Innovative Conceptual Design of Manual-Concrete-Block-Making-Machine

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Abstract
One of the basic human needs is having a proper shelter. Due to the rapid population and urbanization growth, there is an escalating demand for affordable housing in Kenya. This necessitates looking for ways to reduce construction costs, particularly for low-income housing group. Concrete-block construction has recently gained significance, however most of the commercially-available block-making-machines are imported and also expensive. Locally-made affordable block-making-machine would render useful in lowering the cost of construction. This project, therefore, was aimed to complete a conceptual design of an innovative undemanding stationary manually-operated concrete-block-machine that molds concrete-blocks at a fraction of a cost in comparison with power-operated options. The target specifications were derived from the customers' needs data collected during the local workshops' visits and from the secondary sources, mainly patents. Three design alternatives were developed; alternative design #3 was chosen by the engineering design decision-weighted-matrix and by the *drop and re-vote* (D&R) method. The originality of this design is essentially in the ejection system: as opposed to many block-making-machines available which ejects blocks instead of the mould, this machine ejects the mould leaving the blocks on the base plate. Mild steel was a material of choice for the machine. A static simulation study on the frame model, which was fixed at the bottom mounting and an overall normal force of 981N or 100 Kg applied at the base plate was done using Engineering Design Software: SolidWorks, 2013 (design and simulation tool). The study included Stress, Displacement, and Strain analysis. Conceptual design of manual-concrete block-making-machine was optimized according to results of simulations, calculations and fundamental engineering design principles. Cost estimation shows that this simple and economical piece of equipment could have a potential in lowering the cost of construction. To ascertain a potential, however, the authors propose further work on prototyping and testing to be carried out.
Key words: block-making, concrete, design, machine.

1. Introduction, statement of the problem and purpose of the research

Mankind first of all must eat, drink, and have shelter and clothing, before he can pursue politics, art and religion etc. (Frederick Engels, 1883). Indeed, even after all the ground-breaking advances, discoveries, innovations and developments, made for the last 130 years, in science technology engineering and other fields, humanity, still, remains, essentially, the same, as it must, first, satisfy their *basic* needs such as food, shelter and clothing, and only then attend to wants, demands, and desires.

We are living in a world where the majority of people live in cities and 1 billion live in slums, a figure that will double by 2030 (UN Habitat, 2007). Urban populations are growing at a rate much faster than can be absorbed and managed, causing demands on services and infrastructure that massively outstrip supply. In many emerging market cities, this leaves the majority of residents with few options but to live in slums.

Kenya, is not an exception; having one of the world's highest rates of population and urbanization growth. Last census conducted in 2009 revealed Kenya's population to be 38.6 million compared to 28.7 million in 1999. Twenty-two percent of Kenyans live in cities, and the urban population is growing at a rate of 4.2 percent every year (CIA World Factbook, 2010). With this level of growth, capital-Nairobi, alone, requires at least 120,000 new housing units annually to meet demand, yet only 35,000 homes are built, leaving the housing deficit growing by 85,000 units per year. As a result of this mismatched supply and demand, housing prices have increased 100 percent since 2004 (Hass Consult Property Index, 2011). This pushes lower-income-residents out of the formal housing market and into the congested slums establishments (averagely, 5 to 7 people share a single room) or it pushes them even further-to become totally homeless (Union, 2013).

Millions of people of Kenya, especially in Nairobi city, are living in the sprawling slums and also in other informal settlements around Nairobi (UN, 2010). Kenya's housing challenge is extreme. The average price for an apartment in the capital city of Nairobi is currently KES 11.58M (USD 136,000), up from KES 5.2M (USD 61,000) in December 2000. There is no modest home on the formal market below KES 2M (USD 23,000), a level that is still completely unaffordable to low-income populations (Hass Consult Property Index, 2011).

The new constitution of Kenya, 2010 includes Right to Adequate Housing (Article 22), however, this human right, as shown above, is, yet to be achieved and, moreover, guaranteed.

Housing plays a huge role in revitalizing economic growth in any country, with shelter being among key indicators of development (Ireri, 2010). Provision of adequate, affordable and decent housing for low-income-households is clearly in short supply. Though free markets unleash productivity and innovation, they are still bound by economic laws. The most important law is that market-price reflects market-demand. Because half of every population is below median income, market-quality housing commands market-prices. As a result, markets alone will never satisfactorily house a nation's poorest citizens (Smith, 2006).

Owing to inadequate means within developing countries, it is essential to look for ways to reduce construction costs, particularly for low-income housing group. Concrete-block- construction has gained significance in the recent times and has turned into a valid alternative to fired-clay-bricks and bush-shaped-stones. Most of the commercially-available-machines that produce concrete-blocks, however, are imported to Kenya and are very expensive. Locally-made block-making-machine would render useful in lowering the cost of construction, by providing cheaper and readily accessible building-blocks.

The main constituents of concrete-blocks are cement, aggregate (sand, gravel) and water, which are readily available in Kenya. In contrast to clay-bricks production, production of concrete-blocks is carried out in a large variety of shapes and sizes, hollow or solid depending on the end use. The main advantage of concrete-blocks is that it does not require any treatment or fuel that endangers our environment in contrast to clay-bricks fired to a temperature of up to a about 900^{o}C.

This project, therefore, is aimed to complete a comprehensive conceptual design of an innovative undemanding stationary manually-operated-block-making-machine that molds concrete-blocks at a fraction of a cost in comparison with power-operated options. Objectives of the research are to: (1) formulate design-problem with target-specifications; (2) analyze available design-alternatives; and (3) establish optimum conceptual design.

The research is important because Conceptual design Phase is the most important part of the engineering design process. A successful conceptual design will lead to accomplishment of subsequent stages of the design, and as such it could be a good starting point leading to fabrication of affordable manual-concrete-block-making-machine, which in turn would contribute, in its small way, to the reduction of housing problem in Kenya.

2. Research Methodology

Figure1 shows the summary of the research approach, followed by elaboration on the same

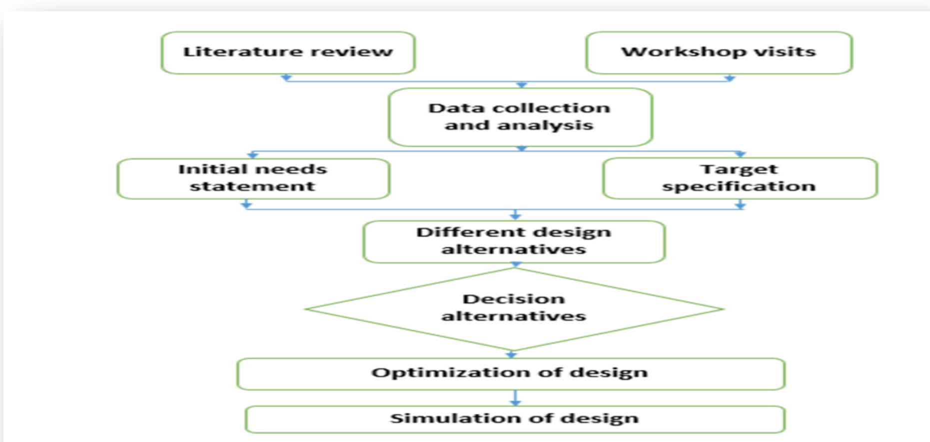


Figure2: Summary of the research approach

To achieve the objectives, the design team used the following steps:

1. The fundamental concepts of engineering design and conceptual design among others were reviewed. Benchmarking was completed to research for existing designs and patents particular to the target-specifications to ensure a unique design.

2. There are several types of concrete-block-making-machines in the market. The block-making-machines can either be manual, partially-manual or automated, therefore four different local block-making-workshops (within Eldoret environments) were visited to evaluate the different machinery utilized. Technology level, mode of operation, local cost of the machines, production rates of blocks produced were evaluated together with reporting problems observed associated with their operation. An initial needs statement was developed from the customer needs, after getting thoroughly familiar with what the machine is intended to accomplish and what special requirements or limitations must be considered.

3. A list of target-specifications for the design was formulated; Issues of Ease of operation, Maintenance requirement, Eco/green-design aspect, Efficiency, Occupational Safety & Health among others were considered.

4. Design problem was formulated (design factors involved such as block sizes/mould sizes, calculation of forces involved, variation in material use, failure modes, cost, etc. were considered; analysis and calculations done according to fundamental engineering principles).

Design characteristics were gathered from the workshops visits. It incorporates: Client's requirements, Quality requirements, Market details and Functional requirements. After design characteristics evaluation, the design team also considered other design features that include: Aesthetic requirements, Performance requirements, Contextual requirements, and Production parameters and limitations, such as health safety requirements, materials and availability of labour among others.

5. Three free-hand sketches of various ways the machine might be constructed were made, at the same time making any preliminary calculations which might be required to substantiate ideas and to establish approximate sizes. Having established what seems to be a feasible construction, layout drawing of the machines was made, paying particular attention to the necessary details of construction.

6. The design-alternatives were brainstormed to choose the most feasible and effective alternative to best satisfy the customer needs. Selection of the best-alternative was done by the use of the engineering design weighted-score-matrix. Factors of consideration involve: Eco-design concepts, Efficiency, Ergonomic design considerations and Safety among others. This choice was also confirmed by *drop and re-vote* (D&R) method, according to Filippo (2012).

7. The materials selection was done according to Ashby (2005). The properties for consideration were limited to: technical properties of materials (density, conductivity, strength…), manufacturing of materials (easy to manufacture with existing manufacturing facilities…), economic properties of materials (cost for material and production, availability…) and ecological properties of materials (recycle-ability, sustainability…).

8. The best-alternative-design was then optimized based on simulations and calculations. The layout was analyzed for forces, stresses, etc., and calculations necessary were made to be certain that the parts can perform satisfactorily. Engineering Design Software SolidWorks, 2013(design and simulation tool) was used. The approximate cost of the machine was estimated using Bill of Quantities of the materials necessary for the machine components according to the market prices in Kenya in 2016.

3. Results and Discussions

3.1. Review of Literature

3.1.1. Concepts of Engineering design and Conceptual design

Design can be described as a set of decisions taken to solve a particular set of product-requirements. Within the product development process, the there are several phases: idea generation, product definition (also called product planning), conceptual design, detail design and embodiment design (Timings, 2000). The inputs into the design process are shown in Figure 2.

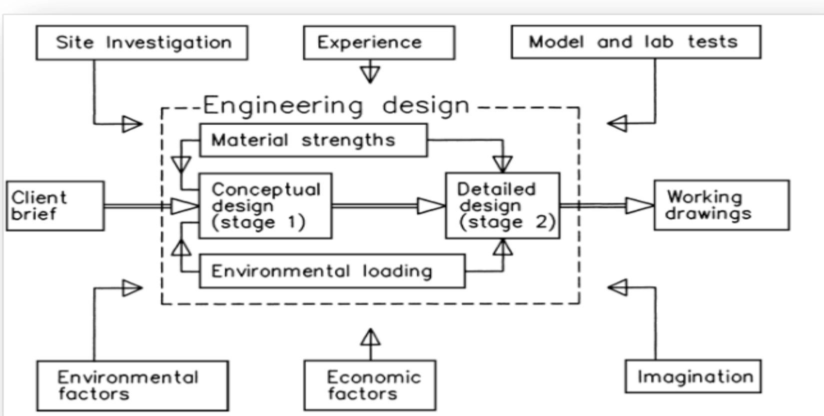


Figure 2: Inputs into the design-process (Arya, 2009)

The conceptual design phase is the most important phase in concurrent engineering after the project planning phase or product definition. Approximately eighty percent of a product's life cycle costs are committed through design choices, such as materials and manufacturing process selections in this phase. Conceptual design comprises concept definition, exploration, evaluation and selection (Allen& Carlson-Skalak, 1998).

The product design-criteria are: *Functionality* (A component consists of different parts. The functional part is the one that really has critical assignment that leads to the performance of the component. The non-functional part does not have major work in component existence but it has something to do with maintenance, covers, inspection and aesthetical value and it must be reduced to the minimum to have low production cost (Timings, 2000)); *Manufacturing issues* (Complexity, Material suitability, Tolerance and surface finish; Surface Treatment; Process cost; and Waste among others) and *Handling and Assembly* (poor design of a component will result to difficulties in manual or mechanical handling of the product. An example of this is a fragile and delicate product or a product with unnecessary weight which makes it too heavy to be suitable for what it is meant for or to serve its purpose).

The features of good design for manufacture and assembly include the following: Orientates one about how the product can be positioned correctly at the first attempt; There should be no resistance to insertion; Assessing the product must not be restricted by any means; There should be no additional joining process such as bolting, soldering or adhesive bonding. To achieve all these criteria, all the components: Should be symmetrical, if possible and this also helps in manufacturing Have polar geometry mark; Have important directions; Should be tangle-proof; Should have consistency in the dimensions used for feeding, orientation and location; Should be self-locating; Should have a datum surface. If volume of production and cost are to be kept in mind, it is important that assembly: Should have location points; Will be designed to start from top; Should be designed to avoid unnecessary turning over of the product; Should be designed to allow series of subassemblies for intermediate checks; Should incorporate standardized parts e.g. fasteners in order to facilitate assembly and correct selection; Should reduce complications and eliminate components that are not important (Juvinall & Marshek, 2012).

Green design/Eco-Design/Environmentally-friendly-design or Design for the Environment (DFE) concept focuses on how to achieve sustainability of human health and environment through science and technology. Green design is regarded as the future of design because it reduces cost, energy consumption, materials consumption, and natural resource consumption. It also creates a healthier living environment. There are 12 principles that provide a framework for engineers to engage in when designing new products or systems depending on the product. A design based on these principles moves beyond the baseline of engineering quality and safety specifications to consider other factors such as environmental, economic and social factors. Among the 12 principles, four of the principles are applicable in this study. They are: Inherent Rather than Circumstantial (Designers need to strive to ensure that all materials and energy inputs and outputs are as inherently non-hazardous as possible), Durability Rather Than Immortality; Meet Need, Minimize Excess (Design for unnecessary capacity or capability (e.g., "one size fits all") solutions should be considered a design-flaw); and Minimize Material Diversity (Hundal, 2002).

This study deals with conceptual design of concrete-block-making-machine.

3.1.2. Concrete-blocks and concrete-block-making-machines

Productions of concrete-blocks are done in various sizes and shapes, load bearing or non-load bearing, either hollow or solid and lightweight or dense. First, the cement (usually Portland cement) is prepared. Next, the other ingredients-aggregates (such as sand or gravel), admixtures (chemical additives), any necessary fibers, and water (free from impurities such as oils, acids, and organic matter)-are mixed together with the cement to form concrete. The concrete is then compacted and cured.

The concrete-blocks are made manually through the use of a mould or produced using machines. The major operations performed by a concrete-block-making-machine include shaping and compaction of concrete to form concrete-blocks. The nominal measurements, (actual length, width and height of block) are commonly used to refer to block sizes. The thicknesses are also added to the entire dimension. These dimensions are usually centered on the modular coordination of design. The commonly used concrete-blocks are the stretcher-blocks with a nominal length of 16 inch (40.64 cm) nominal height of 6 inch (15.24 cm), and nominal widths of 9,6,4 inches (Hornbostel & Caleb, 1991).

3.1.3. Related history, design and patents on block-making-machines.

The review recorded below do not claim to be fully comprehensive account of every instance related to concrete-block-machines, but they do give a fairly good picture of the order of magnitude of activities, achievements, and problems encountered, and probably include the most significant ones identified for which information was available at the time this study was carried out.

The earlier recorded use of concrete was in 200 B.C where the Romans used concrete mortar to bind shaped stones in the construction of structures. The Roman emperor Caligula, in 37-41 A.D., used small blocks of precast-concrete as a building material. Later in the 5^{th} century after the fall of the Roman Empire, most of the concrete technology was lost. In 1890, Harmon S. Palmer designed the first hollow-concrete-block in the United States. The design was patented after 10 years of experimenting. The

Palmer's block were so heavy making them difficult to transport and had to be lifted by a small crane. These blocks were 8 in (20.3 cm) by 10 in (25.4 cm) by 30 in (76.2 cm). In the early 18th century, several companies come into existence with an estimated 1,500 companies manufacturing concrete-blocks in the United States and Europe. These blocks were generally hand-casted, with an output of about 10 blocks per person per hour (Koski & John, 1992).

Major revolution occurred in concrete-block-making-machines and block-designs during early 20th Century. Some of the early patents include: US1442967A patented on Jan. 23, 1923; US1527041A patented on Feb. 17, 1925; US2131803A patented on Oct. 4, 1938; US2193879A patented on March 19, 1940; US2308132A patented on Jan 12, 1943; US2460167A patented on Jan. 25, 1949; US2620541A patented on Dec. 9, 1952; US2706322A patented on April 19, 1955. The patents were based on manual production of concrete-blocks and therefore were the subject of this evaluation.

Critical-evaluation of the designs was conducted. For example, according to US1442967A patent of Godfrey W. Parke regarding an invention of concrete-block-making-machine, the objectives included: (1)Providing a machine of simple construction which will work rapidly and efficiently to produce blocks, with an improved means of raising the tamper element used. (2) Providing a machine having efficient supporting means, (3) Providing a novel means for raising the pallet and molded block when the mould box swings downwards. From the objectives, it is of great importance while designing to consider simplicity in the working principle but without sacrificing efficiency. For stability, supporting means is also very important. It is evident, however, from our criticism of Papke' design, a means of withdrawing blocks is a challenge.

Today, concrete-block-making-process and machines are automated and can produce up to 2,000 blocks per hour (Thorat, 2015).

3.2. Visits reports

Four different local block-making workshops (within Eldoret environments) were visited. Table 1 shows the summary of evaluation.

Table1: Summary-details of the workshops operation

Machines / Details	Mould	Manual machine (multi-mold)	Egg-laying machine	High pressure cement block machine
Blocks/ cycle	1	4	6	5
Blocks/ 8hr shift	100-150	200-250	600	1000-1500
Number of operators	1	1	Minimum 2	Minimum 4
Power requirement	Manual	Manual	1.5hp electrical motor	Two 1.5hp electrical motors
Local cost	About KES 2,000	About KES 100,000.00	About KES 600,000.00	About KES 1,000,000.00
Challenges observed	Low production capacity <100/ shift; Limited to single block design.	Block ejection mechanism. Block transportation in wet state Limited to solid block design	Power dependent for vibration.	Power dependent for vibration. Requires very large workshop and yard.

3.3. Machine target Specifications.

The target specifications were derived from the customers' needs data collected during the workshop visits and from various designs in selected published patents. Different constraints from the customers and their facility also derived the target. Manual machine (multi-mold) was selected as a point of reference. The particular emphasis is put on the ejection-mechanism of the machine, as it was noted that a lot of energy is employed by the machine-operator in lifting the blocks from the mold.

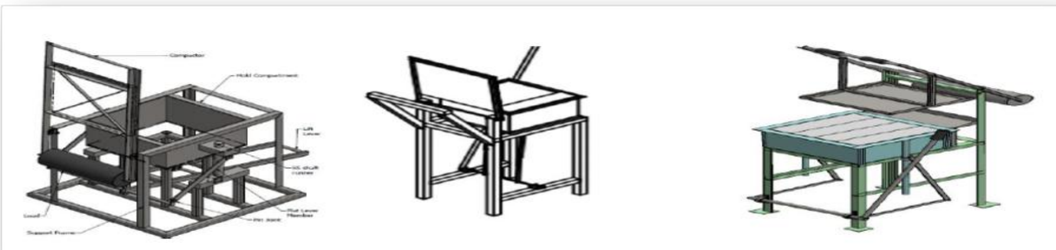
The machine to be designed should have at minimum the following specifications: *Machine type*- Stationary, *Power*- Manual compaction; *Capacity*- Minimum of 200 blocks per 8hour shift, with more than two blocks per press; Light *Weight* to permit portability and for ease of transportation and reduction of the cost, *Block configuration*- Flexible in producing solid and hollow blocks; *Ergonomic*- Vertical operation at arms level with minimum human effort; and *Occupational safety and health* *administration* - Minimum lifting force (There are weight limit guidelines for manual lifting recommended by regulatory agencies like Occupational Safety & Health Administration (OSHA).The Ergonomics Program Standard proposed by the OSHA, identifies lifting more than 75 lbs. at any one time, more than 55 lbs. more than 10 times per day, or more than 25 lbs. below the knees, above the shoulders, or at arms' length more than 25 times per day, or pushing/pulling with more than 20 lbs. of initial as risk-factors (OSHA, 1999).

3.4. Design problem formulation

Design specifications are based on the customer needs as per data collected in the workshop visits and technical standards as per the British Aggregate concrete masonry units standards BS EN 771-3, 2006. Concrete-blocks are characterized by the following category: Dimensions (440mm x 100mm x 215mm) and Tolerance category (D1 in mm, D2 in mm). Configuration of the concrete-blocks can be hollow or solid blocks.

3.5 Design alternatives.

Figure 3 shows three design-alternatives developed.



1 2 3

Figure 3: Design-alternatives

3.6. Selection of the best design-alternative

It was done initially by the standard engineering design weighted-decision-matrix. Weighted attributes, reflecting their importance were chosen as follows: Eco-green design aspects 0.3; Ease of fabrication and assembly@ 0.2; and Occupational Safety & Health @0.2; while Ease of operation, and Efficiency @0.1 each. Alternative design # 3 was selected with the highest score of 0.73, as Alternative 1 scored 0.63 and Alternative 2 – 0.49. To confirm the choice, additional method of selection of best-alternative was used is D&R method, where the members of the design-team each order alternative-concepts in a weak-order, an ordinal ranking with no level of preference. The weak-orders are then compared to some common filtering criterion (such as "choose the best of the best" or "avoid the worst of the worst") and the most poorly ranked concept are dropped from further consideration. The process is then repeated until only one alternative remains.

3.6.1. Description of the best design-alternative

The machine has four major functional systems namely: concrete compaction, block molding; block ejection; and the frame and support system. Figure 4 shows the systems of the machine.

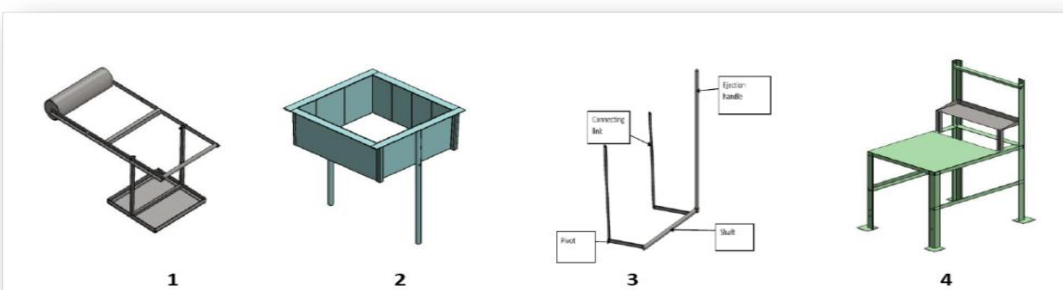


Figure 4: Systems of the machine (1- Compactor; 2- Mould; 3- The mould ejection; 4- frame)

3.6.1.1Compactor system

Concrete in wet state contain up to 20% void of air spaces that require to be eliminated for formation of compact blocks. The level of compaction has a direct correlation to the ultimate strength of the blocks thus the compaction has to be thorough. This system is composed of the compactor plate, the compactor frame and the dead weight.

The compactor plate is made of a flat sheet metal of gauge 5 and 3 mm thickness. The plate is ramped on the concrete poured on the mould to ensure maximum compaction and a quality even-finish of the blocks on the open-end of the mould. The compactor plate is driven or swaged by the help of the compactor frame. The compactor frame is made of L channel bars and handle bar. The essence of the frame is to facilitate the compaction by driving the compactor plate. The frame is pivoted and can swing through an angle of 60^0. At the end of the compactor is a dead weight that counteracts the weight of the frame and the plate, this ensure the compactor system is upright always.

3.6.1.2 The block molding system

The system is essentially consists of the mould. The mould is partitioned into smaller sub-molds divided by separation plates. The separation plates enable the production of four blocks per cycle which is more economical in comparison to the manual mechanism where single block is produced per cycle. The operator exerts a compacting force on this part to ensure the concrete aggregates are properly aligned and voids are reduced to give the block the required density and compressive force. It is composed of a dead weight to balance it during block withdrawal from the mould. Block dimensions will be specified in the order length x width x height (406 mm x152 mm x 229 mm).

3.6.3 The mould ejection system

Once the blocks have been compacted to the desired level the mould has to be vertically cleared to enable the removal of the concrete-blocks. The ejection system incorporates a lever system. It consists of the ejection handle, the shaft, bearings and the connecting links. The system is designed to enable a clearance of mould from the blocks. The bearing at the lever arm and shafts allows smooth motion.

In solving the forces on each link and joint, the forces are resolved along the x and y-axis and moments at pin joint A and B respectively. N_c is the force resisting the breakage of the system due to W_1 (weight of link B). B_1 and B_2 are the reaction at pin B as shown in the free-body-diagram below.

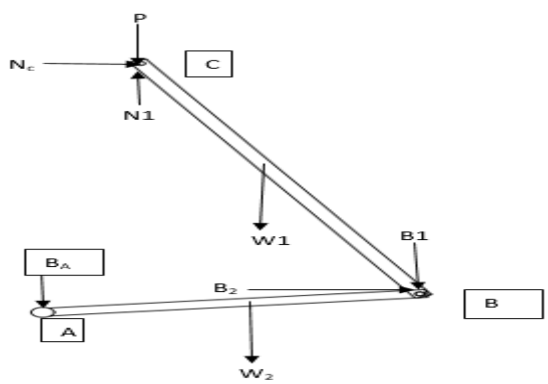


Figure 5: Free-body-diagram of the block-ejection-mechanism

Link B

$$\sum Fx = 0 = N_C - B_2 = 0$$

$$\sum Fy = 0 = B_1 - P - N_1$$

$$\sum M_B = 0 = Pa \times N_C \times b + W_1 \times c$$

Link A

$$\sum Fx = 0 = H_A - B_2 \quad \sum Fy = 0 = B_1 + W_2$$

$$\sum M_A = 0 = B \times d + W_2 \times e + P \times (d - a)$$

Resolving the distances at an angle of 78.62^0 and 30^o and substituting the known forces in the equation ($P=176.4N$, $W_1=68.6N$, $W_2=49N$) the resulting forces on the pin joint are determined to be 121.64N at joint A, 105.34N at joint A and 152.77N. This means that the force applied on the lever must balance the force at joint A to provide sufficient lifting of the mould.

3.6.1.4 Frame and support system

This is the main part supporting all the machine components. It has plate welded to hold the blocks and provides a counter compacting force to compress the concrete giving the desired shape. The compactor mould and ejection system all lie on the machine frame structure. The lower foundation is L shaped beams that can be screwed to the foundation or ground to make the machine more stable and resist the vibrations. The frame also holds a concrete holding plate that is used to store excess or spill over concrete during the compaction.

The design of the base plate is controlled by critical buckling force on the plate during operation. This is dependent on the material strength and thickness of the plate chosen. The allowable deflection ranges from 0.0005 to 0.003 inches due to bending.

$$\text{Deflection} = \frac{PL^3}{KEI}$$, Where:

P is the total downward force on the base plate resulting from compacting force and the supported materials.
I is the second moment of area
K is the factor dependent on loading

The critical buckling force is calculated from the formula,

$$\text{Crtical buckling force} = \frac{\pi^2 EI}{L^2}$$, Where,

E is the Modulus of elasticity of steel
I is the second moment of area
L is the length of each mould box compartment The study of the supporting elements were carried out to obtain the deformation on the various components as a result of forces during operation.

The lever handle is designed based on the torsional characteristics of the material used.

$$\text{Angular displacement}, \theta = \frac{32LT}{G\pi D^4}$$, Where,

L is the length of the handle lever
T is the Torque on the lever
D is the diameter of the lever handle
G is shear modulus. For mild steel, G= 80 GPa

$\text{Torque} = \text{Force on the lever} \times \text{Radius of the lever}$

Therefore, $T = 180N \times 0.01 = 1.8\ NM$; $\theta = \frac{32 \times 0.9689 \times 1.8}{80 \times 10^9 \times \pi \times 0.02^4} = 0.00139$ Radians or 0.0796 degrees

This block-making-machine is designed to produce four blocks per press. In order to provide balance to the machine, it is grounded to the ground through the plates on the frame. This ensures that the vibrations are controlled. As opposed to many block-making machines available which ejects blocks instead of the mould, this machine will be able to eject the mould leaving the blocks on the base plate.

The weight of the mould being less (three times less than the total weight of the blocks) will only require a force of approximately 180N on the lever handle to be able eject the mould at a clearance allowing the operator to pick the blocks and take them to the curing zones. The weight lifted is relevant to the one recommended by OSHA which recommends safe weight to range between 16Kg to 55Kg.

The challenge of production of blocks with different configuration in terms of block dimension is solved by having a mould that can easily be withdrawn and replaced by another mould to help in production of other types of concrete-blocks (such as hollow-blocks).

Chances of the compactor falling back on the operator are eliminated by having a dead weight at the back of the machine to make it stay in position. The compactor is only brought back to compacting position by the operator. All the edges of the metals are also blunted to prevent cuts on the operator.

3.7. Selection of materials

When selecting materials, the requirements that are associated with the components performance while in operation were defined and initially considered. For example, the machines operation speed will heavily rely on the operators' capability to perform the activities in a cycle; the processes include loading the mould, compaction of the concrete to remove the air voids and finally the mould ejection. The machine will work at approximately 5 minutes per cycle. This requires the swiftness of the moving components be very high with minimal friction or interference on the moving parts. The overall weight of the concrete in comparison to the base of the machine is high (around 48kg in wet state) thus it requires the frame structure be able to hold the weight for long periods without wear. To consider the above strength-requirements and the cost, the metal group of materials was selected. Furthermore, the comparative analysis of materials within the group was done. The material availability within the local market without compromising on the productive life of the machine is observed.

The main material chosen for the manual-block-making-machine is mild steel, it is used in the frame structure and the L section beams; it has the following properties: Density of 7.85 gm/cm^3 Young's modulus of 210 MPa; Carbon atoms affixed in the interstitial sites of the iron lattice and make it stronger; A high amount of carbon makes mild steel different from other types of steel, the carbon makes mild steel stronger and stiffer however the strength comes at a price of decrease in ductility of the alloy.

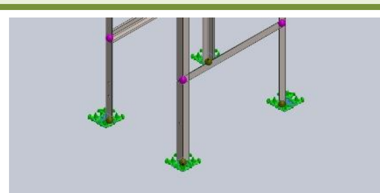
The machine's parts are designed with mild steel, enabling the machine comfortably operate in both indoors or in outdoor environment. To make the machine appealing, the metallic parts can be painted, which also eliminates contact of water with steel.

3.8. Simulation of the frame and the flat-lever-bar, and optimization of design

A static simulation study was done on the frame model with Deformation scale of 1099.25. It was fixed at the bottom mounting and an overall normal force of 981N or 100 Kg applied at the base plate. The following assumptions were made during the study, that: The frame was made of uniform structural members; The joining was uniform all along the model; Material Alloy Steel; Yield strength: 6.20422e+008 N/m^2; Tensile strength: 7.23826e+008 N/m^2; Elastic modulus: 2.1e+011 N/m^2; Poisson's ratio: 0.28; Mass density: 7700 kg/m^3; and Shear modulus: 7.9e+010 N/m^2. Other components such as the flat-linking-bars are also vulnerable to failure; therefore simulation of the flat-lever-bar with 10N/mm load applied on the pin joints as shown below was also done. Table 2 shows Loads and Fixtures**,** while Figure 6 shows the results of the static simulation studies.

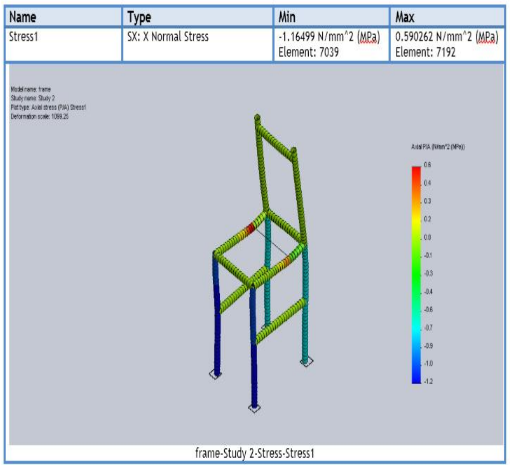
The stress concentration on loading was distributed on the frame with the minimum: -1.16499 Mpa; element: 7,039; and maximum node with a stress concentration of 0.590262Mpa; element: 7,192, which was below the assigned safety level, thus the structure has sufficient strength to handle the loads. The minimum strain attained is 0, element: 6,877; and the maximum -2,31531e-005, element: 1,676. The maximum displacement on the model was 0.1387mm on the compactor connection end which was below the safety factor. The maximum displacement achieved when the flat lever component was subjected to the loads specified was 0.0000008642mm, which was barely noticeable and hence the part was decided to be acceptable to work in those conditions as specified.

Table 2: Loads and Fixtures

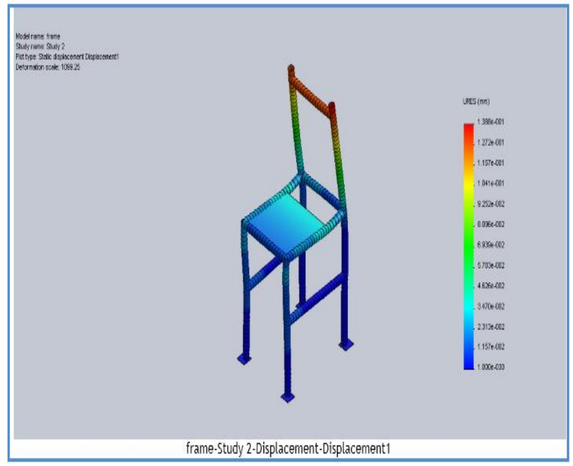
Fixture name	Fixture Image	Fixture Details
Fixed-1		Entities: **4 face(s)** Type: **Fixed Geometry**

Resultant Forces

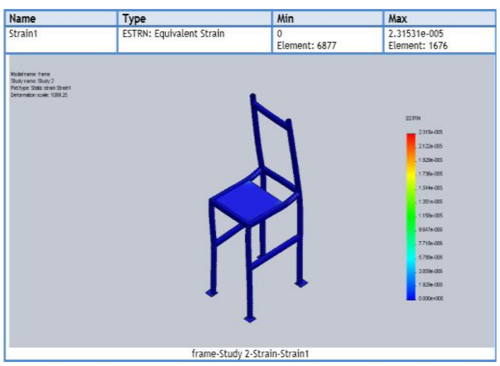
Components	X	Y	Z	Resultant
Reaction force(N)	**-0.0218975**	**1224**	**-0.0610672**	**1224**
Reaction Moment(N·m)	**-0.162701**	**-0.15149**	**0.342737**	**0.408523**



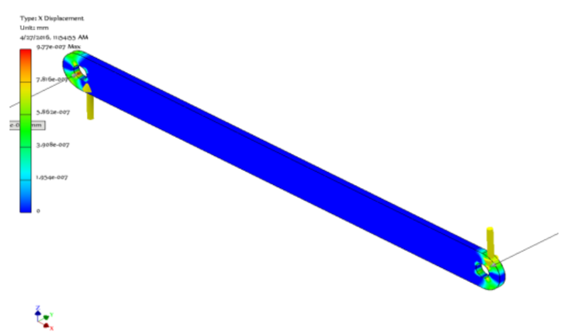
Stress analysis



Displacement analysis



Strain study of frame



Displacement study of the ejection system

Figure 6: Simulation Analysis

Based on calculations and simulation analysis, the design was optimized as shown in Figure 7.The overall dimension of the block-making machine has general measurements of 600mm length, 450mm width and 1581.8 mm height. The Video (*avi format*) of the simulation of the operation of the concrete-block-making machine is attached.

3.8.1 Cost estimation

The price of the machine was estimated, assuming labor cost at 30% of the total cost of the materials. It was found to be at around 24,000KES (around 240USD), which is more affordable (four times cheaper) than KES 100,000 (1,000 USD) as in the case with the one currently evaluated (during workshop visits) model.

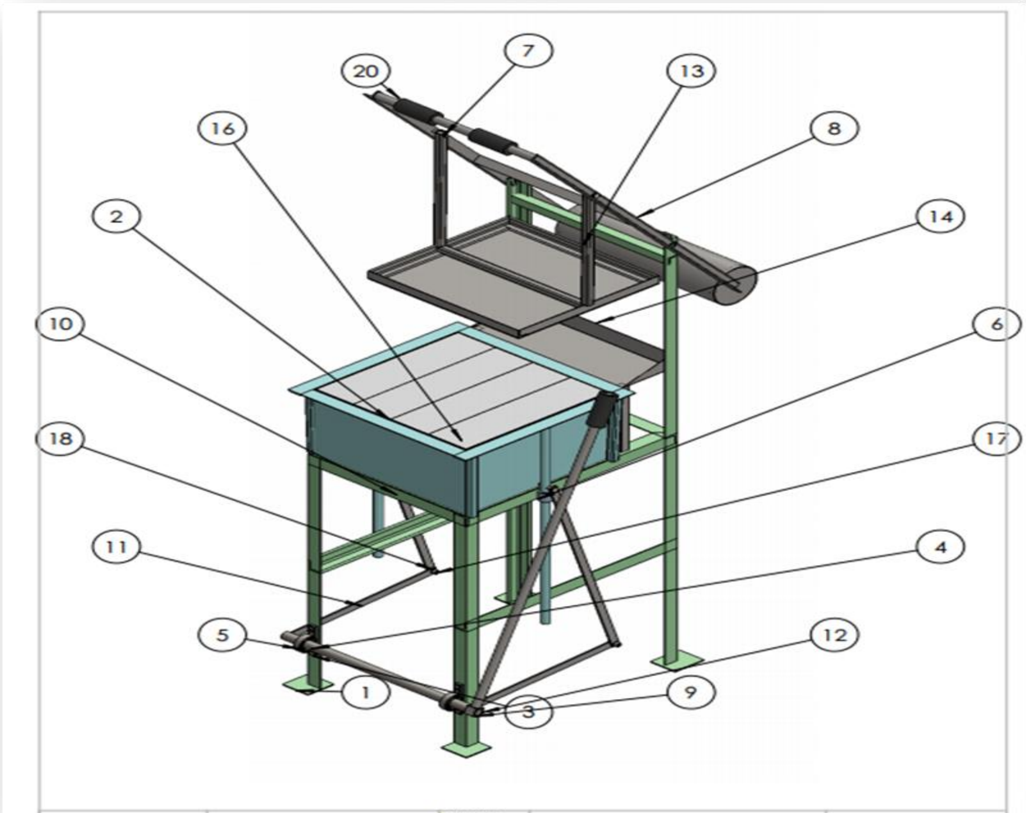


Figure 7: Complete conceptual design of concrete-block-making machine

Keys:

1	The frame	6	Clevis pin ISO 2341
2	Movable mould	7	Holding split rings
3	Bearing casing	8	Top compactor
4	Lower bearing casing	9	Main shaft
5	Bearing BS 6267	10	Link 1
11	Link 2	16	Concrete blocks
12	Handle lever	17	Bolts ISO 4762
13	Compactor frame	18	Washer ISO 8738
14	Compactor plate	19	Hexagon nuts ISO 4043
15	Wooden palate	20	Soft handle rubber

4. Conclusion and Recommendation

The conceptual design of stationary manual concrete-block-making-machine was optimized and completed based on calculations, simulation analysis, and ergonomics considerations (to reduce the load handled by the machine-operator). As opposed to many block-making-machines available which ejects blocks instead of the mould, this machine ejects the mould leaving the blocks on the base plate. The block-making-machine has general measurements of 600mm length, 450mm width and 1582 mm height, and produces four blocks per press/cycle.

From the cost analysis of the block-making-machine, it is four times less expensive than the cheapest currently commercially-available block-making-machine. The price, however, is only one of the ingredients for success. It can be fabricated locally and from the accessible materials. Overall, the results of this concise study are optimistic, providing a good starting point for further exploration on the same.

As stated earlier, the scope of the project was limited to conceptual design. However, prototyping and testing stages, if carried out, can give a real picture of the machine functionality. The authors propose further work on prototyping and testing to be carried out, leading to detail design and embodiment design.

If successful, the outcome of the final product (properly-functioning, affordable, durable, easy to operate machine) can benefit local-communities, particularly in rural-areas in the absence of electricity; it can potentially create business-opportunities and jobs even for un-skilled and un-educated people (as only minimal training is required for the machine-operator). It can also contribute to improved well-being as people will be able to self-construct and upgrade their local houses to much stronger and long-lasting concrete-structures. Due to escalating demand for affordable housing in Kenya, this simple and economical piece of equipment would be the potential answer.

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