PRELIMINARY STUDY ON LIGHTWEIGHT INTERLOCKING BLOCK DESIGN

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A project report submitted in partial fulfilment of the requirements for the award of Bachelor of Engineering (Honours) Civil Engineering

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DECLARATION

I hereby declare that this project report is based on my original work except for citations and quotations which have been duly acknowledged. I also declare that it has not been previously and concurrently submitted for any other degree or award at UTAR or other institutions.

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APPROVAL FOR SUBMISSION

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ABSTRACT

The interlocking block has been brought into the market as building units due to the setbacks of the conventional building units for construction. On account of the disadvantages confronted with conventional building units, for example, slow construction, dependence on skilled labourers and high logistics expenses. Also, conventional building units such as clay bricks have created a huge environmental problem during the manufacturing processes. Countries such as Bangladesh have been suffering a negative impact on food security as clay brick required and used up a huge amount of the topsoil. After all, the need for alternative units and sustainable materials is needed to be investigated. This study presented an overview of the development of the lightweight interlocking block in terms of the design, material and installation methods. The study aims to design and identify a sustainable material that is suitable to be incorporated for the proposed designed interlocking blocks. Meanwhile, all the interlocking blocks design is modelled utilised Autodesk Fusion 360 software. Besides, the consideration aspects for the interlocking block design included the constructability and elimination of the required trimming processes as compared to conventional building units. Besides, the reliability of the proposed material was conducted using SWOT analysis in this study. 4 types of interlocking blocks are designed, which is the full, half, full coping and half coping interlocking block. The sustainable material proposed to be used for the designed interlocking block is palm kernel shell concrete (PKSC), which is known as lightweight aggregate concrete. The data collection and analysis showed that the mix ratio of 1:1:3 and 1:1:2 comprising cement: sand: PKS is suitable to be adopted for the non-load-bearing and load-bearing wall respectively. Lastly, the installation method for the designed interlocking block comprised a total of 5 stages. Specifically, started with the base preparation, laying the first course, laying consequences courses, laying the final course and plaster or skim coat.

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LIST OF SYMBOLS / ABBREVIATIONS

AAC	Autoclaved aerated concrete
ASTM	American Society for Testing and Materials
CT	Compressive test
FT	Flexural test
GBI	Green Building Index
HCB	Hollow concrete block
HL	Hollow
HLI	Hollow-interlocking
INT	Interlocking
IS	Indian Standard
LAC	Lightweight aggregate concrete
LFC	Lightweight foamed concrete
NGTP	National Green Technology Center
NWC	Normal weight concrete
PKS	Palm kernel shell
PKSC	Palm kernel shell concrete
RIB	Rubberized interlocking block
SC	Sandcrete
SCBA	Sugarcane bagasse
UK	United Kingdom
WAT	Water absorption test

CHAPTER 1

INTRODUCTION

1.1 General Introduction

There are lots of varieties of materials used in the industry of construction. By building civil structure, pillar, wall, stairs, support, etc., all required different kinds of materials. When the application of wall materials is taken into consideration, the cement blocks are the number one choice of materials and it is the most commonly used (Cement.org, 2019).

A brick is rectangular and normally made of clay silicate calcium or mud. It is made by blending the raw materials such as lime, sand, quartz, etc., at that point pour it into the steel mould. Blocks are made fundamentally of cement with a size normally larger than brick. Blocks are essentially utilized in load-bearing dividers where the strength of the block plays a crucial role. Throughout the UK, blocks have been verifiably arranged into three sorts, which are solid, cellular and hollow blocks.

There are two main materials used for the making of conventional cement blocks, which are the cement-sand mortar mix. The cement and sand mortar mix, which is heavy, has a density of around 1800 kg/m^3 to 2000 kg/m^3. However, some of the conventional concrete made from the hard rock will have a higher density which is around the range of 2200 kg/m^3 to 2600 kg/m^3. The high density of conventional concrete greatly increased the overall self-weight of the structure, which will affect the overall design. According to Kuhail (2001), the self-weight of the structure will determine the huge portion of the design load. Therefore, to reduce the self-weight of the structure, the reduction in the weight of blocks has become very important. This also can help to reduce the size of the structural members and overall cost. In which, the load contribution of using the conventional wall in a typical project is about 45 % of the overall building weight (Zaidi, 2017).

To achieve lightweight concrete interlocking blocks, there are few types of lightweight materials that can be used. For example sawdust, straw, sintered fly ash, industrial cinders, expanded clay or shale, expanded polystyrene beads, etc (EuroLightCon., 2000). There are also polystyrene beads used as aggregates because of their low density and lightweight properties as well as good thermal insulation.

Besides choosing the materials, the shape in making the block is also important. By incorporating hollow open spaces within the blocks, it can reduce the self-weight. Besides that, the hollow open space also gives good thermal insulation since the hollow spaces are filled with air. The heat from outside will not easily transfer into the inner part or across the block. Figure 1.1 shows an example outlook of the hollow interlocking blocks.

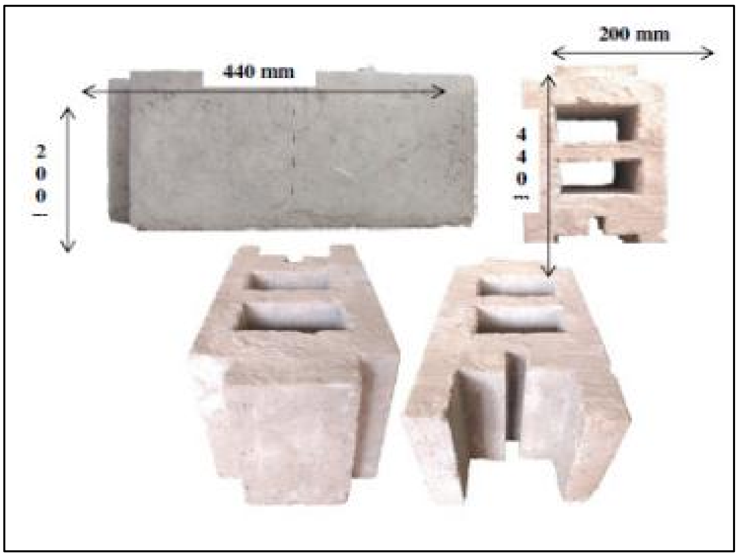

Figure 1.1: Example of hollow interlocking blocks (Ganesh and Lokeshwaran, 2017).

Besides that, sound and fire resistance will increase with the hollow spaces within the interlocking blocks. The hollow open spaces design can also be very useful in practical use, as the piping or wire cables can be crossed through the hollow spaces in the blocks. Masonry systems can be reinforced during the construction since the hollow spaces can be placed on reinforcement bars and infilled with concrete. This reinforced masonry system will result in the wall with higher compressive strength and better lateral stability.

1.2 Importance of the Study

Using lightweight aggregate concrete as the material for interlocking blocks is able to provide many advantages and benefits to cost-saving. Lightweight interlocking blocks can have faster work completion. It has easier applications in construction compared to other use of materials such as steel and woods. The lightweight interlocking blocks also have a good characteristic such as being able to improve the fire resistance. The insulation of sound and noise is higher compared to the high-density concrete. Besides the sound, the insulation of heat is also part of the benefits of lightweight concrete.

Moreover, there is the broad use of lightweight aggregate concrete in civil engineering, many parts of the construction building will use the lightweight aggregate concrete such as superstructure as well as the substructure. The materials used for the conventional load and non-load bearing wall panels can be replaced using lightweight aggregate concrete. By replacing the low density lightweight aggregate concrete block, it is also able to be used as heat and sound insulation panels.

By investigating the interlocking arrangement for these blocks, it can help the achievement in quick and cost-effective construction. With the interlocking tongue and groove nature of these concrete blocks, it is able to help the alignment and maintain the block in both vertical and horizontal directions. Any workers can easily handle this and thus, high skilled workers are not required when using the interlocking blocks. Other than that, by adopting a thin mortar joint construction practice, this can enhance the interlocking nature of the blocks. When the thin layer of cement slurry is applied, only a short duration needed to set, this will benefit the speed of construction (Thamboo, Dhanasekar and Yan, 2011). There are also other advantages such as the structuring by using the interlocking blocks, no special curing is needed or required for most of the ambient situation. Besides that, it also can prevent the joint cracks due to the stress concentration within the mortar joint of the concrete blocks. The heat losses can also be reduced because the thin heat conductive mortar is used. Moreover, the use of lightweight interlocking blocks will reduce much weight which eases the lifting and carrying.

1.3 Problem Statement

Bricks or conventional blocks are created from the topsoil of agricultural land through the baking process and used mainly on the construction of roads and buildings. By making clay bricks, many resources are required for the burning of soil processes such as the huge amount of topsoil and also fuel for burning. According to previous studies, the country such as Bangladesh loses up to 1 % of their agricultural land each year, where more than 17 % is used for the manufacturing of bricks (The Daily Star, 2019). Every year, almost 18,000 hectares of agricultural land is used for the making of bricks, which causes a negative impact on food security. Besides affecting food production, the production of bricks also causes a great impact on the environment due to the mass emission of carbon dioxide. Millions of tonnes of coal and wood were used for the bricks baking process and 60 million tonnes of topsoil is used as the raw material for bricks. The emissions of carbon dioxide have become 20 % of the total global greenhouse gas emission (Imran, et al., 2015). Hence, the environment around the city of Bangladesh has become so polluted and deforestation happened that bring a huge impact on the environment as an example.

Concrete blocks are one of the main materials used in construction for building walls. The high density of the materials used, such as cement and aggregate will result in high self-weight, which represents a bigger portion of the load on the structure. When the structure has a higher self-weight, the support and the pile foundation would require higher requirements and finally will result in higher construction costs. The heavy self-weight of the materials will also increase the difficulty in the handling of construction and transportation. The heavier the materials will cause the handling of material to take a longer duration for both logistics and construction process. Therefore, it will further result in higher costs during the construction period. The productivity of the construction by using heavy self-weight concrete will be decreased compared to the used of lightweight concrete.

Besides that, it will not only cause problems for the construction progress, but also to the manpower. The heavy lifting and conveying can cause low back issues, for example, muscle strain or a disc herniation, which is swelling of disc material conceivably pushing on the spinal cord or nerves that go into the leg. This will affect the health of manpower and may increase the medical costs for the employees.

Clay brick is not a good engineering product for the material of construction because the soils from different sources will cause heterogeneity in the product quality. By using the conventional bricks, the construction will take a longer time and more manpower is required as compared to the interlocking block. For example, the mortar thickness required by conventional bricks is thicker as compared to interlocking blocks. Therefore, a thicker mortar layer may require a longer drying duration. Besides that, it is not suitable for buildings in the area having earthquakes. In which, the tendency for the structures to fail increases during earthquakes due to the higher building weight. Also, the foundation will become much more expensive by using heavyweight material. Efflorescence will also happen due to the bricks able to absorb the water easily. Due to the rough condition and form of the bricks, thick mortar and plaster between two bricks and wall surfaces, respectively, are needed. Bricks need further repairs leading to the heavy water absorption and shrinkage cracks. It is also not ideal for on-site production when needed. Therefore, the usage of clay bricks in the building industry is socially and economically harmful.

1.4 Aim and Objectives

This research aims to design and identify a suitable material to be used for the creation of lightweight concrete interlocking blocks in the future. In order to achieve the aim of this study, there are few objectives in conducting this research which is as follows:

1) To design an attractive and effective shape for interlocking blocks.
2) To identify a sustainable material used to produce the designed interlocking block in Malaysia.
3) To propose the construction assembly method by using the designated interlocking blocks.

1.5 Scope and Limitation of the Study

The scope of the study will be focused on the design of the shape for the lightweight interlocking block. The design has to be practically usable and the sustainability of the lightweight interlocking blocks can be determined. Throughout the study, the inspiration and factors governing the design of the interlocking blocks will be discussed. Besides that, to complete this research and gain a comprehensive perspective on the growing research, the identification of sustainable materials used in the current industry will be carried out. Subsequently, an alternative sustainable material will manage to be determined and discussed. The prioritized countries' consideration for the proposed material was available in Malaysia as the limitation of the study. Beyond that, the constraint set for the material must be sustainable and light density, which is feasible to achieve and serve the requirements of lightweight concrete. In addition, a general idea and guidelines of the construction assembly methods for the designed lightweight interlocking blocks will be outlined and demonstrated with the help of Autodesk Fusion 360 software.

However, due to the limited time frame of the research, the production of an actual lightweight interlocking block could not be executed. Hence, the physical and mechanical tests for the designed block are not covered in the research.

1.6 Contribution of the Study

The outcome of this research serves as a guideline and inspiration to future researchers in terms of the feasibility using palm kernel shells among the industry of the interlocking blocks as all the limitations of the materials are being discussed. By utilizing palm kernel shells as coarse aggregate, it helps in the reduction of waste from the palm oil industry rather than to dispose of it to the landfill site. Hence, this may reduce the environmental pollution issue that is caused by waste from the palm oil industry. Besides that, the designed block may create an insight into future implementation by providing a different kind of interlocking block design, especially coping blocks that seem to be lacked within the current industry.

1.7 Layout of the Report

This report contains a total of 5 chapters. Chapter 1 briefs on the introduction, importance of the study, problem statement, aim and objectives, scope and limitation and contribution of the study are discussed.

In chapter 2, a series of literature reviews is demonstrated starting from the history or background of the interlocking block as well as several interlocking block types in the market all around the world that are invented by researchers were discussed and identified. Besides that, the advantages of interlocking lightweight concrete blocks and factors affecting the strength of block were discussed as well with an ending of the minimum requirements of block review.

In chapter 3, the process and the approach of analysis were outlined by the utilised flowchart in this report known as methodology. The approach used such as SWOT analysis were elaborated and discussed.

In chapter 4, investigated and discussed the finding such as suitable sustainable material for interlocking blocks is being proposed. The design of blocks was justified and ended up with a proposal of an interlocking block assembly guide.

Finally, chapter 5 takes the whole study to an end. Conclusions are taken from the collected information with data and according to the corresponding goals. This chapter additionally spreads out proposals for future exploration.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

The history regarding interlocking blocks would be deeply reviewed in this chapter, whereas the development of multiple types of interlocking blocks will be identified. The properties and also the pros of the lightweight concrete block will be investigated. This part of the study will be able to make new contributions to study and planning for the later phases.

2.2 History of Interlocking block

Mortar-less-technology can be called as interlocking blocks or bricks as well. Both terms can be used and will be used interchangeably in this study. By observing the proper bonding rules of the building construction, interlocking blocks will be stacked up dry and form a wall. The interlocking pattern is the bond between the blocks with the arrangement pattern that will result in a stable wall. This technique or history of interlock blocks was started a century ago. The interlocking bricks were started in the 1900s where the first inventors are from the children's toys (McKusick, 1997). The construction of children's toys, which allow the bricks to be stacked and interlocked between each toy, had given the contributions to the mortar-less technology (Love and Gamble, 1985).

The invention was made from 1863 to the 1900s. There are examples as following:

- Meccano sets by Englishman Frank Hornby, 1863.
- Erector sets by A.C Gilbert, 1884.
- Tinker Toy sets by stonemason Charles Pajeau, 1913.
- Lincoln Logs by John Lloyd Wright, 1920.
- Lego by Ole Kirk Christiansen, 1891 – 1958.

The invention of these toys is to teach the principles of creativity by using toy mechanisms at the beginning. It became the tool that was used to teach the scientific, engineering and architectural principles for the children.

The toy was made using tin, metal, wood and clay in the past as the original materials for the toy construction. However, nowadays the toys are mostly made of plastic. In the multiple types of toy systems, Lego has become one of the most famous and it has become the most similar to walling. The Lego toys were initially invented in Denmark in 1949 as the brick construction toys, able to automatically bind and stack up bricks by bricks. Then the “Lego-Mursten” was progressively given as a new title for automatic-binding equipment, which is also called as Lego Brick in English. Then, the interlocking bricks with Lego bricks had evolved with the stubby cylinders which provide the ability to attach the bricks firmly for one another. Nowadays, Lego has popularly existed in a multitude of features, such as in terms of colors, sizes, functionalities, etc, which makes it become one of the greatest basic forms of mortar-less technology using interlock blocks or bricks.

The start application of interlocking bricks or blocks in house construction was started in 1970. The interlock blocks from Lego have become slightly bigger and tougher. The materials that were consumed to develop interlock concrete blocks are considered a myriad types, such as cement-sand. The use of interlocking blocks was initially adopted in some countries like Middle-East, Africa, Canada and so on (Santosh, et al., 2018).

2.3 Interlocking block for construction

Few types of interlocking blocks can be produced and used for construction such as hollow bricks, perforated bricks and solid bricks. The surface area and the holes within the bricks have become the segregation that separates the hollow-bricks and perforated-bricks. In general, holes that contain over one-quarter of the surface area of the bricks will be defined as hollow blocks while perforated blocks will be less than 25 % (Institution British Standards, 1981). The blocks can be personalized for its sturdiness as shown below:

- Provided it was anticipated for higher sturdiness for the block, the conditions would have to be fulfilled in which to increase the amount of materials needed, higher pressing intensity for the attainment of adequate brick-density. However, the binder will in this case be required less, in order to meet acceptable block-density.

- The greater the amount of perforations, the greater amount of binder needed for mix in order to achieve the desired strength for the hollow block.

Both of the solidity characteristics will affect the cost of producing the bricks, its extreme conditions will give a high impact on the costs of production, therefore, the best percentage of perforation is needed. For perforation, a combination of weight, material needs to be minimised as well as the supremacy needs for the pressing is important. In addition, it should also be concerned in which the size of perforations should also be reduced by reducing the ratio of cement to sand in the mix of hollow blocks.

The construction of different wall joints requires different shapes and parts for the interlocking blocks. There are a lot of different existing commercial interlocking designs with different configurations and each of the configurations will take parts in the performance of construction operations. Interlocking blocks or bricks can be categorized into two groups, one is that bricks' interlocking can restrict the horizontal movement transverse movement to the wall surface while another group is the bricks are allowing the horizontal movement but limiting the transverse movement during assembly. There are types that restrict horizontal movement and transverse movements such as the Thai Interlocking Block, Bamba System Interlocking Block, Auram System Interlocking Block, Tanzanian Interlocking Block System, etc. Meanwhile, the other group of interlock bricks that only limit the transverse movement are Solbric System interlocking blocks and Hydraform System interlocking blocks.

There are famous locking methods that are used in interlocking bricks such as the Tongue and Groove method, and Protrusions and Depressions Method (WoodworkDetails, 2015). There is also the Topological non-planar locking method which is slightly less popular compared to the other two.

2.4 Type of interlocking block

In this part of the study, types of interlocking blocks will be investigated. There are many interlocking blocks systems used all around the world.

2.4.1 Interlocking Hollow Blocks

Firstly, the understanding of interlocking hollow-blocks needs to be made. In modern technologies, interlocking hollow blocks are made from two main materials, which are sand and cement. The modern technologies are different from the conventional technologies in terms of quality, strength and mainly the costing in manufacturing. There are a lot of good promising products of interlocking hollow blocks in the markets since 1988, the examples as shown in Figure 2.1.

Figure 2.1 shows two types of interlocking hollow blocks that are used in Canada. It has a general measurement of 400 mm in length, 400 mm in width and 200 mm in height, which represents over thirty existing types of interlocking hollow blocks. The formwork for the casting of reinforced concrete walls can be replaced by using the interlocking hollow blocks. The strong and high strength of the interlocking hollow blocks allows it to resist the tension exerted on the replacement of solid laitance. Moreover, mixing cement, sand and aggregates with different values of ratios can produce different hollow blocks in strength.

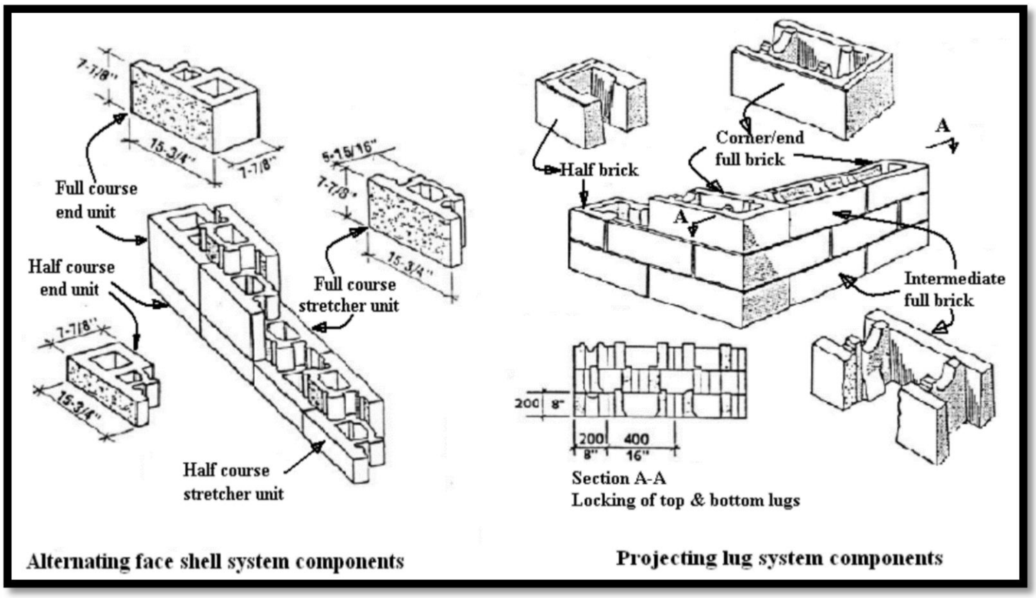

Figure 2.1: Alternating face shell system and projecting lug system (Hines, 1992; Gallegos, 1998; Harris, et al., 1992).

There are a few types of popular low-cost interlocking block systems that are used in certain regions, including Asia and Africa. Fundamentally, they are built and formulated using soothed-soil, in which the methods are through using a practical design. The system is such as the Thai interlocking blocks system, Solbric interlock block system, Hydraform interlocking block system and Bamba interlocking block system from Africa. There are also systems from India such as Auram and Tanzanian type, which are able to produce low-cost housing.

All of the above listed interlocking blocks systems were invented by different inventors with different types of techniques. The main benefit of these techniques is to reduce the cost of production, increase the productivity of construction and also the characteristics of the final product. It will have different kinds of accuracy, stability and also strength with the construction of different types of interlocking blocks. With different kinds of requirements and production methods, different interlocking blocks can be selected and also used on different types of wall creation approaches as well as the bolting instruments.

2.4.2 Thai Interlocking Block

The so-called "Thai-Interlocking" block system was developed in 1980 by the Bangkok's Institute. The design of the block has a dimension of 300 mm × 150 mm × 100 mm as shown in Figure 2.2. The design was studied and developed by the institution in Thailand, which includes the Thai-institute of Scientific and Technical Research. (Institution British Standards, 1981).

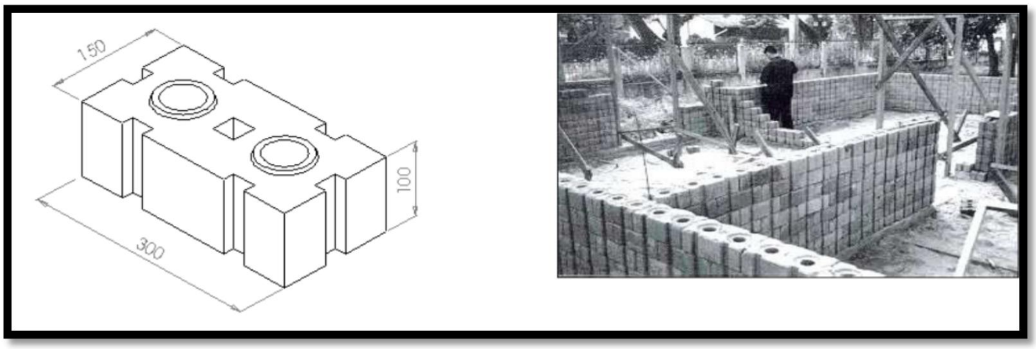

Figure 2.2: Thai Interlocking Block (Kintingu, 2009).

The material used for block production was soil. The Thai interlocking block has some vertical grooves at the sides of the blocks and centre with hollow holes. These features have few purposes, they are able to reduce the total weight of the interlocking block and provide interlocking bonds. The grooves run through the sides of the interlocking block to provide rendering. In addition, the upright perforation covers via the wall in complete-height, in which it can reserve a place for the use of electrical cable passage and piping conduit. This also can reinforce the wall stability at a specific location by adding cement into it.

The amount of rendering required for the inner plastering can be increased by the number of grooves. However, the 5 mm knobs and depressions are too small for the locking mechanism and reduce the strength of the wall built. The overall strength of the block might be reduced with the combination of the hoes and grooves. Therefore, the strength of the interlocking may increase by using the grout filled into the interlocking block's vertical holes, this will also strengthen the stability of the wall. Surface render and additional reinforcements also can be increased to strengthen the interlocks.

2.4.3 Solbric Interlocking block-System (Originated from South-Africa)

Apart from the previously mentioned interlocking blocks, another type of interlocking blocks is Solbric interlocking block systems, which originated from South Africa. The material used for the Solbric block production was soil. The Solbric is very solid compared to other lightweight interlocking blocks because it is a solid interlocking block. As the interlocking blocks are shown in Figure 2.3, it can be observed that the interlocking blocks were formulated via the compressing knock travels correspondingly to the longer-side. The interlocking blocks are guided and controlled by its width and height of the stroke.

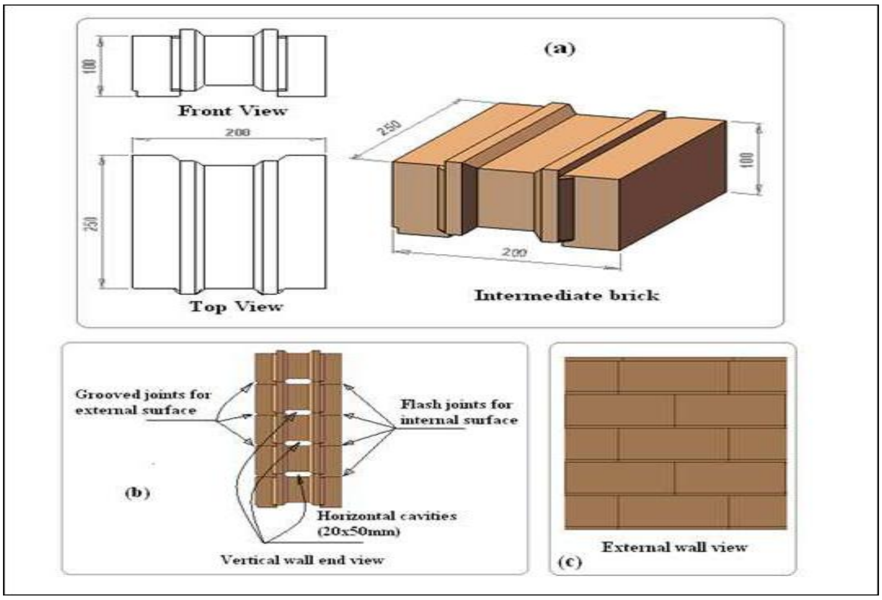

Figure 2.3: Solbric Interlocking Block System (a) Intermediate brick (b) Vertical wall end view (c) External wall view (Kintingu, 2009).

As the external wall view of the interlocking blocks, the wall is a flat and normal bed surface compared to the conventional concrete block. But the holes can be seen on the vertical wall view of the blocks. The Solbric interlocking block system was designed with a dimension of 250 mm ×

200 mm × 100 mm. The horizontal cavities are between the courses of each block which are able to reduce the weight and also provide the function like Thai interlocking block system vertical holes which allow the electrical and piping conduit to be installed within the wall. The strength of the wall also can be increased at a specific location or required places by adding the reinforcement materials.

Meanwhile, it has an externally pointed joint surface that was able to chamfer edges of the block on another side. The joint will make the external appearance attractive. However, this joint has one disadvantage, which is that the interlocking block can only be used in one direction, the block cannot be reversed.

Furthermore, another advantage for this block-system is that it is relatively simple to adopt, employ and become familiar with if being compared to the other existing blocks. The reason is this system's body is being mainly built in an automated way via machines. There is a feasibility to allow only the construction of the external wall, due to the absence of associating panels, like cross-joints. Solbric interlocking has a 15 mm thickness of the vertical and horizontal tongues which will give the ability to the block to interlocking. However, the interlocking still is questionable when using different kinds of materials, the stability of soil and cement is still brittle.

2.4.4 Hydraform System From South Africa

Besides the Solbric interlocking block system invented from South Africa, there are also interlocking block systems called Hydraform. The Hydraform interlocking block system is one of the simplest types of the interlocking block in shape. The interlocking features are coming from the tongue and groove joint of the sides and top of the block. The interlocking is able to hold in both vertical and horizontal directions. It is free to travel along the horizontal axis and pushed along the vertical joints so that it is able to achieve a tighter grip. Figure 2.4 shows the Hydraform interlocking block system, in which the Hydraform interlocking block is pressed along the ends across the length of the block, which is the same technique with Solbric.

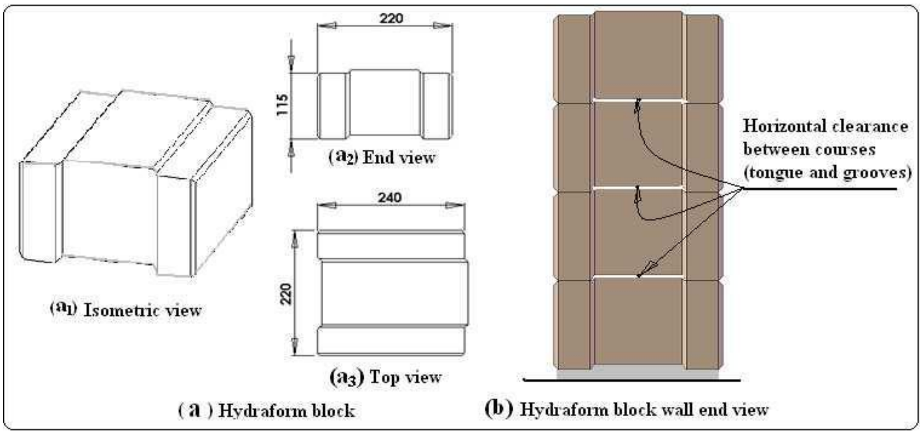

Figure 2.4: Hydraform Interlocking Block System from South Africa (a) Hydraform block (b) Hydraform block wall end view (Kintingu, 2009).

The solid block of the Hydraform block is slightly shorter and thicker in size compared to the Solbric. It has a dimension of 240 mm × 220 mm × 115 mm. The requirement for production is using a suitable amount of force to mould because of their large quantity volume. With the 5 reported types of interlocking block, this interlocking block system using 30 % more soil compared to them. In addition, at the occasion where the brick is migrated to the cured region from the machine places physically, it must be ensured that the compression must be enough to allow the block to withstand the squeezing process. The powerful pressure, which rate between 4 MPa to 10 MPa are used in the moulding process and the machine is motorised for the compact of a huge volume of soil (Hydraform mud stabilized blocks production installation manual, 2015). In contrast, the production of Bamba and Thai types are produced under cheaper cost since the power pressure used for moulding is only approximately 2 MPa (Weinhuber, 1995; VITA, 1975).

However, when the Hydraform blocks reach and meet at the edges, needed to be set perpendicular, slight chopping is required. As a result, it is possible to be encircled inside the construction technique with the purpose of time-optimisation with such placing. In addition, a half-bat is needed to conceal and tongue-and-male.

Afterward, the protracted course intersections within the block have authorisation of 1 mm among the groove of several intersected blocks. The foundation of the concept beyond such kind of construction is the directness of longitudinal-sloppy, to serve as an adjustment to the resting block. For example, the positioning of the compensation blocks can be cut manually by the builders.

2.4.5 Bamba System Interlocking Block

The Bamba interlocking block was made out of a soil-cement mixture. The Bamba interlocking block is punctured with protrusions and depressions. First of all, it can be observed that the Bamba interlocking block from two primary perspectives, namely the top and base aspect. Assessing via both the aspects from their surfaces, the rationale of the negative balance is found there, which indicates that there is a converse-setup that allows for lock-fitting. As depicted from Figure 2.5, the interlocking-block is switched in a rotation of one-hundred and eighty degrees across the z-axis. This implies that the top view will emerge and be shown as the bottom view and vice versa. As the consequences, this offers the applicability for rotation, to seek an appropriate configuration during the laying-brick.

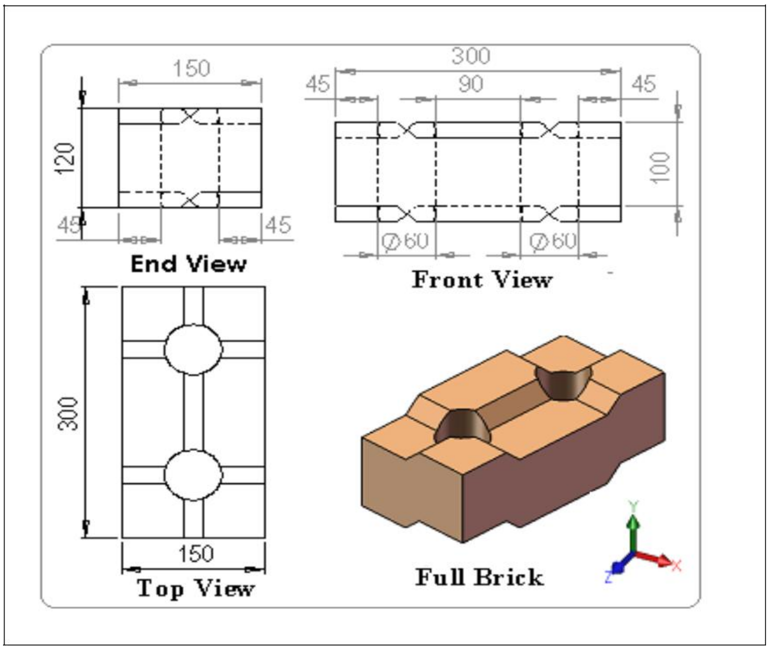

Figure 2.5: BAMBA system interlocking block (Kintingu, 2009).

The main reason that this block system is an ideal choice is because of its shape-in-nature, which means that relatively great accuracy can almost be guaranteed. The degree of accuracy depends fully on the quality of the soil materials used, fabric mix of combinations, a ratio of the cement-to-soil as well as water-to-cement, deliberate identification of fine-apply in manufacturing and toughening. Basically, the patterns will generate a solid building, and thus almost unamendable provided any flaws found at the bricks. Therefore, the BAMBA system is good in certain aspects, but its strength is sometimes becoming its adversity as well. This makes the system to be not an ideal choice for the currently-developing nations since precise automated approaches along with professional competencies in soil options to ensure the product of the block is with the characteristic of consistency. Assuming the circumstance in which the condition is fulfilled, this block has the capability to support the laying of the bricks for a whole house-construction throughout the day. In the opposite cases, if the block is dealing with relatively low precision in the nature of sizes and structures due to complicated production procedures, it could be time-consuming to cope with any brick indiscretions.

2.4.6 Auram System Interlocking Block

Figure 2.6 depicts the family-groups for bricks. For instance, these include the intermediary, 3-quartered bats, half-bat, channel and so on. These groups of combinations associate it to attain the Thai system. However, in the absence of furrows as well as decreased holes. Besides, the material used for the Auram block production was a soil-cement mixture.

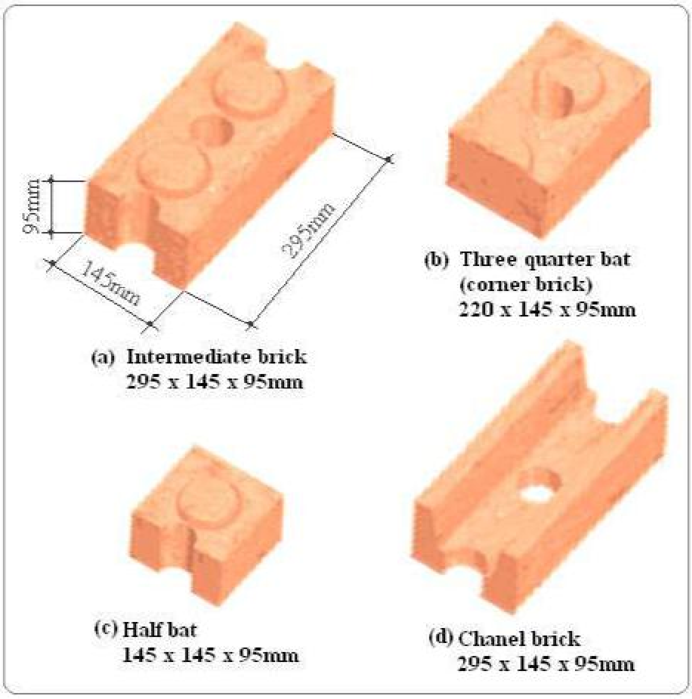

Figure 2.6: Auram Interlocking Block System (a) Intermediate brick (b) Three-quarter bat (c) Half bat (d) Chanel brick (Kintingu, 2009).

This type of interlock a bat with a dimension of 220 mm × 145 mm × 95 mm used as a corner brick. The Auram bricks are typically heavier as compared to the Thai interlocking block up to 2 kg per block. However, it has to be taken into account that the full dependence of locking mechanisms on the person-in-charge. For instance, the whole procedure has to be conducted via an experiment to investigate the optimal height of 'male' as well as the depth of the 'female' characteristics that is lower than 10 millimeters, so that to grant adequate density of strength to wall-punching.

2.5 Advantages of Lightweight Concrete Block

2.5.1 Cost Saving

The price of Hollow Concrete Block within the gift market is just seventy five percent that of typical red bricks. Moreover, autoclaved aerated concrete (AAC) and Hollow Concrete Block (HCB) are lightweight in weight and the volume of one unit is four to five times that of red brick. Lightness saves the price of a structure by reducing member size and steel space and additionally construction of walls needs less quantity of mortar, plaster and fewer range of masons thanks to larger sized blocks that build it economically.

Construction of wall victimisation HCB rather than typical clay bricks will save quite thirty percent value. The AAC Blocks are extremely valued effective in nature. Thus, giving value saving and less investment in the development work. Compared to clay bricks, its weight is a smaller amount than eighty percent. This significantly reduces dead weight. Moreover, the reduction in deadweight by such a large margin leads to a reduction of accidents and steel usage for construction. This protects lots of cash on the money. The creation of AAC Blocks is additionally valued compared to cellular lightweight concrete (CLC) blocks (Sanders and Thomas, 1991).

2.5.2 Rapid Construction

The AAC Block facilitates fast construction work, thereby reducing time and construction prices. In AAC Bricks it is straightforward to use normal tools for cutting the walls for craft, together with the drilling of holes. Even band saws are employed in cutting and alignment of the AAC Bricks. As they are massive in size, the advantage is that few joints are there within the constructions. Thus, sanctioning fast construction, together with robust structural support to the building. Therefore, the period throughout the installation of AAC Blocks is reduced because of less range of AAC Bricks. This leads to less time used for masonry and application work. So, the development work is completed before the development schedule. Lightweight to very light larger sized HCB and AAC blocks with fewer joints facilitate quicker construction work. Also, AAC block is incredibly straightforward to handle, manipulate and use with normal tools for cutting (McGinley, 1995).

2.5.3 Environmentally Friendly

Embodied carbon emission for one HCB is 0.75 kg compared with 4.25 kg for red bricks. Emission from AAC is additionally abundant not up to that of typical bricks. Bulk raw materials for each block are sand or fly-ash. Moreover, each HCB and AAC scale back the incoming heat from outside of the wall thus reducing the load of the air-cooling system. The material used for the AAC Bricks is non-toxic. It does not soil the air, together with land and water similarly. The waste mud from the cutting method at the time of producing them is given additional strength and it once more used for manufacturing new bricks and blocks.

Moreover, the energy consumed within the production of the AAC Blocks method is simply a little amount that may be measured in fractions. Whereas, the assembly of different materials it is abundant. There is no emission of pollution within the producing method. It does not produce by-products or waste products that are nephrotoxic since it is made of natural material. The wonder in it is that the finished product is thrice the amount of the material that is employed. It is the most environmentally friendly and resource economical (Marchal, 2001).

2.5.4 Resistance to Earthquake

The seismic load has a directly proportional relationship when being linked with accumulating-weight. In other words, this indicates that when the weight of the construction is greater, the pressures exerted on the seismic circumstances are greater as well. Therefore, the use of lightweight materials ensures a lot of earthquake-resilient buildings. The natural property it is made of is lightweight in weight. This successively will increase the soundness within the building structures. Usually, the impact of the earthquake is directly on the load of the building. The AAC Bricks employed in the development of high rise buildings, together with single unit constructions are most reliable and safe (Ilki, Demir and Ugurlu, 2013).

2.5.5 Fire Resistant

Fire resistance (endurance) rating worth of HCB starting from one hour to four hours relying upon equivalent thickness or solid fill cores. On the opposite hand, relying upon the thickness of the AAC blocks, they provide fire resistance from two hours up to six hours. These blocks are extremely appropriate for the areas wherever fire safety is of a nice priority. The AAC

Blocks are proof against a fireplace between a particular limit of your time. It is from a two hours minimum time to six hours most closing date. However, their resistance to fireside hazards relies on the thickness of the AAC Blocks within the constructions wherever fireplace safety is given the highest importance. Moreover, holding the fire from spreading may be an excellent and positive factor in safety procedures (Sahu and Singh, 2017).

2.6 Factors affect the strength of the block

2.6.1 The cement to water ratio

First and foremost, the cement-to-water ratio is generally defined as the scale association of the water against cement its weight (Kerali, 2001). Thus, in short, it means the w/c ratio. In the majority of the circumstances, it plays an essential paramount role to enable the investigator to obtain an adequate extent of strength for the concrete blocks. For instance, if the value of the w/c ratio is higher, the solidity power of the concrete would become lower; this implies that if the w/c ratio is reduced, the solidity power of the concrete would relatively increase as well. As the standard magnitude is needed, it shall be managed within 0.45 to 0.60 for more confident usage. Then, filter up and segregate the overdue water in the amount. The concrete should be voided as well following up on the discharge of excessive water. Apart from that, concrete its strength is fully dependent on the value of the water over the cement ratio. For instance, when the magnitude for the water over cement ratio is boosted, the solidity power of the concrete would not be raised but lowered, and vice versa (Kerali, 2001).

2.6.2 Compaction of concrete

This technique is very useful especially in enhancing the concrete density. This is mainly because of the reasons that compaction of concrete is taken into account as an initiative for which the air-voids are discharged from the newly positioned concretes. As a consequence, the concrete would become more compact and higher in density. The voids of air is an essential component to be strictly controlled and managed, as the existence of even slight air can significantly lower down the strength exerted on the concrete. For example, when the air voids comprise at least 5 %, this can lead to undesired impacts in which the strength can be horrendously affected by more than 30 % of the overall proportion. Sometimes, there is even possible that a large variation between the w/c related strength when being assessed also with the precision and levels of compaction. However, if the concrete is completely being compacted, the strength could exceed the inadequately-compacted concretes (G.Marzahn, 1998).

2.6.3 Aggregates characteristic

Larger size aggregates provide a lower strength. As a result, they have a lower expanse for the event of a gel bond. The duty of the gel bond presence is mainly to provide adjustment for strength. As the mixture of combinations is grouped in bigger sizes, the concrete will become theoretically varied and thus term as 'heterogeneous'. In such circumstances, the weight and burden are not disseminated uniformly, if the concrete is being pressured. According to Kozul and Darwin (1997), the formulation of tiny cracks might unanticipatedly occur, provided there is a bigger lump sum of mixtures is adopted for the application of concrete. The possible reason here can be potentially led by internal haemorrhage.

Categorizing, sorting and classifying the aggregates is an undeniably necessary task as well. An efficient process of classifying the aggregates enables the developer to efficiently identify the dissemination size of the particles elements contained in the aggregates. There are several types of sorted-combinations. For instance, these include Gap Hierarchical combination, poorly-graded combination as well as a properly-graded combination. In addition, the process of how good in handling the aggregates can significantly influence the production of a concrete mix as well.

Besides that, the shapes for the combination of aggregates are also considered to exist in a myriad type. For example, they can incorporate angular shape, elongated shape, cubical shape and flaky fundamentals. Also, there are additional types of shapes such as elongated and flaky, rounded as well as asymmetrical (Ophoven, 1977). Basically, there are minor differences between angular and rounded aggregates, in which the former one is slightly rough, but the latter one is more sleek-rough oriented. As a result, the rounded aggregates end up leading to the shortage of linkage that correlates between cement paste and the combination of aggregates. In general, the angular aggregates tend to demonstrate high and intense interlocking influence towards the concrete. However, in comparison, the angular combination could possess a larger quantity of voids, and thus a properly-graded combination would be relatively required. In addition, the figures and structures of the aggregates shall be progressively emphasized, if a relatively low w/c ratio in an association is applied. Hence, for this kind of circumstance, the podgy form aggregates with unvarying and constant grade would be inextricably needed in order to yield greater practicability (Ophoven, 1977).

2.7 Requirements for non-load-bearing masonry units (ASTM C129)

According to ASTM C129, the classification for concrete masonry units can be classified into a lightweight, medium weight and normal weight based on the density of the unit as shown in Table 2.1. The classification standard is both applicable for non-load-bearing and load-bearing masonry units. As based on Table 2.1, is clearly stated the density for lightweight concrete units shall be less than 1680 kg/m^3. Besides, non-load-bearing masonry units are not suitable to be used for the exterior wall. In contrast, it can be used for a partition wall within the structures.

Table 2.1: Classification for concrete masonry units (ASTM C129, 2000).

Density classification	Lightweight	Medium weight	Normal weight
Oven-Dry density of the concrete (kg/m^3)	Less than 1680	1680 to 2000	2000 or more

Although, these units are not recommended to be used for the exterior wall construction. However, ASTM C129 has set the minimum compressive strength requirements for these units. Based on Table 2.2, the units are needed to comply with both the individual and average of 3 units compressive strength standard. The individual unit compressive strength for the non-load-bearing masonry is not less than 3.45 MPa, while for the average of 3 units shall not be less than 4.14 MPa.

Table 2.2: Minimum requirement of the compressive strength for non-load-bearing masonry units (ASTM C129, 2000).

	Individual unit	Average of 3 units
Compressive strength (MPa)	3.45	4.14

Meanwhile, in terms of moisture, the units can be classified into Type 1 and Type 2 units. Type 1 refers to moisture controlled units, while Type 2 refers to non-moisture controlled units. Figure 2.7 shows the Type 1 moisture content requirements with respect to the total linear drying shrinkage and the site humidity conditions. This standard is used as a guideline prior to the delivery of the units to buyers. Similarly, the total drying shrinkage for Type 2 units shall not exceed 0.065 % for the check prior delivery to the buyer (ASTM C129, 2000).

Total Linear Drying Shrinkage, %	Moisture Content, max, % of Total Absorption (Average of 3 Units) Humidity[A] Conditions at Job Site of Point of Use		
	Humid[B]	Intermediate[C]	Arid[D]
Less than 0.03	45	40	35
0.03 to less than 0.045	40	35	30
0.045 to 0.065, max	35	30	25

[A] See Appendix X1 (Fig. X1.1) for map of mean annual relative humidity.
[B] Mean annual relative humidity above 75 %.
[C] Mean annual relative humidity 50 to 75 %.
[D] Mean annual relative humidity less than 50 %.

Figure 2.7: Type 1 moisture content requirements for non-load-bearing masonry units (ASTM C129, 2000).

2.8 Requirements for load-bearing masonry units (ASTM C90)

The specifications adopted for load-bearing masonry units as in ASTM C90 consisted of two main components. Firstly, is the masonry unit maximum water absorption for individuals and an average of 3 units with respect to the density class. Table 2.3 clearly stated that the masonry categorised as lightweight, medium weight and normal weight masonry, all has its own maximum water absorption standard. In addition, since this requirement is set for use as load-bearing masonry units. Hence, the compressive strength as shown in Table 2.4 is rather higher as compared to the criteria in ASTM C129, which is for non-load-bearing units. Table 2.4 stated that the minimum compressive strength is 11.70 MPa and 13.10 MPa for individuals and an average of 3 units respectively. This standard is applicable for all classes of masonry units ranging from lightweight to normal weight.

Table 2.3: Maximum water absorption for the load-bearing masonry units (ASTM C90, 2009).

Density classification	Maximum water absorption (kg/m^3)	
	Individual unit	Average of 3 units
Lightweight	320	288
Medium weight	272	240
Normal weight	240	208

Table 2.4: Minimum compressive strength requirements for the load-bearing masonry units (ASTM C90, 2009).

	Individual unit	Average of 3 units
Compressive strength (MPa)	11.70	13.10

2.9 Summary

In summary, there are many types of the interlocking block in the current industry, which are known as Thai, Solbric, Hydraform, Bamba and Auram interlocking block. All these blocks have their strengths and weaknesses as well as its unique interlocking system. Besides, there are a variety of advantages in adopting lightweight concrete blocks in the construction. Hence, this drew the idea that lightweight concrete can be utilized in the production of interlocking as well. Table 2.5 shows the summary of engineering properties tested for different types of blocks with different materials used by previous researchers. By referring to Table 2.5, the most common type of block tested is the interlocking block. Subsequently, followed by hollow-interlocking block and hollow block. Besides that, typical materials used for the block are normal weight concrete. While for the engineering properties test, Table 2.5 indicates all of the research has carried out the compressive test. In contrast, flexural tests are only tested by 2 out of 8 researches. Hence, the research on interlocking blocks with lightweight aggregate concrete and lightweight foamed concrete has not yet been done previously. Likewise, none of the studies is using sustainable material for the interlocking block investigation.

Table 2.5: Summary of engineering properties tested for types of blocks with different materials used.

Author(s)(year)	Type of Block			Type of Materials					Engineering Properties Test			
	INT[1]	HL[2]	HLI[3]	NWC[4]	LFC[5]	LAC[6]	SC[7]	Others[8]	CT[9]	FT[10]	WAT[11]	Others[12]
Raheem, et al. (2012)	✓	✓					✓	✓	✓			✓
Ramakrishnan, et al. (2013)	✓							✓	✓		✓	
Pattnaik, et al. (2018)	✓			✓					✓	✓	✓	✓
Ganesh and Lokeshwaran (2017)			✓	✓					✓			✓
Sarath, Pradeep and Babu (2015)			✓	✓					✓	✓		✓
Ma, Ma and Gaire (2019)			✓					✓	✓			✓
Malavika, et al. (2017)	✓			✓					✓		✓	
Raheem, Falola and Adeyeye (2012)	✓							✓	✓		✓	✓

Note:

[1]INT = Interlocking, [2]HL = Hollow, [3]HLI = Hollow-interlocking, [4]NWC = Normal weight concrete, [5]LFC = Lightweight foamed concrete, [6]LAC = Lightweight aggregate concrete, [7]SC = Sandcrete, [8]Others = Other materials, [9]CT = Compressive test, [10]FT = Flexural test, [11]WAT = Water absorption test, [12]Others = Other engineering properties test

CHAPTER 3

METHODOLOGY

3.1 Introduction

This chapter clarifies the methodology approaches in order to fulfill the aim and objectives of the study. Since this study is mainly a preliminary investigation in terms of designing concept, identifying suitable materials to be used for the interlocking blocks as well as the general guideline for installing will be discussed. Moreover, 4 types of interlocking blocks are drawn by adopting Autodesk Fusion 360 to display the overview and dimensions of the blocks. Where the 4 types of interlocking blocks are the full, half, full coping and half coping interlocking block. Figure 3.1 shows the flowchart for this research as an overview.

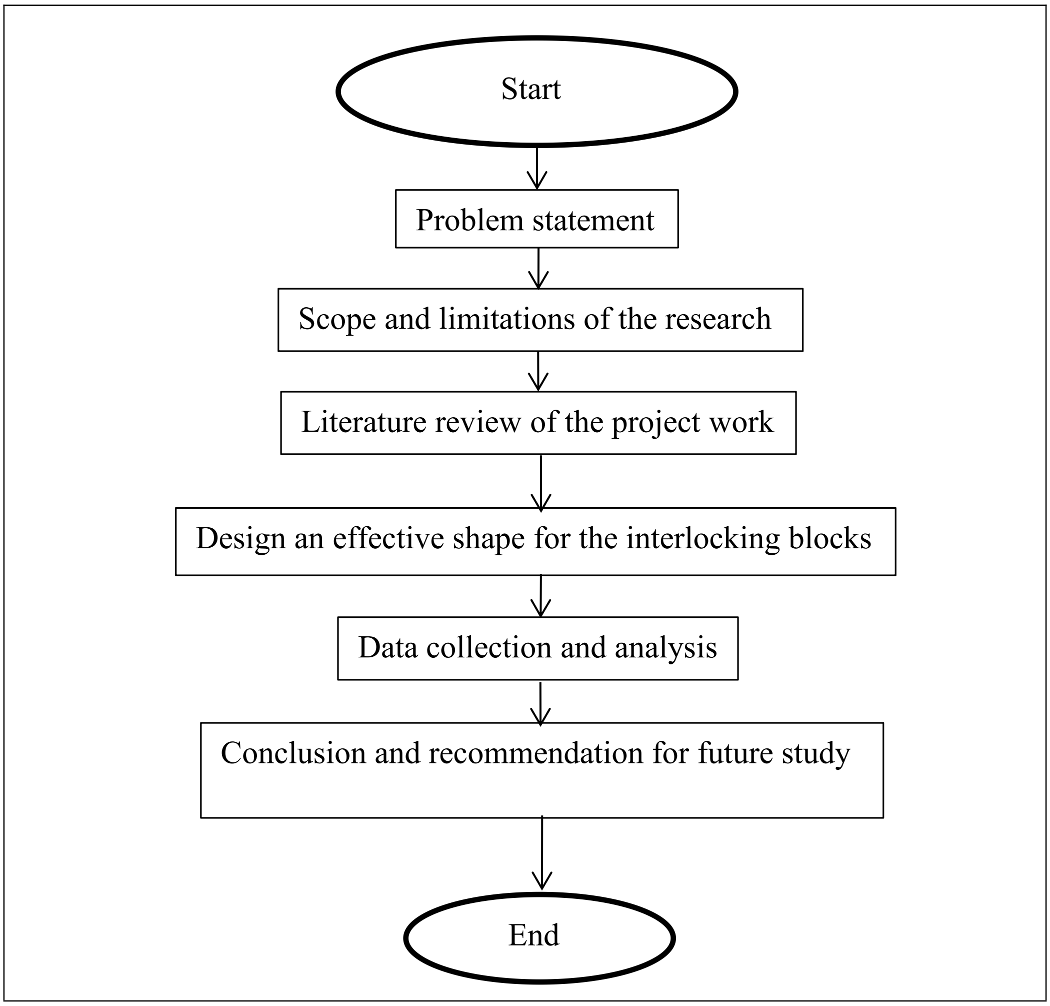

Figure 3.1: Flowchart for the research.

3.2 Design of the interlocking blocks

As mentioned earlier, 4 types of interlocking blocks are designed which is the full, half, full coping and half coping interlocking block. All the design concepts are based on the aspect of constructability and eliminate the troublesome trimming and cutting processes as the stacking arrangement adopted for this block is running bond. After all the design of the interlocking block is drawn by utilized Autodesk Fusion 360 software and all the steps is as shown in the following:

Step 1: Click on the Autodesk Fusion 360 icon to start the programme (refer to Figure 3.2).

Figure 3.2: Icon of Autodesk Fusion 360.

Step 2: Click on “New Design” from the file tab (refer to Figure 3.3).

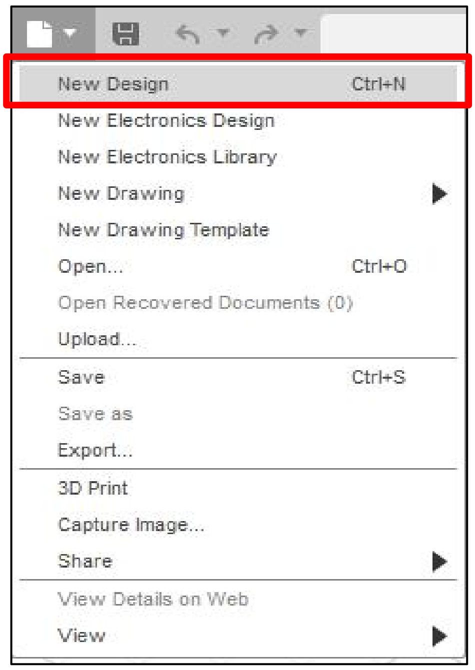

Figure 3.3: Create a new design file.

Step 3: Click on the create sketch manual to start the design of the interlocking blocks (refer to Figure 3.4). The main function of this sketch tool is to draw the 2D top view or bottom view as a base prior to creating the full 3D appearance using the extrusion function.

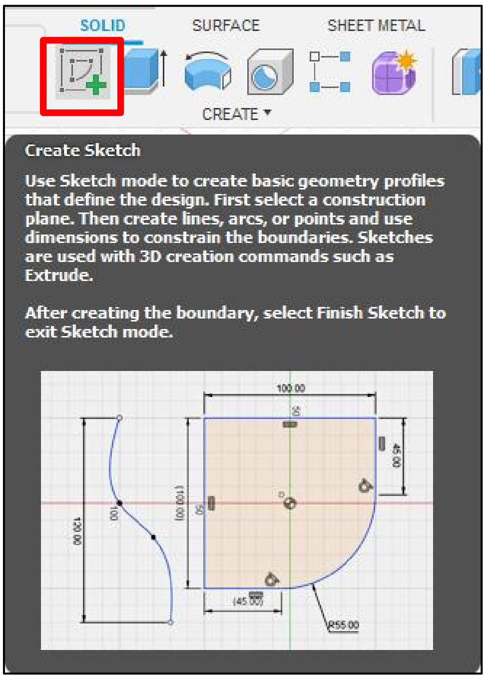

Figure 3.4: Create a sketch.

Step 4: A drawing tools tab will pop out with a variety of functions. In this study, only a line, two-point rectangle and trim is used to sketch the interlocking blocks and end with a click on “Finish sketch” (refer to Figure 3.5). The main purpose of using a two-point rectangle function is to draw the perimeter of the designed block. Besides, a line was used to form the interlocking part within the perimeter for the block. Meanwhile, the trim function is utilized to adjust any excessive line that is beyond the block perimeter or boundary.

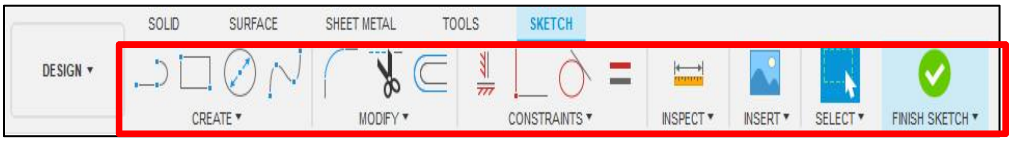

Figure 3.5: Drawing tools tab.

Step 5: Select “Extrude” to create the extrusion and protrusion of the blocks based on designed dimensions from the sketch created (refer to Figure 3.6). Besides, extrusion components for the block are the main body and the male parts. While the protrusion component for the block is the female parts. In this study, the main body extrusion depth for all the blocks is 90 mm. Whereas, both the male extrusion and female protrusion parts depth are 15 mm.

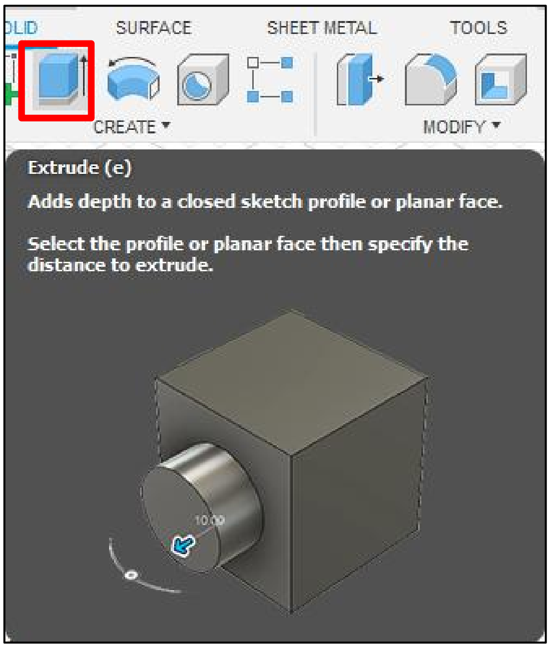

Figure 3.6: Create the 3D parts of the blocks using the extrude function.

Step 6: Completed the 3D parts for all the blocks (refer to Figure 3.7). The blocks can be viewed on the home screen.

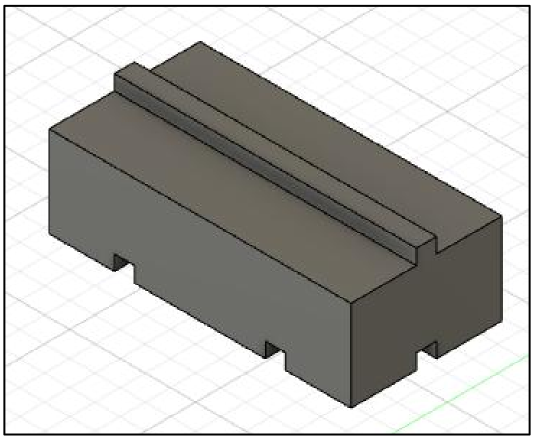

Figure 3.7: Completed view of the 3D block.

Step 7: From the browser manual, right-click on "Body" to create a component in the home screen in order to mate or join the blocks to display the arrangement of the walls as well as use "Copy" and "Paste" to duplicate the blocks (refer to Figure 3.8).

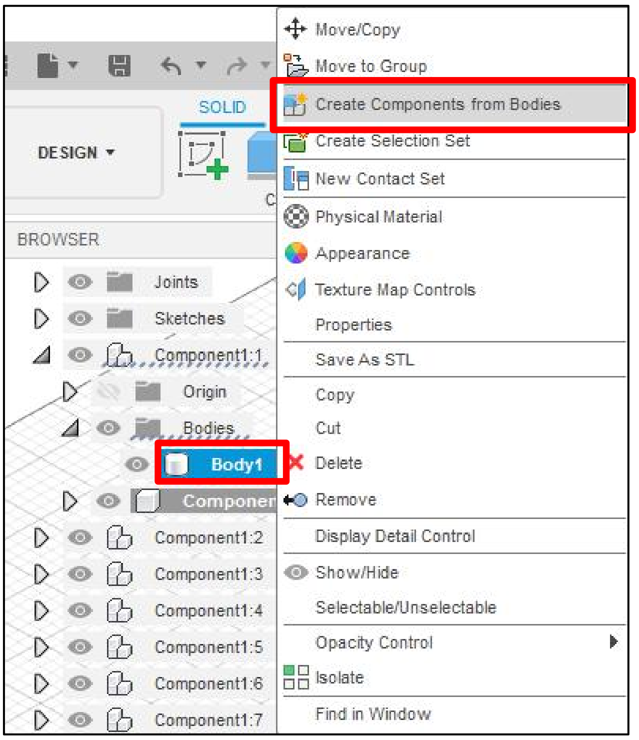

Figure 3.8: Create components from the sketched body.

Step 8: Click on the "Assemble" options and select "Joint" to mates the blocks (refer to Figure 3.9). The main purpose of using the joist function is to assemble and display a virtual wall arrangement by using the designed interlocking blocks. Meanwhile, this step allowed the designer to identify the suitability of whether the blocks created can be interlocked to one and another. If an error was found, this will be the best opportunity for the designer to make certain adjustments before producing an actual block.

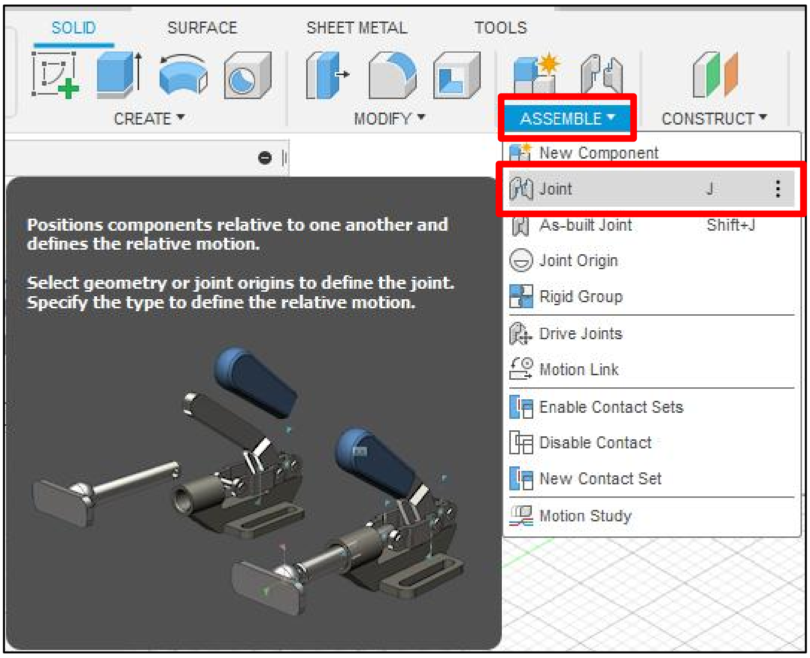

Figure 3.9: Used the joint function to mates the blocks.

Step 9: Click "Create drawing" from the "Design" manual and select the components that wish to be displayed in the drawing and click "OK" to create (refer to Figure 3.10). In this study, 4 isometric drawings will be prepared to show dimensions for all the 4 designed types blocks. The scale used for the isometric drawings will be 1 to 2 and the appearance presented will be shaded with hidden edges. Besides, drawings for the simple and corner wall arrangement will be shown by using a scale of 1 to 5 and are presented using a shaded appearance. All the dimensions shown will be using millimeters.

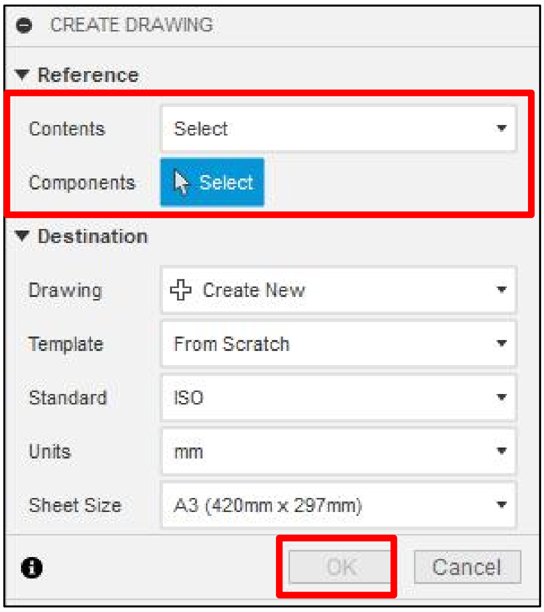

Figure 3.10: Create drawing for respective components.

Step 10: The template for the dimensions of the blocks is arranged and displayed in such by referring to Figure 3.11.

Front view	Side view
Top view	3D view

Figure 3.11: Template for dimensions of the blocks.

Step 11: The last step is to save the file of the project.

Lastly, Figure 3.12 showed the flowchart to reveal the overview of all the steps involved in using Autodesk Fusion 360 software in this study.

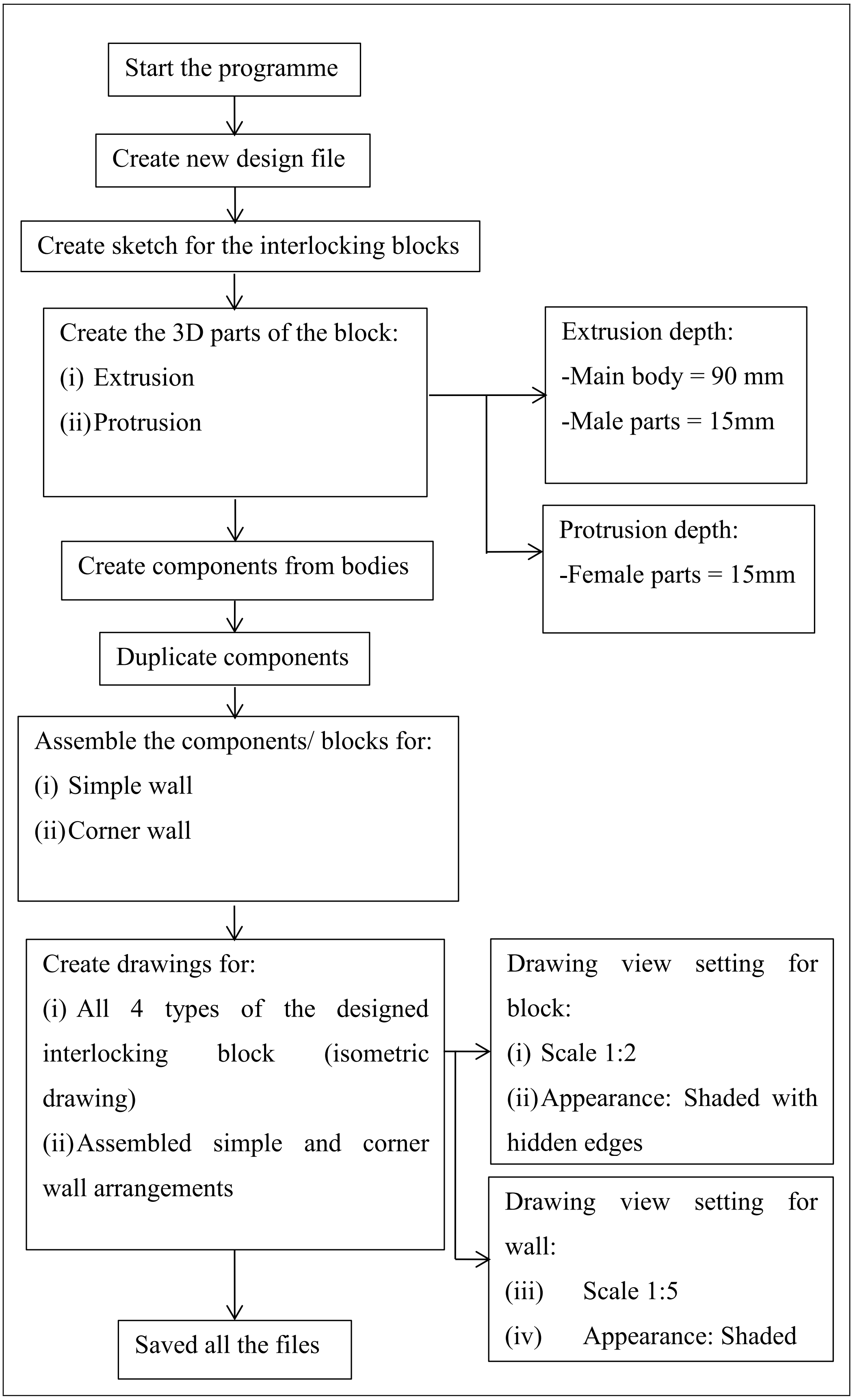

Figure 3.12: Summarised steps involved in utilized Autodesk Fusion 360.

3.3 Data collection and analysis

For an investigation, there are generally explicit strategies for doing information assortment. For instance, polls from reviews, interviews, field perceptions, explore or even optional information from other researchers' works. It is consistently important, however, that choosing the type of information assortment can impact the level of reliability, consistency and sufficiency of the tests.

Meanwhile, in this study majority of the information and data are gathered from secondary sources typically from journals. This approach is meant to extract and separate desired informational indexes from other researcher's investigations and afterward do information reanalysis. Besides that, the greater part of the gathered information was constrained to the economical material utilized for current interlocking blocks.

After gathering all the information, the way toward sorting out the information is of specific significance to have an overview of the interpretation during the analysis stage. There are a couple of approaches where the information might be masterminded or arranged to show the data concisely. In this study, the data arranged in the table format is majorly used to present the physical and mechanical properties of the blocks as well as making a comparison of the materials. Whereas, the graph is utilized to show the trend of block's strength, change in palm oil planted territory and etc. In addition, in order to propose an ideal sustainable and economical material to be used for the designed interlocking blocks, a SWOT analysis was conducted to enhance the reliability of the material further.

3.3.1 SWOT analysis

This particular analysis is used to determine the feasibility of the proposed material to be used for the designed interlocking blocks. As shown in Table 3.1, the SWOT analysis comprises the strength, weaknesses, opportunities and threats. The SWOT analysis can be separated into two main parts, which are the internal and external factors. Hence, it is considered to be a comprehensive analysis to be adopted with.

Table 3.1: Overview of SWOT analysis.

Division	Basic concepts
Strengths	The division ought to incorporate internal aspects which would give the choices an upper hand.
Weaknesses	The division should make reference to the absence of qualities in specific aspects which could be viewed as an internal shortcoming.
Opportunities	The division involves external factors that give chances to development and growth.
Threats	The division ought to demonstrate the possibility and serious exercises that could adverse development and growth.

3.4 Summary

Basically, the methodology involved in this study is mainly a preliminary investigation for the interlocking block. The investigation was done in terms of the design and sustainable materials used for existing interlocking blocks in the industry. The major sources of data collection are the journal from the previous researchers. While the data analysis and information assortment is displayed or shown by using tables in this research. Moreover, a SWOT analysis approach was adopted to enhance the reliability of the proposed sustainable material to be used for the designed blocks. All models of the blocks and drawings are created using Autodesk Fusion 360.

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 Design of the interlocking blocks

4 types of interlocking blocks are designed for this study. The main concept and inspiration of these designs were referred to in the aspect of constructability and avoiding complicated trim and cut processes during the stacking of the blocks. Initially, the full interlocking block is designed as shown in Figure 4.1 as both the intermediate and corner block consideration. In order to serve the purpose, full interlocking blocks must be in the ratio of 1 to 2 for the traverse and longitudinal direction respectively. Hence, the full interlocking block is designed as 150 mm in width and 300 mm in length. The major highlight for the block is the two grooves in the traverse and one groove in the middle of the longitudinal direction at the bottom of the block that allowed the tongue designed at the top longitudinal direction to be interlocked with the bottom groove in either direction. Similarly, the half interlocking block as shown in Figure 4.2 is designed to be inserted at the end of the alternate courses since the blocks were stacked in a running bond pattern. With the half interlocking block, the block cut process at the end of the courses is avoidable at ease and remains wall stability.

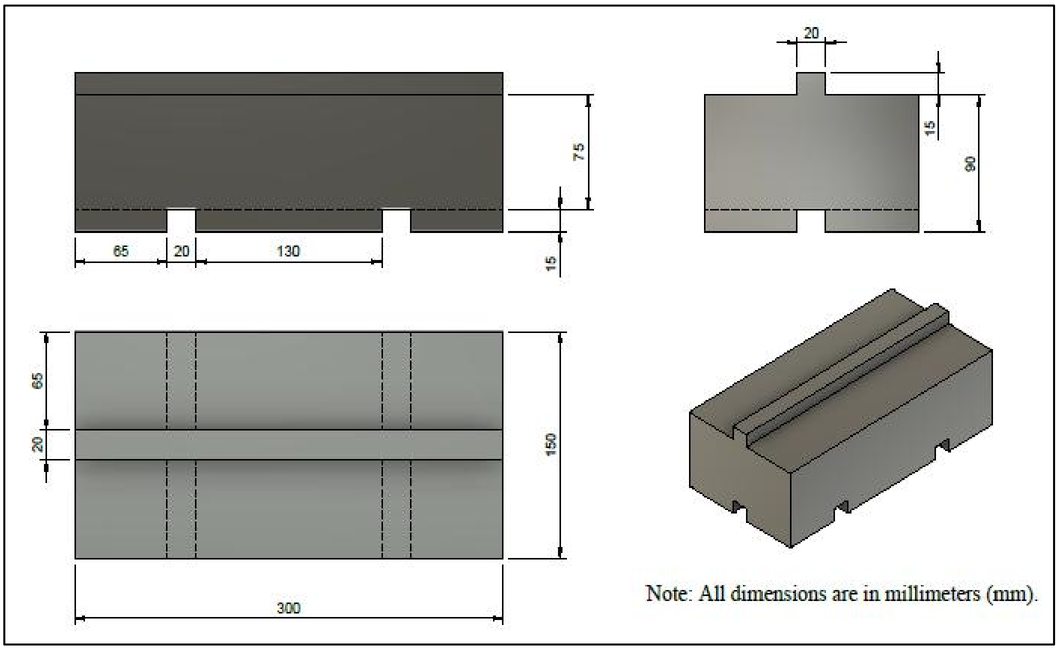

Figure 4.1: Dimensions of full interlocking block design.

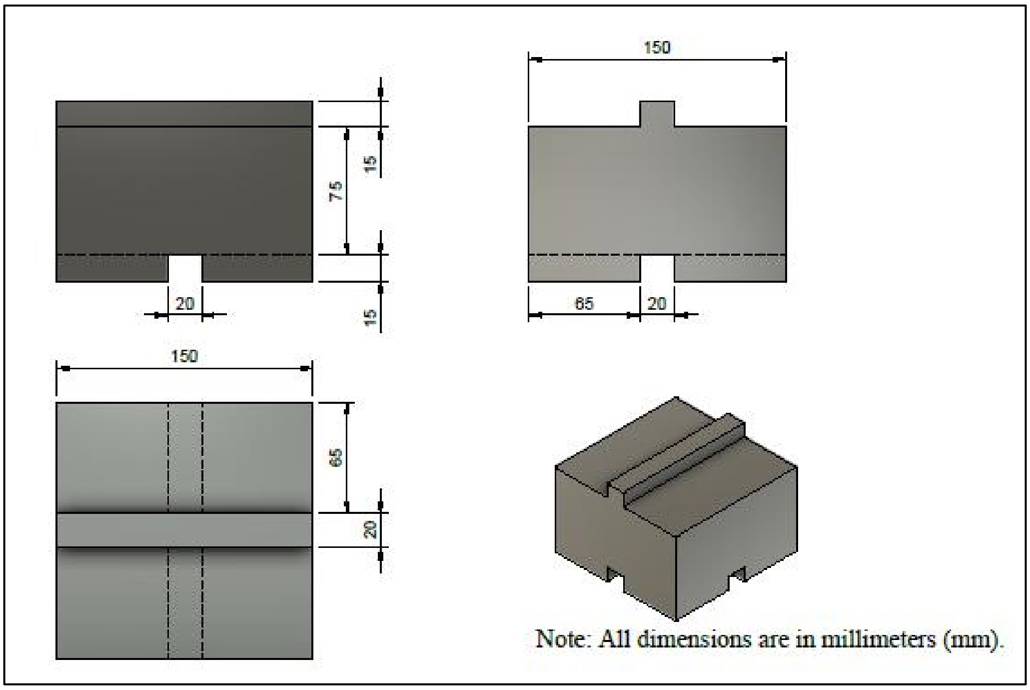

Figure 4.2: Dimensions of half interlocking block design.

Meanwhile, after plenty of consideration, the full and half coping interlocking block having a similar shape and dimensions as compared to full and half interlocking block as shown in Figures 4.3 and 4.4 were designed, where the top face tongue is removed at the longitudinal direction. The main function of coping interlocking blocks is used as the final courses to ease the trimming process required if using full or half interlocking blocks. The removed tongue is meant to create a flat and nice surface that allows the block to end the structure based on the desired structures.

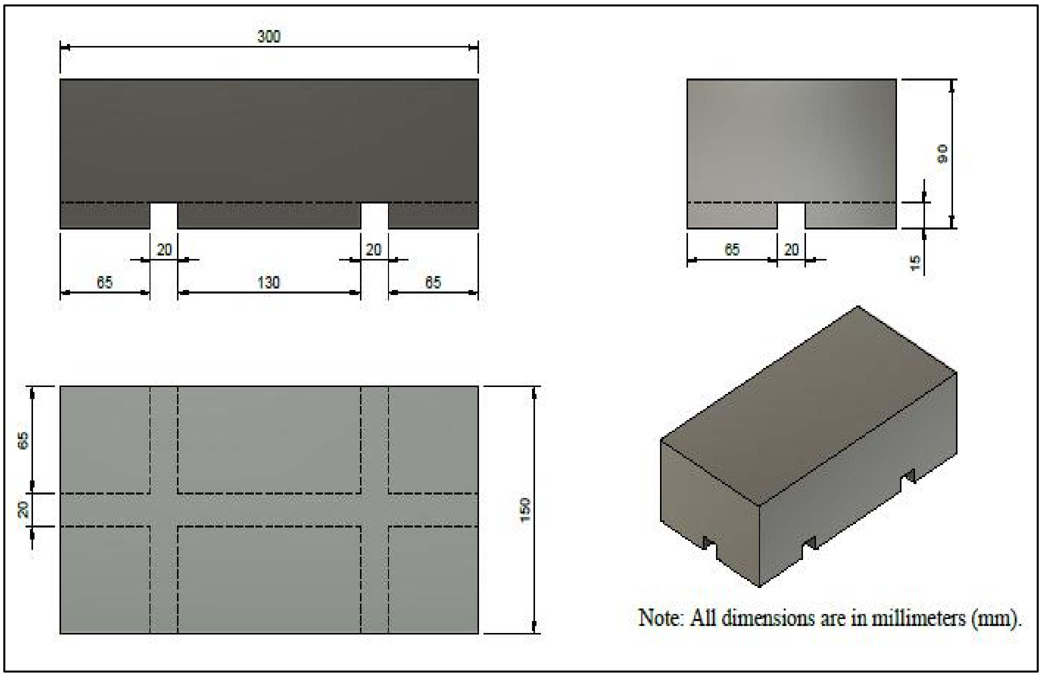

Figure 4.3: Dimensions of full coping interlocking block design.

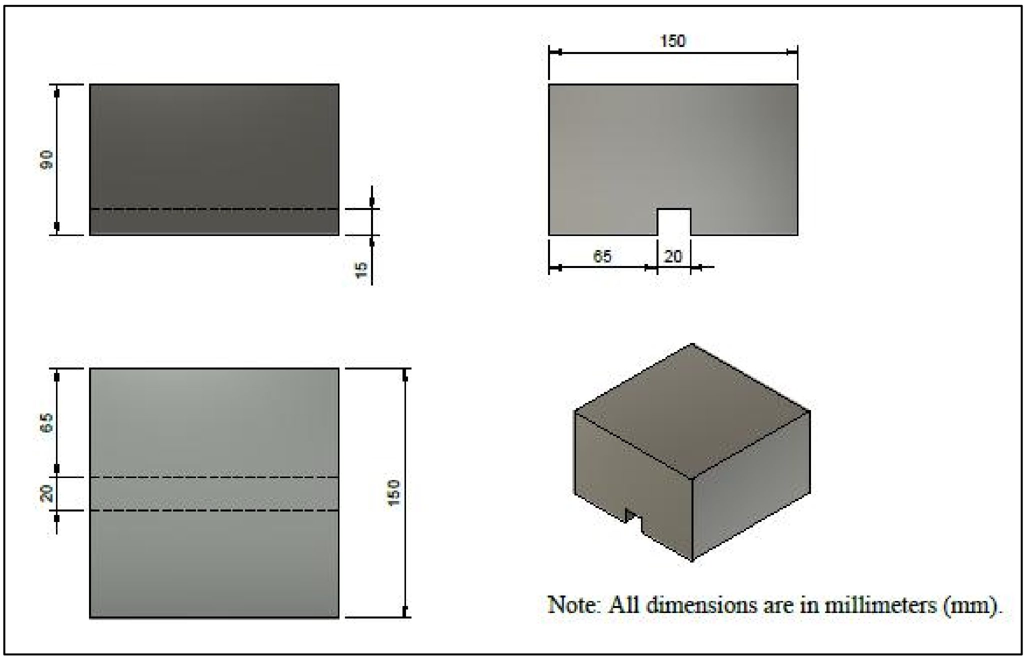

Figure 4.4: Dimensions of half coping interlocking block design.

4.2 Sustainable materials used for current interlocking block

In this era, sustainability has become a popular topic and concern in the neighbourhood in creating the least impact on the environment and human health. It is very often that the impact during manufacturing, logistics, disposal of construction waste, etc in the civil engineering field is invisible, which engineers have to utilize and choose wisely in the selection of materials. One of the main components used during the construction is brick. As the awareness of sustainability increases, engineers have started to develop interlocking blocks for the replacement of conventional brick that required the burning process for its production. This reduced environmental impacts typically the emission of carbon dioxide and other hazardous gases during the manufacturing of conventional brick. Besides that, researchers also keep on improving the materials used for block production, which further improves the properties and sustainability. Typically, interlocking blocks are made of concrete and compressed soil. Moreover, several researchers have made investigations on the potential by incorporating waste materials in the production of interlocking blocks. For example using crumb rubber, roof tile waste, sugarcane bagasse, sewage sludge and etc as a partial replacement for the aggregate and cement. With this, the discarded waste can be reused to further reduce the major environmental impact created by the waste.

4.2.1 Rubberized interlocking block (RIB)

A research conducted by Al-Fakih, et al. (2008) utilized crumb rubber and fly ash as a partial replacement for the fine aggregate and cement in the production of the rubberized interlocking block. One of the reasons for using crumb rubber in this design was to tackle the scrap tires issues. Besides, part of the cement is replaced by fly ash in order to reduce the use of raw material. The dimensions of the RIB that are developed are 250 mm, 125 mm and 105 mm in length, width and height respectively as shown in Figure 4.5. Throughout the research, the physical properties such as the density and water absorption have been tested followed by the mechanical properties. Moreover, the replacement percentage for the partial replacement was 10 % of crumb rubber for the sand, whereas 56 % of cement is replaced by fly ash. The mix proportion of fine aggregate and cementitious materials is in the ratio of 2 to 1. The water-cement ratio adopted was 0.55 in this study.

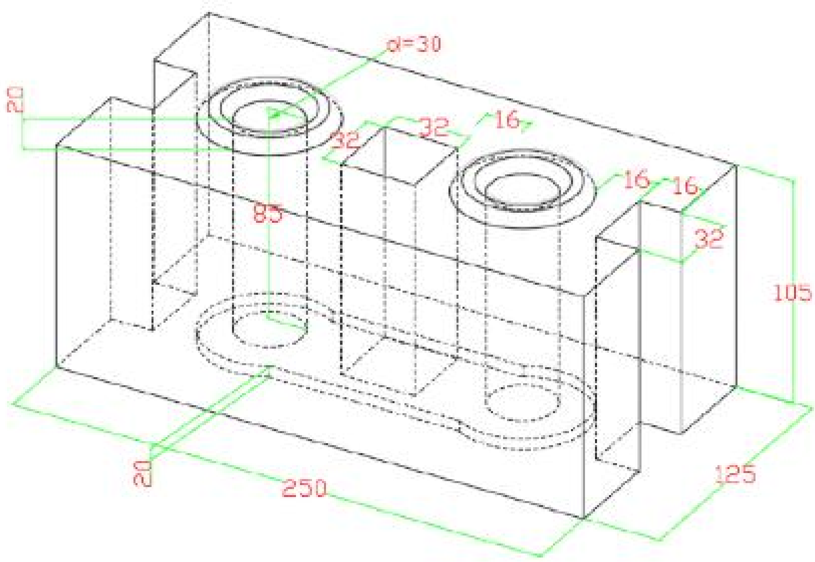

Figure 4.5: Dimensions of the RIB (Al-Fakih, et al., 2018).

The density results obtained for the developed RIB have jotted down to have an average of 1891.5 kg/m^3 as shown in Table 4.1. The density result is considered to be accurate and tally to the finding of research carried out by Ortega, et al. (2016), which a RIB with 10 % crumb rubber can achieve a dry density of approximately 1930.3 kg/m^3. However, there are reasons for the developed RIB in the study is way lower compared to the research by Ortega, et al. (2016). For example, it can be due to the high fly ash content as 56 % of cement have been replaced as well as the specific gravity of the crumb rubber used for the investigation is considered low.

Table 4.1: The results density of RIB (Al-Fakih, et al., 2018).

Sample	Weight (kg)	Density (kg/m^3)
1	5.61	1928.90
2	5.45	1940.90
3	5.41	1937.70
4	5.29	1822.00
5	5.14	1827.90
Average	5.38	1891.50

Moreover, the water absorption was carried out by using two methods, which are the cold immersion and boiling test. The specimen block is submerged for 5 hours and 24 hours for the boiling test and cold immersion respectively. The water absorption results obtained for the boiling test were approximately 9.73 %, while the cold immersion test showed 3.07 % as an average for the specimen. Based on the results, it showed the RIB has relatively lower water absorption as compared to normal concrete blocks. This happens mainly due to the hydrophobic properties of the substituted crumb rubber.

Lastly, the average compressive strength achieved for the hollow RIB and solid rubberized block is 18.03 MPa and 24.29 MPa as shown in Table 4.2 respectively. The compressive strength of the RIB block is comparatively lower than the pure concrete block. Theoretically, it is caused by the solid load in a RIB that is lowered that is replaced by the scrum rubber as well as the hydrophobic properties of rubber that tend to entrapped air near the surface (Al-Fakih, et al., 2018).

Table 4.2: Compressive strength of the RIB (Al-Fakih, et al., 2018).

Block type	Average weight (kg)	Average max load (kN)	Compressive strength (MPa)
Hollow	5.47	338.06	18.03
Solid	6.55	685.61	24.29

4.2.2 Incorporating roof tile waste in interlocking block

A research conducted by Malavika, et al. (2017) has investigated the best proportion of roof tile waste that can be incorporated and replace the M-sand in the concrete composition and further produce interlocking blocks based on the proportion. In the study, the researcher has run through two trials for the concrete cube test with the composition of 53-grade cement, coarse aggregate and M-sand in the proportion of 1:2:4 and 1:3:6. The results obtained for the first proportion have listed an average compressive strength of 15 MPa which is higher than the second proportion that achieved 9 MPa. Besides, several specimens with a different percentage of roof tile waste that replaced the M-sand have been tested by using the ratio of 1:2:4 that has been obtained previously. The percentage replacement of M-sand that is ranged from 0 % to 30 % and it is found out that 20 % of replacement of M-sand by roof tile waste is optimum.

The interlocking blocks that are produced in this study have a dimension of 300 mm in length, 220 mm in width and 150 mm in depth. The block consists of one tongue which protrudes in the middle and depression groove part at the side of the block as shown in Figure 4.6.

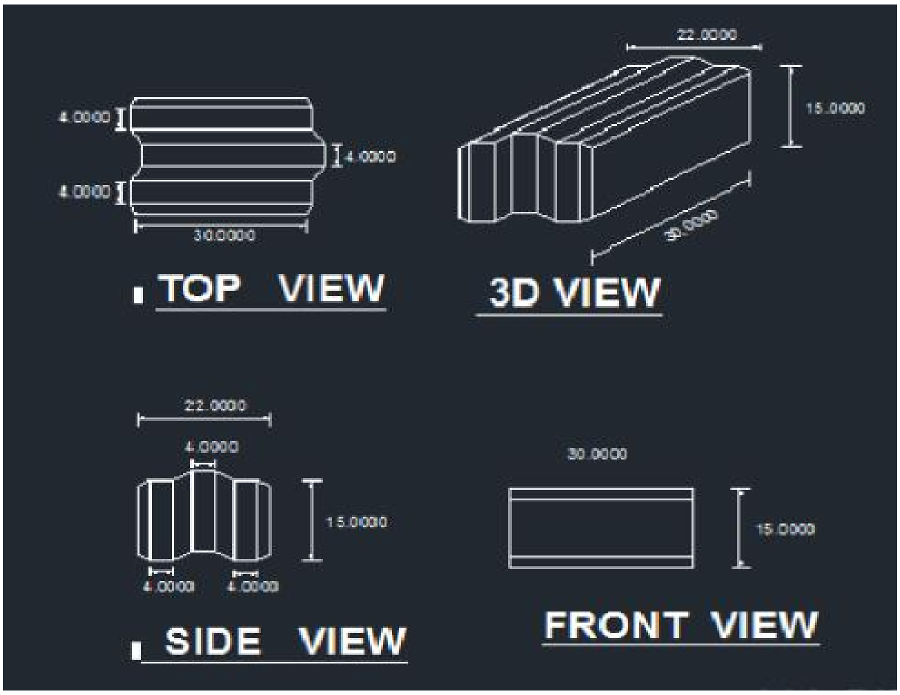

Figure 4.6: The dimensions of the interlocking block incorporated roof tile waste (Malavika, et al., 2017).

In addition, the average dry density of the interlocking block achieved was 1815.15 kg/m^3 as shown in Table 4.3. Besides that, this block has satisfied the physical requirements as stated in IS 2185 (Part1), which can be categorised as a solid load bearing block with a density of not less than 1800 kg/m^3 or known as block grade D.

Table 4.3: Block density for the interlocking blocks.

	Density (kg/m^3)	
	Before drying	After oven drying
Sample 1	1837.37	1816.16
Sample 2	1841.41	1814.14
Average	1839.39	1815.15

Next, the water absorption for the block is approximately 1.73 % as an average and it satisfied the bottom line of not more than 10 % of water absorption as stated in IS 2185 (Part 1). The last part of the studies was investigated the compressive strength of the block after curing for 28 days. The average crack load and collapse load value recorded are 200 kN and 350 kN respectively as shown in Table 4.4. After all the compressive strength for the collapse load is 5.30 MPa (Malavika, et al., 2017). Hence, the block is classified as a grade D(4.0) block based on IS 2185 (Part 1).

Table 4.4: Compressive strength of the blocks (Malavika, et al., 2017).

	Crack load (kN)	Collapse load (kN)
Sample 1	195.00	350.00
Sample 2	205.00	350.00
Average	200.00	350.00

4.2.3 Incorporating sugarcane bagasse in interlocking earth block

Since a typical interlocking block is produced either with concrete and soil. Therefore, multiple researchers have undergone the research in finding a suitable waste material as a replacement for cement, which acts as a stabilizer for interlocking earth blocks. One of the suitable waste materials to be used are sugarcane bagasse (SCBA). According to Onchiri, et al. (2014), a series of experiments had been conducted in terms of linear shrinkage box test, mechanical analysis for the soil, compaction proctor test, Atterberg limits and compressive strength test. The test is conducted to determine the appropriate amount of stabilizer, the suitability of the soil, water content required in order to produce the desired compressive strength.

For the investigation, 6 mix proportions are prepared in terms of percentage of sugarcane bagasse that replaced the cement, which is ranged from 0 % to 8 % with an increment of 1.6 %. The plasticity index for the proportion shows an upward trend, in which the SCBA volume is directly proportional to the plasticity index. Moreover, the shrinkage for the soil recorded is roughly about 8 %.

In the last stage of the investigation, it is found out that 3.2 % is the best percentage of substitution for cement in the interlocking earth block as shown in Figure 4.7. Based on Figure 4.7, the strength of the block is in an upward trend as the proportion of SCBA increases started from 0 % to 3.2 % of replacement. However, it declined after approaching 3.2 %. Besides that, the best proportion of replacement shows in the investigation might not be true, as a result, is also dependent on the type of soil used (Onchiri, et al., 2014).

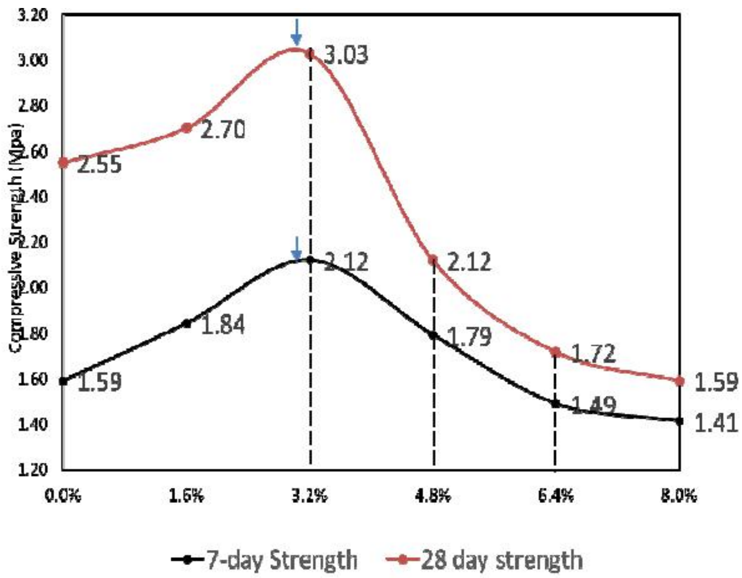

Figure 4.7: Compressive strength (MPa) against SCBA + OPC content (Onchiri, et al., 2014).

4.2.4 Incorporating sewage sludge and fly ash for interlocking block

Due to the ecological, the management of sewage sludge has become a significant issue for water treatment plants in recent decades. Due to the high overwhelming metal substance, the substance is not ordinarily allowed to be covered in soil or utilized as farming manure. A few examinations have been done on the use of these materials especially in concrete mix design for the development of materials (Jamshidi, Jamshidi and Mehrdadi, 2012).

According to Pavithra, et al. (2018) a study was conducted to test on mechanical and physical properties of the Hydraform interlocking block. The composition of the mix used consisted of cement, fly ash, stone dust and sewage sludge. In the research, three proportions were set for the investigation as shown in Table 4.5 with sample code of A1, A2 and A3.

Table 4.5: Mix proportion of the mix in percentage.

Mix proportion	Cement (%)	Fly ash (%)	Stone dust (%)	Sewage sludge (%)
A1	25	25	40	10
A2	25	25	30	20
A3	25	25	20	30

The water absorption of the interlocking block recorded is in the range from approximately 9 % to 12 % under the research as shown in Table 4.6. However, if the water absorption is drawn in a graph, it will resemble a bell curve. Besides, the water absorption might not have a direct relationship with the material porosity itself. This is because only part of the pores provide a free water passage, while the rest of the pores are unable to access for the cold water absorption test. Therefore, it is recommended to use the boiling method as a second test to compare further and confirm the value obtained.

Table 4.6: Water absorption of the interlocking block (Pavithra, et al., 2018).

Mix proportion	A1	A2	A3
Dry weight (gm)	6836	8052	8510
Wet weight (gm)	7492	9022	9280
Water absorption (%)	9.60	12.05	9.05

In the end, the highest compressive strength obtained was 7.91 MPa for the A1 mix proportion. As referring to Table 4.7, it revealed that as the percentage of composition of sewage sludge increases, the compressive strength tends to be reduced. However, the mix proportion of A1 to A3, all show a rising trend that the compressive strength increased with age.

Table 4.7: Compressive strength of the block (Pavithra, et al., 2018).

Mix proportion	Compressive strength, MPa		
	7 days	14 days	21 days
A1	7.14	7.65	7.91
A2	3.57	4.08	4.84
A3	3.06	3.57	3.82

4.3 Propose material for designed interlocking block

4.3.1 Palm kernel shell (PKS)

Malaysia stands as a nation that brought oil palm from a minor yield to the status of a significant product crop in world exchange. Besides, the oil palm industry in Malaysia has grown exponentially from 1960 to 2016, which the area planted for oil palm has changed from 55000 to 5.74 million hectares respectively. Oil palm is also known as one of the high productivity crop products that are expected to fulfil the future vegetable oil demand in 2050 (Barcelos, et al., 2015). Oil palm is genuinely a brilliant harvest of Malaysia as far as financial resources exporting the production of the nation. Oil palm is developed for its oils. As a vegetable oil seed crop, the oil palm is a productive converter of sun based vitality into biomass. Other than being a productive palm producer it likewise creates various products and by-products or waste. The buildups of the oil palm industry are from the field and factory.

The waste from the field incorporates trunk and fronds at replanting and pruned fronds. The oil palm trunks are accessible just when the palms arrive at their monetary existence of around 25 years and are replanted. The fronds, then again, are accessible at replanting and during the normal pruning.

The industry waste from the factory is delivered during the processing of the new natural product packs for the extraction of oil and packaging. The waste is palm kernel shell, palm oil mill effluent, empty fruit bunch, heater debris, and bundle debris. The extension of the palm oil industry followed by the age of gigantic amounts of side-effects at the estate grounds, oil factories and processing plants. When all is said in done the new organic product bundle contains about 27 % palm oil, 6-7 % palm bit, 14-15 % fiber, 6-7 % shell and 23 % unfilled natural product pack material (Triyono, et al., 2019).

It has been evaluated that the processing forms produces about 10.3 million tons of palm mesocarp fiber, 4.3 million tons of PKS and 2.4 million tons void organic product packs as deposits or waste yearly (Uemura, et al., 2017). PKS is one of the losses from the palm oil industry, which some time has been utilized as a fuel in the evaporator to create steam and power for plant forms. Palm kernel shell is the oil palm natural product seed that is broken and the part takes out and utilized for separating palm kernel oil. Therefore, it is the side-effects of palm oil preparation during which the palm oil is extricated.

According to Adebayo (2012), the squashed stone having the coefficient of consistency was 6 while the coefficient of curvature was 1. This shows the squashed stone total utilized categorize as well-graded aggregates with sizes going from 0.4 mm to 30 mm. For PKS, the coefficient of consistency was 2.3 and the coefficient of curvature was 1.35, indicating that the piece shells utilized were gap graded with sizes running from 0.5 mm to 30 mm, falling inside the medium or coarse sand division and the fine or medium rock part. In addition, the utilization of PKS as aggregate tends to reduce the quality of concrete nearly half as compared to using crushed stone.

However, the decrease in quality could be caused by numerous variables, for example, the lightweight, flaky shape or semi-permeable nature of PKS. It is along these lines clear that palm part shells not suitable as a fill-in for squashed stone as total in concrete with the exception of producing low strength masonry units. Nonetheless, concrete with PKS as a total could be utilized for lightweight development work.

4.3.2 Palm kernel shell effects on lightweight interlocking blocks

The research conducted by Adebayo (2012) shows the strength of solid samples for water curing with submersion is more prominent than the strength of those cured by wetting, which is thus more prominent than the strength of samples which were left uncured. The research shows that appropriate and sufficient curing is required during development for the concrete strength. Moreover, in the study, the strength of laterite samples is directly proportional to age. The laterite samples strengthened with PKS in a ratio of 1:4 (PKS: laterite) had higher strength than plain laterite samples that are about 15 % contrast. Along these lines, the utilization of PKS as a total in laterite ought to be empowered. Besides that, concrete with crushed stone as a coarse total has higher strength than concrete with PKS as aggregate. This shows PKS is not suitable to be filled in for squashed stones as coarse total in concrete aside from stylish purposes. Be that as it may, concrete with PKS as total could be utilized for lightweight development work.

Laterite blocks fortified with palm kernel shells are about 15 % more grounded than plain laterite blocks. In any case, it has been found that the extent of using part shells that would bring about the most extreme quality of solid laterite blocks is 25 %, above which there could be a decrease in quality. In request to reduce the cost of masonry block and to likewise improve the engineering properties of PKS block is suitable to replace sandcrete block and used as a non-load-bearing wall. Hence, palm kernel shells, the result of agro-handling from oil palm, are large progressively utilized alternatives for the used in concrete.

4.3.3 Density of palm kernel shell concrete (PKSC)

In general, the density of construction material contributed to the overall dead load of the structure. The density of the concrete depends on the specific gravity of the aggregate used in the concrete mix. A study on the effect of using palm kernel shell (PKS) as a partial replacement as the coarse aggregate by Azunna (2019), a total of 40 samples is prepared and is tested on the 7, 14, 21 and 28 days. Since the compressive strength of a typical masonry unit is important, hence the density is one of the determinant factors. The optimum density achieved is 2429 kg/m^2 for the pure concrete on days 28. In contrast, as the ratio of substitution of PKS increases, the density of the block decreases as shown in Table 4.8. However, when the coarse aggregate is replaced in total by PKS a minimum density listed was 1425 kg/m^3 that can be classified as lightweight concrete based on ASTM C90 or ASTM C129.

Table 4.8: Density of palm kernel shell concrete with the variation of PKS aggregate replacement (Azunna, 2019).

	Density (kg/m^3)					
Days PKS replacement (%)	0	10	25	50	75	100
7	2326	2193	1956	1719	1541	1363
14	2311	2252	2104	1629	1529	1378
21	2400	2178	2104	1659	1541	1393
28	2429	2311	2222	1636	1481	1425

Apart from that, the density of palm kernel shells is recorded in the range of 1863 kg/m^3 to 1910 kg/m^3 depending on the ratio of water and cement as well as the portion of superplasticizer in the research conducted by Okafor (1991). An investigation about the concrete strength for the PKSC with incorporate fly ash revealed that the attributable to a lower compacted bulk density of PKS aggregate is around 60 % lower in comparison with crushed stone, meanwhile the 28-day air-dry density of PKSC is around 22 % lower than standard weight concrete. PKSC for air-dry densities seen in days 28 with 10 % and 15 % fly ash is 2 % lower and 3 % lower than PKSC without fly ash.

Besides, the plain concrete without PKS is frequently announced as 1 % lower and 2 % lower for with and without fly ash. However, throughout the test, it shows that lower volumes of fly ash tend to produce higher density concrete (Mannan and Ganapathy, 2004).

Besides, a minimum density of 1400 kg/m^3 is recorded by Muntohar and Rahman (2014) using the mix proportion of 1:1:3 in terms of cement, sand and PKS as shown in Figure 4.8. Figure 4.8 also revealed that as the size of the PKS used in the mix increases, the density of the blocks tends to reduce. This result is also tally with the research from Azunna (2019) whereas the substitution of the PKS rises, the density will be reduced, no matter the type of PKS size is applied for the mix.

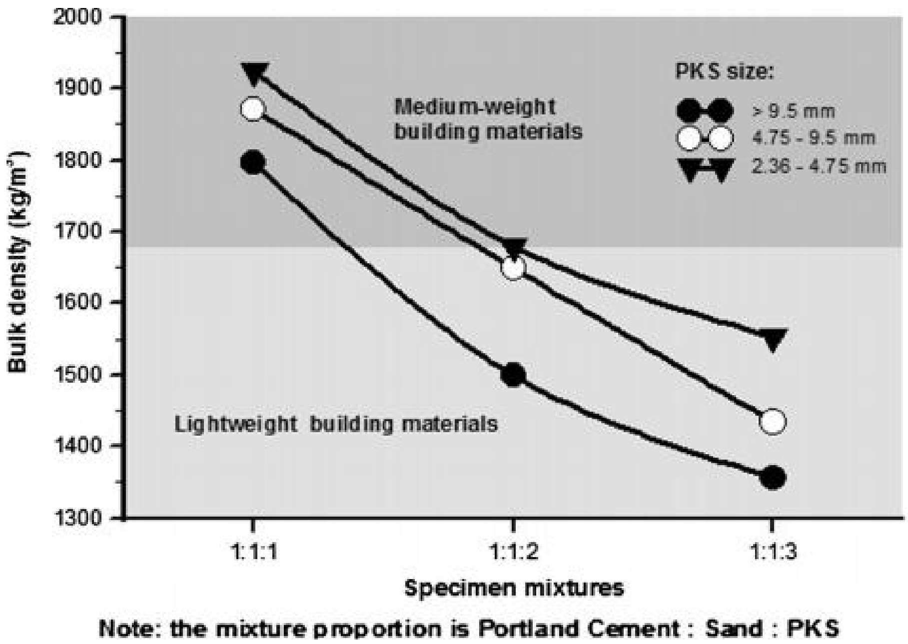

Figure 4.8: The density of palm kernel shell concrete with a variation of PKS aggregate proportion (Muntohar and Rahman, 2014).

Although palm kernel shell concrete (PKSC) says lower about 22 % in terms of density as compared to normal weight concrete. However, it is suitable to be used as a lightweight construction material that can be adopted in the development of lightweight interlocking block since the lowest density recorded for coarse aggregate that is fully replaced by PKS is approximately 1425 kg/m^3, while the density of using PKS size larger than 9.5 mm is able to achieve approximately 1350 kg/m^3 for the proportion 1:1:3. Therefore PKSC is feasible to be utilized in lightweight interlocking blocks typically for non-load-bearing walls.

4.3.4 Water absorption of palm kernel shell concrete (PKSC)

Water absorption is mainly caused by the amount of free water passage of the aggregate itself that allowed water to be stored. According to Maghfouri, Shafigh and Aslam (2018), research has been conducted including the water absorption among normal weight concrete and palm kernel shell concrete. The result revealed that PKSC possesses a higher water absorption as compared to normal weight concrete, in which the water absorption for NWC is approximate 3 % or less. Whereas, for PKSC the maximum water absorption achieved if the coarse aggregate is fully replaced by palm kernel shell was 8 %. As based on Figure 4.9 clearly illustrated the relationship between PKS substitution and its water absorption. Hence, as the substitution of the shell increases, the water absorption rises as well. In addition, Azunna (2019) shows a similar trend that the higher the kernel shell content of the palm as shown in Figure 4.10.

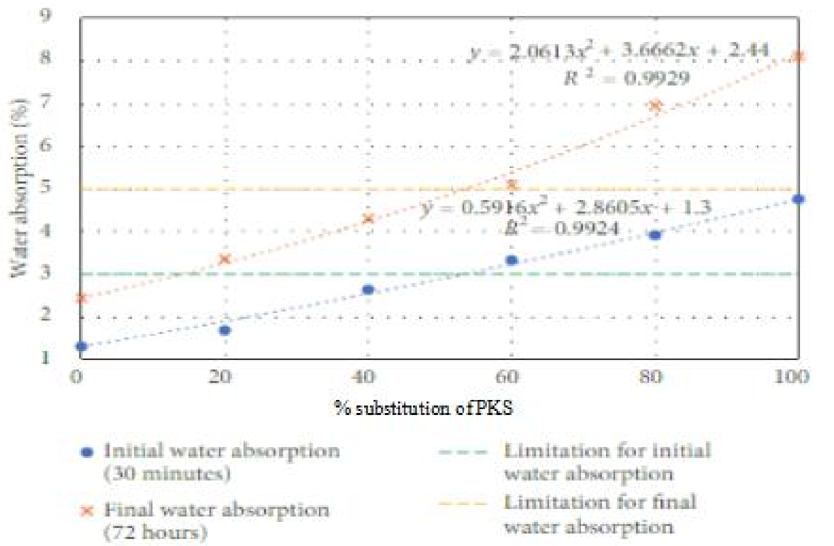

Figure 4.9: Water absorption versus % substitution of palm kernel shell (Maghfouri, Shafigh and Aslam, 2018).

Cube no.	% Replacement of coarse aggregate	Weight before immersion (kg)	Weight after immersion (kg)	Absorption gain (kg)	% Gain in moisture	Average % gain in moisture
A_{11}	10%	7.2	7.5	0.3	4.17	3.48
A_{12}		7.2	7.4	0.2	2.78	
B_{11}	25%	6.5	6.7	0.2	3.08	3.06
B_{21}		6.6	6.8	0.2	3.03	
C_{11}	50%	5.7	5.9	0.2	3.51	3.48
C_{21}		5.8	6.0	0.2	3.45	
D_{11}	75%	5.1	5.3	0.2	3.92	3.89
D_{21}		5.2	5.4	0.2	3.85	
E_{11}	100%	4.1	4.3	0.2	4.88	4.88
E_{21}		4.1	4.3	0.2	4.88	

Figure 4.10: Water absorption in percentages for various substitution of palm kernel shell (Azunna, 2019).

Moreover, PKSC water absorption is also affected by the size of the shell used for its production. This is because larger shell sizes seem to have more interparticle-void and microspores that allowed the water to access. Based on Muntohar and Rahman (2014) a typical large size PKS has about 37 % in terms of its porosity. The values obtained to reflect the theory behind seem to be true, which have been conducted as shown in Figure 4.11. It is reflected that the water absorption is directly proportional to PKS size regardless of any shellcrete composition. Although, PKSC possesses higher water absorption as compared to normal weight concrete, which might reduce the strength of blocks. However, PKSC is still suitable to be used as a non-load bearing block or masonry by replacing sandcrete for example. This is due to sandcrete has comparatively higher in water absorption in comparison with PKSC. Thus, the water absorption fulfilled the minimum requirements for the samples as lightweight concrete based on ASTM C90.

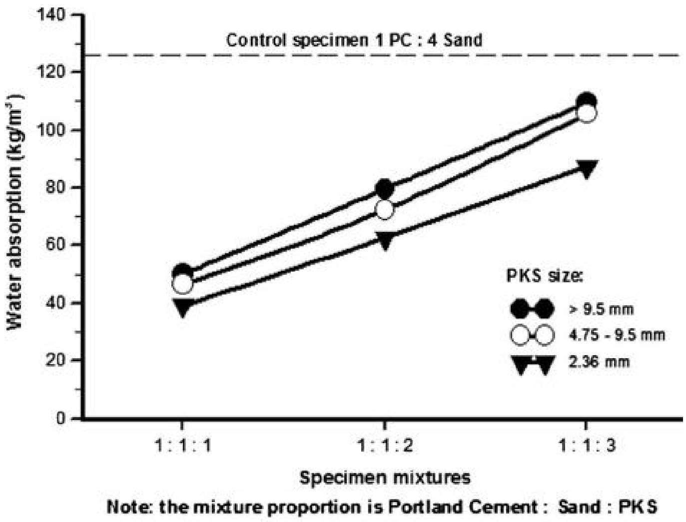

Figure 4.11: Relationship between water absorption and PKS size (Muntohar and Rahman, 2014).

4.3.5 Compressive strength of palm kernel shell concrete (PKSC)

After all, compressive strength is the main component that influences and is related to other properties tests, such as the flexural test, modulus of elasticity, triaxial strength, etc. In general, concrete samples required a proper duration of time to be mature or to achieve 90 % of its strength, which usually takes around 21 to 28 days. Hence, in the study conducted by Oti, Okereke and Nwaigwe (2017), 5 compositions of mixtures for PKS replacement is utilized from 0 % of substitution to fully replaced with an increment substitution of 25 %. As based on Table 4.9 the compressive strength recorded in days 28 is in a range from 12.71 to 16.63 MPa for 25 % to 100 % replacement respectively. This means the replacement of shells tends to reduce the compressive strength of samples. However, the compressive strength of 12.71 MPa still achieved the minimum individual block compressive strength, which is based on ASTM C90 for the use as a load-bearing wall. Besides that, the compressive strength of PKSC can reach about 20 to 24 MPa in 28 days with the right proportion (Mannan and Ganapathy, 2004). Meanwhile, Okafor (1991) obtained results with 25 to 30 MPa as the maximum compressive strength that comprised PKS as aggregate.

Table 4.9: Compressive strength with variation percentage replacement of palm kernel shell as coarse aggregate, MPa (Oti, Okereke and Nwaigwe, 2017).

	Compressive strength (MPa)				
Days PKS replacement (%)	0	25	50	75	100
7	15.10	12.11	9.16	8.44	3.90
14	18.97	15.19	13.70	13.03	6.59
21	19.44	15.58	14.18	13.88	7.95
28	21.73	16.63	15.60	14.63	12.71

Finally, PKS size affects certain aspects of the compressive strength of blocks such as the mechanical bond between the shell or aggregates and the cement matrix. Figure 4.12 showed that the mix proportion 1:1:2 revealed a trend that larger PKS mix lowered block compressive strength. In contrast, the compressive strength trend for mix proportion 1:1:1 and 1:1:3 is vice versa. According to Muntohar and Rahman (2014), the contribution of the shell aggregate toward the load resistance seems to be low in the case for mix proportion 1:1:1 with the cement matrix. Moreover, for mix proportion 1:1:3 possibly there is an inadequate mechanical bond form between the small size aggregate as well as the cement matrix, therefore revealing smaller PKS size with lower compressive strength. However, for the mix proportion of 1:1:2, the smaller PKS recorded a high compressive strength can be due to the flaky and sharp shape of the aggregate. Thus, it allowed the mechanical bond to be well-formed with the cement matrix. After all, based on the case it seems mix proportion 1:1:1 is much more reliable to produce lightweight concrete block by giving fulfilment toward the minimum compressive strength requirements of the block based on ASTM C90 for the use as a load-bearing wall, which the bottom line of average compressive strength of blocks shall not less than 13.1 MPa.

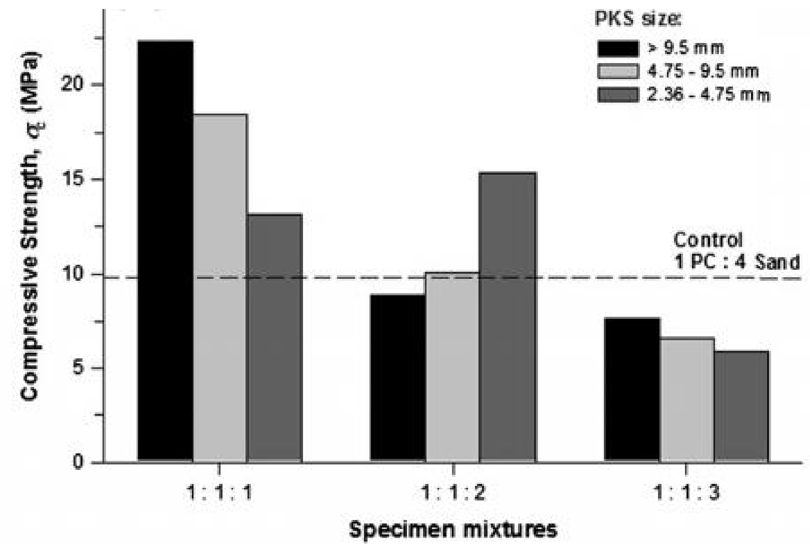

Figure 4.12: Compressive strength relationship with a variation of PKSC mix (Muntohar and Rahman, 2014).

4.4 Comparison of the sustainable materials

After all, the current market of sustainable materials used for interlocking blocks seems to be fewer in options. Hence, an overview comparison between proposed and existing materials used was listed in Table 4.10 for its density. In terms of density, the interlocking block incorporated crumb rubber and roof tile waste is within the range of 1680 kg/m^3 to 2000 kg/m^3. Both of these materials have relatively similar values of density, which can be categorized as medium-weight concrete based on ASTM C90 or ASTM C129. However, the density of the crumb rubber interlocking block has room to further reduce its density. This is because the study carried out were only replaced 10 % of crumb rubber as the sand. As a result, the density may be reduced with certain replacement increments since the unit weight density of crumb rubber is ranged from 640 kg/m^3 to 720 kg/m^3, which is comparable lighter than 1442 kg/m^3 for sand density. Meanwhile, palm kernel shell concrete result obtained from Muntohar and Rahman (2014) achieved an average density of 1350 kg/m^3, which makes it fall under the lightweight concrete class by referring to ASTM C90 or ASTM C129 with a full replacement for coarse aggregate. The result revealed is using a mixed ratio of 1:1:3 in terms of cement, sand and palm kernel shell respectively.

Table 4.10: Density of proposed and existing sustainable material used for interlocking block.

Author(s)	Material	Density, kg/m^3
Al-Fakih, et al. (2008)	Crumb rubber	1891.50
Malavika, et al. (2017)	Roof tile waste	1815.15
Onchiri, et al. (2014)	Sugarcane bagasse	-
Pavithra, et al. (2018)	Sewage sludge	-
Muntohar and Rahman (2014)	Palm kernel shell	1350.00

Moreover, the water absorption is frequently related to the durability of the concrete material. For example, the carbonation and chloride attack may happen due to the high water absorption of the material. Particularly, the water absorption is mainly due to the porosity and properties of the substituted material. Based on Table 4.11 displayed the roof tile waste incorporated block has the least water absorption capacity, while the rubberized block was undertaken as the second least with 3.07 % of water absorption. Besides that, the low percentage shown is relatively low caused mainly due to the hydrophobic properties especially for crumb rubber as its nature. Therefore, the water absorption of the block utilise is merely the same as the conventional normal weight concrete, which typically has 3 % of water absorption. In contrast, block utilized sewage sludge and palm kernel shells have way higher water absorption than conventional concrete block. For palm kernel shell concrete, the high water absorption is due to the aggregate porosity and most importantly are the water passage that is formed within the concrete itself. As mentioned the porosity of materials is not the main factor governing the water absorption, whereas the water passage formed is main. Therefore, the 8 % high water absorption for PKSC is still acceptable as according to ASTM C90 requirements for blocks under the mix ratio of 1:1:3 comprising cement: sand: PKS.

Table 4.11: Water absorption of proposed and existing sustainable material used for interlocking block.

Author(s)	Material	Water absorption, %
Al-Fakih, et al. (2008)	Crumb rubber	3.07
Malavika, et al. (2017)	Roof tile waste	1.73
Onchiri, et al. (2014)	Sugarcane bagasse	-
Pavithra, et al. (2018)	Sewage sludge	9
Muntohar and Rahman (2014)	Palm kernel shell	8

At last, the compressive strength plays a major role to undertake the load from structure especially for load-bearing wall and pillar type structures. From Table 4.12, the rubberized block has the highest compressive strength with a value of 18.03 MPa. The values were gradually ranked from sewage sludge block, PKSC, roof tile waste block and sugarcane bagasse block in a descending manner. Moreover, out of all only rubberized blocks has success complied with the requirements as according to ASTM C90, which the minimum criteria were 13.1 MPa for all classes. This means the rubberized block is suitable to be used for the construction of a load-bearing wall. In such a case, PKSC is still possible to be adopted in manufactured interlocking blocks. Although the 7.5 MPa using a mix proportion of 1:1:3 failed to satisfied ASTM C90 for the load-bearing wall that may due to excess replacement of PKS as aggregates. However, with the 7.5 MPa using a mix proportion of 1:1:3 can be used for non-load-bearing wall based on ASTM C129. Moreover, the mix proportion for PKSC can be adjusted to 2 portions of PKS with 1 portion for both cement and sand. This change contributed to an increase in compressive strength and may achieve approximately 15 MPa if using PKS size ranging from 2.36 mm to 4.75 mm. Therefore, the 15 MPa compressive strength is said to be adequate especially for the construction of load-bearing walls for example.

Table 4.12: Compressive strength of proposed and existing sustainable material used for interlocking block.

Material	Compressive strength, MPa				
	Crumb rubber	Roof tile waste	Sugarcane bagasse	Sewage sludge	Palm kernel shell
Days Author(s)	Al-Fakih, et al. (2008)	Malavika, et al. (2017)	Onchiri, et al. (2014)	Pavithra, et al. (2018)	Muntohar and Rahman (2014)
7	-	-	2.12	7.14	-
14	-	-	-	7.65	-
21	-	-	-	7.91	-
28	18.03	5.30	3.03	-	7.5

4.5 SWOT analysis of propose material for designed interlocking block

4.5.1 Strengths

Palm has been Malaysia's single most significant item crop. In the early years, Malaysia was the largest palm oil producer and Indonesia bypassed it in 2006 and now is the second-largest palm oil producer. As the demand rate increases throughout the decades as well as initiatives carried out by local governments in encouraging youngsters to invest in the palm industry. At the same point, palm oil waste rises. Besides that, following 1960, the planting area had grown at a steady pace. 1.5 million hectares of palm trees were planted in 1985, and are steadily growing. Figure 4.13 showed that in 2005 the planted territory for palm is approximately 4 million hectares and it had ascended to about 1.5 million hectares annually.

State	2005	2006	2007	2008
Johor	667,872	671,425	670,641	na
Kedah	75,472	76,329	75,096	na
Kelantan	89,886	94,542	99,763	na
Melaka	52,015	52,232	49,113	na
N.Sembilan	155,164	161,072	170,843	na
Pahang	606.821	623,290	641,452	na
Perak	340,959	348,000	350,983	na
Perlis	278	258	260	na
P.Pinang	14,074	14,119	13,304	na
Selangor	132,100	128,915	129,315	na
Terengganu	163,967	164,065	161,287	na
Peninsular Malaysia	**2,298,608**	**2,334,247**	**2,362,057**	**-**
Sabah	1,209,368	1,239,497	1,278,244	na
Sarawak	543,398	591,471	664,612	na
Sabah & Sarawak	**1,752,766**	**1,830,968**	**1,942,856**	**-**
Malaysia	**4,051,374**	**4,165,215**	**4,304,913**	**4,487,957**

Figure 4.13: Malaysia palm planted territory in hectares (Abdullah and Sulaiman, 2013).

Moreover, there are mainly 5 types of waste generated from the palm industry as shown in Table 4.13. Since the waste brings environmental pollution and in need to be disposed of, hence a channel of recycling of the waste is needed. In light of its low ash content, plentiful sturdiness, low water absorption rate and generally solid fixed properties, palm kernel shell is a potential wellspring of producing sustainable lightweight concrete. Therefore, in terms of cement and aggregate substitution in concrete production, the palm kernel shell was chosen. Plenty of researches have confirmed the appropriateness and composition of using palm kernel shell in producing normal and lightweight concrete materials. Where a summary of the strengths incorporating palm kernel shell is revealed in Table 4.14 throughout the finding from previous researchers. Finally, the availability of palm kernel shells is said to be consistent especially in Malaysia and Indonesia, which revealed the potential and advantages of local concrete manufactured to incorporate such a waste.

Table 4.13: Palm industry generated waste in kilo tonnes (Abdullah and Sulaiman, 2013).

Wastes	Fronds	Empty fruit bunches	Palm pressed fibres	Oil palm trunks	Shell
Quantity (kilotonnes)	46837	18022	11059	10827	4506

Table 4.14: Summary concluded the strengths of Palm kernel shell concrete (PKSC) by previous researchers.

Author(s)	Concluding remarks
Oti, Okereke and Nwaigwe (2017)	● Concrete incorporating palm kernel shell experience gradually cracking trend, while normal weight concrete happens to be explosive crack.
Mannan and Ganapathy (2004)	● Palm kernel shells can engage approximately 40 % of the overall concrete volume.
Emiero and Oyedepo (2012)	● Incorporating palm kernel shell and palm fibre in concrete is suitable and is classified as lightweight concrete.
Alengaram, Jumaat and Mahmud (2008)	● Lesser in terms of crack width of palm kernel shell concrete compared to normal weight concrete. ● Palm kernel shell concrete exhibits high ductility behaviour for large deflection.

4.5.2 Weaknesses

In contrast, palm kernel shells do exhibit weaknesses in certain aspects and conditions. In most of the cases, PKSC has lower in terms of compressive and flexural strength and also hard to achieve the minimum water absorption requirements due to the natural properties of the PKS. In previous studies, the researchers concluded that the fresh concrete with replacement of PKS has reduced the workability. In most cases, a superplasticizer is needed to be added to ease the issues. Therefore, the mixed ratio of replacement for the shell is crucial if utilized as an aggregate for example. At this point, a variety of aspects are needed to be considered before manufactured palm kernel shell concrete. Table 4.15 has summarised various weaknesses from previous researchers, in which concluding on the mix ratio and behaviour, this can be a certain reference line for its percentage replacement for the future investigation based on the functionality that is desired to obtain.

Table 4.15: Summary concluded the weaknesses of Palm kernel shell concrete (PKSC) by previous researchers.

Author(s)	Concluding remarks
Maghfouri, Shafigh and Aslam (2018)	● Replacement of palm kernel shell as aggregate shall not more than 50 % in order to have water absorption below 5 %. ● Palm kernel shell replacement as coarse aggregate ranged from 80 to 100 % has higher shrinkage strain.
Muntohar and Rahman (2014)	● Palm kernel shell tends to reduce the compressive and flexural strength of the concrete.
Emiero and Oyedepo (2012)	● Natural materials are prone to degradation after some time and in this manner concrete manufactured with palm kernel shell ought to be observed routinely and replaced if appropriate.
Alengaram, Jumaat and Mahmud (2008)	● Early crack in palm kernel shell concrete beam happens due to the low modulus of rupture. ● Lower flexural strength for palm kernel shell concrete as compared to normal weight concrete.
Philips, Mutuku and Mwero (2017)	● The workability of palm kernel shell fresh concrete is reduced due to higher water absorption properties of the shell.

4.5.3 Opportunities

Moreover, the major opportunities of palm kernel shell concrete are coped with the local government. As an example, during the dispatch of the Green Building Index in 2009, the Government of Malaysia has made various approaches under the 2010 Budget. The National Green Technology Strategy was likewise acquainted with what is more with rebranding Pusat Tenaga to the National Green Technology Center, with a designation of RM20 million to advance green activities. This NGTP added to the requirement for manageability principles in government obtainment, and the advancement of assets and advances to fund sustainable products and advances. One significant impetus for the green structure industry is that to get the previously mentioned qualification, each endorsed green structure venture may claim a 100 % charge exception for additional capital consumptions. Another huge factor for the green structure area is that to accomplish the previously mentioned accreditation, each endorsed green structure task will guarantee a 100 % charge derivation for any capital uses. For actuality, these might be utilized to join against available benefits worth 100 %. Also, land proprietors are qualified for a stamp obligation exception reliant on the additional cost of getting GBI confirmation. Therefore, policies provided by the government have enhanced the utilization of sustainable materials in construction, which subsequently reflected the opportunities and potential of incorporating palm kernel shells in concrete as an additional option to the industry.

4.5.4 Threats

Even though the palm kernel shell is considerably cheap at the moment. However, the price of palm kernel shells has a tendency to surge based on the global demand rate. As mentioned earlier, the threats of utilizing palm kernel shells in concrete are the fluctuation of palm kernel shell price. The pricing was mainly affected by the demand and supply trend. In recent years, countries such as Japan and South Korea have introduced biomass schemes or policies that encourage local manufacturers to use sustainable energy. Based on Figure 4.14 it clearly shows the upward demand for palm kernel shells in Japan as more new renewable energy projects are emerging. One of the major surges of the demand from Japan was started from the year 2015 to 2018, which the imports nearly increased 3 times with a number of approximately 1,300,000 tonnes. After all, the situation may potentially cause a certain shortage in terms of supply in the future.

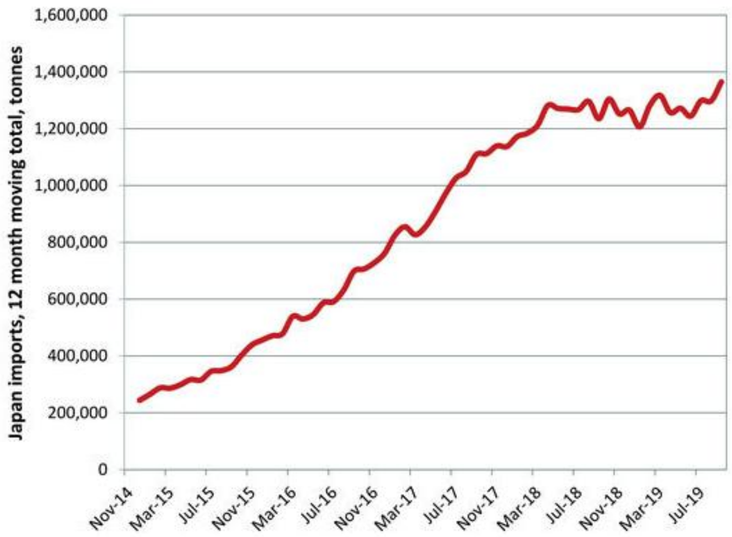

Figure 4.14: Japan imports demand (Levinson, 2020).

4.6 Installing method for designed interlocking block

First of all, when all the drawings are gathered from the engineers, the casting of the base as indicated by the plan is first to be done. This is significant that the ground floor is levelled while framing the base and floor slab. The deviation of the cast base shall be between 25 mm in height. This permits the block to be stacked at a consistent level and ensure that the last floor is levelled as based on the development drawings. In addition, appropriateness of the levelling is firmly encouraged to forestall the need to trim the first layer of blocks to suit the measure of the uneven completed concrete base. After the levelling process is done, the concrete is left over to cure for 3 days prior to laying of the first course of blocks. Besides that, it is recommended to water the base three times each day in the meantime, this forestalls cracking throughout the curing process.

Next, users can start by identifying the primary course of the blocks as indicated by design, as referring to the drawing or layout given. Then, identify and select the desired blocks to be utilized as well as the arrangements. The selection can be chosen from 2 different designed blocks at this point, which is the full and half interlocking block as shown in Figure 4.15 and Figure 4.16 respectively. This bit gives an overview thought regarding each block's size, measurements and positioning. At the moment, users shall not place any mortar blend yet. If some change is required or missing blocks are identified, this will be the best and ideal opportunity to do as such.

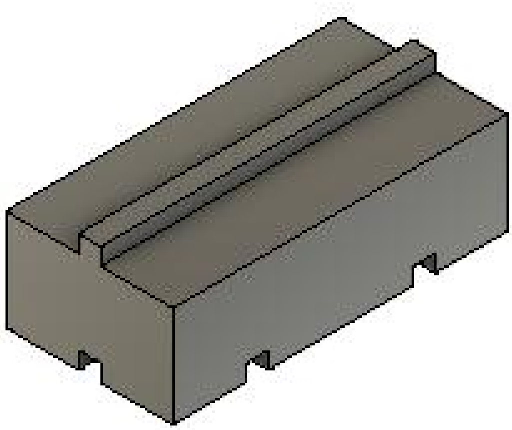

Figure 4.15: Full interlocking block.

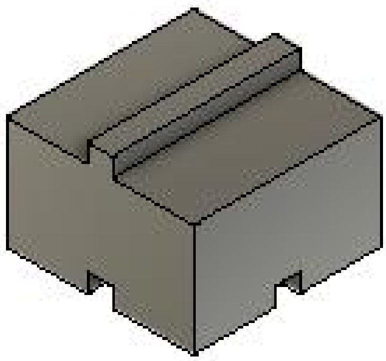

Figure 4.16: Half interlocking block.

Then, the user can start to lay the first permanent course. If there ought to be some distinction in the degree of the floor, investigate the variety in level and start lying at the highest location of the floor. Meanwhile, the mortar mix shall be prepared according to local authorities' requirements and put the mortar mix on the field where the blocks should be found and put the blocks on the head of the mortar mix in with the blocks tongues face upward and the grooves face downwards. It is ideal to start laying with the corners and gradually advance toward the opposite finish of the house or end of the wall. During the laying, the user can utilize a spirit level while setting to safeguard the principal course is completely levelled. Utilizing a rubber hammer delicately adjust the blocks into the place that reach a satisfactorily level. If the primary course has been done, leave the blocks at least one day prior to starting the stacking of the second course.

Subsequently, users may start to lay the second course with dry stacking by starting at the end of the structure and gradually advance to the finish end. This step is to prevent any undesirable movement of the blocks as well as its stability. During the process, users need to make sure that the blocks are well-bonded to each other and it is recommended to fill the gap with mortar if any noticeable separation is found. The reason is to avoid potential and excessive cracking of the wall. Moreover, the block shall be stacked based on the running bond to ensure an appropriate load transfer between blocks.

Then, the subsequent course procedure is repeated as in the second course until the final second course. At this point, the last level was stacked with full or half coping interlocking blocks as shown in Figure 4.17 and 4.18 respectively that allow the structure to have a flat top surface and to ease the trimming process. However, if the height of the structure is more than 2 meter for example, a user is recommended to place mortar or cement glue in each course to ensure the stability of the structure.

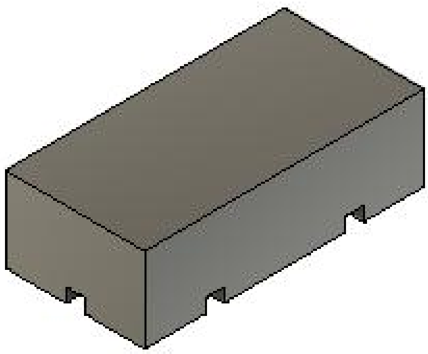

Figure 4.17: Full coping interlocking block.

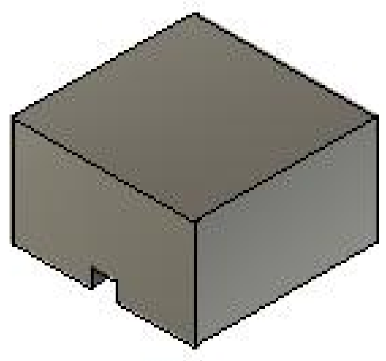

Figure 4.18: Half coping interlocking block.

Finally, apply to plaster or skim coat after ensuring all the blocks are stacked appropriately for a perfect outer look based on the requirements from local authorities as well as per construction drawings. Hence, the installing methods are summarised as shown in Table 4.16 to illustrate the overview of the installation method, which consists of 5 stages. Figure 4.19 to Figure 4.21 show the arrangements of the interlocking blocks for both the simple and corner wall.

Table 4.16: Summary installing method of designed interlocking blocks.

Stage	Description	Steps
1	Cast the base	• Setting out. • Cast the base or ground floor.
2	Laying the first course (Figure 4.19)	• Prepare and apply mortar on the field (according to local authorities' requirements). • Laying the full interlocking block by using a spirit level.
3	Laying subsequent courses (Figure 4.20)	• Prepare and apply mortar on the bottom course (if needed) or else dry stack. • Laying full or half interlocking block.

Table 4.16(cont.): Summary installing method of designed interlocking blocks.

4	Laying the final course (Figure 4.21)	● Prepare and apply mortar on the bottom course (if needed) or else dry stack. ● Laying full or half coping interlocking block.
5	Plastering or skim coat	● Apply to plaster or skim coat (according to local authorities' requirements and design).

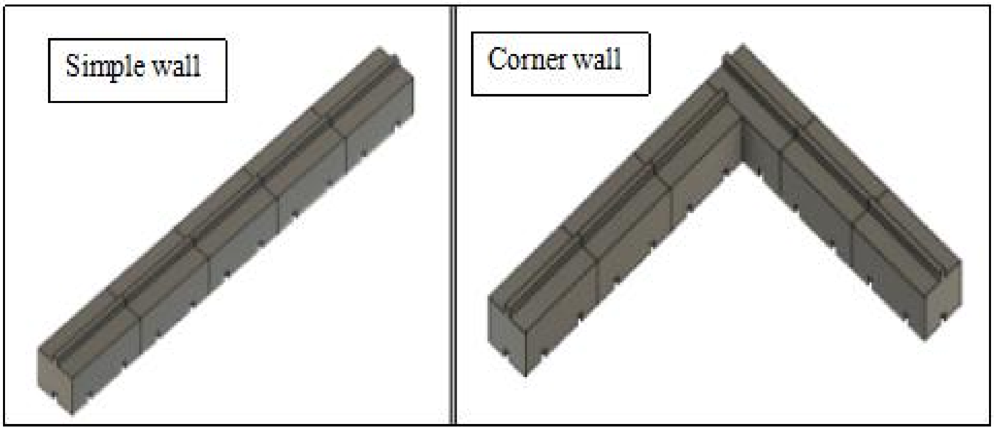

Figure 4.19: Laying the first course for both simple and corner wall.

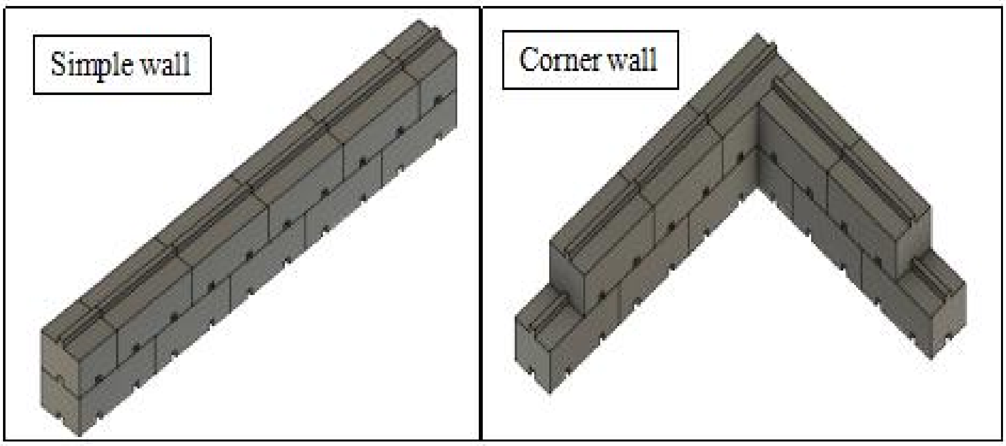

Figure 4.20: Stacking the subsequent courses in running bond pattern for both simple and corner wall.

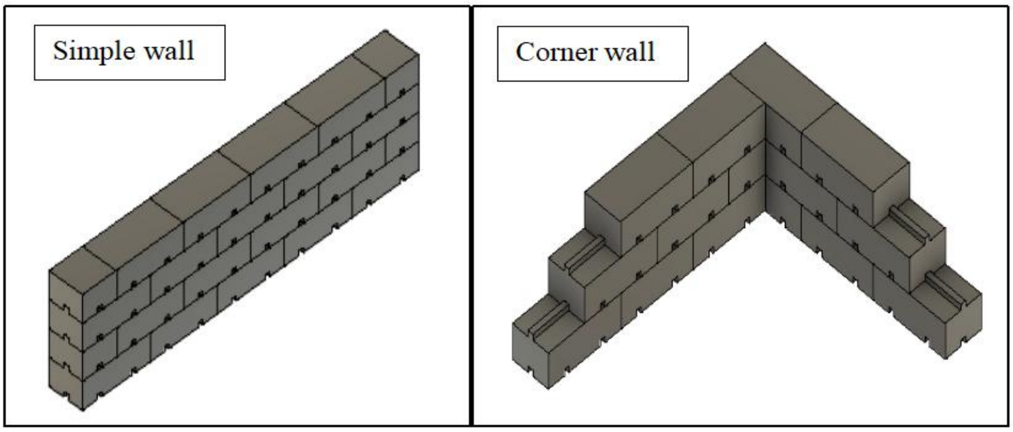

Figure 4.21: Stacking the coping interlocking blocks as the top of the wall for both simple and corner wall.

4.7 Summary

In summary, there are 4 types of interlocking block designed in the study. Types of the interlocking block are the full, half, full coping and half coping interlocking block. The blocks can be separated into two groups by referring to the block function, which can be categorised as the standard block and coping block. Standard block refers to the full and half interlocking block that is used from the first courses to final second courses during the wall construction. In contrast, the coping blocks are only used for the final courses during the wall construction. All the blocks with dimensions have been drawn and presented using Autodesk Fusion 360 software. Besides, the types of sustainable materials used in the current existing interlocking block are the crumb rubber, roof tile waste, sugarcane bagasse and sewage sludge. Meanwhile, palm kernel shells were identified as an appropriate, sustainable material for replacing the coarse aggregate in the concrete mix. Alternatively, PKSC is suitable for the manufacture of the designed interlocking blocks. The mix ratio of 1:1:3 and 1:1:2, consisting of cement: sand: PKS is suitable for use on the non-load-bearing and load-bearing walls. Also, the installation method proposed was comprised of a total of 5 stages. After all, the physical and mechanical study shall be carried out to further confirm the suitability of PKSC in such blocks design.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

After going through all the study and analysis starting from chapter 1 to chapter 4, few conclusions can be made with respect to the objectives that have been established at the beginning of the study.

This entire study has designed 4 types of interlocking blocks. The types of interlocking blocks are the full, half, full coping and half coping interlocking block. All these block designs are based on the running bond for the wall arrangements. The full and half interlocking block is designed for extrusion and protrusion for the top and bottom surface respectively. This allowed the block to be interlocked with one and another. Besides, a full and half interlocking block is meant to be used for the first course until the final second course in the wall construction. In addition, the half interlocking block is designed to ease the trimming or cutting processes during the construction. While, coping blocks have a different design and function compared to the full and half interlocking block, which is designed to be used for the final courses of the wall construction. With these blocks, the wall allowed it to end with flat and nice top surfaces. This reflected the blocks is effectively and reliably in terms of the design. Hence, the first objective of the study is accomplished.

Meanwhile, palm kernel shells have been identified to be a suitable sustainable material for the replacement of the coarse aggregate in the concrete mix. Also, PKSC is appropriate to be used for the production of the designed interlocking blocks. The mix ratio of 1:1:3 and 1:1:2 comprising cement: sand: PKS is suitable to be adopted for the non-load-bearing and load-bearing wall respectively. The analysis of the strengths and weaknesses has also been done using the SWOT analysis method which is focused within Malaysia. Therefore, the second objective has also been completed.

Finally, a general guideline of the installation method for the designed block has been made in chapter 4. The installation method revealed the block can be easily stacked and is easy to be used according to the need of the user.

The virtual arrangements for the stacking process were also modelled using Autodesk Fusion 360 software to further verify the validity of the installing method. Hence, it is concluded that the third objective of this study is successfully completed.

5.2 Recommendations

The following recommendations should be taken into account for potential future studies in order to enhance further and validate the reliability of the findings obtained from this review.

(i) Investigate the optimum mix proportion by incorporating PKS as the coarse aggregate replacement for the lightweight interlocking blocks.

(ii) Produce the real interlocking block and investigate the physical and mechanical properties such as the density, water absorption, compressive strength and flexural strength.

(iii) Investigate the modifications that can be done to further enhance the block design to be used for load-bearing walls, such as introducing hollow spaces.

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