- Mixing the mortar
- Mixing concrete which is required in more quantity as compared to using expanded polystyrene panels.
- Putting allowances for fixture and fittings which is more involving conventionally than using expanded polystyrene panels. In the latter, a torch gun can be used to make holes or gaps in the wall to allow for the same as shown in plate 4-9 below.

Plate 4- 9: Putting allowances for fixture and fittings (Emedue 2011)

- Supervision for the tasks above by skilled foremen

This shows there is a greater need for skilled workers (due to increased supervision) when constructing using the conventional method as compared to using expanded polystyrene panels. The cost of a skilled laborer is almost twice the cost of a non-skilled worker. The former is paid between Kshs. 1,000-1,300 per day while the latter is paid between Kshs. 400-600 per day.

4.4.2.4 Savings in time leads to savings in opportunity cost.

If the building was to be leased or rented out, rent income would be achieved earlier using expanded polystyrene panels than the conventional mode of construction using masonry stone. Contractors using these panels are achieving almost 50% saving in construction time. This would mean if the three bedroom house above would be finished in 4 months using the conventional method, it would take about 2 months to do so using expanded polystyrene panels.

The cost of renting a three bedroom house ranges between Kshs. 25,000-30,000 per month in areas such as Kileleshwa, Uplands, Nairobi West or South C in Nairobi. This would mean that the landlord would have made Kshs. 50,000 earlier for the two months taking an average of Kshs. 25,000 monthly rent income. This money could go into paying back a loan if he or she used to debt to finance the construction and reduce the amount of interest he would have to pay eventually. Even better, if the house was being sold, there are higher chances that it would find a buyer earlier; therefore real estate developers would achieve their profits earlier.

4.4.2.5 Savings in transportation cost of materials

One achieves reduced transport costs in ferrying building materials to the site. This provides the biggest saving currently when using expanded polystyrene panels. For example, a 9 tonner truck can comfortably carry 70 panels which are enough to build the three bedroom apartment above (which would require 56 panels). The same house would require 1,740 machine cut masonry stones which are 230mm*230mm*400mm in size. The same 9 tonner truck can ferry 400-500 of such size of masonry stones at a go. This would mean the client would incur three times more the transport cost for doing the walling using the conventional method assuming the distance from the quarry and the expanded polystyrene panels are the same.

Furthermore, expanded polystyrene panels use less quantity of sand and cement as compared to the conventional method as shown in table 4-9 below using our three bedroom apartment as the specimen.

Table 4- 9: Comparison of amount of cement and sand required for the two methods

Material required for the 3 bedroom house above	Expanded polystyrene panels	Conventional method of building with masonry stone
Cement bags required	55	96
Sand in tons	12.479	21.216

Only the quantities required for walling have been used for analysis since the expanded polystyrene floor slab uses 7.496 m^3 of concrete which is far less to 45.21m^3 which is required for building the same house conventionally. This means that the bulk of the cost causing expanded polystyrene panels to be more expensive to potential clients is the cost of purchasing the wall and floor panel.

To elaborate more on the savings in transport cost, 19 tons of sand would cost someone Kshs. 19,000 to buy if he gets it directly from the quarry or supplier. It would cost Kshs. 28,000 if the same 19 tons were to be delivered to the person within Nairobi. This makes a transport cost of Kshs. 9,000 which would be saved by less trips of sand are being made.

4.4.2.6 Savings in maintenance and running costs

Buildings made using expanded polystyrene panels prove to be very comfortable for the inhabitants in terms of heating and cooling as well as sound insulation for a peaceful indoor environment. The expanded polystyrene filler has a low thermal conductivity value; therefore, in summer it keeps the interior cooler while in winter it keeps the building warmer by preventing the external effect of environment. This minimizes the energy required for heating or cooling up to 60-80% (Raj et. al 2014).

The expanded polystyrene wall also prevents the attack of termites, insects and rodents therefore reducing the potential cost of calling a pest or rodent exterminator. Furthermore, the walls are impermeable so there is minimal requirement for long-term maintenance, especially in areas prone to extreme weather and temperature conditions such as summer heat, winter snow, heavy rains and high wind.

For now, the material cost for projects using the conventional method are lower than those using expanded polystyrene panels. Factories producing expanded polystyrene have an unfair disadvantage compared to quarries producing masonry stone for construction. They have to pay more in taxes due to running, maintenance cost and licenses required by government authorities. However, there are savings in transportation, labor and maintenance cost.

In general, contractors using expanded polystyrene panels are achieving about 30% reduction in construction costs (Nasca 2013).

4.5 How use of expanded polystyrene panels for construction conserves the environment

As urbanization rapidly grows, there is an exponential increase in construction of residential houses. Meanwhile, the world is facing a shortage of resource energy such as building materials. This has brought the need to modify housing designs and construction technologies used that reduce the cost of construction while ensuring minimal CO2 emission, more indoor comfort and less energy needs. Use of expanded polystyrene sheet (EPS) reduces the energy consumed by houses during construction and usable lifetime when they are occupied in the following ways

4.5.1 Saving on energy spent during construction

- During construction, energy is spent in transporting materials to the construction site and building the structure. When one uses expanded polystyrene panels for building, one uses less energy since less number of truck loads would be required for building the same area
- Construction using expanded polystyrene panels uses less amount of both skilled and unskilled labor on site for the same period allocated for construction time. For example, a bungalow house can be done by 9 workers who can finish building and doing the house finishes in 30 days which it would take about 20 workers to finish in the same period of time who would feel quite time constrained
- Construction equipment is used for shorter time when using expanded polystyrene panels. This means that less amount of fuel such as petrol, diesel or electricity is used in running the equipment during that period.

4.5.2 Saving on energy spent during the lifetime of the house

- Houses made using expanded polystyrene panels have less heat loss, in the range of 60 to 80%. The expanded polystyrene foam has a thermal conductivity of within the range of 0.032-0.038 watts per meter Kelvin (W/(m·K)) as compared to concrete whose thermal conductivity falls in the range of 0.4-0.7 W/(m·K). This minimizes the energy required for heating, ventilation and air-conditioning up to 60-80% depending upon the thickness as well as density of expanded polystyrene foam used. Therefore in summer, the interior of the house is cooler and during winter, the building is warmer by preventing the external effect of environment (Raj et. al 2014).
- Houses made using the expanded polystyrene panels prove to be very comfortable in terms of sound insulation too leading to a peaceful indoor environment. This prevents sound pollution due to traffic, construction or other activities from affecting the inhabitants of the house. Furthermore, buildings that house noisy activities or equipment can have their walls made using expanded polystyrene panels leading to less noise pollution affecting people outdoors.

4.5.3 Other ways use of expanded polystyrene panels helps conserve the environment

a. There will be reduced need to have stone quarries which lead to deterioration of the environment in the following ways
    - Visual intrusion: The aesthetics of nature and the natural landscape are eroded as quarries clear the land so that masonry stone can be extracted.
    - Damage to landscapes: the natural landscaped is destroyed leading to possible calamities such as landslides and mudslides. Earthquakes could also be activated due to blasting of rocks
    - Smoke, noise and dust fill the air during quarrying activities which can lead to deterioration of health of the surrounding communities. In addition, it also makes the surrounding area to become more inhabitable leading to loss of income to landlords and homeowners in the surrounding environment.
    - Damage to natural caves above and underground can occur due to quarry activities as the personnel in the quarry dig deeper in search of quality stone material.

- Areas with quarries attract heavy traffic due to lorries and other big vehicles accessing the site. This can potentially lead to damage of existing roads due to over-loading of trucks carrying stone.
- Loss of land: the land used as a quarry becomes inhabitable due to holes and other land defects such as uneven ground and rock levels. Surrounding landowners are also affected since their land reduces in value due to the quarrying activities
- Deterioration in water quality: this can especially happen if quarries are situated near water catchment areas or nearby lakes or flowing rivers.

b. The factory process that makes expanded polystyrene foam does not lead to degradation of the environment. Expanded polystyrene is made from polymerization of styrene which is infused with pentane which is an organic compound with the formula C_5H_{12} (Balabin 2009). Pentane does not pollute the environment, or affect human health. The production process does not also include halogens which usually deplete the ozone layer. In addition, factories that manufacture expanded polystyrene units do not have remaining solid waste at the end of the production process. All cut-offs or waste are recycled into the production process making the process environmental friendly (Foam technology (2013).

Therefore, use of expanded polystyrene panels is an environmental friendly way of building with optimum use of materials, recycling of waste products, less noise and dust.

Chapter 5

5. Discussion

5.1 Reasons why engineers using expanded polystyrene appreciate the method of building

- Better structural performance of buildings made using expanded polystyrene compared to those made using masonry stone. Expanded polystyrene panels are a composite material made of several components that give it improved properties such as fire and earthquake resistance and sound proofing apart from being structurally strong.
- Ease of construction using expanded polystyrene panels.
- New government research that has revealed that construction using alternative materials such as expanded polystyrene can improve the construction industry by reducing construction time and cost.
- Less time and cost spent in construction.
- The New building code which motivates professionals in the industry such as engineers, architects and quantity surveyors to be creative and innovative in building materials they choose

The government wants to encourage Kenyans to adopt other modes of construction and it consequently passed the new building code in 2009 in an effort to do so.

5.2 The New Building Code of Kenya 2009

The objective of the new code was to give millions of Kenyans a chance to own a decent home by broadening the range of acceptable construction materials beyond brick and mortar. The former building laws were reviewed and a draft Planning and Building Bill was prepared and tabled before Parliament.

The bill was approved and named as the New Building Code. The main aim of the new law is to encourage use of construction materials that reduce construction time and cost. It also advocates that professionals in the industry should shift their mindset to building materials that are centered on material performance instead of materials specification as is the norm (National Planning and

Building authority 2009). For example, expanded polystyrene panels are a composite material made of wavy undulated panels of polystyrene that are reinforced with welded galvanized wire mesh on either side. They are used to make structural and partitioning walls, roof panels, floor slabs and staircases. The walls are covered using shotcrete which is a form of concrete plaster and stronger than ordinary mortar.

The New Building Code is expected to move the building industry away from brick and mortar that some players claimed has made construction a rich man's business, locking out many Kenyans of average means from the chance of owning homes. Though cement will remain a vital component of any construction, locally available materials and latest building technologies could help offer faster and cheaper solutions for housing in the semi-permanent segment. Among the materials being considered are timber and UN blocks and bricks made from earth across many parts of the country, modern construction technology such as prefabricated boards (like expanded polystyrene) and interlocking blocks which are cheaper than the preferred brick and mortar. Eco-friendly materials for roofing such as the traditional grass for thatching and prefabricated panels used are also being considered. This law removes the perception that houses built from these materials are considered temporal and the approval of local authorities must be sought (National Planning and Building authority 2009). The code is a major boost to the housing sector and could slow down the proliferation of slums that has emerged as the best alternative to the lower class on a low supply of housing. The appetite for housing currently stands at 150,000 units annually but the country can only produce 50,000 units, with most targeting the high-end of the market due to the high returns from this segment. About 60% or 1.9 million of the three million Nairobi residents live in slums and informal settlements, according to UN. Building experts reckon that the cost of putting up a house could fall by up to 30 per cent under the proposed code (UNISDR 2010).

5.3 Reasons why contractors using expanded polystyrene appreciate the method of building

•Simplicity in construction

•Versatility and flexibility of expanded polystyrene panels. It can be used as structural walls, partitioning, making floor slabs swimming pool construction and underground car parks.

•Less number of skilled laborers are required on construction sites

•Less construction time is incurred

•It is easier to get financing for tenders given to contractors to use expanded polystyrene since the financiers are assured of faster return on investment holding other factors constant.

•A contractor’s property is held for a shorter time by a financing institution that has issued a performance bond on behalf of the contractor guaranteeing client about the fulfillment of a particular contract.

•Contractors can seek insurance for building contracts over shorter period of time since this method is faster than using masonry stone; this leads to savings in premiums to be paid to insurance companies.

•It is an environmentally friendly way of building with optimum use of materials from recycled waste products.

•It is a cost effective solution to reducing the housing deficit in the country

•Safer in construction with less noise and dust on the site

•Increased quality of construction due to introduction of factory setting

•Reduced construction waste

Most of the contractors who have been using expanded polystyrene panels for building got interested in this mode of construction between the years 2004 and 2010.

5.4 Challenges that contractors may face when using this method of building

Initially contractors who started using this mode of construction faced the challenge of acceptability by other stakeholders in the industry for example, engineers, architects, homeowners, and other members of the public. Stakeholders in the industry had to be assured that houses made with expanded polystyrene panels had a long life and were durable. So far, that is a challenge that they managed to overcome and they constructed residential houses in several estates in Nairobi, for example, Rongai, Balozi estate, Muthaiga, Ruai and executive apartments at the Nairobi State House.

The current challenge that contractors and engineers using expanded polystyrene are facing is acceptance of this mode of construction by architects. This form of construction takes a shorter time in project completion and one can easily fabricate the panels at the factory to suit different building shapes and designs. These two aspects reduce an architect's expected remuneration in terms of site visit and consultation fees. If architects were to broadly embrace this idea and help to develop it further, Kenya can reduce her housing deficit and lead to more professional input which would improve the building construction industry.

In an effort to encourage spread of this form of construction in the country, the government intends to perform 30% per cent of its projects using expanded polystyrene method through its parastatal the National Housing Corporation (National Housing Corporation). Furthermore, they have revised the New Building Code in 2009 which encourage use of alternative materials other than masonry stone that save on building cost and time.

Contractors using expanded polystyrene panels insist that more needs to be done by the government to encourage more use of this method of building. For example, the government could pass a broad policy that will encourage stakeholders in the industry to uptake this method of building that reduces construction time. In general, these contractors foresee a bright future in construction using expanded polystyrene panels and many more stakeholders getting involved in this method of building construction. Industry has started accepting this mode of construction. Engineers and contractors are generally getting interested in this form of construction.

5.5 Concerns of homeowners and real estate developers who know about the use of expanded polystyrene panels for building

Most of the homeowners and real estate developers mentioned that sometimes they face difficulties working with engineers and architects when wanting to use alternative construction material such as expanded polystyrene to construct. Reasons for this could be

- Ignorance by engineers and architects to update themselves on upcoming alternative construction methods and materials such as use of expanded polystyrene panels
- Reluctance by building professionals to shift from conventional building methods using masonry stone to other materials
- Lack of adequate trainings and seminars to teach building professionals on alternative construction materials and methods
- Slow pace by government in approving alternative construction materials and methods

5.6 Feasibility of the requirement for home owners to have the bulk of money before construction commences

It is feasible to start construction using this method of building if adequate planning is done prior. The project can be able to spring up faster and evade radical changes in market dynamics such hiking of the cost of labor, construction materials or insecurity. If prospective homeowners and real estate developers persevere this initial period, which is demanding financially, they will achieve their returns faster. Financial institution such as banks would also feel more motivated to fund the project since they are assured of faster return on investment holding other factors constant.

5.7 Reasons why the cost of construction using expanded polystyrene in Kenya is higher than in other countries

The costs of processes that are used to compute the final price of expanded polystyrene panels are high in Kenya and include the following

- High import tax on oil product such as polystyrene beads and galvanized wire mesh. The cost of galvanized wire mesh is $ 1per kg in China or India while in Kenya it is valued at

$ 2.5 per kg. Polystyrene beads go for $ 0.8 per kg in Dubai or Brazil while they are valued at $ 1 for the same quantity in Kenya (National Housing Corporation 2013).

- High shipping cost of polystyrene beads and galvanized wire mesh
- High running costs at the National Housing Corporation factory which produces expanded polystyrene due to high cost of electricity and licenses needed for operation. The cost of electricity is usually the highest factor for factories producing expanded polystyrene since most of the machines used are automated.

5.8 Why the use of expanded polystyrene panels should be embraced fully in the country

The economic, technical and constructive features that make the expanded polystyrene panels symbolic in comparison with the "traditional methods" can be summarized as follows:-

1. The panel typology is flexible: it gives room for all simple, creative, adaptations to the architectural requirements of the project, enabling the creation of any curved and flat form of walls and coverings.
2. It is easy to work with the panels during the erection phase. Before concrete is applied, it is possible to create necessary spaces like plumbing, openings and electrical fixtures.
3. Addition of reinforcement to the panel before concrete is applied is easy enabling the perfect camouflage of the "monolithic" shape of the structure and additions without compromise on the quality of the final product.
4. The panels are light weight in comparison to the traditional prefabricated structure; their weight varies approximately between 4 and 15 Kg/m^2. This enables easy handling of the panels from the production phase to the erection phases of the building.
5. It is fast, economical and uses simple tools. Mounting of the panels by a non-specialized operator is also very easy.
6. The structure of a building is not made of deformable frames but rigid ones thus in contrast to traditional structures, it can be considered as "one block".
7. From an architectural perspective, these houses offer a high degree of flexibility in aesthetic treatment and floor plan design. This enables inclusion of an exciting lifestyle and building features without the need for costly or extensive engineering

8. It enables faster construction which enables the country to meet its present and projected housing supply and demand needs.
9. It allows saving of energy since the insulating properties of expanded polystyrene panels replaces the use of AC systems and heaters in rooms especially in chilly local climate conditions.
10. It saves on construction time and cost.
11. It is more environmentally friendly compared to the conventional method using masonry stone.

Chapter 6

6 Conclusions and recommendations

6.1 Conclusions

It can be concluded that the use of the expanded polystyrene panels for construction in Kenya is yet to achieve momentum. Stakeholders in the industry who have embraced this form of construction are experiencing its benefits such as

1. Reduced energy consumption
2. Use of recycled waste products
3. Incorporating cost effective solutions in construction projects
4. Reduction in construction time
5. Increased safety in construction
6. Less noise and dust allowing workers on site to maintain their health
7. Reduction of construction waste which is a norm in construction sites after completion

The study also proved that expanded polystyrene wall and slab panels are strong enough to be used for construction of walls and floor slabs in buildings as prove. A time saving of 50% and cost saving of 30% though labor, transport and hiring of construction equipment and formwork, are being achieved. Use of expanded polystyrene panels also conserves the environment by saving on the energy spent in construction, reducing visual intrusion due to construction activities, reducing damage to landscapes caused by stone quarries, reduction in smoke, noise and dust, less damage to roads leading to quarries and less incidences of loss of land due to quarrying activities and less deterioration in water quality.

6.2Recommendations

To increase the use of expanded polystyrene panels in building construction, the following measures should be taken

- ✓ More sensitization of the public on this mode of construction through the TV, newspapers, social media, seminars
- ✓ Reduction of the price of expanded polystyrene panels so that more savings on cost of construction are achieved
- ✓ More organizations of events such as exhibitions, housing expos and seminars by the government that advocate for use expanded polystyrene panels for construction
- ✓ The government should pass a broad policy that advocates the use of expanded polystyrene panels for housing projects

The cost of expanded polystyrene panels can be reduced if

- Import tax on oil product such as polystyrene beads and galvanized wire mesh is reduced
- Subsidies on shipping cost of polystyrene beads and galvanized wire mesh are placed
- Subsidies are given on electricity and licensing fees for factories producing expanded polystyrene panels
- More favorable policies are passed that encourage competition in the production of expanded polystyrene panels to mitigate the monopoly by the National Housing Corporation

REFERENCES

Aganto 2013. *The beginnings of the prefabricated building*. A brief history of prefabricated buildings. Retrieved 26th Feb 2013 from

http://www.aganto.co.uk/prefabricated-buildings-a-brief-history.

Balabin R. M. (2009). *Enthalpy Difference between Conformations of Normal Alkanes.* “Raman Spectroscopy Study of n-Pentane and n-Butane".

Dow chemical company (2014). *Invention of Styrofoam*. Building solutions. Web. Retrieved 15th March 2014 from

http://building.dow.com/about/invention.htm.

Emedue. *Walls built with polystyrene panels.* “Operators handbook 2011”.

Foam technology (2013). “*What is EPS? Expanded polystyrene particle foam*”. Retrieved 1/4/14 from

http://www.iwi-gmbh.com/iwi/pdf/IWI_EPS_en.pdf.

Handojo T. (2009). *Use of Water Reducers, Retarders, and Superplasticizers*. Pennsylvania state university. Retrieved 2/4/14 from

http://www.engr.psu.edu/ce/courses/ce584/concrete/library/materials/Admixture/AdmixturesMain.htm.

Jackie Craven 2013. *Concrete home withstands storms*. About Architecture. Retrieved 16th March 2014 from

http://architecture.about.com/cs/buildyourhouse/a/concretehomes.htm.

Koerner, R. M. (1990). *Designing with geosynthetics*. Englewood Cliffs, N.J: Prentice Hall

Barnesplastic (2014).

MacGinley T. J. and Choo (1990). Reinforced concrete. Design Theory and Examples.

http://www.barnesplastics.co.nz/Environment_Manufacture.html.

Nasca (2013). Nasca Construction limited. "Construction using polystyrene system."

National Housing Corporation (2013). *EPS factory*. Retrieved 20th March 2014 from http://www.nhckenya.co.ke/index.php?option=com_content&view=article&id=109&Itemid=68.

National Planning and Building authority. (2009). "*Planning and Building regulations 2009"*

Republic of Kenya.

Postcards 2009. *Friend's Meeting House: Keith explores some early history in the Adelaide City region of South Australia.* Adelaide City. Retrieved 26th Feb 2013 from

http://www.postcards-sa.com.au/features2009/quakers_meeting_house.html.

Raj et. al (2014). "*Prospects of Expanded Polystyrene Sheet as Green Building Material"*. University of Indiana

Schnell (2014). *"Industrial structures building system in reinforced concrete casted on site. Concrewall."*

Styron 2014. *Polystyrene*. Innovation timeline. Retrieved 15th March 2014 from

http://www.styron.com/company/history/polystyrene.htm.

Texas Department. (2006). *"Construction and Material tips*." Retrieved 2/4/14 from

http://ftp.dot.state.tx.us/pub/txdot-info/cst/tips/fullcure.pdf.

Wong R. M. (2013). "*Prefabricated Building Construction Systems Adopted in Hong Kong*." Retrieved 15th March 2014 from

http://personal.cityu.edu.hk/~bswmwong/pp/PrefabricatedConstruction.pdf.

UNISDR. (2010). "*Country's position paper on risk reduction"* Republic Of Kenya. Retrieved 1/4/14 from http://www.unisdr.org/2005/mdgs-drr/national-reports/kenya-report.pdf.

APPENDICES

QUESTIONNAIRE FOR ENGINEERS USING EXPANDED POLSTYRENE PANELS FOR BUILDING

1. What reason(s) could have made you shift from using ordinary masonry stone to expanded polystyrene panels for building construction? (Tick where appropriate)

   ☐ Job requirement ☐ Better material properties

   ☐ Ease of design ☐ New government policy

   ☐ I still prefer using masonry stone

   Please indicate any other reason

2. Is shotcrete a form of mortar/concrete?

3. Why was shotcrete chosen as opposed to using mortar (cement, sand, water mix)?

   ☐ Better bond strength ☐ Higher durability

   ☐ Better workability

   ☐ Better compatibility with the inner expanded polystyrene core

   Please indicate any other reason

4. What is the ratio of the constituents that make up the shotcrete used for expanded polystyrene construction in Kenya, indicating cement, sand and quarry chippings ratio respectively (for example, the ratio is 1:2:3)

5. Why was quarry chippings chosen as the coarse aggregate?

   ☐ Enables the shotcrete to be more workable

   ☐ Allows use of a pump to spray the shotcrete

   ☐ Because of its size and shape properties

   ☐ Other properties

   Please state the reasons for you answer above

6. Are there other additives that can be added to shotcrete to alter its characteristics? Yes/No

   Please indicate which additives

7. Which one is stronger

- ☐ A wall made using masonry stone and plaster
- ☐ A wall made using expanded polystyrene panels and shotcrete

8. What thickness of expanded polystyrene foam is used in Kenya? (e.g)

   Please state the reasons for you answer above (for example due to geography or climate)

9. Have you tested the strength of the material? Yes/No

   Please state which tests were done and the results

10. This mode of construction conforms to which building standards?

    ☐ Eurocode ☐ British standards

    ☐ KEBS

    Please specify any other

11. How many floors can a building built from single expanded polystyrene panels be?
12. How many floors can a building built from double expanded polystyrene panels be?
13. What modes of failure and defects can be experienced from houses built using expanded polystyrene panels and slab, for example, cracking, creep or zones of weakness?
14. What can lead to these modes of failure?
15. How can the above be prevented?
16. Are there any improvements you think can be added to the expanded polystyrene panels material produced at the NHC factory? Yes/No

    Please state which improvement (s) and the intended purpose (for example thicker foam which can lead to greater strength)

17. Are there any inherent weaknesses with building with expanded polystyrene that have already been mitigated for? (For example weakness in shear has been mitigated by…..)
18. What makes expanded polystyrene panels to be earthquake resistant?
19. The floor panel has a rib in the middle where a beam made of 3 Y-12 bars are used?

    Yes/No

Which links are used for the number of reinforcement bars and what is the spacing? (e.g R6 or R8 links at a spacing of 200mm)

Please comment on how the beam assists the floor panel to handle loading?

20. How does the wavy shape of the polystyrene foam improve the structural performance of the floor and wall panels?
21. Do buildings that are made from polystyrene panels have

    Columns? Yes/No

    Please comment on the answer above

    Beams? Yes/No

    Please comment on the answer above

    Slab made from expanded polystyrene floor panel? Yes/No

    Please comment on the answer above

22. Concrete used for the floor slab uses a cement, sand, ballast ratio of 1:2:3 or 1:2:4? Please comment on the ratio above

QUESTIONNAIRE FOR CONTRACTORS BUILDING USING EXPANDED POLYSTYRENE PANELS

1. Have you used the expanded polystyrene panels for building? Yes/No
2. When did you start using expanded polystyrene panels as a construction material? (e.g 2005, 2010)
3. In which country ()s have you implemented this? E.g (Kenya, South Africa)
   What sparked the interest to start using it in the country above?
4. What were the reasons that influenced your choice to build using expanded polystyrene panels rather than conventional stone masonry method?
5. Does one achieve reduced transportation cost using expanded polystyrene panels for construction? Yes/No
   Please comment how if Yes or why if No
6. What challenges have you encountered so far while using this mode of construction
   Which ones have you overcome so far since you began?
7. What are the current challenges you face, as a contractor, in using expanded polystyrene panels as compared to conventional construction methods?
8. What efforts has the government made in making use of expanded polystyrene panels for building spread in the country?
9. What more could the government do to grow the construction industry through expanded polystyrene panels for building?
10. What future do you see for alternative construction material use in Kenya, especially for expanded polystyrene? (e.g. a bright or a poor future)
11. What are your general/personal views on the construction industry's acceptance of the same, with reference to engineers, architects, fellow contractors and the general public who form prospective clients?
12. Generally, what is the percentage saving in cost that you have achieved while using expanded polystyrene panels?
13. How could the cost of expanded polystyrene panels be reduced further in order for it to be more competitive?

Questionnaires for stakeholders in the construction industry yet to start using this method of housing in Kenya included

QUESTIONNAIRE FOR ENGINEERS, ARCHITECTS, CONTRACTORS NOT ACTIVELY USING EXPANDED POLYSTYRENE PANELS

The information you will give is taken in confidentiality and will be used for research purposes only

Name (Optional):

Profession/speciality:

Which sector of the construction industry are you engaged in? (Tick where appropriate)

Govt: ☐

Private sector: ☐

Non-Governmental Organisation: ☐

Consultant: ☐

Otherwise (Please specify): ☐

For how many years have you participated in this sector? (Tick where appropriate)

☐ 0-5 Years ☐ 5-10 Years ☐ More than 20 years

☐ 10-15 Years ☐ 15-20 Years

1. Have you heard of the mode of construction above? Yes/No
2. Do you agree that use of prefabricated elements as opposed to in-situ construction can reduce construction time? Yes/No
3. Are you aware that the government approved use of the same in Kenya in 2004?
4. Are you aware it has been implemented through the National Housing Corporation and approved by KEBS? Yes/No

5. The government intends that 30% of government housing projects in the country to be done using expanded polystyrene, do you approve of this government move? Yes/No. Please comment on the reasons for your answer above
6. Use of this mode of housing achieves a 50% reduction in construction time and 30% reduction in cost; do you think that this move will substantially reduce the housing deficit in the country? Yes/No
7. Please give rough estimates for the following scenario for construction of a standard two storey building which has 3 bedrooms for every floor?

- The number of workers required indicating how many are skilled and unskilled
- Current wage rate per worker per day
  Skilled -
  Semi-skilled -
- The number of days it will take for completion that is from foundation to finishing (plumbing, electrical fittings and painting)

8. In your opinion, has the government done enough to increase awareness of this mode of construction? Yes/No
9. What could the government do to increase awareness and motivate stakeholders in the industry to participate in the same? (tick where appropriate)

☐ Showcase on construction using Expanded polystyrene projects through the media (TV, newspapers and construction journals)

☐ Organize trainings and seminars on the same through bodies such as E.B.K, I.E.K, A.A.K, N.C.A

☐ Invite engineers, architects and contractors to visit sites done using Expanded polystyrene panels in Kenya and worldwide

☐ Include in the education curriculum for students doing civil engineering in Kenyan universities and colleges

Please comment on any other way the same could be achieved

QUESTIONNAIRE FOR HOME OWNERS / REAL ESTATE DEVELOPERS NOT YET USING EXPANDED POLYSTYRENE PANELS FOR BUILDING

The information you will give is taken in confidentiality and will be used for research purposes only

Name (optional):

Please indicate how you interact with the building/construction industry (Tick where appropriate)

☐ Home owner ☐ Landlord

☐ Real estate developer ☐ Real estate agent

Please indicate the size of the building/real estate you have ticked above e.g 3 bedroom house, 4-storey residential building

1. What kind of construction materials are you aware of, when it comes to building construction? (Tick where appropriate)

- ☐ Stone
- ☐ Mud
- ☐ Timber
- ☐ Expanded polystyrene
- ☐ Bamboo
- ☐ Bricks
- ☐ Galvanized iron sheets (mabati)

i. Have you used another form of construction material apart from the ones above? Yes/No.

Please indicate which material it was

Did you achieve your intended purpose for using alternative construction material? Yes/No

Please indicate your achievement or challenges in the same

ii. Have you heard of use of Expanded Polystyrene panels as a construction material in Kenya or other parts of the world? Yes/No

iii. Where did you find out about it?

- ☐ T.V
- ☐ Newspapers
- ☐ Construction Journal
- ☐ A friend
- ☐ On social media

iv. Do you find information about Expanded Polystyrene housing readily available when you want it? Yes/No

v. Would you consider using it as construction material? Yes/No

vi. Do you consider the material cheap or expensive?

vii. If the material saves on construction time, would you prefer to use it?

viii. Construction using expanded polystyrene panels takes a shorter time span therefore clients need to have the bulk of the money required for project completion readily available, is this feasible for home owners/real estate developers?

Please state the reasons for your answer above

ix. Have you faced any difficulties when working with engineers or contractors when it comes to building with alternative construction materials? Yes/No

x. Use of this mode of housing achieves a 50% reduction in construction time and 30% reduction in cost; do you think that this move will substantially reduce the housing deficit in the country? Yes/No

xi. Would you consider using it as a construction material? Yes/No. Please state your reasons for the answer above

xii. If yes, how do you think the information can be best spread to the public about alternative construction materials and especially using Expanded Polystyrene panels?

- ☐ T.V
- ☐ Newspapers

☐ Construction Journal

☐ A friend

☐ Social media

You are invited to make any further comment

QUESTIONNAIRE FOR MEMBERS OF THE PUBLIC NOT YET USING EXPANDED POLYSTYRENE PANELS FOR BUILDING

The information you will give is confidential and will be used for research purposes only

Name (optional):

(Tick where appropriate)

Male ☐ Female ☐

Age bracket ☐ 10-20 ☐ 20-30 ☐ 30-40 ☐ 40-50 ☐ 50-60 ☐ 60-70

Education level ☐ KCSE level ☐ Diploma level ☐ Degree level

☐ Masters level ☐ Phd level ☐ Other

1. What kind of construction materials are you aware of, when it comes to building construction? (Tick where appropriate)

☐ Stone

☐ Mud

☐ Timber

☐ Expanded polystyrene

☐ Bamboo

☐ Bricks

☐ Galvanized iron sheets (mabati)

2. Have you heard of use of Expanded Polystyrene panels as a construction material in Kenya or other parts of the world? Yes/No
3. Where did you find out about it?

- [ ] T.V
- [ ] Newspapers
- [ ] Construction Journal
- [ ] A friend
- [ ] On social media

4. Would you have any problem with living in a house constructed using expanded polystyrene panels? Yes/No

   Please state the reason(s) for your answer above
5. The government intends that 30% of government housing projects in the country to be done using expanded polystyrene, do you approve of this government move? Yes/No.

   Please state the reason(s) for your answer above
6. Use of this mode of housing achieves a 50% reduction in construction time and 30% reduction in cost; do you think that this move will substantially reduce the housing deficit in the country? Yes/No
7. Would you support the government if they passed a policy for government projects to be done using expanded polystyrene panels? Yes/No.
8. Would you consider using it to build your home? Yes/No. Please state your reasons for the answer above
9. Please indicate other ways the government can sensitize the public on this mode of construction (e.g through the media- TV, newspapers, social media, seminars)

   You are invited to make any further comment