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Design, Fabricate, and Quality Optimization of a Fully Automated Interlocking Brick Manufacturing System

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Abstract: Interlocking bricks are mostly used in existing construction areas. They minimize the amount of mortar required and save time. Brick industries are among the largest industries in the world. Most existing brick-making machines are manual or semi-automated. These machines are very slow and cannot accurately control brick quality. Also, these kinds of machines need more than three workers to operate. There is a need for a low-cost, fully automated interlocking brick-making machine that can produce high-quality bricks at a lower cost. The main goal of this research is to design and develop a fully automated interlocking brick-making system capable of producing high-quality bricks at high production speed. This machine can perform multitasking. Existing machines can do one job at a time. But this machine can perform multiple tasks simultaneously, including mixing, filling, pressing, and brick removal. Load cells measure compressive force, and encoders mix material ratios. This machine uses a microcontroller to control and operate the full machine. The quality of bricks produced by the developed machine is compared with current market standards for compressive strength and brick dimensions. This developed machine can produce bricks of equal or higher quality than those on the market. It helps to reduce human effort. This research project provided a practical, low-cost solution for small- and medium-scale industries. It helps produce high-quality interlocking bricks with uniform performance and high production speed.

Index Terms: Automation, Brick quality, Interlocking bricks, Load cells, Microcontroller control, Multitask machine.

1 INTRODUCTION

These days, the construction industry faces a big challenge. It needs to develop new, sustainable ways to produce building products [1]. However, it still provides enormous demand for low-cost homes and infrastructure [2]. The interlocking brick industry is among the largest in the world. Interlocking bricks are commonly used for modern construction. Because they minimize the need for mortars and increase the production speed [3]. These types of bricks are built to fit together easily. Because of these advantages, these bricks can be used to install walkways, footpaths, driveways, and playgrounds. Sri Lanka is a developing country [4]. The brick industry provides construction materials for the growing urban and rural development in countries like Sri Lanka.

Although interlocking bricks have some benefits, some available bricks have shown quality issues. Some bricks have low compressive strength and poor dimensional accuracy. These problems arise due to certain drawbacks in the manufacturing process. Because of these problems, it is hard to control the brickmaking process. The quality of the bricks depends on some parameters [3]. They are the material mixing ratio, compressive pressure, moisture level, and drying method [3]. If we cannot control these parameters correctly, these bricks can get weak. So, we can’t get weak bricks for construction processors.

There are some existing interlocking brick manufacturing machines. Most machines are manual or semi-automated [2]. These machines are used in small-scale and medium-scale industries [5]. It needs the most experienced workers to operate these machines [1]. And it needs more than 3 workers to operate these machines [1]. And it needs more than 3 workers to operate [1]. Production speed and production capacity are very low in these manual or semi-automated machines [5]. Low-capacity machines can produce only a few bricks, reducing production efficiency. These machines cannot easily change operating parameters, such as material mixing ratios [5].

Fully automated machines are very large. The production capacity of these machines is very high [2]. These machines are also available on the market. These machines can produce a large number of high-quality bricks [5]. But these machines are very expensive and require high investment costs [6]. To operate these machines, they need robust support systems, such as a JCB (Front Loader), for the material filing process. These machines are hard to use for small-scale and medium-scale industries. There is a need to develop a low-cost, automated brick manufacturing system to improve productivity and quality.

We can improve the brick manufacturing industry by leveraging new automation and control engineering technologies. To measure parameters precisely, we can use sensors, encoders, load cells, and microcontrollers [7]. Sensors and microcontrollers can be used to measure and control compressive pressure and material mixing ratios [8]. Automated machines can track production in real time and adjust settings to maintain brick quality [7]. This technology reduces human errors. Also, it can increase the production speed and brick quality.

My research aims to design, fabricate, and quality-optimize a fully automated interlocking brick manufacturing machine. Existing machines can do only one task at a time. But my machine can do more than one task at the same time [5]. That's why this machine is called a multitasking machine. Because my machine can mix materials, fill molds with materials, press the mixture into molds, and remove bricks from molds simultaneously. This multitasking process can increase production speed and production capacity. My main goal is to produce high-quality interlocking bricks that are superior to market-standard bricks using my machine. Also, these automated systems help reduce the need for skilled workers and manpower. This machine has a low-cost and compact design. So, these machines are easy to use in small-scale and medium-scale communities.

This research helps increase production speed and efficiency and reduce construction waste. This improves green building processes. It also helps to find cheap construction materials for infrastructure development and economic growth in local communities. So, this research provides clear solutions to problems in the brick manufacturing industry.

2 LITERATURE REVIEW

2.1 Evaluation of Brick Manufacturing

Interlocking brick making technology has improved from manual systems to fully automated systems over time [2]. In traditional brick making, bricks are made by hand [9]. They mix the soil and pour it into the molds. Finally, they press it using simple tools [6]. These manual systems are very cheap. And these have low strength, low dimensional accuracy, and low production speed [3]. To address this problem, they introduced semi-automated brick-making machines [2]. These systems use mechanical or hydraulic Pistons to make bricks [1]. This improves brick quality and reduces manpower requirements [1]. But semi-automated machines require workers to load materials and monitor their operation. It can cause brick quality issues.

Most fully automated machines are used in large-scale industries [2]. These machines use sensors and microcontrollers to increase production speed, production accuracy, brick quality and dimensional accuracy [2]. So, these machines are very expensive [2]. Small-scale or medium-scale industries cannot use these kinds of machines [2]. There is a strong need to develop a low-cost, medium-scale, fully automated brick-making machine [2].

2.2 Find optimal material ratio to make interlocking bricks

2.2.1 Materials used for Interlocking Bricks

Compressed Earth Blocks (CEBs) are ecofriendly construction material that can be produced with soil and stabilizers. After mixing these materials, they are compressed in molds. These bricks use low energy, simple technology and local materials. So, these bricks are very important. Brick quality depends on material ratio, moisture content, and compaction pressure [10].

This research paper shows that compressed earth blocks are normally made using soil, stabilizers, fibers, and water. Cement and lime are used as stabilizers [10]. They help increase mechanical strength [10]. One study used polypropylene (PP) fibers to increase the strength of the compresses earth blocks [10]. Another study used recycled waste glass particles (RWGP) and lime to stable the blocks [11]. The fiber-reinforced matrices were produced with fiber mass fractions of 0.2, 0.4, 0.6, 0.8, and 1.0 [10]. In a fiber-reinforced study, use 8% ordinary Portland cement (OPC) as the stabilizer and a fiber content of 0.2% to 1.0% to make bricks [10]. Adding polypropylene fibers increases the flexural strength and toughness of the bricks.

One study tested recycled waste glass particles mixed with 10% lime [10]. This result shows that these particles increase the compressive and tensile strengths of the bricks.

Table 1. Physical properties of soil

Property	Composition
Liquid Limit (%)	33%
Plastic Limit (%)	(non-plastic)
Plasticity Index (%)	-
Sand (%)	87.3%
Clay (%)	12.2%
Silt (%)	1.5%
Optimum Moisture Content	9%
Maximum Dry Density	1784.5 kg/m3

Table 1 shows some of the physical properties of the soil used to make compressed earth blocks [10]. This includes sand, silt, clay content, optimum moisture content and maximum dry density.

2.2.2 Optimal Material Ratio for Interlocking Bricks

The mechanical performance of the compressed earth blocks depends on the material ratio. This study shows that combining these stabilizers and reinforcing materials increases the blocks' strength and durability.

One study used recycled waste glass particles (RWGP) with 10% lime, varying the RWGP content from 0% to 25% for testing [11]. The highest compressive strength of 5.77 MPa was achieved at 10% RWGP and lime CEBs, while the unstabilized specimens achieved 3.03 MPa at 28 days of curing. That represents about a 90% improvement [11].

This study also shows that the 5% RWGP and lime CEBs achieved the lowest water absorption of 3.06%, compared with the unstabilized specimens at 8.60%, representing about 181% reduction in water absorption [11]. This was a reason for the increase in brick durability.

Therefore, this research recommends using 10% RWGP and 10% lime to make compressed earth blocks with high mechanical properties [11].

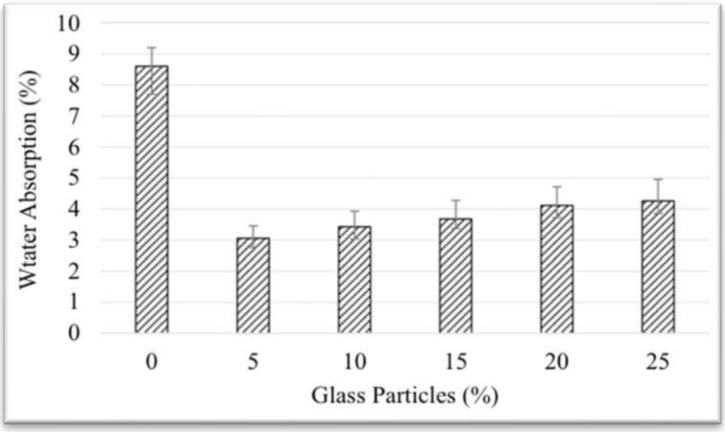

Fig. 1. Water absorption of CEBs stabilized with RWGP and lime.

Fig. 1 shows a line graph of compressive strength as a function of increasing RWGP percentage. Using 10% lime and 10% RWGP results in higher strength [11].

2.2.3 Mechanical Tastings for Interlocking Bricks

After making the bricks, they conducted several tests. We also plan to perform these tests on our bricks before producing the final product.

2.2.3.1 Compressive strength Test

Compressive strength test means one of the tests used to measure the maximum load that bricks can withstand before failure [11]. Compressive strength can be measure using equation (1).

$$\sigma c = \frac{P}{A} \tag{1}$$

- σc = Compressive strength
- P = Maximum applied load
- A = Cross sectional area of the brick

This study shows that stabilized bricks are stronger than unstabilized bricks.

2.2.3.2 Tensile Strength Test

Tensile strength means how much crack resistance there is [11]. One study shows that using 10% RWGP and lime yields a tensile strength of 0.52 MPa. Higher-compressive-strength bricks have higher tensile strength [11].

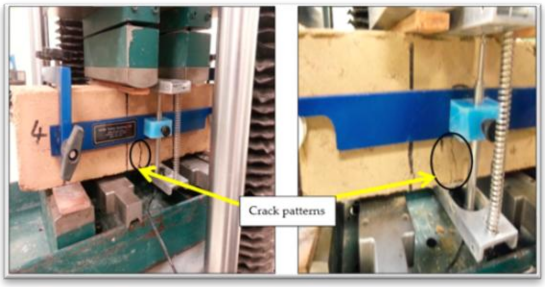

Fig. 2. Cracking Examples

Fig. 2. Cracking Examples. Figure 2 shows some examples of crack patterns made during tensile strength tests. This figure helps explain how bricks resist cracks and how cracks affect material strength.

2.2.3.3 Water Absorption Test

Water absorption test measures how much water content is absorbed by the compressed earth blocks. This study calculated water absorption quantity using equation (2) in here [11].

$$\text{Water Absoption } = \frac{Wwet - Wdry}{Wdry} \times 100 \qquad (2)$$

- Wwet =Wet weight
- Wdry = dry weight

The results show that stabilized blocks absorb much less water than unstabilized blocks.

2.2.4 Fiber Reinforcement and Flexural Strength

Adding polypropylene fibers to compressed earth blocks increases the flexural performance of CEBs. This study tested fiber contents from 0.2% to 1.0% [11]. Results show that when the fiber content exceeded 0.6%, the blocks exhibited deflection-hardening behavior [11]. This increases the block durability and energy absorption capacity. CEBs are more suitable for structures that are subject to wind loads or earthquake (seismic) forces. Because of flexural behaviors.

I found one research study that shows how fiber content affects the load–deflection behavior of compressed earth blocks. When the fiber content increases from 0.2% to 1.0%, the flexural performance of the blocks increases [11]. When the fiber content is reduced, the blocks break easily [11]. Higher fiber content helps carry greater loads and resist cracking [11]. At about 0.6% or more, it still shows deflection hardening behavior. So it can carry loads after cracking.

Fig. 3. Flexural Performance of Interlocking Blocks

Fig. 3. Flexural Performance of Interlocking Blocks. Figure 3 shows the load-deflection behavior of blocks with fiber contents ranging from 0.2% to 1.0%. Deflection hardening begins at a fiber content of 0.6% [11].

2.3 Compressive Pressure for Interlocking Brick Manufacturing Process

2.3.1 Introduction to Compressed Earth Block

When making interlocking bricks, compressive pressure is very important. It affects the strength and density of the bricks. Recent researchers found that most modern compressed earth block (CEB) machines can produce pressures of 8 MPa to 20 MPa. CEB means mechanically manufactured blocks made from a moist soil mixture inside a mold. After giving pressure, the block is removed from the mold and cured [11]. Most researchers found that pressures of 8 MPa to 10 MPa, with 8% to 12% cement content, produced good-quality interlocking bricks [11]. This pressure reduces the space between the soil grains and increases the durability of the bricks [11]. One study shows that when pressure increases from 4 MPa to 10 MPa, the compressive strength of the blocks doubles [11]. So, the recommendation is to use 10 MPa hydraulic pistons to produce high-strength interlocking blocks [11]. The strength of the CEBs depends on these factors. They are [14],

- Clay content is included in the soil.
- Used stabilizers type
- Applied compressive pressure
- Water content and curing type

CEBS normal dry density is between 1700 and 2300 kg/m³ [14]. CEBs can produce interlocking bricks. This helps to make the walls strong and correct without using mortar during construction.

2.3.2 Compressive Pressure in Manufacturing.

They did an experiment under these conditions. sample diameter is 100 mm, final specimen height is 200 mm, consolidation time is 3 hours, curing period is 28 days, and hydraulic press capacity is 5000 kN [13]. These parameters are very important when designing to make bricks. If we can give the correct pressure, the bricks cannot get the correct quality and strength.

This Study checked three Production pressure levels. They are [13],

- 20 MPa (conventional pressure)
- 200 MPa (high pressure)
- 400 MPa (ultra-high pressure)

These results show the production pressure strongly affects these details [13].

a) Density
b) Microstructure Unconfined
c) Compressive Strength (UCS)

If we increase the pressure from 20 MPa to 200 MPa, the strength increases highly [13]. But if the pressure exceeds 400 MPa, the strength decreases because the soil particles are damaged [13]. The optimal production pressure is 200 MPa [13].

a) Density

The density of the blocks will increase with the comparison pressure [13]. Compressive production pressure significantly affects the density of compressed earth blocks [13].

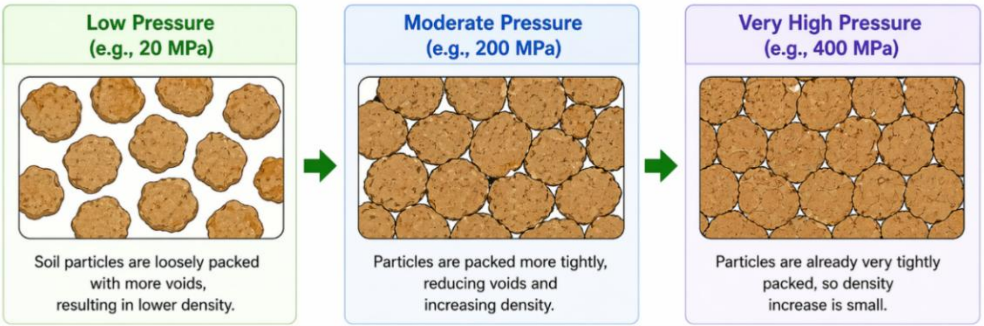

Fig. 4. Why Does Pressure Increase with Pressure

Fig. 4. Why Does Pressure Increase with Pressure? Figure 4 shows how different pressure levels affect the packing of soil particles during compaction. When pressure increases, the particles become more tightly packed. It also reduces voids and increases the material's density.

I found a research paper that represents the relationship between density and production pressure. If we increase the pressure from 20 MPa to 200 MPa, the density increases [13]. If we also increase the pressure from 200 MPa to 400 MPa, the density increases slowly [13]. So, this shows that we can’t use a pressure greater than 200 MPa to achieve high progress [13]. 200 MPa is the optimal pressure for obtaining density [13].

b) Microstructure Unconfined

This study shows that there are some reasons for the brick strength. First, these strengths increase and then decrease at high pressure [13].

- Densification - The more pressure, the fewer voids, and the more the particles are in contact. This makes them stronger [13].
- Binder Effect - Bio-binders, such as animal glue and xanthan gum, form a gel-like effect. The bio-binders produce platy microstructures and bond the particles more strongly [13].
- Particle Damage at 400 MPa - When subjected to ultra-high pressure, big particles of soil and rocks are damaged, the way that the particles are arranged to bear the load is disturbed [13].

c) Compressive Strength (UCS)

When we increase the pressure from 20MPa to 200MPa, the Strength will increase significantly [A]. However, if the pressure exceeds 400 MPa, the strength decreases [13].

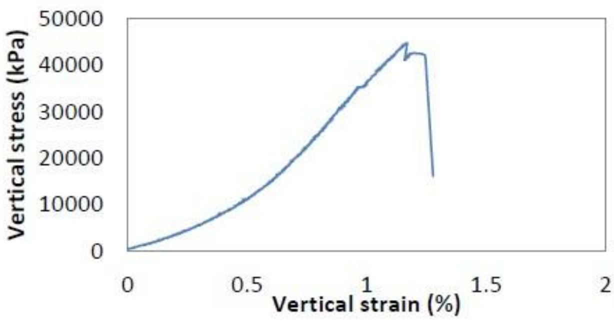

Fig. 5. Stress-strain curve of the Unconfined Compression Test for a specimen.

Fig. 5, a line graph, represents the relation between strength and production pressure. The strength is reduced by 19% in stabilizer blocks [13]. The strength is reduced by 17% with xanthan gum [13]. The maximum strength of 11.85 MPa was reported at 200 MPa pressure using animal glue [13]. This strength is equal to that of fired clay bricks [13].

2.4 Soil-Cement Moisture Content on Brick Quality

Soil-cement moisture content is very important for brick manufacturing. Past research shows that soil-cement bricks should be produced with water. Soil-cement moisture content maintains workability, density and durably of interlocking bricks [12]. That is close to the Optimum Moisture Content (OMC) of the soil, which is determined by the Proctor test. OMC is normally between 10% and 20% [11]. It depends on the soil type which they use [11]. For sandy soils, the OMC is about 9% [12]; for clay soils, about 14.5% [13]; and for some mixed soils, about 19% [11]. One study in Ethiopia reports that bricks with a 24% moisture content, above the OMC, were produced to improve workability [11]. But this reduces the strength of the bricks. Using too much water also reduces brick strength. One study found that compressive strength decreases by 0.03 MPa for every 1% increase in moisture content [14]. So, when we mix materials near or above the OMC value, we can get the maximum possible density and strength. We also need to maintain the water-cement ratio when using cement.

There is a simple empirical relationship between compressive strength σc (MPa) and moisture content m (%) in equation (3) [12].

$$\sigma_c = -0.031m + 5.171 \tag{3}$$

This equation is valid only for the mixtures they tested (a 1:6 cement-to-soil volume ratio and their soils) [12]. Fig. 6 represents the relationship between the moisture content and strength.

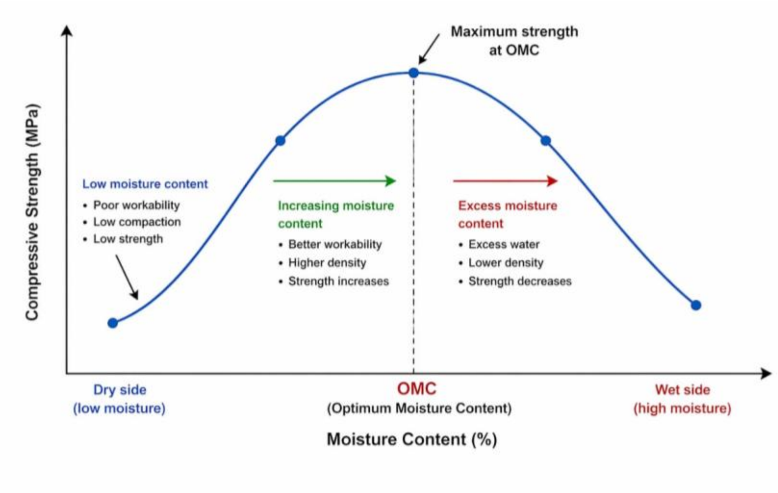

Fig. 6. Relationship between the moisture content and strength

2.4.1 How to Moisture React with other Parameters

a) **Compaction pressure / density**

High compression pressure helps reduce air voids, and cement particles help bind the soil particles tightly. If the water content equals the Optimum Moisture Content (OMC), maximum density and better compressive strength can be achieved [16]. This test shows the best compressive pressure is 8-10MPa [16]. Strength increases significantly to 8 MPa [16]. But beyond 10 MPa, the improvement is very small [16].

b) Cement content

If we use more cement for bricks, it can increase strength and reduce water absorption. Some soils require 6% or more cement to meet the main structural requirements [16]. If we press the bricks, we can reduce the cement content while making the bricks stronger.

c) Soil type & particle size (OMC and MDD)

Different types of soil need different optimum moisture content (OMC). For example, lateritic soil's MDD is 1.87 Mg/m^3, and OMC is 14.5% [12]. Manufacturers need to measure local OMC using common values.

d) Nondestructive monitoring - UPV

Ultrasonic Pulse Velocity (UPV) is a very important measurement for water content and quality of the bricks [12]. UPV helps to find the cement percentage. uniformity coefficient predicted the moisture content well. UPV can be used as a quality control tool in factories.

2.4.2 Water absorption and Durability

They used this formula to find water absorption test results [16].

- Mc = Moisture absorption (%)
- Mw = Wet sample mass (g)
- Md = Dry sample mass (g)

The water absorption range for compressed stabilized earth blocks (CSEBs) is 15% to 20% [16]. We can reduce the water absorption content by increasing compaction and increasing cement ratio.

2.4.3 High Pressure Changers and Microstructures

$$\text{Mc} = \frac{Mw - Md}{Md} \tag{4}$$

Very high-level comparison pressure and good stabilizers help to reduce air voids and make bond tightly between particles [15]. SEM images show some of the relations between micro-cracks and platy particles under better compaction [15]. This is a reason for higher compressive strength.

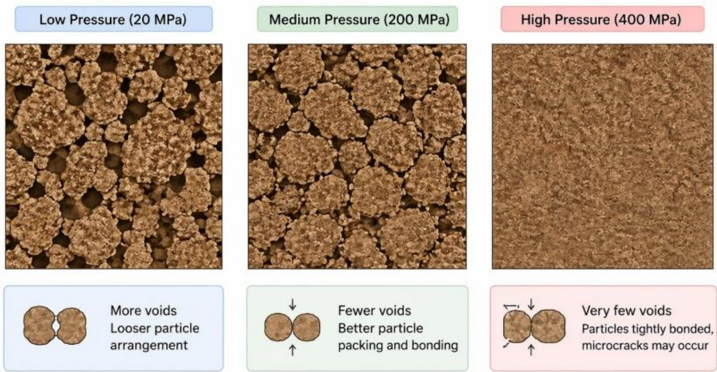

Fig. 7. High Pressure Changers and Microstructures

Fig. 7 shows the effects of low, medium, and high pressure on particle arrangement and void spaces in the material. As pressure increases, particles become more tightly packed, reducing voids and increasing particle bonding. But very high pressure can break particles into small pieces. This reduces the strength. Polypropylene (PP) fibers can change the cracking behavior and increase toughness [15]. These are more helpful for bricks, including fibers.

2.5 Relationship Between Compaction Ratio (High Ratio)

The compaction ratio is most important when making bricks and compressed earth blocks (CEBs). Compaction Ratio means that in the production of interlocking bricks, the mold must be filled to a height greater than the final block height before pressing. It can be called a high ratio [1 8]. In a fully automated system, the compaction ratio varies with strength, density, and durability. High compaction helps reduce air voids and improve particle bonding. It also increases the dry density and compressive strength [15]. The Auram 3000 Earth Block Press achieves a high compression ratio of 1.83 using 15 tons of force. This helps produce strong, sustainable building bricks [15].

2.5.1 Calculation for Compaction Ratio

According to the Potential Utilization of Oil Shale as a Stabilizing Material for Compressed Earth Block, the compaction ratio can be calculated using equation (4) [18],

$$\text{Compaction } Ratio = \frac{H}{T} \tag{4}$$

- H = Highest of loosely packed mix
- T = Block Thickness

Example from study.

- H = 13.7 cm
- T = 8 cm

$$\text{Compaction } Ratio = \frac{13.7}{8} = 1.70$$

Researchers found that the Compaction Ratio should be equal to or greater than 1.70 [18]. This means we need to fill the mold before pressing, 1.7 times the mold’s final height [18]. For example, if the final block height is 60 mm, the mold should be filled to about 102mm. For a 50mm block, the fill height should be 85mm. In one of the study machines, for an 8cm block, they used a brick with a 13.7cm fill height [18]. Some machines use a higher ratio than 1.7 to increase their strength. A higher Compaction Ratio helps press the mixture tightly, resulting in denser, stronger bricks. For better-quality bricks, the Compaction Ratio needs to be between 1.7 and 2.0 [19]

2.5.2 Effects Between High Compaction Ratio and Density

High compaction helps to reduce the air voids, increase the relationships between the particles, provide a soft and smooth surface and improve interlocking requirements [15].

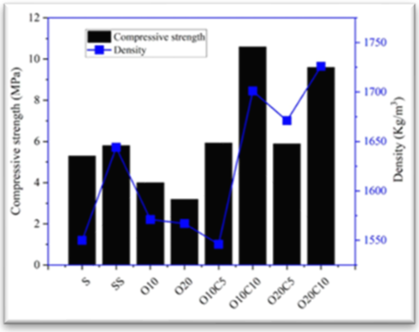

Fig. 8. Effects Between High
Compaction Ratio and Density

Fig. 8 shows that as dry density increases, compressive strength also increases [15]. This is because soil particles form strong internal bonds when they are packed closely together.

2.5.3 Effects of Compaction Ratio on Compressive Strength.

In compressed earth block (CEB) tests, several specimen types are used to assess brick quality and strength. They are s, ss, O10, O20, O10C5, O10C10, O20C5, O20C10 [15]. The best mix according to the flexural strength test was O10C 10 [15]. This mix includes 10% oil shale, 10% cement, and 30% sand [15]. For this mix compaction ratio was 1.70, and the compressive strength was 10.6 MPa [15].

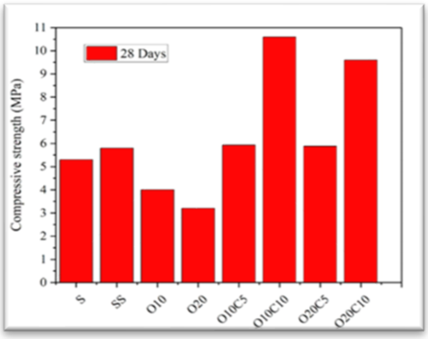

Fig. 9. Compressive Strength results of
Compressed Earth Blocks (CEB)

Fig. 9, a line graph, presents the Compressive Strength results for Compressed Earth Blocks (CEB). Proper mixing of materials and better compaction help increase strength [15]. This makes buildings more stable and stronger.

In equation (5), this study shows that the minimum required compressive pressure is [15],

$$f_c = >1.3 \text{ MPa} \tag{5}$$

But this study achieved high compaction with a strength of 10.6 MPa. This value is higher than that reported in previous studies [15].

2.5.4 Effects Between Shrinkage and Cracking

This result represents these problems. If soil lacks compaction and stabilization, large cracks can form. Adding more sand reduces the number of cracks. If we add oil shale and cement, it stops visible shrinkage cracks [15]. High compaction reduces the volume shrinkage [15]. Volume Shrinkage percentage shows in equation (6).

$$\text{Volume Shrinkage (\%)} = \frac{Vo - Vf}{Vo} \times 100 \qquad (6)$$

- Vo = Initial Volume
- Vf = Final Volume

When compaction is high, drying shrinkage is low. This is because the initial voids are very small.

2.5.5 Effects Between Water Absorption and Durability

This study used calculation (7) to calculate water absorption [15].

$$\text{A [\%]} = \frac{Wh - Ws}{Ws} \times 100 \qquad (7)$$

- A [%] = relative difference in percentage in weight that is compared to the dry block weight
- Wh = wet block weight (g)
- Ws = dry block weight (g)

They consider the best mix is high-density bricks. So, the water absorption range is 12.%. Lower water absorption is a reason for higher durability [17]. This research shows that high compaction reduces air voids in bricks, reduces water absorption, and increases resistance to erosion. This makes bricks strong and of high quality.

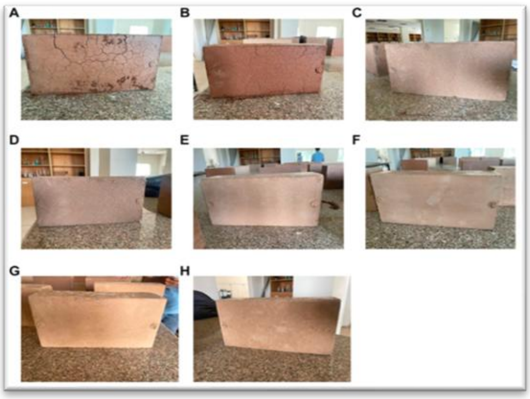

Fig. 10. The difference between brick samples after kiln drying.
(A)S mix, (B)SS mix, ©O10mix, (D)O20mix, (E)O10C5mix,
(F)O10C10mix, (G) O20C5mix. (H)O20C10mix.

Fig. 10 shows the differences in bricks after kiln drying for various soil mixes. This shows the durability and water absorption of compressed earth blocks with different stabilizers and mixtures. Looking at some changes and drying conditions helps to increase water resistance and durability.

2.6 Applications of load cells for real-time pressing force monitoring.

In an automated interlocking brick machine, the pressing force must be controlled because it is very important. This compression force depends on brick density, strength, and durability [8]. During pressing, we need to accurately measure this value to maintain product quality.

Fig. 11. Load Cell
Used in My Machine.

Fig. 11 shows the load cell type I used for my automated interlocking brick-making machine. Load cells are types of sensors mostly used in factories. These sensors measure weight and torque. They can convert mechanical force into electrical signals [8]. Also, it can measure and analyze it. Load cells can be used in industrial machines and manufacturing systems due to their high accuracy and consistency. We can measure the pressing force in real time between the piston and the machine frame in a fully automated interlocking brick pressing machine. The load cell helps measure the real-time compression force applied to the bricks during pressing. Normally, Concrete bricks require a pressure of 7 MPa to 8 MPa [8]. So, we can use load cells to maintain this pressure level correctly.

2.6.1 Types of Load Cells

There are many different types of load cells used in factories to measure forces. These load cells are categorized by design and working principle. Fig. 12 shows some load cell types.

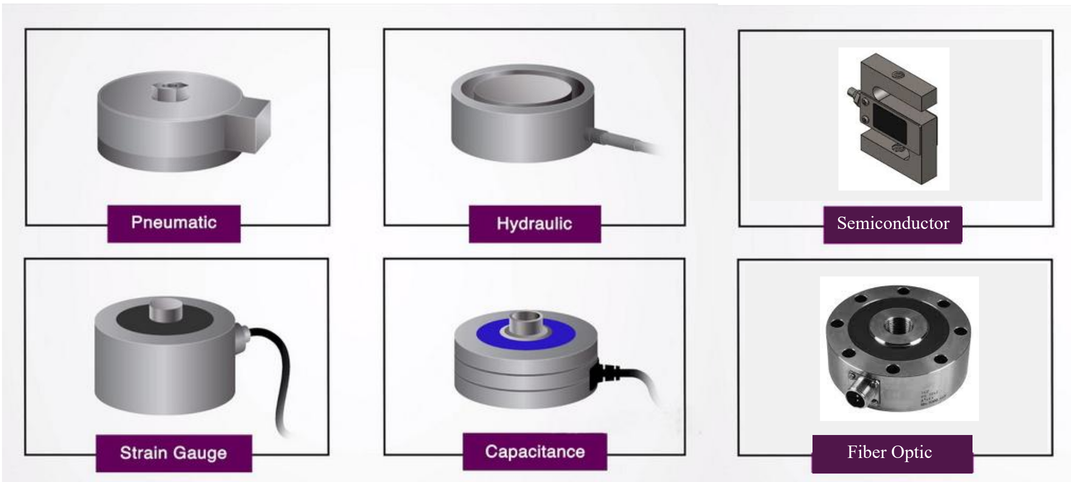

Fig. 12. Types of load cells

Among these types, strain gauge load cells are the most used. This is because they supply long-term consistency and high accuracy. Strain gauge load cells come in various structural designs. They are,

- Shear beam load cells
- Bending beam load cells
- Ring type load cells

- Canister load cells
- Column type compression load cells

Normally, column-type compression load cells (such as ZTF load cells) are used in brick manufacturing systems. These sensors measure high forces given by hydraulic pistons.

2.6.2 Working Principles of Load Cells

Load cells work as a transducer that can convert force to the electrical signal. We apply the external forces to the load cell's surface; the metallic structure is minimally deformed. This deformation causes a small strain inside the strain gauge on the metal surface. Strain gauges measure this deformation as a small change in electrical resistance. This change is very small, but it can be measured using a Wheatstone bridge circuit, which converts it into a voltage signal. The load cell works like a high spring. A small deformation (10^{-3} strain) occurs here due to the applied force [8].

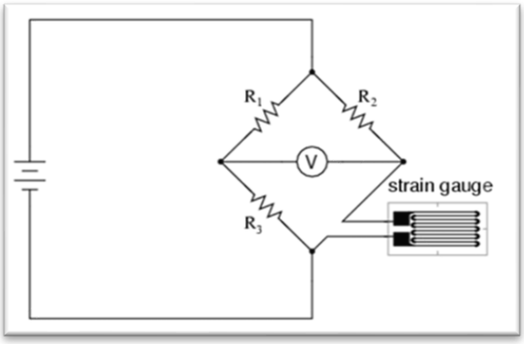

Fig. 13. Quarter-Bridge stain Gauge Circuit

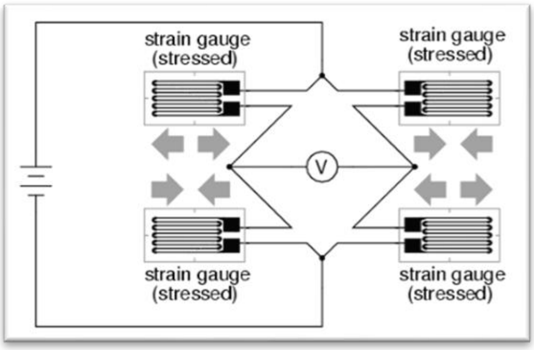

Fig. 14. Full-Bridge stain Gauge Circuit

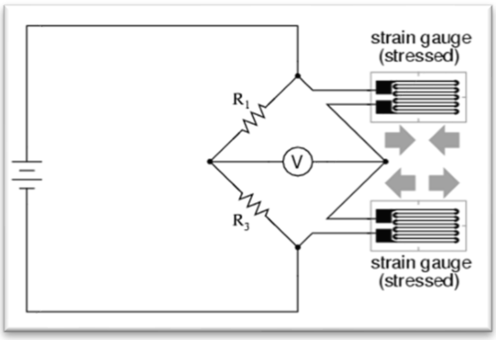

Fig. 15. Half-Bridge stain Gauge Circuit

Fig. 13, 14, and 15 show quarter-, half-, and full-Wheatstone bridge circuits, which can be used in strain gauge load cells. These help measure deformations, such as small changes in electrical resistance.

2.6.3 Strain-Resistance Equation

Strain means the ratio between the change in length and the original length [8]. Longitudinal Strain can be calculated using equation (8).

$$\varepsilon_l = \frac{\Delta x}{x} \tag{8}$$

- ε_l = Longitudinal Strain

- x = Original Length
- Δx = Change in Length

So, transverse strain means (9),

$$\varepsilon_t = \frac{\Delta y}{y} \tag{9}$$

Using Poisson's ratio represents (10),

$$\varepsilon_t = -v\varepsilon_l \tag{10}$$

- ε_l = Longitudinal Strain
- ε_t = Transverse Strain
- v = Posson's ratio

Normally, the electrical resistance of the conductor is dependent on the cross-sectional area and the conductor's length [8]. It can be shown that equation (11),

$$R = \rho\frac{l}{A} \tag{11}$$

- R = Electrical Resistance
- l = Length
- A = Cross Sectional Area
- ρ = Resistivity

When the strain gauge extends, the length increases and the cross-sectional area decreases [8]. As well as the electrical resistance increases. Gauge Factor (GF) is the ratio of the change in resistance to the change in strain. It shows using equation (12) in here.

$$Gauge\ Factor = \frac{\Delta R/R}{\Delta L/L} \tag{12}$$

Because stress increases electrical resistance [8], the material undergoes dimensional change when compressed. Because of this small dimensional variation, the strain gauges exhibit a small resistance variation of 0.1% to 0.3% of the nominal value. Then we can calculate the weight based on that value [8].

2.6.4 Comparison with pressure sensors

Pressure sensors are used to measure the pressure of liquids in hydraulic systems, but they cannot directly measure the mechanical pressure in brick materials. Instead, load cells measure the actual compression force applied by the piston.

There are many advantages of load cells compared to pressure sensors.

- It has high accuracy.
- It can measure compression force directly.
- It is a real-time monitoring system.
- It is suitable for automated control systems.

So, load cells provide more consistent data for brick manufacturing systems.

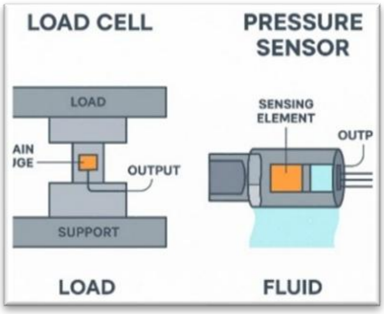

Fig. 16. Difference Between
Load Cells and Pressure Sensors

Fig. 16 shows the working principle of load cells and pressure sensors. These sensors are primarily used in automated systems and industrial applications to accurately measure force and pressure.

2.6.5 Value of Force Measurements during Brick Manufacturing

In interlocking brick manufacturing systems, applying pressing force depends on brick density and brick quality.

- If the compressive force is low, the brick density is low, and the compressive strength is low [8].
- If the compressive force is high, machine parts can get damaged, and energy usage is high [8].

So, we need to keep a better compression force (7-8MPa) to control the brick quality [8]. Load cells help measure and automatically control pressing force. It helps to improve the production process.

2.7 Accurate Material Feeding Using Stepper Motors and Encoders

2.7.1 Accurate Material Feeding

In brick manufacturing systems, material feeding is a very important process. When making interlocking bricks, materials such as soil, cement, and water must be supplied correctly to the mixing and molding processes.

Manual feeding can change the quality of the mixture. This affects the strength and durability of bricks. So, stepper motors and sensors can be used in automated feeding systems to accurately control material flow. In the automation industry, stepper motors are mostly used. Because they can move with fixed steps. Each step gives a small rotation, which helps control the speed and position. When a stepper motor is used with an encoder feedback system, the feeding mechanism becomes more consistent.

2.7.2 Stepper Motors

2.7.2.1 Working Principle and Types of Stepper Motors

A stepper motor works as an electrical motor [22]. It has two main parts [22].

- Stator - moving part
- Rotor - rotating part

Coils are connected into teeth on the stator, while the rotor is made of an iron core with variable reluctance or a permanent magnet [22].

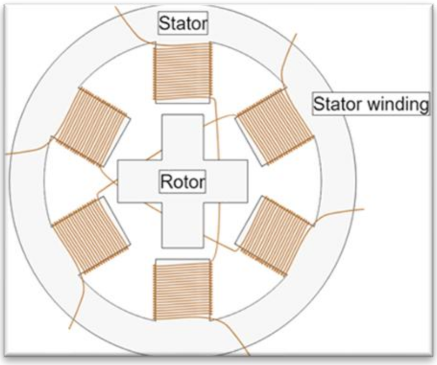

Fig. 17. Stepper Motor Parts

Fig. 17 shows how the stepper motor works. First, current flows through the stator coil, creating a magnetic field [22]. The next rotor aligns with the magnetic field [22]. By sequentially energizing the coils, the rotor rotates in steps to reach the correct position [22].

As an example, coil A is turned on, and the rotor aligns with the magnetic field it generates [22]. The rotor rotates 60 degrees clockwise to align with the new magnetic field when coil B is activated [22]. When coil C is turned on, the same thing happens [22].

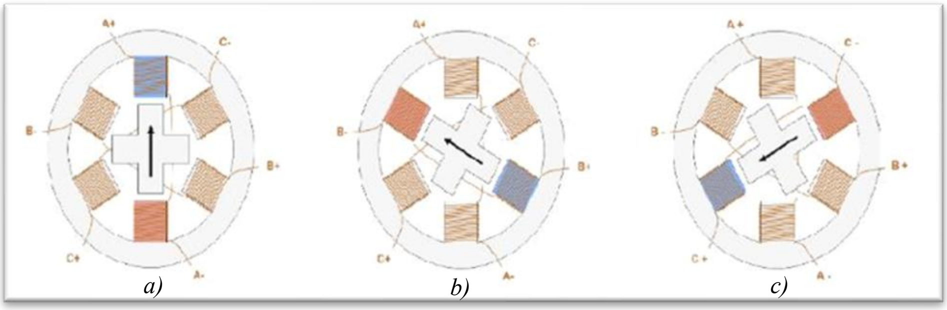

Fig. 18. Types of Stepper Motors a) VR b) PM c) Hybrid

Fig. 18 shows three types of stepper motors. They are,

- Variable Reluctance (VR) - VR motors are high resolution but lack torque holding due to their toothed iron rotors [22].
- Permanent Magnet (PM) - PM motors provide torque but lower resolution because they use permanent magnets for the rotor. By employing a permanent magnet with teeth for high torque and high resolution [22].
- Hybrid - hybrid motors combine the greatest features of both technologies [22].

2.7.2.2 Stepper motors in Accurate Material Feeding

Stepper motors are small electric motors that move in small, fixed steps. So, stepper motors are suitable for many applications that require accurate position and speed control. Stepper motors convert electrical pulses into mechanical motions [22]. Each rotor moves by the step angle with each pulse. For example, a stepper motor has a 1.8 ° step angle. It takes 200 steps to complete one full revolution [22]. There are some stepping modes to improve motor performance.

a) Wave Drive Mode

In this mode, only one phase is exerted at a time. It helps reduce power consumption and torque [22].

b) Full Step Mode

In this mode, two phases are exerted at one time. It helps to produce higher torque. This mode is mostly used in industrial systems [22].

c) Half Step Mode

It combines full-step and wave modes. This mode comes from single-phase and two-phase excitation. It increases resolution and softens the surface [22].

d) Microstepping Mode

Each step is divided into small steps. It helps to increase the motion revolution and reduces vibration. This method is very important to material feeding systems [22].

For the material mixing part, we plan to add screw conveyor belts and a stepper motor. We can get the volume of the material we need to drop using the cross-sectional area and the pitch. It can be find using equation (13) in here [22],

$$V=\pi\times r^{2}\times pitch \tag{13}$$

V= Volume

r = radios of the screw conveyor belt

We use stepper motors to get the correct pitch. Because we can, we can use the rotation angle of the screw to determine the stepper motor step counts. Then we can calculate the pitch.

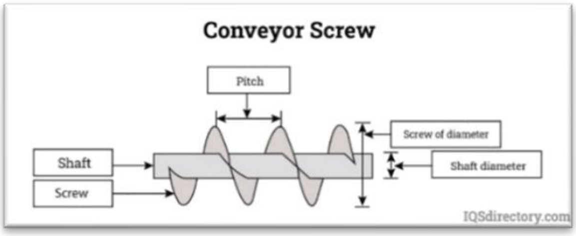

Fig. 19. details of the convey screw

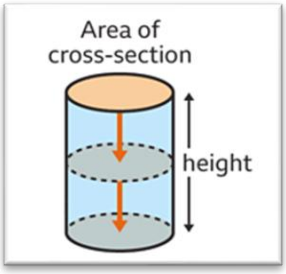

Fig. 20. Coney Screw Cross Sectional Area

Fig. 19 shows the structure and working mechanism of the screw conveyor in the system. This helps to move the materials continuously during production. Fig. 20 shows cross sectional area of the screw conveyor.

2.7.3 Traditional Gravity Feeding Limitations

Normally, like in Sri Lanka, brick manufacturing industries use their own measuring units instead of kilograms (kg) [26]. They use some kind of bucket, barrel or plates. Mass manufacturers use front-end loaders as units. Ideally, it is fine, but in math terms, it is wrong. A bucket cannot fill the exact same amount every time. Sometimes we fill 1 kg, sometimes 900 g [26]. Losing 100 g is not a big problem [26]. In this type of industry, manufacturers typically design their cement mixers to produce many bricks at once. If we aim to produce that many bricks, we need to mix a corresponding number of materials. Imagine if we lose or add more cement per bucket, around 100g, how many grams will we lose or add more than the correct level [26]? This is the real problem. That’s why the existing market brick did not perform well; as researchers, we cannot meet the required performance standards.

2.7.4 Encoders in Close-Loop Control to get Feedback

Encoders are a type of sensor used to measure the position and speed of rotating shafts [22]. When it connects to the stepper motor, it can give feedback about the motor’s current position [22]. In open-loop systems, we assume that the controller rotates according to the motor's command. The motor can miss steps because of high load and mechanical resistance. Therefore, an error can happen. We can correct these system errors by using an encoder. Stepper motors and encoders together create a closed-loop control system. This increases accuracy and consistency in automated machines.

2.7.5 Hopper Design for Material Feeding

Normally, a hopper is included in the feeding system. A hopper stores raw materials before feeding them to the mixing system. The hopper shape depends on the flow of granular materials. The hopper includes two main parts. They are [23],

- Cylindrical section
- Conical bottom section

This study used these equations to calculate the hopper's total volume [23].

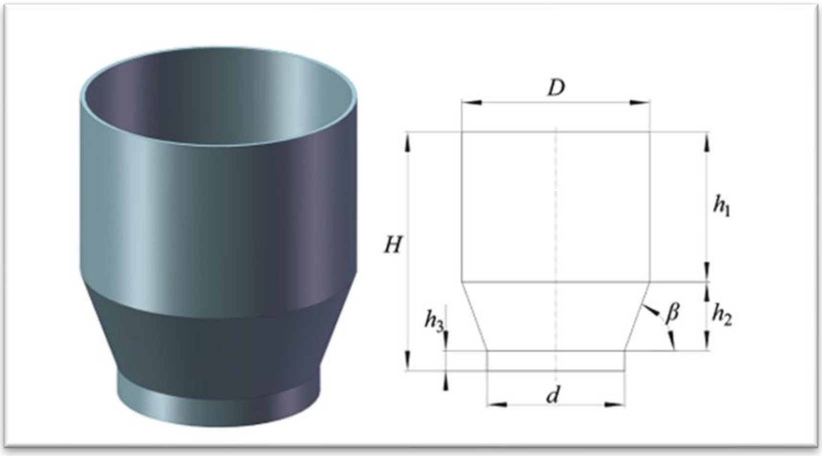

Fig. 21. Hopper design Structure

Fig. 21 shows the hopper's design structure and dimensions. This hopper feeds material into the system. Hopper includes cylindrical and conical sections to smoothly store raw materials and guide the mixing process. Equation (14) shows the total hopper volume, equation (15) shows the volume of the cylindrical body, equation (16) shows the volume of the conical bottom, equation (17) shows the Height of hopper cone and equation (18) shows the height of upper hopper section.

$$V = V1 + V2 \tag{14}$$

Where,

$$\mathrm{V1} = \frac{1}{4}\pi D\hat{}2h1 \tag{15}$$

$$\mathrm{V2} = \frac{1}{12}\pi h2(d\hat{}2 + D\hat{}2 + D.d) \tag{16}$$

$$\mathrm{h2} = \frac{1}{2}(D - d)tan\beta \tag{17}$$

$$\mathrm{h1} = \mathrm{H} - \mathrm{h2} - \mathrm{h3} \tag{18}$$

- V = Total hopper volume

- V1 = volume of the cylindrical body
- V2 = volume of the conical bottom
- H = Overall hopper height
- h1 = height of upper hopper section
- h2 = Height of hopper cone
- h3 = Height of feeding outlet
- D = Diameter if cylindrical hopper section
- d = Diameter of hopper outlet

This equation provides clear ideas about storage capacity. With a better design, materials flow smoothly and stop blockages during feedings.

2.7.6 Particle Flow behavior and DEM Analysis

The performance of the feeding mechanism is analyzed using the Discrete Element method (DEM) [23]. DEM is a simulation method. DEM simulations are used to model the movement and interactions of particles within the hopper and feeding systems [23].

There are four main particle simulation movements.

- Particle Producing and Falling
- Particles settle inside the hopper.
- Particles are stirred by the rotating disk.
- Particle discharge and separation

The basic Hertz–Mindlin (no-slip) model was adopted for DEM simulations in this study and has been widely employed in similar studies of objects such as coal and fertilizer particles [24]. The Hertz–Mindlin (no-slip) model is based on classical elastic contact theory, combining the Hertz normal contact model and the Mindlin tangential contact model [25].

Equation (19) is the force equation used in this study [23],

$$\mathrm{Fn} = \frac{4}{3} * \sqrt{\ } E * \delta n\hat{}(\frac{3}{2}) \qquad (19)$$

Equation (20) is the tangential force equation is [23],

$$\mathrm{Ft} = -8G * \sqrt{\ } R * \delta n\ \delta t \qquad (20)$$

- Fn = Normal contact force
- Ft = Tangential force
- E = Equivalent Young’s modulus
- G = Equivalent shear modulus
- R = Equivalent radius
- δn = Normal overlap
- δt = Tangential overlap

This equation describes the feeding processes and contact forces. This also helps analyze the system's stability.

2.7.7 Feeding Speed and Material Distribution

In this research, we need to focus on motor speed and feeding quality. If the rotation speed of the feeding disk increases, the feeding quality also improves [23]. Therefore, instability will occur due to high speed and low feeding accuracy [23]. Therefore, we need to achieve high productivity and stable feeding performance by optimizing motor speed [23].

Experimental and simulation results show that both the feeding quantity and the motor speed change gradually.

2.8 Automation and Control Systems for Brick Manufacturing

Automation and control systems are very important for brick manufacturing industries. Traditional brick manufacturing needs the most manual labor and time. But automated machines can perform material feeding, compression, and brick removal using sensors and microcontrollers. These automated machines help increase production speed. Also, it helps reduce labor and maintain consistent brick quality.

2.8.1 Fully Automated Brick Manufacturing Systems

Fully automated systems can perform all processes from material mixing to brick production without manual work. The operator only needs to enter the number of bricks needed and the raw materials. Therefore, the system automatically controls the material ratio, production process and brick count [29].

We can use an ESP32- or Raspberry Pi-based microcontroller system to control these kinds of fully automated machines [29]. These controllers can control sensors, motors, hydraulic systems and display interfaces. User interfaces can display this kind of information. They are the material ratio, the number of bricks produced, the machine status and the production rate [29].

2.8.2 Control System Structure

Automation system includes three main parts. They are [29],

- Electrical and Electronic
- Mechanical System
- Software and Monitoring System

2.8.2.1 Electrical and Electronic System

This system includes microcontrollers, sensors, relays, LCD displays and communication modules [29]. Microcontrollers receive signals from sensors and send control signals to actuators, such as motors and solenoid valves [29].

These are some electronic components used in automated brick machines [29].

- Microcontrollers (Arduino / ESP32)
- LCD display for monitoring production
- Keypad for entering production parameters
- Relay modules
- Ultrasonic sensors Wi-Fi modules for IoT communication

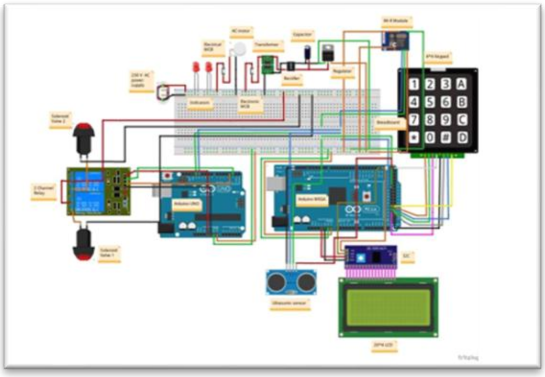

Fig. 22. Example electrical and electronic System of their automated brick machine

One study attempted to build a brick-making machine using some components. Fig. 22 shows the electrical and electronic System of their automated brick machine. They used an Audino controller, sensors, relay modules, keypad, LCD display and a servo motor [29]. They use these components for material feeding, system monitoring and controlling brick production [29].

2.8.2.2 Mechanical System

The mechanical system includes a hopper mold, a hydraulic cylinder, a pump and a conveyor system [29]. First, put the raw materials into the hopper [29]. Net, put into the mold. A hydraulic cylinder presses the material in the mold to make a brick [29].

These are the main components in the mechanical system [29].

- Hopper
- Hydraulic
- Solenoid valves
- Motor and pump

2.8.2.3 Software and Monitoring System

We can connect automation systems to a mobile app using IIoT technology [29]. This can monitor production speed and machine status on a smartphone [29].

Ultrasonic sensor is used to get the brick quantity**.** Sensor data is sent to the cloud using Wi-Fi modules like ESP8266 [29].

One study used formula (21) to calculate the distance from the sensor to an object [29].

$$\text{Distance} = \frac{Speed\ of\ sound\ \times Time}{2} \tag{21}$$

It measures how long it takes a sound wave to reach the object and return, which indicates the distance [29].

2.8.3 Material Ratios

Brick quality depends on using the correct materials and correct material ratios [29]. Different bricks need different material ratios [29].

Table 2. Different types of bricks with their physical characteristics

Type of brick	Composition	Compression Pressure	Weight in Kg	Standard dimension in mm
Clay brick	Clay=60% Silica=30% other=10%	4-5 MPa	2.5-3	190x90x90
Concrete brick	Cement=16.66% Sand=33.33% Gravel=50%	7-8 MPa	5.2-5.8	250x210x140
Fly Ash brick	Fly Ash=60% Slaked lime=30% Gypsum=10%	10-12 MPa	2.5-2.7	230x110x70

We can automatically display these material ratios on the control system display.

2.8.4 Mechanical Properties

After manufacturing bricks, we need to test the bricks to check their durability and strength [29].

- Compressive strength test
- Water absorption test
- Tensile test

2.8.5 Production Efficiency

Normally, Existing automating brick manufacturing machines can produce 3600 bricks per day. It depends on machine design and operating conditions [30].

One research paper represents equation (22) to calculate production rates [30].

$$\text{Production Rate} = \frac{3600\ \times Working\ hours}{Time\ per\ Bricks} \tag{22}$$

Automation increases efficiency and reduces manpower.

2.9 Multitasking Brick Manufacturing Systems.

Traditional brick-making machines usually can perform only one task at a time. Some machines can only perform mixing tasks; others can perform pressing tasks; others can pour the mixture into molds; and others can remove the bricks from the molds separately. This process follows a step-by-step operation. And this reduces production speed and accuracy and requires more labor [2]. According to recent research papers, we can see that multitasking brick manufacturing systems [2]. Multitasking machines can perform several tasks simultaneously [2]. These machines can mix materials, fill, press, and remove bricks simultaneously. Multitasking systems help to reduce idle time and the number of bricks produced per hour. The machines perform more operations simultaneously, with fewer errors, thanks to mechanical optimization, synchronized conveyor systems, and automated controls [2]. Existing market machines can perform multiple tasks, but this machine can multitask, increasing production speed, accuracy, and brick quality [2].

3 RESEARCH GAPS

Existing Research and Brick manufacturing machines have some problems. Most systems did not improve automation, optimization, and other qualities. We can find these gaps in these.

- No fully Automated material mixing method.
- No sensor calibration and measurement uncertainty analysis.
- No real-time data logging or automated quality inspection system.
- No HMI and Automated control system.
- No maintenance and reliability analysis.
- No energy consumption and cycle time optimization.
- No production speed and multitasking system.
- No machine health monitoring system.

These gaps show a strong need for a fully automated brick manufacturing system. If we can reduce these problems, we can increase production speed and quality, reduce human errors and protect the system.

4 DISCUSSION

This review paper shows some factors that affect the quality of the interlocking bricks. Material mixing ratio, compressive pressure, moisture content, and compaction ratio are different factors. If we do not control these factors well, the bricks can have low strength, high water absorption, and low durability. Because we need to control these factors correctly during the brick manufacturing process.

Most research shows that brick strength and density increase with compressive pressure during brick manufacturing. When pressure increases, soil particles are packed closer together. This helps reduce air voids and increase particle bonding. If we apply too much pressure, the soil particles become weak and break. We must focus on the optimum pressure level during manufacturing.

In the soil-cement brick manufacturing industry, moisture content is a key parameter. If the water is near the optimum moisture content (OMC), it can easily compact and produce high-density bricks. But if there is too much water, the compressive strength decreases and shrinkage increases. Compaction ratio also affects the quality of bricks. High compaction reduces internal voids, increases dry density, and strengthens the bricks. These studies show that compaction ratios from 1.7 to 2.0 are best for making interlocking bricks.

Another important factor is material feeding to make interlocking bricks. In traditional brick making, hand-feeding materials can make the mix uneven, leading to inconsistent bricks. Using stepper motors and encoders in automatic feeding makes the mix accurate and consistent. Load cells are important for brick manufacturing processors. Load cells need to measure the pressing force during pressing. Load cells help machines to keep the proper pressure, strength and density to make bricks.

Automation and control systems are a major and essential part of the brick production industry. Sensors, microcontrollers, and automatic control systems can monitor and control steps like mixing, feeding, pressing, and removing bricks. These technologies can reduce manpower requirements, increase production speed and maintain consistent brick quality. With automation, sensors, and accurate control systems, the production of interlocking bricks can be greatly improved. A fully automated system can help in the reduction of labor and increase the speed of the production process. Also, it ensures the production of high-quality interlocking bricks for modern construction.

5 CONCLUSION

This research project is very important. Because it provides lots of solutions for existing brick manufacturing industries. Many existing brick manufacturing machines are manual or semi-automated. These kinds of machines have low production speed. Also, these machines can produce low-quality bricks and incur high labor costs. Small brick manufacturing machines can produce a small number of bricks. So, large brick machines can produce large numbers of bricks. But it gets high cost. This research aims to design, fabricate and optimize the quality of a low-cost, fully automated interlocking brick manufacturing system. The compressive pressure and material mixing ratios are measured and controlled using sensors and a microcontroller. It helps to make this system more accurate and safer. This helps to produce bricks with good strength and dimensional accuracy every time. The main goal of my research is to design, develop, and optimize the brick production process using automation and multitasking. Existing machines can do only one job at a time. But my machine can do several jobs at one time. It means multitasking. This system does not require a skilled workforce and is more efficient in production, automatically controlling pressure and multitasking simultaneously. There are some results we expected from this research. They are making high-compressive-strength, high-quality bricks with improved dimensions, reducing human labor and operator dependency, and increasing the production speed and capacity of existing machines. a machine suitable for small- and medium-scale production. This project is very feasible because we can easily find equipment and places. Some equipment includes hydraulic pistons, load cells, sensors, and microcontrollers. It is a very easy and low-cost technology. This brick machine can be used for large-scale production or for future uses of eco-friendly materials. This research also shows that it helps develop industries in Sri Lanka and promotes sustainable construction.

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