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USE OF SHIPPING CONTAINERS AS A SUSTAINABLE BUILDING CONSTRUCTION METHOD

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KeyWords
Carbon Emissions, Embodied Energy, Shipping Containers, Sustainable Building, Construction Method

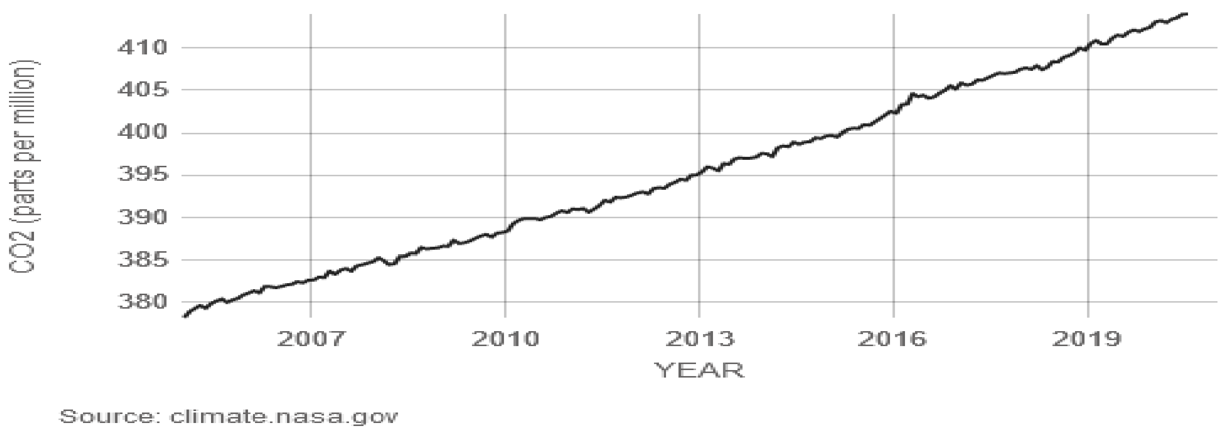
ABSTRACT

General hypotheses are that increase in building construction has an effect on the rate of climate change and the climate change is attributed to increased green house gas emissions in the atmosphere as building materials are being extracted and or manufactured. This paper however presents the sustainable means of building construction using shipping containers in relation to ordinary masonry construction. Two structures of the same size and shape (29m x 20m, three storeys) but of different materials (shipping containers and masonry) were designed and the quantities of carbondioxide and embodied energy emissions computed for each of the structures and results compared. The Process-based analysis method was chosen and used in embodied energy calculation as its one of the most widely used method of embodied energy (EE) analysis and it delivers more accurate and reliable results and data required can usually be obtained [1], [2] , the QE-CO_2 method was used in the computation of carbondioxide emissions. Results indicated that the Container Building had a smaller amount of embodied energy (2,073,201MJ (Mega Joules) compared to the Ordinary Masonry structure at 3,657,718MJ. Similarly the Container Building had a smaller amount of Carbon Emissions (221,118KgCO_2/Kg) compared to the Ordinary Masonry structure at 435,754KgCO_2/Kg and thus the study concluded that by using shipping containers we considerably save 43.3% in Embodied energy and 49.3% CO_2 emissions and therefore the choices of materials and construction methods can significantly change the amount of energy embodied and carbondioxide emissions in a building structure since embodied energy and carbondioxide content varies enormously between products and materials hence the findings of the study recommended the use of shipping containers than masonry type of building.

INTRODUCTION

The sustainability of building construction is the practice of creating structures and using processes that are environmentally responsible and resource-efficient throughout a building's life-cycle from siting to design, construction, operation and maintenance and Embodied energy is the energy consumed by all of the processes associated with the production of a building, from the mining and processing of natural resources to manufacturing, transport and product delivery. Embodied energy does not include the operation and disposal of the building material, which would be considered in a life cycle approach [3].

In the last hundred years the Earth has warmed by about 0.5^0C [4]. There is a strong evidence that this is due to an increase in the concentrations of certain trace greenhouse gases. Principal amongst these is carbon dioxide and embodied Energy which are produced whenever fossil fuels are burnt to obtain energy. According to the National Aeronautics and Space Administration (NASA), carbondioxide gas in the atmosphere has continued to increase year after year as indicated in the group below (direct measurement 2005 to present) and the parts per million of carbondioxide (ppm CO_2) has reached 414 ppm CO_2 in the year 2020.



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Buildings are the largest energy consumers and greenhouse gases emitters, both in developed and developing countries caused by extraction of the various construction materials by quarrying that provides most of the construction materials [4]. Rock quarrying and stone crushing is a global phenomenon, and has been the cause of concern everywhere in the world, including advanced countries as it gives rise to noise pollution, air pollution, production of significant amounts of waste, damage to biodiversity and habitat destruction.

Currently there are four different methods that can be used to calculate the amount of embodied energy in structures and these include; Process- based analysis, statistical analysis, input- output analysis and hybrid analysis which are among the major methods used for embodied energy computation [1].

In the past, embodied energy studies have been performed on a number of building types, including commercial, residential and recreational, and building related products, including, but not limited to, washing machines and other household appliances, hot water systems and photovoltaic systems [2]. These studies have used a range of methods outlined above, and thus, depending on which method used, end up with varying and in some cases conflicting results are obtained. An individual residential building embodies approximately 2000 gigajoules (GJ) [2]. Previous studies, now shown to be incomplete in system boundary, have shown significantly lower values for example, Hill 1978, Bekker 1982, Baird and Chan 1983, Lawson 1996, Adalberth 1997, Pullen 2000, Fay, Treloar and Iyer-Raniga 2000 [2].

The values from these studies are at most around half of that figure given by [2]. This trend does not necessarily suggest that the energy intensity of material manufacture is increasing, nor is it a factor of increasing house area. The fundamental cause of the difference in values is often the use of different embodied energy analysis methods. Therefore, a comparison of methods was made by different researchers and it was found out that the Process-based analysis method delivers more accurate and reliable results and data required can usually be obtained.

As earlier stated, buildings are the largest energy consumers and green house gases emitters, the choices of materials and construction methods can significantly change the amount of carbon emisions and embodied energy since these two vary enormously between products and materials. These significant impacts of construction materials remain largely overlooked in most construction design projects. Sand and gravel have long been used as aggregates for construction of roads and buildings in this Country, however over the last ten years the mining sector has been growing positively with growth rates peaking 19.4% in FY 2006/07 and today, the demand for these materials continues.

Taking a look at the annual development mineral production report for Uganda 2015/16 (Table 1), bricks production takes the lead in all the minerals that are produced and from past research [5] discovered that a kiln stack of 10,000 bricks on average require 14 tons of wood which translate to 3 mature trees of 1 and 1/2 ft basal diameter [5]. This means that with more kilns burnt, the resultant tree cover loss becomes significant and hence accumulation of greenhouse gases and emboded energy. The forestry cover in Uganda, for example, has reduced by 25% from 45% coverage in 1990 to around 20% in 2005. This means an annual deforestation rate of 1.7% which is still increasing year by year [6]. In 2010, Uganda had 6.93mha (million hectares) of tree cover, extending over 29% of its land area. In 2019, it lost 63.3kha (thousand hectares) of tree cover, equivalent to 12.6Mt (million tones) of CO_2 of emissions [7]. Therefore, by adopting shipping container structures as an alternative to ordinary masonry structures we shall be highly protecting the enviroment while ensuring cost minimization.

Table 1, the annual development mineral production report for Uganda 2015/16 [8]

Commodity	Medium and Large Scale[1]		Artisanal and Small Scale[2]		Total	
	Production (tonnes)	Value of Production million (USD)	Production (tonnes)	Value of Production million (USD)	Value of Production million (USD)	Percent Attibuted to ASM (%)
Clay Bricks[3]	270,407,259	23.2	5,137,737,929	266.0	289.2	92
Sand	349,100	0.99	3,141,390	8.9	9.89	90
Stone Aggregate	677,490	6.5	6,097,410	58.2	64.7	90
Dimension Stones[3]	-	-	1,461,119	8.8	8.8	100
Limestone	891,295	31.6	297,026	11.9	43.5	27
Kaolin	-	-	40,774	0.06	0.06	100
Salt	-	-	48,927	0.96	0.96	100
Pozzolanic Ash	742,423	4.6	15,928	0.1	4.7	2
Vermiculite	1,213	0.2	-	-	0.2	0
Total		67,090,000	-	354,920,000	422,010,000	84

Notes: 1 See Box 2 for explanation of how estimates were derived.

2 Volume of bricks provided in number of burnt, solid clay bricks rather than tonnes and excludes other brick products (e.g.

ventilators, half bricks, face bricks etc).

3 Although some entities have been granted rights to exploitation of dimension stones in 2017 (See section on "Profile of the Development Minerals Sector: Profile of the Development Minerals Private Sector: Medium- to Large-Scale Businesses"), as of 2015 production had not been officially declared.

Soil is a one of the natural resource made up of gravel, sand, clay, loam which constitutes the different types. Pit sand, river sand and gravel are components of this soil which takes years to be formed but extracted in a matter of days for majorly building construction [4].

As a worldwide economic activity, pit and river sand extraction and gravel extraction have both positive and negative impacts on the environment. The United States of America and many states like California and Michigan rely on extraction of pit sand and gravel for road and cement aggregates [9].

The extraction industry in Uganda has reached peak levels in the recent years with the sector accounted for up to 30% of Uganda's export earnings and therefore has the bigger environmental impacts than any other sector since it's directly linked to the economy of which global warming is the most disastrous impact [10]. As a result, The United Nation's Inter-governmental Panel on Climate Change states that global warming is caused by greenhouse gases and energies due to human activities of which these mineral extractions are part.

Addressing carbon emissions and embodied energy from buildings have hence been identified as a key component of the global fight against climate change. These operational emissions represent part of a building's life cycle. The International Energy Agency (IEA) has stated that the reduction of embodied energy and Green House Gas emissions from buildings "may have a tremendous effect on the reduction of global energy consumption and GHG emissions".There is therefore a growing understanding that it is important to take a full lifecycle view towards construction-sector carbon emission and embodied energy reductions, thereby addressing embodied emissions as well as operating emissions [11].

Globally, energy use, and the associated emissions, have been rising rapidly over the past few decades. The main consumers are developed countries which enjoy high standards of living to which the developing countries aspire; the consequences of the continuing growth of energy use are potentially catastrophic. Extraction of natural resources as building materials itself consume energy, cause environmental degradation and contribute to global warming [12].

Urgent changes are therefore required relating to energy saving, emissions control, production and application of materials with immediate suggestions related to use of renewable resources, and the recycling and reuse of building materials being necessary.Hence this paper presents the use of shipping containers as a sustaible building method that is expected to reduce the amount of carbondioxide and embodied energy emissions.

Materials and Methods

The study was particularly taken in Mubende district (Uganda) because of the high presence of resources booming construction business and the terrain that makes it a great harbor for extraction process. Within mubende district, Kisojo, Kibyayi and Lweyayi are some of the areas favorable for aggregate crushing, sand extraction and brick making. The areas are overlying Katebe Lake from which the water that supplies the entire District is obtained. As a result, the effects of the extraction activities are direct to the environment around the lake that includes air pollution from the extraction and also burning of bricks. To this effect the forest vegetation is also felled to provide wood to burn the bricks.

In the method analysis, two dimensionary similar structures were designed; one structure was designed as an ordinary masonry structure with respect to EC2 and another structure was entirely made of shipping containers with respect to EC2 and/EC3, material specifications were obtained from the designs and the standard method of measuring for Building works (7th Edition) was used to obtain quantities (Qi) of each of the major construction material to be used for the implementation of each of these structures. And later on, volume of CO2 emission and/embodied energy from each structure were estimated according to equation (1) using the process-based analysis method below;

$$E=\Sigma^{n}_{i=0}[Vi * Wi * Ei] \qquad (1)$$

Where Vi, and Ei, represent quantity of material (m3) and material's embodied energy coefficient (MJ/Kg) respectively. The term "i" denotes the materials used in the structure; Wi is Density of building materials (Kg/m3).

The QE-CO2 method was used to compute the amount of carbon emissions in construction materials. The method involves multiplying the quantity of product used in the construction by the loss factor and by the sum of emissions generated by energy consumption (Kg CO2 /Kg).

EmissionsMT, j = QTj x Wj x FEPj Where:

EmissionsMT, j = CO2 emissions due to the use of product j in buildings (kg of CO2); QTj = quantity of product j necessary in the site construction (kg); Wj = Density of product j (kg/m3), FEPj = CO2 emission factor due to use of the product j in buildings (kg of CO2 / kg of product j, Table 3) [14].

Table 3 was used to calculate the carbondioxide emissions and embodied energy for each of the materials of the two structures.The carbondioxide emission and embodied energy compositions (Table 3, columns 2,3 &4) were drawn from the available literature [15] and basing on the obtained data of embodied energy and carbon emissions, comparisons were made using the Life Cycle Assessment method of Computation to identify which of the two structures had lesser or more carbon emissions and embodied energy and there after a conclusion was drawn on which of the two structures can be adopted for a sustainable building construction.

Choice of Materials

Abate the consumption of construction materials: The natural resources are gradually reducing with growing population and people's demand. By recycling and reusing the construction materials would thus avoid the need for new resources and thus saving the natural resources or reducing the consumption of constructionmaterials.

Selection of construction materials was done by choosing materials with the least carbon emissions and embodied energy.

Results

Table 2 gives a summary of the materials required to put up both a shipping container structure and an ordinary masonry structure in the same locality.

Tables 3 provides the General Calculations for the carbon emmissions and embodied energy from both the shipping container and ordinary masonry structure.

Table 4 provides the quantity of construction materials required to put up a shipping container structure.

Table 5 provides the Quantity Estimation of Ordinary Masonry structure.

Table 2, Summary Sheet of Estimates

	Summary Sheet of Estimates			
Item No.	**Description**	**Unit**	**CONTAINER Quantity**	**MASONRY Quantity**
1	CONCRETE C25	CM	49	421
2	STEEL (REINFORCEMENTS)	KGs	96,650	20,316
3	INTERNAL WALL FINISHES	SM	9,730	3,201

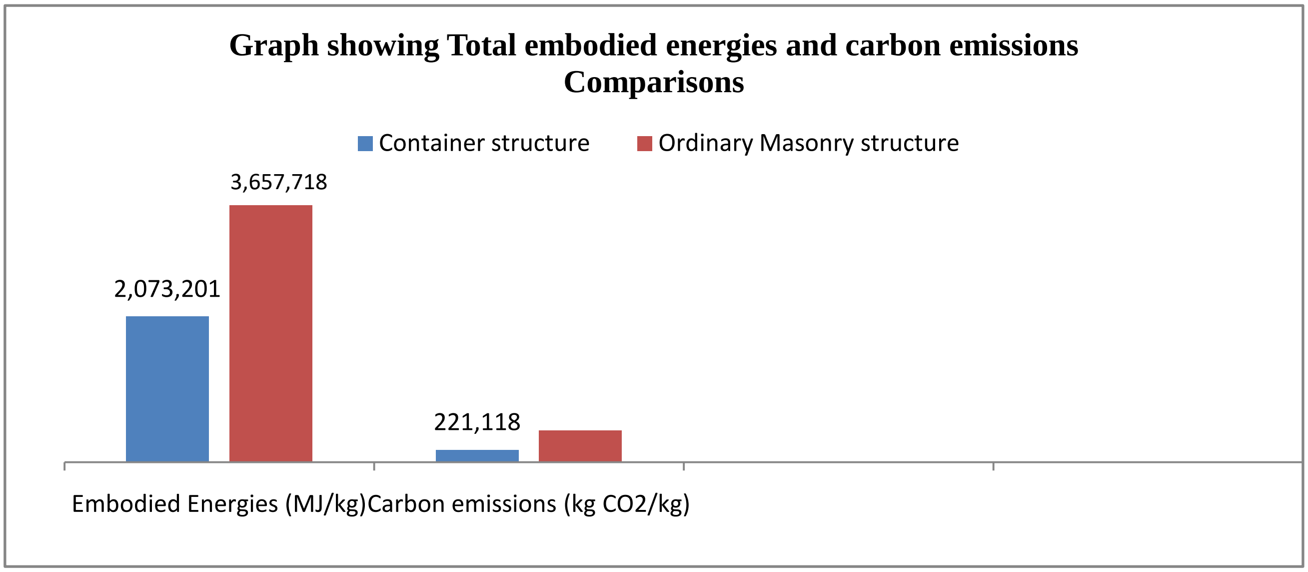
4	EXTERNAL WALL FINISHES	SM	5,573	3,201
5	INTERNAL FLOOR FINISHES	SM	375	375
6	EXTERNAL FLOOR FINISHES			
7	CEILING FINISHES	SM	375	1,047
8	200mm BLOCK WORK	SM	0	3201.36
9	OPENINGS	KGs	0	3490

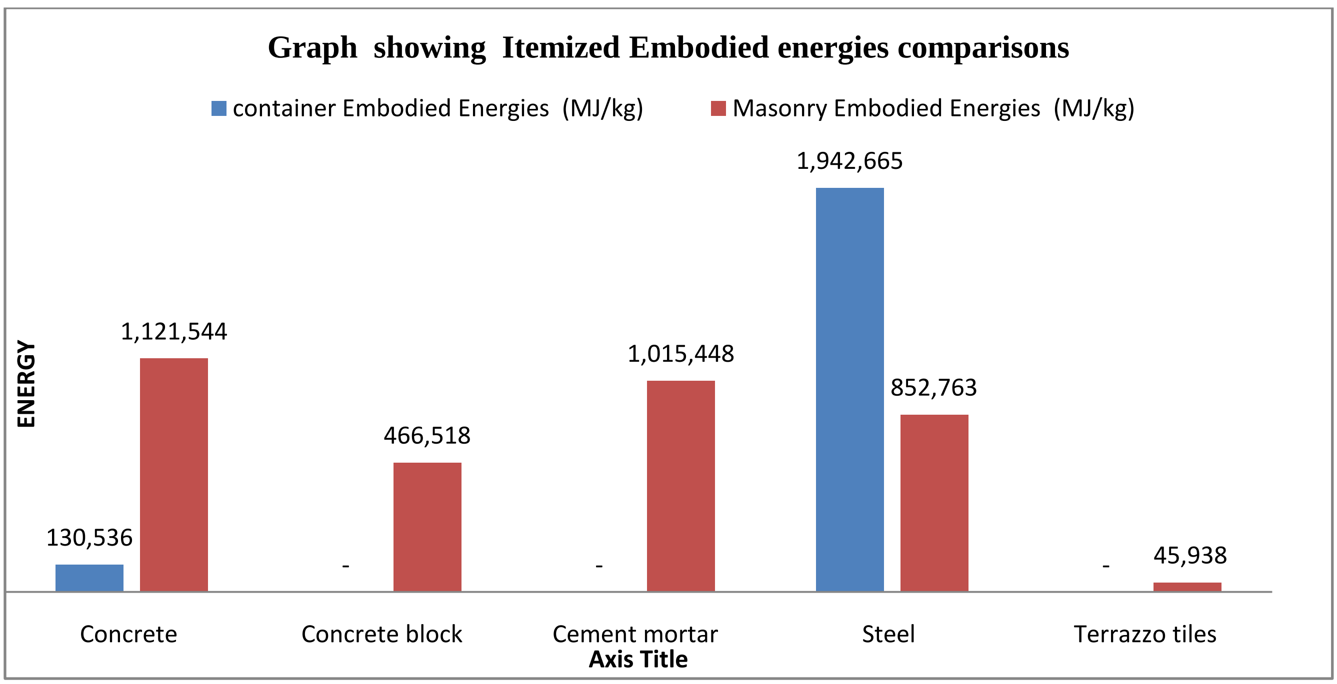
Embodied Energy and Carbon Emission findings

- The Container Building had a smaller amount of embodied energy (2,073,201MJ) compared to the Ordinary Masonry structure at 3,657,718MJ.
- The Container Building had a smaller amount of Carbon emissions (221,118KgCO_2/Kg) compared to the Ordinary Masonry structure at 435,754KgCO_2/Kg.

Table 3, General Calculations

S/N	Description	Quantities (kg)		Carbon emission factor (kg CO_2/kg)	Embodied Energy (MJ/kg)	Material total carbon emission		Material total embodied energy	
		Container	Masonry			Container	Masonry	Container	Masonry
1	Concrete (1:1.5:3 in-situ floor slabs, structure)	117,600	1,010,400	0.16	1.11	18,816	161,664	130,536	1,121,544
2	Concrete block (Compressive Strength 10 N/mm^2))	0	696,296	0.07	0.67	0	48,741	0	466,518
3	Cement mortar (1:3)	0	763,495	0.21	1.33	0	160,334	0	1,015,448
4	Steel (general - average recycled content)	135,000	42,426	1.37	20.1	132,411	58,124	1,942,665	852,763
5	Terrazzo tiles	0	32,813	0.21	1.4	69,891	6,891	0	45,938
	TOTAL					221,118	435,754	2,073,201	3,657,718





Conclusion

In order to understand the total CO_2 emission from a building, it is necessary to access the emission from each material independently. Initially all the quantities of the building are evaluated using centre line method.

Selection of appropriate construction materials can considerably cut down CO_2 emissions and make our buildings more sustainable and energy efficient. The analysis indicates that by using the container as an alternative we considerably save 20% in Embodied energy and 49.3% CO_2 emissions. It is important to note that a building passes through many processes before reaching the end of its life time and its point of demolition or reuse.

When looking at existing buildings, because the possibilities in terms of material replacement are limited, most research has focused on the reduction of carbon content through the reduction of operational energy. Amidst the limited amount of work on decarbonizing existing buildings, research explaining different methods of reducing energy consumption in buildings is limited.

In an existing building, the flexibility and impact of this section is relatively limited because the building has already undergone most construction processes and materials have already been consumed.

There is limited statistics on embodied Energy and carbon emmissions for East Africa and Uganda in particular since it experiences tropical climate.

It further indicates that we should cut down the use of cementious materials and those in the non renewable category.

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APPENDIX 1

Table 4, Densities of Materials

Material	Concrete	Steel	Concrete Blocks (Compressive Strength 10N/mm^2)	Cement Mortar (1:3)	Terrazo
Densities (Kg/m^3)	2,400	7,860	1,450	2,162	1,750

Table 5, Quantity Estimation of Shipping Container Structure

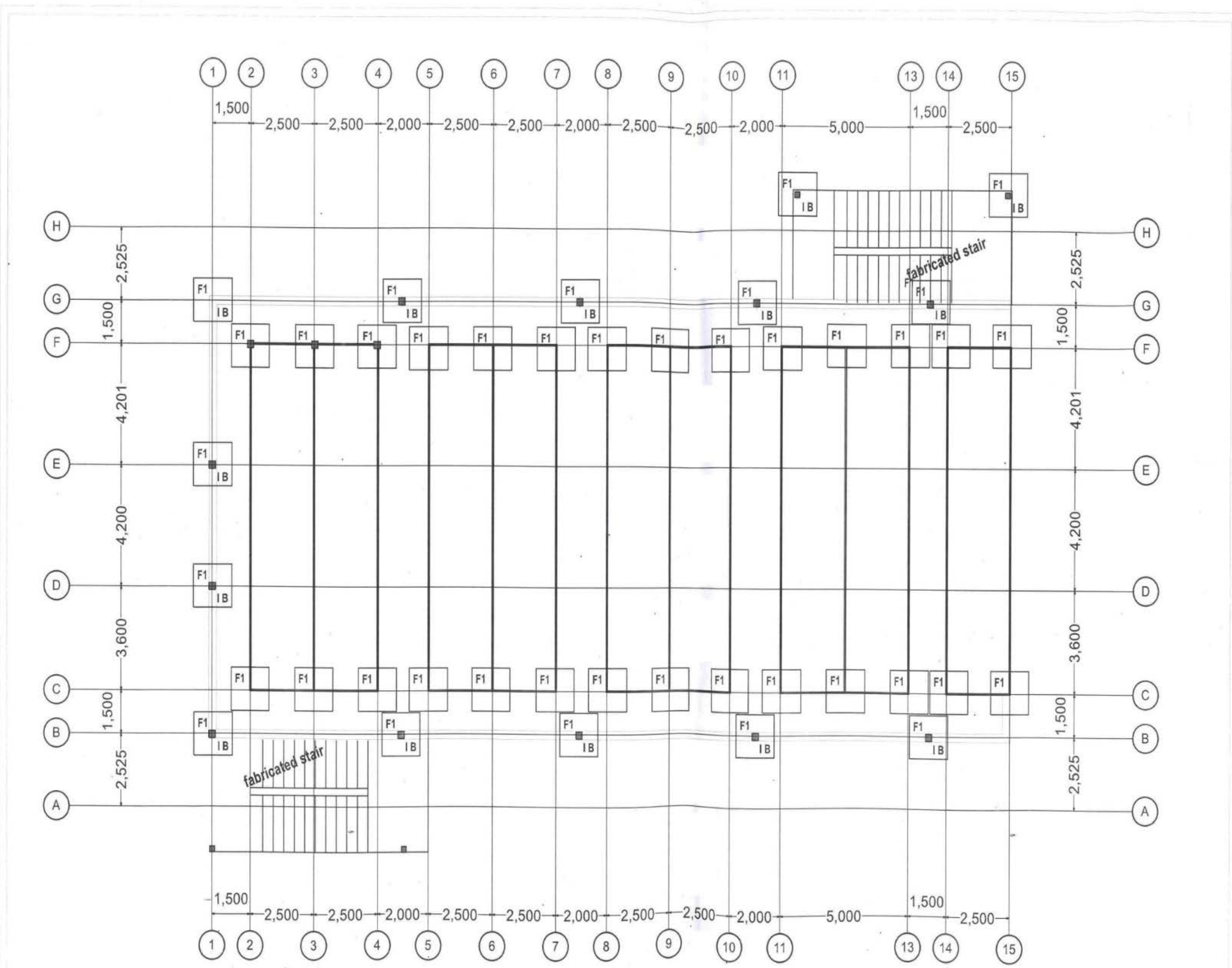
			Measurement sheet						
SITE	**MUBENDE**								
		CONTAINER							
					Dimensions				
Pg	**Item**	**Description**	**Unit**	**No**	**Length (m)**	**Breadth (m)**	**Height (m)**	**Measured Quantity**	**Computation**
	1	**Concrete**	**CM**						**49.28**
		Footings		52	1.20	1.20	0.45	33.70	
		Footings		12	1.20	1.20	0.45	7.78	
		Footings		2	0.20	1.20	0.45	0.22	
		Stud columns		52	0.30	0.30	1.50	7.02	
		Stud columns		12	0.30	0.30	0.45	0.49	
		Stud columns		2	0.30	0.30	0.45	0.08	
								49.28	
	2	**Steel**	**Kgs**						**219,151**
	a	Reinforcements	Kgs						**579.29**
		Footing T12		26	1.20			27.73	
		Stud column T12		208	1.50			277.34	
		Stud column T12		48	1.50			64.00	
		Stud column T12		8	1.50			10.67	
		Stud column T8		421	1.20			199.55	
								579.29	
	b	40ft Containers	Kgs	36					**135,000**
		Weight per contain-						3750	

		er (kgs)							
	c	6mm Chequed plates	Kgs						**8,863**
		Corridors		4	12.00	2.00		96.00	
				1	12.00	1.50		18.00	
				2	23.50	1.50		70.50	
								184.50	
		weight per sq metre (kgs/m^2)						48.04	
	d	Steel columns (254x254x73UC)	Kgs						**33,193**
				32	10.32			330.24	
				10	10.32			103.20	
				2	10.32			20.64	
								454.08	
		weight per metre (kgs/m)						73.1	
	e	Steel Beams (610x229x101UB)	Kgs						**41,516**
				32	10.32			330.24	
				2	25.00			50.00	
				1	12.00			12.00	
				2	1.50			3.00	
				10	1.50			15.00	
								410.24	
		weight per metre (kgs/m)						101.2	
	5	Internal floor area (Terrazo)	SM						**375.00**
				1	25.00	15.00		375.00	

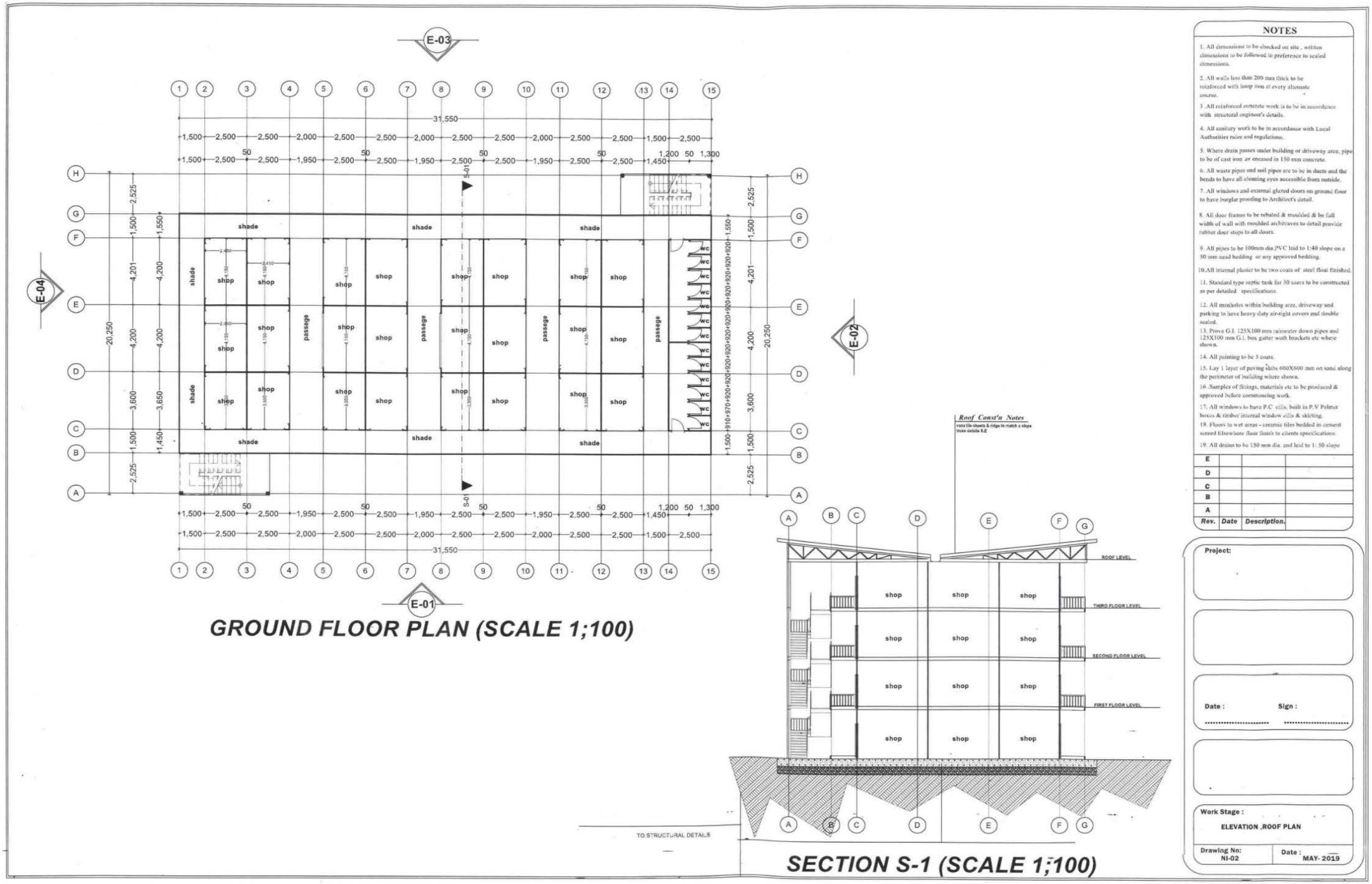
Table 6, Quantity Estimation of Ordinary Masonry structure

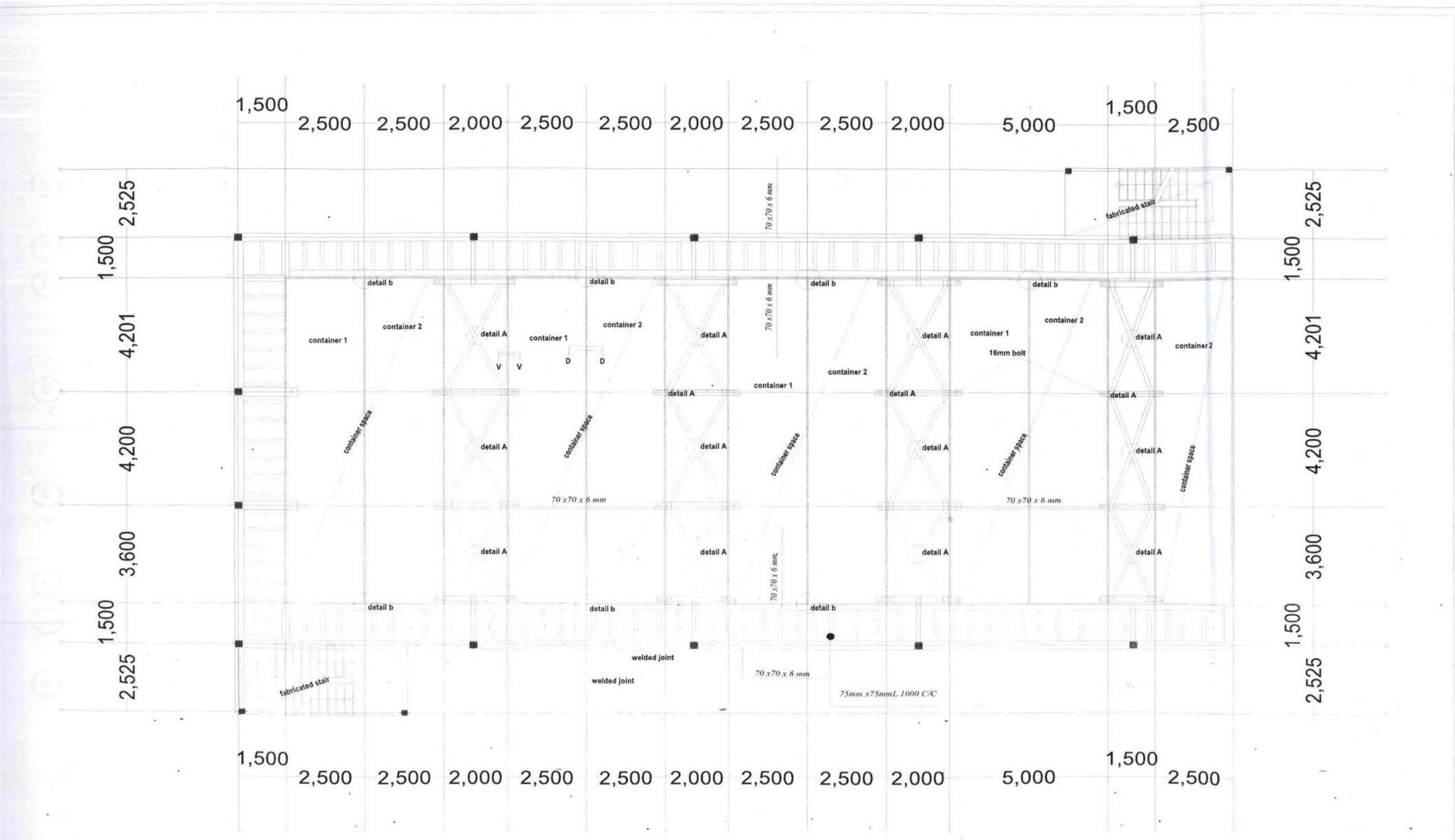
			Measurement sheet						
SITE	**MUBENDE**								
		ORDINARY MASONRY BUILDING							
					Dimensions				
Pg	**Item**	**Description**	**Unit**	**No**	**Length**	**Breadth**	**Height**	**Measured Quantity**	**Computation**
	1	**Concrete**	**CM**						**421.33**
		Bases		38	1.20	1.20	0.35	19.15	
		Bases		12	1.80	1.80	0.35	13.61	
		Strips		18	4.73	0.60	0.20	10.22	
		Strips		2	2.75	0.60	0.20	0.66	
		Strips		2	5.50	0.60	0.20	1.32	
		Strips		4	8.65	0.60	0.20	4.15	
		Strips		2	4.00	0.60	0.20	0.96	
		Strips		2	4.30	0.60	0.20	1.03	
		Ground Beam		1	152.84	0.20	0.35	10.70	
		Columns		152	3.40	0.35	0.35	63.31	
		Columns		48	3.40	0.45	0.50	36.72	
		Slab		4	54	8.43	0.15	273.13	
		Beam		4	152.84	0.30	0.50	91.70	
	Total							**421.33**	
	2	**Reinforcements**	**Kgs**						**25,395**
		T16 bases		38	2.60			156.10	
		T16 bases		12	3.80			72.05	
		T20 Columns		38	15.50			1454.83	
		T20 Columns		12	15.50			459.42	
		Ground beam T12		6	152.84			814.33	
		BRC A142		4	54.00			479.52	
		Slab T12		1493	8.43			11178.85	
		Slab T12		225	54.00			10779.61	
	Total							**25,395**	
	3	**Internal wall finishes**	**SM**						**3,490**
				36	24.06	4.78		4140.24	
		Openings		-108	2.4	2.4		-622.08	
				-52	0.9	0.6		-28.08	
	Total							**3,490**	
	4	**External wall finishes**	**SM**						**3,490**
				36	24.06	4.78		4140.24	
		Openings		-108	2.4	2.4		-622.08	
				-52	0.9	0.6		-28.08	
								3,490	
	5	**Ceiling finishes**	SM						**2562.50**
				4	31.5	15.00		1890	
		Beams		4	152.84	1.1		672.50	

	Total							**2562.50**	
	6	**200mm Block work, 150mm thick**	**SM**						**3201.36**
				36	24.06	4.78		4140.24	
				-163	2.40	2.4		-938.88	
								3201.36	
	7	**Floor Finishes (Terazzo)**	**SM**						**375.00**
				1	25.00	15.00		375.00	

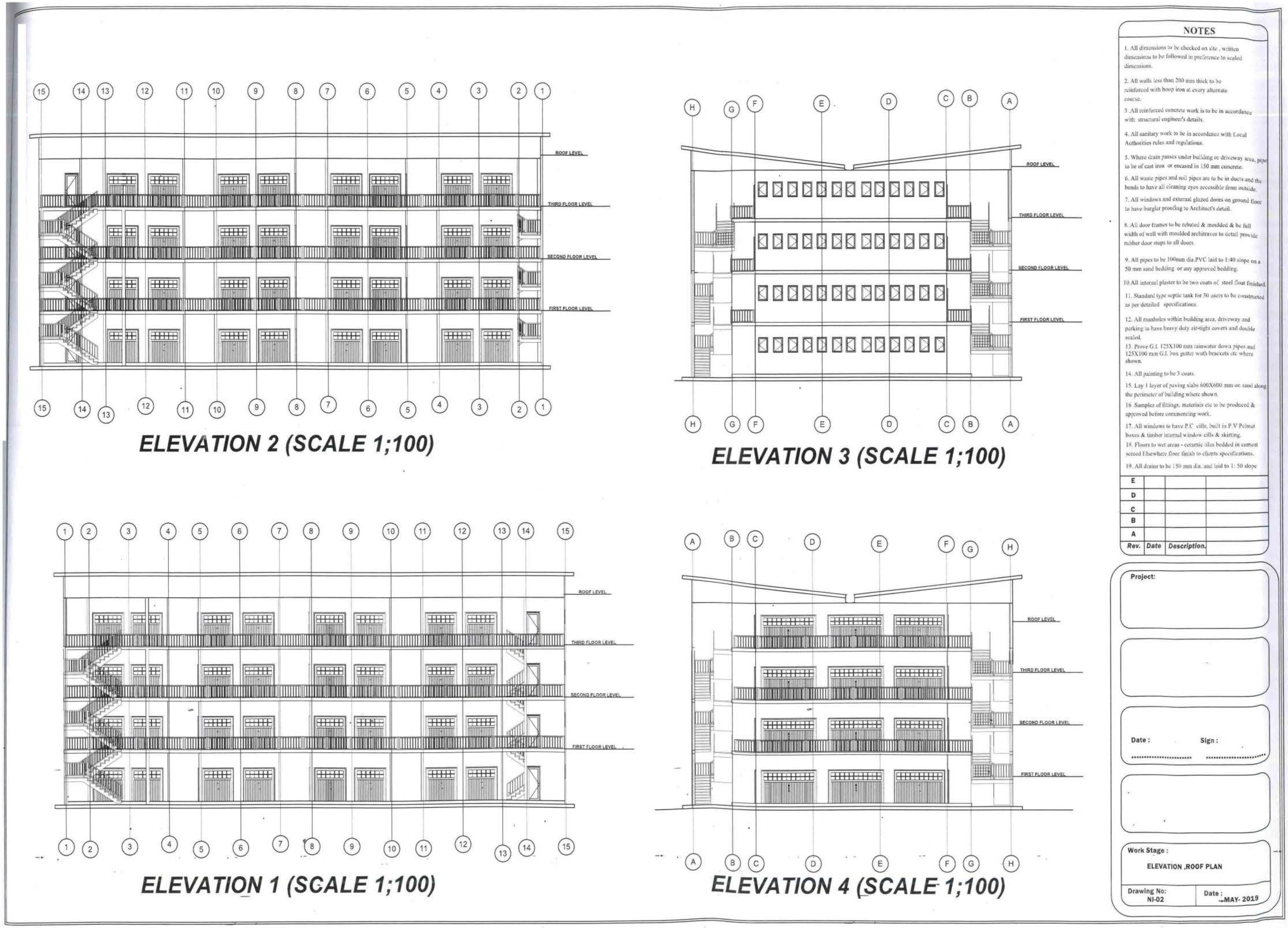


FOUNDATION LAY OUT


GROUND FLOOR PLAN (SCALE 1;100)
SECTION S-1 (SCALE 1;100)
E-01
E-02
E-03
E-04
S-01
31,550
20,250
shade
shop
passege
wc
Roof Const'n Notes
ROOF LEVEL
THIRD FLOOR LEVEL
SECOND FLOOR LEVEL
FIRST FLOOR LEVEL
TO STRUCTURAL DETAILS
NOTES
1. All dimensions to be checked on site , written dimensions to be followed in preference to scaled dimensions.
2. All walls less than 200 mm thick to be reinforced with hoop iron at every alternate course.
3. All reinforced concrete work is to be in accordance with structural engineer's details.
4. All sanitary work to be in accordance with Local Authorities rules and regulations.
5. Where drain passes under building or driveway area, pipe to be of cast iron or encased in 150 mm concrete.
6. All waste pipes and soil pipes are to be in ducts and the bends to have all cleaning eyes accessible from outside.
7. All windows and external glazed doors on ground floor to have burglar proofing to Architect's detail.
8. All door frames to be rebated & moulded & be full width of wall with moulded architraves to detail provide rubber door stops to all doors.
9. All pipes to be 100mm dia.PVC laid to 1:40 slope on a 50 mm sand bedding or any approved bedding.
10.All internal plaster to be two coats of steel float finished.
11. Standard type septic tank for 30 users to be constructed as per detailed specifications.
12. All manholes within building area, driveway and parking to have heavy duty air-tight covers and double sealed.
13. Prove G.I. 125X100 mm rainwater down pipes and 125X100 mm G.I. box gatter wuth brackets etc where shown.
14. All painting to be 3 coats.
15. Lay 1 layer of paving slabs 600X600 mm on sand along the perimeter of building where shown.
16 .Samples of fittings, materials etc to be produced & approved before commencing work.
17. All windows to have P.C cills, built in P.V Pelmet boxes & timber internal window cills & skirting.
18. Floors to wet areas - ceramic tiles bedded in cement screed Elsewhere floor finish to clients specifications.
19. All drains to be 150 mm dia. and laid to 1: 50 slope
Rev.
Date
Description.
Project:
Date :
Sign :
Work Stage :
ELEVATION ,ROOF PLAN
Drawing No:
NI-02
Date :
MAY- 2019



TYPICAL SLAB LAY OUT
scale 1;50


ROOF LEVEL
THIRD FLOOR LEVEL
SECOND FLOOR LEVEL
FIRST FLOOR LEVEL
ELEVATION 2 (SCALE 1;100)
ELEVATION 3 (SCALE 1;100)
ELEVATION 1 (SCALE 1;100)
ELEVATION 4 (SCALE 1;100)
NOTES
1. All dimensions to be checked on site , written dimensions to be followed in preference to scaled dimensions.
2. All walls less than 200 mm thick to be reinforced with hoop iron at every alternate course.
3 .All reinforced concrete work is to be in accordance with structural engineer's details.
4. All sanitary work to be in accordance with Local Authorities rules and regulations.
5. Where drain passes under building or driveway area, pipe to be of cast iron or encased in 150 mm concrete.
6. All waste pipes and soil pipes are to be in ducts and the bends to have all cleaning eyes accessible from outside.
7. All windows and external glazed doors on ground floor to have burglar proofing to Architect's detail.
8. All door frames to be rebated & moulded & be full width of wall with moulded architraves to detail provide rubber door stops to all doors.
9. All pipes to be 100mm dia.PVC laid to 1:40 slope on a 50 mm sand bedding or any approved bedding.
10.All internal plaster to be two coats of steel float finished.
11. Standard type septic tank for 30 users to be constructed as per detailed specifications.
12. All manholes within building area, driveway and parking to have heavy duty air-tight covers and double sealed.
13. Prove G.I. 125X100 mm rainwater down pipes and 125X100 mm G.I. box gutter wuth brackets etc where shown.
14. All painting to be 3 coats.
15. Lay 1 layer of paving slabs 600X600 mm on sand along the perimeter of building where shown.
16 .Samples of fittings, materials etc to be produced & approved before commencing work.
17. All windows to have P.C cills, built in P.V Pelmet boxes & timber internal window cills & skirting.
18. Floors to wet areas - ceramic tiles bedded in cement screed Elsewhere floor finish to clients specifications.
19. All drains to be 150 mm dia. and laid to 1: 50 slope
E
D
C
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A
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