A COMPARATIVE ANALYSIS BETWEEN STEEL, MASONRY AND TIMBER FRAME CONSTRUCTION IN RESIDENTIAL HOUSING

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A COMPARATIVE ANALYSIS BETWEEN STEEL, MASONRY AND TIMBER FRAME CONSTRUCTION IN RESIDENTIAL HOUSING

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Study Leader

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Declaration by student

I, the undersigned, herby confirm that the attached treatise is my own work and that any sources are adequately acknowledged in the text and listed in the bibliography.

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Signature of acceptance and confirmation by student

Abstract

Title of treatise	:	A comparative analysis between steel, masonry and timber frame construction in residential housing.
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Masonry has been used for frame construction in residential housing for many years and is still a popular building method today. In South Africa masonry is the most common construction material which is not the case in other countries. America and Australia has a big market for timber frame construction in residential housing.

The objective of this study is to determine whether the conventional masonry building method can be replaced by the light steel frame construction method which is starting to make its appearance in South Africa or the timber frame construction method commonly used in America and Australia. A comparison is made between steel, timber and masonry by comparing advantages, disadvantages, structural strength and durability, cost effectiveness and a study is done to see which material is more sustainable.

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Chapter 1: Introductory chapter

1.1 Introduction

The choice of construction has always been an issue large in the mind of all self builders and has been a subject of debate in the industry, comparing the relative merits of masonry, timber and steel frame construction. Broadly speaking, traditionally there have been two technologies used for residential architecture worldwide. One is traditional masonry, and the other is lightweight construction with predominantly timber or timber products. Each of these technologies has evolved over thousands of years, influenced by climate, culture, and the technological advances and experience of the society that utilizes it. Residential construction now shows a movement towards lightweight and modular construction. Lightweight pre manufactured steel frames for residential housing also stepped into the market recently.

Masonry is one of the key construction materials used in South Africa and is used both as a load bearing material and as a cladding to framed structures. Brick and block masonry remain the primary construction materials for houses in South Africa and are used extensively in buildings of all types. Historically reliance was placed on the great compressive strength of masonry to produce structures such as the Arch of Ctesiphon, the Pyramids and the large Roman Aqueducts and Dams. These structures have withstood the test of time and proven the inherent durability and structural integrity of masonry. Today's modern masonry structures are slim in comparison and make use of modern materials and design methods. Masonry has a lot of advantageous properties like acoustics, durability, low maintenance, strong structural frame, fire resistance, esthetics etc. and is made from earth itself witch means there should be enough resources. Because masonry has been used in South Africa, most builders is in a comfort zone and don't want to change their building method and adapt to new technologies.

Steel frame construction has been used in residential housing construction before but is not very common in South Africa. The structural frame is manufactured with light weight

gauge steel frame members and some steel frames are pre manufactured. Cladding or dry walling is normally used to cover the steel frame and masonry can also be used. Problem areas might include delays and disputes arising from drafting new building regulations and agreement certificates, suppliers (brick, sand, cement) to the traditional building sectors may see the new technology as a threat to their business and builders might have to familiarize themselves with new building methods. Some advantages of light weight steel frames in residential houses is among others speed of erection, good for sites with bad soil conditions because of light weight, resistant to cracking, rot and termites, corrosion resistance, dimensional accuracy etc. and will be discussed later in this study.

America and Australia is known to make use of light weight steel construction in residential housing, and to implement such a system in a country that is not familiar with the system will require a lot of education and new technology.

Timber-frame homes has come into the picture in South Africa recently and one of the reasons that timber-frame homes have taken so long to become the tradition in South Africa is the early lack of suitable indigenous timber. Now, however, with greatly improved forestry and milling techniques, a much higher quality of locally grown structural timber has made this construction method not only feasible but extremely attractive too. Now that South African National Building Regulations accept it as a high-standard construction method, there is little doubt that timber-frame homes will become a choice for new home builders. The chances of timber engineering and of the use of timber as load- bearing material depend on the quality criteria. The most important factor is the economical use of timber in order to increase its utilization in construction and make it competitive in comparison to other constructional materials. Timber as a material for supporting systems is an indicative orientation for the use of wood in further constructions. Therefore, all kinds of wood and timber, from round wood to squared timber through composite sections made of boards and squared timber, as well as glue-laminated timber, plywood, etc., especially when combined with other materials, must be developed and employed. Some advantages include light weight, recycling, easy to

erect and demolish thermal properties etc. The Iwo biggest disadvantages are infestation of insects and fires and will be discussed later in this study.

Different materials are being used in different countries and in South Africa as mentioned masonry are being used mainly for the construction of residential housing and steel more for bigger structures like warehouses etc. Wood is not usually used in construction of housing in South Africa but more commonly used in other countries like America but is making its appearance. The question is why different countries use different materials in the construction industries. There must be one superior material between the three and reasons why it is being used.

A comparative analysis should be done in order to determine which material will stand out above the rest of them for frame construction in South African residential housing.

1.2 Main problem

Will steel or timber frame construction be a better alternative for masonry construction in South Africa?

The goal of this study is to determine whether masonry being the most used material in residential housing construction in South Africa can be replaced by steel or timber to improve the quality and durability while being cost effective. It is also an objective to find out whether these materials can be combined in a way to reach a better result.

1.3 Sub problems

1. What does the three building methods consist of, how it is constructed and which method has the most advantages and the least disadvantages?
2. Which of the construction material is more sustainable?
3. Which of the three materials will be more durable and structurally the strongest?
4. Which of the construction materials will be the most cost effective?

1.4 Hypotheses

I think that wood and steel can be used more efficiently in the construction of housing in South Africa if better management and planning is done long before construction commences, Because timber and steel is difficult to obtain and forestry is not what it is supposed to be, South Africa uses masonry as the main construction material in the fame construction of residential housing. Wood and steel can be used in a more eco friendly manner than masonry because it can be recycled and broken down and removed easily. Wood and steel will also have less waste than masonry. Steel frame construction can be erected quickly and services will be easier to install maintain and remove. There is a lot more advantages to steel frame construction and one cannot see why steel will not be fit to replace masonry as building material.

1. Steel frame housing consists of steel members bolted together to form a frame and is then covered by cladding or brickwork. Wood frame construction consists of the same concept but will be of wood members. Masonry is a common building material and is well known in South Africa and needs no explanation. Wood will have the most advantages but will have a lot of disadvantages as well. Masonry will have the least disadvantages.
2. Wood is the most sustainable and is very easy to recycle even if for use for something else than construction. Wood also doesn't unleash chemical gases when harvested which damages the surrounding areas, and is produced naturally. Steel can also be recycled and is easy to melt and mould into a new shape. The production process of steel might be harmful to the environment. Masonry is extracted from the earth and has a negative impact on the environment. Timber would in this instance be the most eco friendly material to use in frame construction.
3. Masonry will probably be the strongest structurally although wood and steel will come very close and might even bigger in certain cases. The way the building is planned however will have a big effect on the structural strength of the material for example how close the columns are to each other or the height of the building

etc. When it comes to durability, steel would probably be the most durable between the three materials because it is protected against corrosion if treated and is immune to infestations by insects etc. Wood's durability on the other hand can be affected by insects and become weak in wet weather if not treated correctly.

4. Wood will be the most cost effective if managed correctly and forestry affairs plan ahead for construction projects planting enough trees to supply enough wood. The more wood is available the less it will cost and will also boost forestry which in turn is good for the environment. Masonry was always the most cost effective way because it is harvested from the earth itself. Steel at the moment is very expensive and would probably be the most expensive of the three building materials but other costs can be cut in the labor trade and time saved on the erection of the building.

1.5 Research methodology

1. One must look at designs already developed for these three building methods to find out how the components is put together and to see of what the designs consist of by means of internet, contractor's brochures, advertisements etc. Advantages and disadvantages will be discovered on designs already implemented and one will find case studies in books and internet.
2. Green features will be evaluated and compared. This can be determined by using the internet. The environmental impact of producing these 3 materials should be evaluated and compared.
3. The properties of the three materials should be determined to find out which material is more durable and witch material is the strongest, or if it is flammable etc. This will have to be determined from sources such as books, internet and physical tests if necessary. All structural strength tests already done should be evaluated and compared. This includes compression and tension tests because as we know some materials are weaker or stronger in tension or compression. The thickness of the material should also be taken into account. There will also

have to be looked at how the different weather conditions can influence the durability of the different materials and if it would influence the structural strength of it. Water will have an impact on wood for example and it should be looked at and ways to treat the wood to be weather resistant should be applied.

4. The cost of the different materials will be compared by doing an estimate using square meter rates.

Chapter 2: What does the three building methods consist of, how it is constructed and which method has the most advantages and the least disadvantages?

2.1 Introduction

Most South African citizens know what masonry brick construction consists of and therefore one must look at the composition of steel and wood construction which is not very popular under the common South African citizen but more popular in America, Australia and Europe. To implement a new building method will be challenging because people in the construction business will have to change their ways and learn a new system. With enough motivation on can implement such system. Steel frame construction is already starting to make its appearance in South Africa but wood frame construction is not so popular in South Africa yet. Some of the elements will still be the same than the conventional brick masonry construction method for example foundations, roof construction, windows, doors etc.

2.2 Body of the chapter

2.2.1 Components of the different building methods

There are many different steel construction systems in the market today but all of them will relate to the following explanation of steel frame construction.

The main element of lightweight steel construction is a light gauge steel-framing member, made from structural quality sheet steel that is usually formed by cold rolling through dies. As implied, this production method does not involve heat input and its associated expense. Elements are thinner, production rate faster, and the finish is smoother. All these factors add up to lower production costs when compared with equivalent, but heavier hot rolled steel products such as I-beams or channels. The wall and roof structure of a house would be built with these lightweight sections onto a floor

slab. A suspended floor can also be used which in turn will make it easier to include installations in the floor. Cladding of the roof would follow, providing a protected area for installing services and cladding the walls, typically with gypsum sheet. Wall exterior would then be constructed on the outside, materials being of a wide choice, examples being brick skin, fiber cement, timber, or metal sheet, as are the possibilities in the case of equivalent timber frame constructions. The foundations will be similar to the conventional masonry building method for example strip footings, raft foundations etc. but will require less reinforcement because steel frames and wooden frames is lighter than masonry frames.

There are two basic approaches to the construction of a steel frame:

- The American system has evolved directly from the popular 4”x2” timber frame method. Standard steel sections are commonly available to homebuilders, who can cut and assemble them on site to complete the steel frame required.
- The Australians, in contrast, submit their house plan to a framing company, who designs the framing system and manufactures all the structural components at their factory. The materials are then brought to site as a kit for assembly. This method has the advantage of superior quality control that can be offered by an experienced, clean and fully equipped professional fabricator, compared with the sometimes less-than-perfect resources, including wrong tools and poor workmanship that might prevail on a building site. Less steel is also used; as there are no offcuts or wastage at the site for the client’s account. This would appear to be the preferable alternative for South Africa, at least until local expertise has grown to a point where both methods could be competitive. (http://www.hdgasa.org.za)

Figure 1: Typical steel frame house under construction. (www.ecotechousing.co.za)

The most common method of light-frame construction for houses and small apartment buildings as well as some small commercial buildings is Platform framing.

The framed structure sits atop a concrete (most common) or treated wood foundation. A sill plate is anchored, usually with 'J' bolts to the foundation wall. Generally these plates must be pressure treated to keep from rotting. The bottom of the sill plate is raised a minimum 6 inches (150 mm) above the finished grade by the foundation. This again is to prevent the sill-plate from rotting as well as providing a termite barrier.

The floors, walls and roof of a framed structure are created by assembling (using nails) consistently sized framing elements of dimensional lumber (2×4, 2×6, etc.) at regular spacing's (12″, 16″, and 24″ on center), forming stud-bays (wall) or joist-bays (floor). The floors, walls and roof are typically made tensional stable with the installation of plywood or composite wood "skin" referred to as sheathing. Sheathing has very specific nailing requirements (such as size and spacing); these measures allow a known amount of shear force to be resisted by the element. Spacing the framing members properly

allows them to align with the edges of standard sheathing. In the past, tongue and groove planks installed diagonally were used as sheathing. Occasionally, wooden or galvanized steel braces are used instead of sheathing. There are also engineered wood panels made for shear and bracing.

The floor, or the platform of the name, is made up of joists (usually 2x6, 2×8, 2×10 or 2×12, depending on the span) that sit on supporting walls, beams or girders. The floor joists are spaced at (12″, 16″, and 24″ on center) and covered with a plywood subfloor. In the past, 1x planks set at 45-degrees to the joists were used for the subfloor.

Where the design calls for a framed floor, the resulting platform is where the framer will construct and stand that floor's walls (interior and exterior load bearing walls and space-dividing, non-load bearing "partitions"). Additional framed floors and their walls may then be erected to a general maximum of four in wood framed construction. There will be no framed floor in the case of a single-level structure with a concrete floor known as a "slab on grade".

Stairs between floors are framed by installing stepped "stringers" and then placing the horizontal "treads" and vertical "risers".

A framed roof is an assembly of rafters and wall-ties supported by the top story's walls. Prefabricated and site-built trussed rafters are also used along with the more common stick framing method. "Trusses" are engineered to redistribute tension away from wall-tie members and the ceiling members. The roof members are covered with sheathing or strapping to form the roof deck for the finish roofing material.

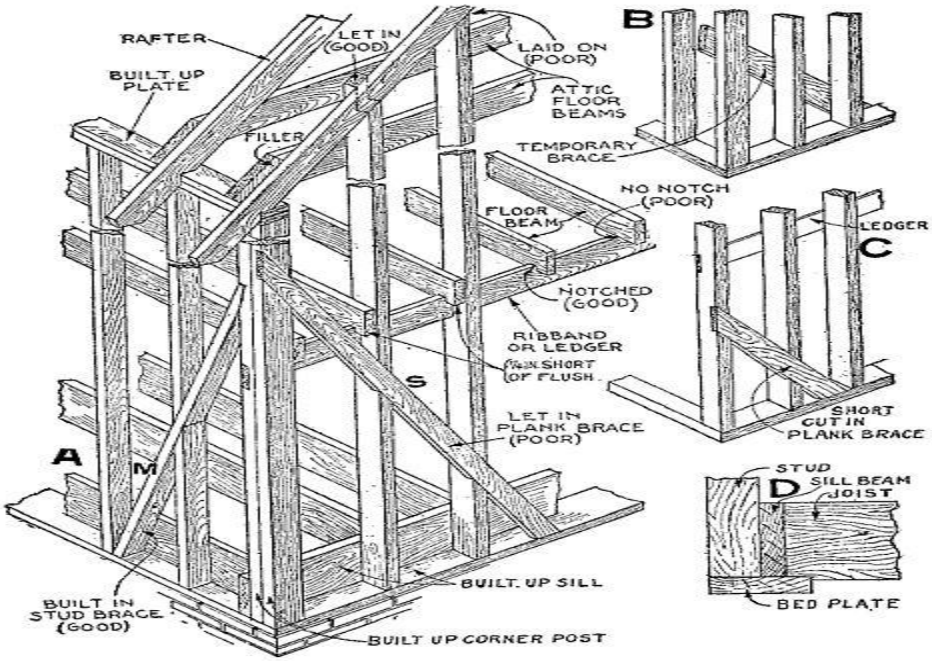

Figure 2 - Different timber components (http://en.wikipedia.org)

Floor joists can be engineered lumber (trussed, I-beam, etc.), conserving resources with increased rigidity and value. They allow access for runs of plumbing, HVAC, etc. and some forms are pre-manufactured.

Double Framing is a style of framing used to reduce heat loss and air infiltration. Two walls are built around the perimeter of the building with a small gap in between. The inner wall carries the structural load of the building and is constructed as described above. The exterior wall is not load bearing and can be constructed using lighter materials. Insulation is installed in the entire space between the outside edge of the exterior wall and the inside edge of the interior wall. The size of the gap depends upon how much insulation is desired. The vapor barrier is installed on the outside of the inner wall, rather than between the studs and drywall of a standard framed structure. This increases its effectiveness as it is not perforated by electrical and plumbing connections. (http://en.wikipedia.org)

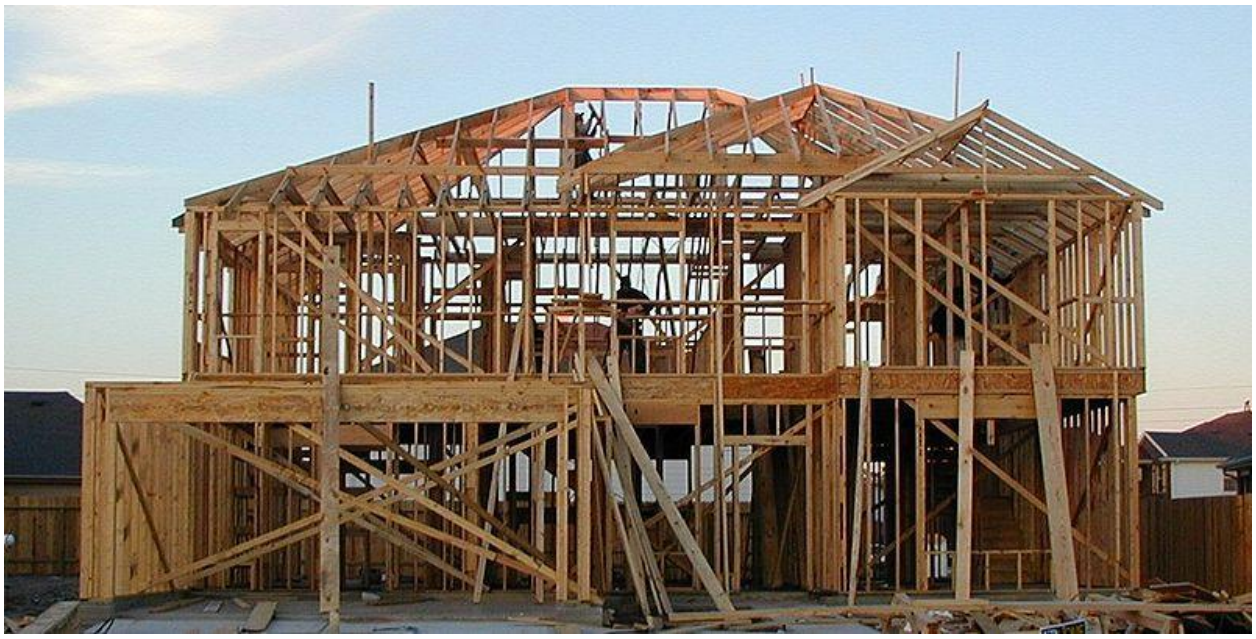

Figure 3 - Typical timber house under construction (http://en.wikipedia.org)

Masonry is the building of structures from individual units laid in and bound together by mortar; the term masonry can also refer to the units themselves. The common materials of masonry construction are brick, stone such as marble, granite, travertine, limestone; concrete block, glass block, and tile. Masonry is generally a highly durable form of construction. However, the materials used, the quality of the mortar and workmanship, and the pattern in which the units are assembled can strongly affect the durability of the overall masonry construction.

Solid brickwork is made of two or more layers of bricks with the units running horizontally (called stretcher bricks) bound together with bricks running transverse to the wall (called "header" bricks). Each row of bricks is known as a course. The pattern of headers and stretchers employed gives rise to different bonds such as the common bond (with every sixth course composed of headers), the English bond, and the Flemish bond (with alternating stretcher and header bricks present on every course). There are no significant utilitarian differences between most bonds, but the appearance of the finished wall is affected. Vertically staggered bonds tend to be somewhat stronger and less prone to major cracking than a non-staggered bond. (www.en.wikipedia.org)

The foundations for masonry frame houses will be similar to steel frame housing but will have more reinforcement because it will carry heavier weights (raft foundations, strip footings etc.).

The floor is constructed of a concrete surface bed which can be used for the wood and steel frame housing as well.

The roof is constructed of timber trusses and battens nailed together and connected with plates and most roof trusses will be pre manufactured and delivered to the construction site ready for installation. The trusses will be tied to the masonry walls by means of roof ties.

Figure 4 - Brick house (www.building-construction.co.za)

2.2.2 Advantages and disadvantages of the 3 different building methods

2.2.2.1 Masonry frame construction

2.2.2.1.1 Advantages

- The use of materials such as brick and stone can increase the thermal mass of a building, giving increased comfort in the heat of summer and the cold of winter, and can be ideal for passive solar applications.
- The appearance, especially when well crafted, can impart an impression of solidity and permanence.
- Masonry is very heat resistant and thus provides good fire protection.
- Masonry walls are more resistant to projectiles, such as debris from hurricanes or tornadoes than walls of wood or other softer, less dense materials.

(http://en.wikipedia.org)

2.2.2.1.2 Disadvantages

- Extreme weather causes degradation of masonry wall surfaces due to frost damage. This type of damage is common with certain types of brick, though rare with concrete block. If non-concrete (clay-based) brick is to be used, care should be taken to select bricks suitable for the climate in question.
- Masonry tends to be heavy and must be built upon a strong foundation (usually reinforced concrete) to avoid settling and cracking. If expansive soils (such as adobe clay) are present, this foundation needs to be quite elaborate and the services of a qualified structural engineer may be required, particularly in earthquake prone regions. (http://en.wikipedia.org)

2.2.2.2 Steel frame construction

2.2.2.2.1 Advantages

- High strength results in safer structures, less maintenance and slower aging of structure.
- Not vulnerable to any type of fungi or organism.
- Less probability of foundation problems - less weight results in less movement.
- Not vulnerable to termites.
- Less probability of damage in an earthquake.
- Highest strength-to-weight ratio.
- Non-combustible- does not burn and will not contribute fuel to the spread of a fire.
- Inorganic - will not rot, or warp.
- Dimensionally stable - does not expand or contract with moisture content.
- Consistent material quality - produced in strict accordance with national standards, no regional variations.
- Lighter than other framing materials
- Easy material selection - no need to cull or sort.
- Straight walls.
- Square corners.
- Small punch list.
- Less scrap and waste (2% for steel vs. 20% for lumber).
- More steel recycled in North America each year than aluminum, plastic and glass combined - with the industry's overall recycling rate of 64%.
- Every ton of steel recycled saves 2,500 pounds of iron ore.
- Through the basic oxygen furnace steel making process, steel framing uses a minimum of 25% recycled steel.

- Easy to install services such as water pipes etc. between dry wall panels and also easy to remove and replace without causing considerable damage. (www.steelfd.co.za)

2.2.2.2.2 Disadvantages

- Steel is less energy-efficient (steel being a good conductor of heat).
- Because steel conducts heat well, condensation can form in the walls and cause mildew and mold. Insulation on the outer surface of the walls can address this issue.
- Because steel framing is new to the residential building industry, many builders are not familiar with the construction methods.
- It is not clear how steel would hold up after flooding. Flood water often contain corrosive contaminates, or salt, and could damage the steel framing. No studies could be found that tested this situation. (www.steelfd.co.za)

2.2.2.3 Timber frame construction

2.2.2.3 .1 Advantages

- The use of timber framing in buildings offers various aesthetic and structural benefits, as the timber frame lends itself to open plan designs and allows for complete enclosure in effective insulation for energy efficiency.
- Wood framing is more energy-efficient.
- Wood is renewable and is grown and processed. Environmentalists indicate wood is a key to “green” housing. It is biodegradable.
- New manufacturing processes are utilizing less-valuable species of trees to produce application-specific construction members.
- New processes make wood less susceptible to insect damage and decay. (www.lsuagcenter.com)

2.2.2.3 .2 Disadvantages

Because the structure is made from wood, it inherits any disadvantages wood exhibits as an engineering material. Some possible disadvantages of wood as opposed to some other building materials include:

- Noise from footsteps in adjacent rooms above, below, and on the same floor in such buildings can be quite audible
- The possibility of infestation by insects such as termites, cockroaches or powderpost beetles, or by other pest animals such as mice and rats.
- Various types of rot including dry rot.
- Other fungi that are non-destructive to the wood, but are harmful to humans such as black mold. These fungi may also thrive on many "modern" building materials.
- Wood burns more readily than some other materials, making timber-frame buildings somewhat more susceptible to fire damage, although this idea is not universally accepted: Since the cross-sectional dimensions of many structural members exceed 15 cm × 15 cm (6" × 6"), timber-frame structures benefit from the unique properties of large timbers, which char on the outside forming an insulated layer that protects the rest of the beam from burning.

- Many older timber-frame buildings are more vulnerable to damage during an earthquake.
- Wood is less uniform in strength characteristics. It is a natural product with knots and flaws.
- It is combustible. (http://en.wikipedia.org)

2.3 Summary

From this study one can see that steel and wood frame construction does not appear to be difficult and with proper training one should be able to handle the construction of the two building methods. It is also clear that one can save a lot of time with steel frame construction which in turn will save a lot of money (time=money). Steel and wood

frames can be pre manufactured to save time but masonry construction can’t be pre manufactured. This might play a big role in construction and if houses can be pre manufactured in South Africa it will change the construction industry.

2.4 Testing of hypothesis

Steel, wood and masonry frame construction will have more or less the same foundations and roof construction but the external envelope will differ substantially. Steel has the most advantages and will be the best building method to use if one looks from a construction point of view and will save a lot of time.

Chapter 3: Which of the construction material is more sustainable?

3.1 Introduction

Eco-friendly, or ecological, construction is building a structure that is beneficial or non-harmful to the environment, and resource efficient. Otherwise known as green building, this type of construction is efficient in its use of local and renewable materials, and in the energy required to build it, and the energy generated while being within it.

Eco-friendly construction has developed in response to the knowledge that buildings have an often negative impact upon our environment and our natural resources. This includes transporting materials hundreds or thousands of miles, which has a negative impact in the energy required to transport them, and also in emissions of hazardous chemicals from a poorly designed building that creates, and traps them.

Many options are now available to those wishing to design and build an eco-friendly dwelling. Architects, engineers and builders worldwide are now using construction techniques that have been developed throughout human history, in response to local environmental concerns and the physical resource opportunities available, coupled with 21st century technological refinements.

Examples of eco friendly materials range from rammed earth construction, which involves clay-based material mixed with water and then rammed into brick or solid wall form, suitable in hot and dry climates, to straw bale houses, literally using bales of straw as the core structure. Straw is a great insulator, is a breathable material that filters the air passing through it, and contrary to expectation, is fire-resistant when compressed.

There is an urgent need to address the great challenges of our times namely climate change, resource depletion, pollution, and peak oil. These issues are all accelerating rapidly, and all have strong links with the building industry.

With the inevitability of declining fossil fuels, and the threat of global climate change, reducing our energy consumption is an essential survival strategy. Choosing to build green saves energy. The low embodied energy of green products ensures that very little energy went into their manufacture and production, with a direct reduction in carbon emissions. Eco friendly design methodology can further reduce energy consumption by minimizing energy inputs for heating, cooling and light, and incorporating energy efficient appliances. Saving energy for the occupant also saves money - an issue that will become increasingly important as the cost of fossil fuels inevitably rises in the near future.

There are many good reasons why we should use eco-friendly construction methods and materials. It can improve the health of our planet, and the health of our own lives. It also supports local business and helps strengthen the local economy, which in turn helps to build our communities into vibrant, prosperous and desirable places to live. (McHenry, Paul Graham, Jr. *Adobe and Rammed Earth Buildings:Design and Construction*. New York: John Wiley, 1984.)

3.2 Body of the chapter

To compare which material is more eco friendly and will contribute to sustainable building some properties of wood, steel and masonry will be evaluated.

The three phases of the building material lifecycle will be illustrated in the following figure.

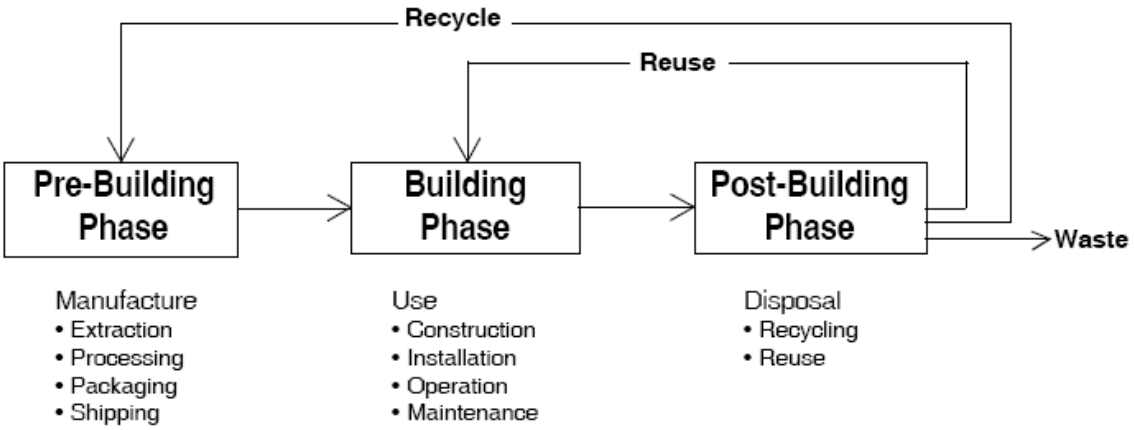

Figure 5: Three phases of the building material life cycle. (Qualities, Use, and Examples, December 1998, Sustainable Building Materials)

Products selected for this survey illustrate the difference between wood, steel and masonry that are designed and manufactured with environmental considerations. The selection criteria include sustainability in regard to a wide range of environmental issues: raw material extraction and harvesting, manufacturing processes, construction techniques, and disposal of demolition waste among other illustrated in table 1.

Green Features		
Manufacturing Process (MP)	**Building Operations (BO)**	**Waste Mgmt. (WM)**
Waste Reduction (**WR**)	Energy Efficiency (**EE**)	Biodegradable (**B**)
Pollution Prevention (**P2**)	Water Treatment & Conservation (**WTC**)	Recyclable (**R**)
Recycled (**RC**)	Nontoxic (**NT**)	Reusable (**RU**)
Embodied Energy Reduction (**EER**)	Renewable Energy Source (**RES**)	Others (**O**)
Natural Materials (**NM**)	Longer Life (**LL**)	

Table 1: Key to the green features of sustainable building materials. (Qualities, Use, and Examples, December 1998, Sustainable Building Materials)

Table 1 is a chart of the criteria, grouped by the affected building life-cycle phase. This chart helps compare the sustainable qualities of different materials used for the same purpose. The presence of one or more of these "green features" in a building material can assist in determining its relative sustainability.

All the features in table 1 are explained under the following headings.

3.2.1 Waste Reduction (WR)

The waste reduction feature indicates that the manufacturer has taken steps to make the production process more efficient, by reducing the amount of scrap material that results. This scrap may come from the various molding, trimming, and finishing processes, or from defective and damaged products. For products with this feature, scrap materials can be reincorporated into the product or removed for recycling elsewhere. Some industries can power their operations by using waste products generated on-site or by other industries. These options reduce the waste that goes into landfills. *(Qualities, Use, and Examples, December 1998, Sustainable Building Materials)*

3.2.2 Pollution Prevention (P2)

The pollution prevention feature indicates that the manufacturer has reduced the air, water, and soil pollution associated with the manufacturing process, implying measures that exceed the legislative minimums required of manufacturers. These reductions may be achieved through on-site waste processing, reduced emissions, or the recycling of water used in the manufacturing process. Environmentally sound packaging is another pollution prevention feature, as the way in which a product is packaged and shipped affects the total amount of waste generated by the product. *(Qualities, Use, and Examples, December 1998, Sustainable Building Materials)*

3.2.3 Recycled Content (RC)

A product featuring recycled content has been produced partially or entirely of post-industrial or post-consumer waste. The incorporation of waste materials from industrial processes or households into usable building products reduces the waste stream and the demand on virgin natural resources. *(Qualities, Use, and Examples, December 1998, Sustainable Building Materials)*

3.2.4 Embodied Energy Reduction (EER)

The embodied energy of a material refers to the total energy required to produce that material, including the collection of raw materials. Any revision to a manufacturing process that saves energy reduces the embodied energy of the material. A conventional material with high embodied-energy content can often be replaced with a low-embodied-energy material, while still using conventional design and construction techniques. *(Qualities, Use, and Examples, December 1998, Sustainable Building Materials)*

3.2.5 Use of Natural Materials (NM)

Natural materials are generally lower in embodied energy and toxicity than man-made materials. They require less processing and are less damaging to the environment. Many, like wood, are theoretically renewable. When low-embodied-energy natural materials are incorporated into building products, the products become more sustainable. *(Qualities, Use, and Examples, December 1998, Sustainable Building Materials)*

3.2.6 Energy Efficiency (EE)

Energy efficiency is an important feature in making a building material environmentally sustainable. Depending on type, the energy efficiency of building materials can be measured with factors such as R-value, shading coefficient, luminous efficiency, or fuel efficiency. The ultimate goal in using energy efficient materials is to reduce the amount of artificially generated power that must be brought -to a building site. *(Qualities, Use, and Examples, December 1998, Sustainable Building Materials)*

3.2.7 Water Treatment/Conservation (WTC)

Products with the water treatment/conservation feature either increase the quality of water or reduce the amount of water used on a site. Generally, this involves reducing the amount of water that must be treated by municipal septic systems, with the accompanying chemical and energy costs. This can be accomplished in two ways: by physically restricting the amount of water that can pass through a fixture (showerhead, faucet, toilet), or by recycling water that has already entered the site. Graywater from cooking or hand-washing may be channeled to flush toilets. Captured rainwater can be used for irrigation. *(Qualities, Use, and Examples, December 1998, Sustainable Building Materials)*

3.2.8 Use of Non-Toxic or Less-Toxic Materials (NT)

Non- or less-toxic materials are less hazardous to construction workers and building occupants. Many materials adversely affect indoor air quality and expose occupants to health hazards. Some materials, like adhesives, emit dangerous fumes for only a short time during and after installation; others can reduce air quality throughout a building's life. *(Qualities, Use, and Examples, December 1998, Sustainable Building Materials)*

3.2.9 Renewable Energy Systems (RES)

Renewable energy systems replace traditional building systems that are dependent on the off-site production of electricity and fuel. Solar, wind, and geothermal energy utilize the natural resources already present on a site. Passive solar heating, and on-site power generation are included in this category. *(Qualities, Use, and Examples, December 1998, Sustainable Building Materials)*

3.2.10 Longer Life (LL)

Materials with a longer life relative to other materials designed for the same purpose need to be replaced less often. This reduces the natural resources required for manufacturing and the amount of money spent on installation and the associated labor. Durable materials that require less maintenance produce less landfill waste over the building's lifetime. *(Qualities, Use, and Examples, December 1998, Sustainable Building Materials)*

3.2.11 Reusability (RU)

Reusability is a function of the age and durability of a material. Very durable materials may outlast the building itself, and can be reused at a new site. These materials may have many useful years of service left when the building in which they are installed is decommissioned, and may be easily extracted and reinstalled at a new site. *(Qualities, Use, and Examples, December 1998, Sustainable Building Materials)*

3.2.12 Recyclability (R)

Recyclability measures a material's capacity to be used as a resource in the creation of new products. Steel is the most commonly recycled building material, in large part because it can be easily separated from construction debris with magnets. *(Qualities, Use, and Examples, December 1998, Sustainable Building Materials)*

3.2.13 Other (O)

Now that all the green features of sustainable building have been identified a comparison can be made between wood, steel and masonry. The following tables will identify the features of wood, steel and masonry according to Jong-Jin Kim and Brenda Rigdon. *(Qualities, Use, and Examples, December 1998, Sustainable Building Materials)*

MP	BO	WM
		B
		R
RC	NT	RU
NM	LL	

Table 2: Green features of steel. (According to the abovementioned information).

MP	BO	WM
	EE	
RC	NT	RU
		O
NM	LL	

Table 3: Green features of masonry (bricks). (According to the abovementioned information)

MP	BO	WM
WR		
	WTC	R
RC	NT	RU
EER		
	LL	

Table 4: Green features of wood. (According to the abovementioned information)

3.3 Summary

Sustainable building will have to become a priority and will start to become more important in the future. It is difficult to determine which material is the most sustainable between the three construction materials because all of them have different advantages as seen in the body of this chapter. By looking at the comparison between wood, steel

and masonry to see witch material is more sustainable one can clearly see that wood has the most green features and will probably be the most eco friendly construction material of the three. The construction material with the second most green features is masonry and with the third most is steel. One can also rate the appropriateness of the construction material green features in a country but will not be included in this study. The best way to go about picking a construction material is to plan ahead because planning can also contribute to an eco friendly environment.

3.4 Testing of hypothesis

The hypothesis tested positive that wood will be the most sustainable construction material between wood, steel and masonry.

Chapter 4: Which of the three materials will be more durable and structurally the strongest?

4.1 Introduction

Steel is used commonly all over the world for its structural strength and the physical properties of steel include high strength, low weight, durability, flexibility and corrosive resistance. Steel, as we all know, offers great strength though it is light in weight. In fact, the ratio of strength to weight for steel is the lowest than any other building material as of now. Steel can be molded into different shapes and sizes because of its flexibility. Unlike the constituent element iron, steel does not corrode easily, on being exposed to moisture and water. The dimensional stability of steel is a desired property, as the dimension of steel remains unchanged even after many years or being subjected to extreme environmental conditions. Steel is a good conductor of electricity, i.e. electricity can pass through steel.

In the case of steel, structural engineers are concerned about the tensile strength in terms of both the ultimate strength and the yield strength. When a specimen reaches its yield strength, it will begin to stretch and transition from elastic to plastic behavior. As more force is applied, the steel will reach its ultimate tensile strength and break. Structural engineers take advantage of this property in their designs. In an extreme event, such as an earthquake or major structural failure, this plastic phase is useful because it allows the structure to sag and absorb extra loads. If steel is too brittle, it will shatter instead of stretching, possibly causing the structure to come crashing down. In either case, the structure is ruined, but the plastic behavior of the steel allows time for escape.

Wood differs from other construction materials because it is produced in a living tree. As a result, wood possesses material properties that may be significantly different from other materials normally encountered in structural design. Although it is not necessary to have an in-depth knowledge of wood anatomy and properties, it is necessary for the engineer to have a general understanding of the properties and characteristics that affect the strength and performance of wood. This includes not only the anatomical, physical, and mechanical properties of wood as a material, but also the standards and practices related to the manufacture of structural wood products.

In the broadest terms, trees and their respective lumber are classified into two general classes, hardwoods and softwoods. Hardwoods normally have broad leaves that are shed at the end of each growing season. Softwoods have needlelike leaves that normally remain green year round. The classification as hardwood or softwood has little to do with the comparative hardness of the wood. Several species of softwoods are harder than many low- to medium-density hardwoods (www.citywood.co.uk, Retrieved November 24, 2006). With few exceptions the structural wood products used are manufactured primarily from softwoods. Although hardwoods are not widely used at this time, structural grading procedures for hardwoods have been developed recently, and their use is increasing in some regions of the country.

Masonry units are available in sizes, shapes, colors, textures, and profiles for practically every conceivable need. Historically, units came from a variety of sources and included materials such as rock and stone, either natural or cut. Today, units most commonly used are concrete block or clay brick, offering standardized sizes and mechanical properties. The units are joined together by mortars made from a binder consisting of one or more cements for masonry, sand, and water. Portland cement plaster, or stucco, is made from the same material as mortars, and as such, is sometimes considered to be a masonry product as well.

Masonry is widely used to construct small and large structures because of its attractive appearance, minimum maintenance, structural strength, safety (fire resistance and wind/earthquake resistance), and economy. Masonry provides an effective barrier to sound and reduces internal temperature variations and peak loads on heating and cooling systems. It provides architectural freedom and versatility with striking aesthetic appeal. Almost any shape of structure is possible. Masonry also resists weathering and vandalism. The durability and minimum maintenance extend a building's useful life, providing an enduring, high-quality appearance. Today's designers, who often choose it for its decorative value, can also benefit from its many structural advantages. Engineered and reinforced masonry can be used effectively for bearing walls and shear walls. Depending on the building's configuration and function, structural masonry can be used alone or integrated with a steel or reinforced concrete frame. Often, building features already planned for masonry, such as brick faced exterior walls or concrete masonry service cores, can easily be adapted to serve additional structural purposes.

4.2 Body of chapter

A comparative analysis is to be done by comparing the structural properties, durability and maintenance of wood steel and masonry.

4.2.1 Strength properties

Wood is an orthotropic material with unique and independent properties in different directions. Because of the orientation of the wood fibers, and the manner in which a tree increases in diameter as it grows, properties vary along three mutually perpendicular axes: longitudinal (L), radial (R), and tangential (T). Strength properties describe the ultimate resistance of a material to applied loads. They include material behavior related to compression, tension, shear, bending, torsion, and shock resistance. Strength properties vary in the three primary directions. Although wood properties differ in each of these three directions differences between the radial and tangential directions are normally minor compared to their mutual differences with the longitudinal direction. As a result, most wood properties for structural applications are given only for directions parallel to grain (longitudinal) and perpendicular to grain (radial and tangential). Wood has the strongest structural strength in compression perpendicular to the grain and in tension parallel to the grain.

Factors effecting structural strength of wood include.

- Moisture content
- Density of wood.
- How it is cut (middle of tree, outer edge etc.)
- Knots

Steel can be molded into different shapes and sizes because of its elasticity which means that different shapes equal different structural properties (Steel – A New and Traditional Material for Building). Typical sections among others include H-sections, L-sections, angles, lat bar and round bar. For residential housing H-sections and L-sections are commonly used and round bar is normally used as reinforcement in concrete. Different types of steel can be used for construction and there are over 4000 different types. Each type of steel has different structural properties (Proceedings of the International Conference in Metal Structures 2006, 20-22 September 2006).

Masonry has a very high compressive strength and also like steel varies in strength because of different types of bricks produced. Masonry can also be strengthened by reinforcement which gives it stronger shear properties (Masonry, j. Borchelt, American Society for Testing and Materials. Committee C-7 on lime). As mentioned masonry has no tensile strength which can cause limitations. Some factors that can change the structural strength of bricks among other are pour production, sun damage, bad mixing of mortar etc.

Table 5 illustrates a comparison of strength between steel wood and masonry and is not an exact indication because there are different types of steel wood and masonry materials.

	Wood	Steel	Masonry
Strength in compression	1	1	1
Strength in tension	2	1	3
Shear strength	1	1	2
Building strength	2	1	3
Torsion strength	2	1	3
Shock resistance	2	1	3

Table 5: Material strength comparison according to my conclusions (www.wikipedia.org).

1 – Strongest/Highest 2 – Second strongest/highest 3 – Weakest/Lowest

4.2.2 Durability

Wood is fairly durable and can be very durable if treated correctly. Because wood is targeted by some insects like termites it should be treated regularly and could be very expensive and time consuming. The maintenance level in this case will be much higher than in the case of wood and steel. Wood also absorbs moisture and expands in heat and contracts in the cold. This is also a very important factor and wood should in some cases be treated for moist. Moist can cause wood to rot and will have a very big impact on the structural strength of the material.

The type of wood used will also make a difference in the durability of the material because some woods are stronger or harder and more insect resistant than other. Wood is normally treated by applying a coat on the outer skin of the wood which would then prevent moist from coming in or any insects from investing (American Institute of Timber Construction. 1983. American national standard for wood products-structural glued laminated timber. ANSI/AITC A190.1. Englewood, CO: American Institute of Timber Construction, page 16). Another important point to remember is to keep wood dry when storing it before construction as to prevent decay.

Steel is very durable and will last long but like wood should be treated regularly to keep it from corrosion. This will also demand regular maintenance. Unlike wood it will not be affected by termites and other insects but only my moist.

Masonry will be the most durable between the three materials and will not be affected as badly by moist and insects. Masonry won't require maintenance like steel and wood in regular intervals.

	Wood	Steel	Masonry
Durability	3	2	1

Table 6: Durability comparison according to my conclusions (www.wikipedia.com).

1 – Strongest/Highest 2 – Second strongest/highest 3 – Weakest/Lowest

4.2.3 Fire resistance

Wood is a very flammable material and is a safety risk. South Africa is known as a country with a lot of fires. The proper safety precautions should be taken to avoid any safety risks for example fire escape routes etc. should be planned before construction of a building. Because wood burns, it is intuitively assumed that the performance of wood under fire conditions must be poor. In fact, the heavy wood members typically used in bridges provide a fire resistance comparable to, or greater than, that of other construction materials.

When wood is exposed to fire, the exterior portions of the member may ignite. If enough energy is focused on the member, sustained, self-propagating flaming will occur. The wood beneath the flame undergoes thermal decomposition and produces combustible volatiles that sustain the

flame. However, as the wood burns, a char layer is formed that helps insulate the unburned wood from engrossing flames (http://www.timber-frame.org, accessed on 25 March 2009).

Even materials that do not sustain fire do not guarantee the safety of a structure. Steel, for instance, quickly loses its strength when heated and its yield point decreases significantly as it absorbs heat, endangering the stability of the structure. Steel contracts heat it will lead the heat to other parts of the structure which is not even close to the heat source. Steel is probably the most dangerous material when it comes to fire.

Masonry does contract heat to a certain degree but not as much as steel but the structural strength won't be affected as bad as in the case of steel.

4.3 Conclusion

There are many different types of materials available for construction of housing in South Africa and it is difficult to determine which material is stronger and more durable because of this. There are also a lot of different forces on structural materials applied at the same time in some cases which means that different materials will have better structural properties than other for example steel has a better tensile strength than masonry and will be more suitable for bridge construction. There are ways to strengthen materials by means of admixtures reinforcement among other which concludes that it is even more difficult to conclude which material is structurally stronger. A combination between wood, steel and masonry will make the best structural frame because of their different structural properties. Masonry will probably have the lowest maintenance and wood the highest in South African conditions.

4.4 Hypothesis

4.4.1 Statement of hypothesis

Masonry will probably be the strongest structurally although wood and steel will come very close and might even be stronger in certain cases. The way the building is planned however will have a big effect on the structural strength of the material for example how close the columns are to each other or the height of the building etc. When it comes to durability, steel would probably be the most durable between the three materials because it is protected against corrosion if treated and is immune to infestations by insects etc Wood's durability on the other hand can be affected by insects and become weak in wet weather if not treated correctly.

Masonry can be damaged by the sun's heat and will start to show small cracks after a while in the heat and cold (expansion and contraction cracks). The durability has been proven to be very reliable in the past years if looked at medieval buildings still standing today.

4.4.2 Testing of hypothesis

It is impossible to determine which material is structurally the strongest because of all the factors mentioned. There are also different forces working on materials in a structural frame and you have to look at each force individually. If looked at the comparison in the tables in this chapter one can see that steel has the best structural properties and that it is the most versatile material. Masonry is the most durable followed by steel and then wood according to my findings. Masonry is also more fire resistant than the other materials and is followed by wood and steel.

Chapter 5: Which of the construction materials will be the most cost effective?

5.1 Introduction

As we all know cost is the most important factor in construction. In this chapter some rates will be compared to see which building method will be the most cost effective.

There are material savings to be harvested in the areas of material costs. More significant are the savings arising due to the speed of construction and the minimal use of specialized equipment. Soil conditions play a major role in the foundation costs and could vary significantly from site to site. This technology, however, reduces the impact of poor soil conditions on the cost of the foundation due to the fact that the walls are much lighter for wood and steel frame constructed housing. Volume is a key determinant of cost – the more units of the same design that are constructed at the same location, the cheaper the building cost. In order to manage material costs, it is best to determine volumes as early as possible in order to secure prices with suppliers as soon as possible.

Other things that impact price:

- Site preparation
- Availability of water, electricity and sewage points and proximity to the location of each house
- Geographical spread of houses – i.e. are they spread out throughout townships or are they all in the same place
- Security to prevent the theft of materials
- Cash flow – due to the speed of construction, materials need to be purchased in huge volumes. Slow payment has a crippling effect on cash flow and slows down the entire process.

There are many different factors influencing the cost of construction and that is why one cant do an exact estimate of how much a building will cost. For this reason m² rates will be used and only a rough estimate will be done.

5.2 Body of the chapter

Light steel frame housing will cost approximately R1180 per square meter (www.steelframes.co.za)

Coupled to the speed of construction, reduced wastage and lower transport costs contribute to render this building method cost-efficient.

Minimal wastage: As light steel frame is an engineered process, wastage of materials during manufacturing as well as the building process is minimized.

Lower logistical costs: Due to the low mass of the building elements (11 tons for the walls of a 200 m² house compared with 180 tons for an identical masonry building), transport costs are much lower than for a conventional building. After completion, it is also not necessary to remove truck loads of building rubble. (www.sasfa.co.za)

Because a lot of different designs are available this study will be based on m² rates.

According to woodland woodcraft bk. a single storey house with a premier finish would cost R1263.36 per square meter. Woodland woodcraft bk. is a contractor specializing in timber frame houses. This rate is only based on what information the contractor could provide. This is including labor cost and all services and excludes delivery cost. These houses are not pre manufactured and time and cost can be saved by pre manufacturing these houses.

A typical house will include the following.

- 1.8m SLIDING DOOR

- CORRUGATED IRON ROOF
- CEILING
- ISOLATION ON PREMIER FINISH AND LOG PROFILE
- 22mm TOUGUE + GROOVE FLOORING
- BUILD ON .500m STILTS

The conventional brick masonry construction method will cost approximately R 1200 per square meter according to Gerhard Brummer in the African region property and construction handbook 2009 (African region property and construction handbook, 2009, Davis Langdon, 22nd edition). This rate will also include labor costs.

Comparing costs is always a challenging task. With housing construction, you have to consider both labor and material when comparing different prices. Steel in non-load bearing applications (such as interior walls) is generally cheaper because non-bearing steel studs are approximately 20 percent cheaper than their wood counterparts, while the labor involved in installing them does not differ significantly for the two materials. In bearing walls, floors, and roof framing applications, the cost differential is not that straightforward. With steel prices currently inflated, and the added labor cost to frame with steel, it is reasonable to estimate that steel is more expensive. This cost difference can be as high as 15 to 30 percent for inexperienced steel framers, but can be brought to single digits with experienced steel framers.

The cost will also depend on the location of the house. In colder climates where exterior insulation is required for steel-framed homes but not for wood homes, the cost difference will be higher. Steel can be competitive with wood in areas where engineered design is required regardless of the material used and where other environmental factors dictate additional protection for wood framing. This was done according to a study done in England. (www.toolbase.org)

The prices will differ in different countries but in South Africa according to the contractors and Davis Langdon the prices is more or less the same per square meter.

This means that one will have to look at speed of construction to determine which material will be the most cost effective initially.

5.3 Summary

With all the different costs in construction and the different contractors it is difficult to say which material will be the most cost effective. There are also many different construction methods and everyone will construct a building differently. Because of these two reasons and more one cannot base your study on one specific design.

5.4 Testing of hypothesis

My hypothesis tested inconclusive because steel will probably be the most cost effective material because of its quick construction and the quick development of the system in South Africa at the moment although it is unclear because there are too many variables which determine the cost of construction and building materials fluctuate daily.

Chapter 6: Summary and conclusion

6.1 Problem statement

The goal of this study is to determine whether masonry being the most used material in residential housing frame construction in South Africa can be replaced by steel or timber frame construction to improve the quality and durability while being cost effective and a sustainable building method.

6.2 Summary

The construction method of wood, steel and masonry frame construction in residential low rise housing will differ substantially in the external envelope and the way the components are put together but foundations and roof construction will be similar with minor differences in reinforcement in the foundations because of the big weight difference in the frame. Steel and wood frames will be substantially lighter than masonry frames. It is substantially quicker to construct a steel or wood frame house than it is to construct a masonry house and a lot less labor is required to finish the construction process. Steel houses can even take five days to erect fully if the design is simple enough and skilled people are used. The new light weight steel building method has a lot of advantages and is starting to develop in South Africa. There are a few contractors already constructing these types of housing. If people start using steel frame construction and developing the right training it must be successful with all the advantages related to it. One problem with these light weight frames is that it is quick and easy to install which means it will require less labor in turn take away jobs of the conventional bricklayers etc.

Sustainable building is starting to become a very important part of the construction industry and will have to be implemented. The current trend in South Africa is moving towards green building and there are talks of a point system being implemented similar to the point system in Australia which determines how sustainable and energy efficient a building is. There is an urgent need to address the great challenges of our times namely climate change, resource depletion, pollution, and peak oil. These issues are all

accelerating rapidly, and all have strong links with the building industry. According to the study wood will be the most sustainable material with the greenest features.

A reasonable comparison was made between the structural properties of steel wood and masonry as structural materials and the conclusion was that steel is structurally the strongest in all directions but it is difficult to say because of weather conditions in different regions which affect the structural capability of these materials. Masonry is the most durable if one looks at non treated materials. Wood can be treated to stop insect infestations and to stop moist from entering and steel can be treated to avoid rust. This treatment can make these materials just as durable as brickwork. Masonry will be the most fire resistant and steel will fail under heat which makes it very unsafe in heated conditions.

If construction cost of wood, steel and masonry housing is compared per square meter for a single storey building one can see that there is not a big difference. The saving in cost will come in with the time saved in construction of wood and steel frame houses if proper management is applied and if the correct skilled people are used.

6.3 Conclusion

It is a big possibility that steel and wood frame construction will be implemented in South Africa for residential housing. In the comparison done in this study one can clearly see that steel frame construction holds a lot of advantages in comparison to wood and masonry. Steel is also structurally the strongest in all directions. Steel framing will also save money if one looks at the construction time saved (time=money). Steel also has good green features and reduces waste.

Steel will definitely be the best replacement for masonry construction in residential housing in South Africa and if implemented correctly and proper training is introduced it can definitely work. The big question one must ask is if people would want to adapt to this new construction system. As indicated in this study there are already contractors introducing and developing this construction method.

Light weight wood frame construction can also be a replacement but is not developed in South Africa enough yet. And with very moist conditions one would think that wood as material will give problems and cost extra money over time in maintenance.

The development of new light weight frame construction can be a very exciting time for South Africans if implemented and I would like to encourage it.

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