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Emerging Natural Fiber-Reinforced Cement Materials and Technology for 3D Concrete Printing: A Review

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Abstract: Additive Manufacturing (AM) technology has been widely used in various industries like automotive, manufacturing and construction. The application of AM technology in the construction industry is a chance of significant improvement and advancement for constructing processes. AM is consist of creating layer by layer of slices to print 3-dimensional (3D) construction parts. In this regard, along with the technology and process of 3D printing in construction; many researchers worked on different materials included natural fibre reinforced cement for the 3D construction advancement. On such, the review has been done for 3D printing technology, process, latest machinery for construction, the construction flow process and emerging materials for 3D construction. For this, the most recent and critical research work since last 8-years was highlighted and argued. Different research articles and numerous latest reports from web blogs are used for furnishing this review work. Based on the review, few research gaps are discovered. Finally, the use of 3D printing in the construction industry depends on the accuracy of the printing job. Not only that, the availability of printing materials and the cost of the printing process and the time taken to print also become the factors in the technology revolution in the construction industry.

Keywords: Additive Manufacturing, 3D Concrete Printing, Concrete Composite Fibre, Kenaf Fibre

1. Introduction

It has been a decade since the construction industry around the world using the workforce to run any construction work. Until today, even though the technology has revolved until 4.0, in the perspective of the developer, the use of general worker in construction industry is still reliable. In Malaysia, for example, there are vast number of foreign workers hired by the developer to work in Malaysia in their construction site. Regarding this matter, the cost of construction process where a developer needs to spend for a specific project is very high. The cost of the construction process involves the labour cost, raw material, and transportation cost [1]. Due to that matter, properties in Malaysia, for example, is prohibitive and incapable of being owned by youth as their first properties. Figure 1 shows the annual report from Bank Negara Malaysia (BNM). The number of unsold housing properties in the first quarter of 2017 was 130,690 units, which is close to double the average per year between 2004 to 2016, which is 72 239 units [2].

In 1960, the precast or Industrialized Building System (IBS) technology was begin to be implemented in Malaysian construction industries and the technology is similar to Modern Method Construction or Off-Site

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Manufacturing (OSM) which both used by the developer in Australia and United Kingdom [3]. By definition, IBS is a building system in which parts are produced in factories or off-site and then transferred to the assembly site in a framework. By the implementation of IBS technology, the cost of the construction process became cheaper due to the construction activities which differ from conventional method. However, in that year the precast was stuck to traditional means because of public impression towards the structure completed by using IBS system is weak. One of the contributions of negative perception from the public toward the fabrication using the IBS system is the lack of knowledge and the skills of workers in structural analysis and design of pre-fabricated components [4]. Any structure that has a built-in weak condition will lead to many other problems such as leakage on the construction, which can affect the corrosion on the lighting system and the beam [4]. Due to this matter, the government has taken the initiative by setting up the Construction Industry Development Board (CIDB) to educate the industry. The number of IBS factories was increased from 21 to 143 in 2009 by government initiative from 1998 to 2002 [3]. It is because of the technology is promising in terms of quality, efficiency, competency, and sustainability. Due to the world economic situation, the cost of raw material and transportation was increased but not affecting the IBS industries and the technology is well accepted in Malaysia.

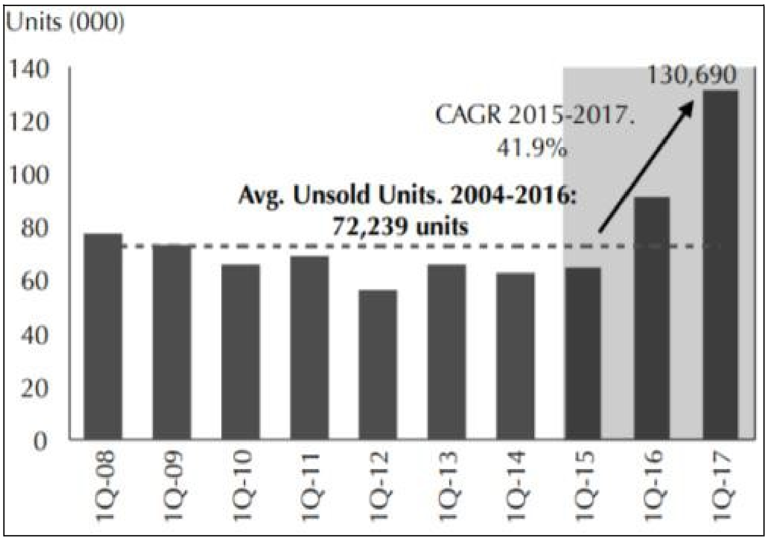


Fig. 1 - Total unsold residential properties in Malaysia stood at 130,690 units, the highest in a decade [2].

To overcome the problem, many researchers from around the globe conducting their research activities by implementing Additive Manufacturing (AM) technology to develop new technology for construction activities. Additive Manufacturing (AM) technology has been widely used in various industries today, for example, the automotive industry and manufacturing industry commonly. Additive Manufacturing is consist of the development of printing technology. As we know, the advantage of printing technology is low cost in production [5]. Therefore, the use of Additive Manufacturing (AM) technology in the construction sector is a chance to improve construction technology significantly. 3D printing technology, process, latest machinery for constructing, the construction flow process and emerging materials for 3D constructing technology has been highlighted in this review paper. The most recent and critical previous research work since 8-years was argued. In the end, there are a few research gaps were achieved based on reviewed literature.

2. Review on Conccrete Printing Technology

Concrete printing is a new technique of construction that attracted researchers ' interest because of the technology is promising huge advantages for construction industries over traditional construction method in terms of optimizing construction time, the flexibility of geometrical design, reducing the number of workforces and environmentally friendly instead of reducing the construction cost [6]. For concrete material, the printing method is adapted from plastic-type material such as ABS (Acrylonitrile Butadiene Styrene) or PLA (Polylactic Acid) material to form the structure using layer by layer method [7]. For architecture industry, this technology gives advantage to those working as building designer because by this technology, they can create any complex geometrical design structure with freedom without the need to think multiple designs in certain identical element to save material and cut labour or mould expenses owing to the machine's ability to print complicated design structure [8 & 9]. For example, WinSun and HuaShang Tengda from China; both companies have succeeded in building the structure using concrete printing technology. Not only them, Apis Cor, a company from Russia and Total Custom, another company from the USA, also have succeeded in printing a building structure using their concrete printing machine. Table 1 below shows the details of building structure they build using printing technology.

Table. 1 - Type of building made by a different company in a different country by using 3D Printing construction method with detail building structure.

Company	Refrences	Type of building	Detail of building structure
WinSun 3D (Yingchuang Building Technique Co. Ltd (Shanghai, China)	[10, 11]		Measurement of the office building in Dubai, UAE 250 m2 build on 2016 using printer size of 120 x 40 x 20 ft.
			Five – Floor apartment building finished in Suzhou, China in 2015
			Villa with 1100 m2 dimension also build at Suzhou, China in 2015
			10-house series built in Suzhou, China in 2014. Reported by Wu.
Beijing – based HuaShang Tengda, China	[12]		Double floor house in China with 400 m2 build finish in 2016.

Total Custom	[13]		Children's Castle completed build at Minnesota, the USA in 2014.
Apis-Cor	[14]		Residential house completed the build in 24 hours at Russia.

2.1 Type of Printing Machine

We know that the type of machine being used to produce a product is different from one another developer or manufacturer just because to compete to prove their qualities and standard. However, the primary purpose of the machine build will always be the same with each other no matter what the physical machine look like. Until today there are three types of 3D concrete printers used either in universities for research purpose or in industries for commercialization namely gantry system [4-9,15], robotic arm [16], and crane system [17].

After reviewing the article from previous researcher and comment from blogger, it can be summarized that the purpose of development for every type of machine is the same. They think that only make the difference is the technology used where every technology has its capabilities. For example, Paul [17] reported, as shown in Figure 2(a) below is the gantry-type machine, which is the same as a crane type where the height is typically fixed. Unlike crane type machine as in Figure 2(b) build by Apis-Cor where the machine can be adjusted in the vertical direction with free-high. Both types of the machine easily scaled in size, which cannot be done for robot type machine and its an advantage in terms of machine size. As shown in Figure 2(c), the robot arm has advantages in term of speed and degree of freedom to perform any task which is not be possibly done by gantry and crane printer especially in constructing a sophisticated geometry. A robot arm type printer is most preferred to be used instead of gantry and crane type printer machine. Since the cost of a robot arm is expensive, the usage of gantry type or crane type of machine is considered efficient technology for the development of concrete printing technology.

(a)

(b)

(c)

Fig. 2 - Type of machine used in structure printing for concrete material - (a) Gantry type build in Loughborough University for research activities [18]; (b) Crane type build by company name apis-cor [56]; (c) 6-axis robotic arm printer [14]

2.2 Flow Process for Concrete Printing Construction and Printing Technique

The development of the suitable device for the concrete mix that would work as a 3D printer is critical for the achievement of the project. During the design, several criteria need to be considered as the machine must be suitable to be used for new and printed concrete characteristics. The machine consists of three primary parts, which are the mechanism for concrete tank and pumping, the nozzle for printing and the movement control. At the container, the concrete starts flowing aided by manual pumping to the nozzle as to initiate the printing activities. The printing machine is designed to move on the axial plane, which is on the x-axis, y-axis, and z-axis to print an element of 3D [3]. According to Bogue and Wu, 3-D printing is an automated process for the manufacture of 3D objects from a digital model such as Computer-Aided Drawing (CAD). The 3D CAD model is separated into a series of 2D layers in 3D printing process. Then it will be deposited by the printer to construct the model until the product structure cycle completed in the form of 3D object [15 & 17].

However, Lim. S [55] added that in 3D concrete printing, data preparation is similar to other AM processes except for an additional post-processing step which optimizes the generated printing path of the deposition head to reduce printing time and possibility of material overprinting due to the on/off operation of the nozzle by minimizing non-printing deposition head movement. The capability in reducing construction time depends on the complexity of the design structure where the greater structure complexity will provide more scope to minimize printing time. The printing element is modelled as a 3D CAD model and then converted into the STL file format. The printing path and the G-Code file generated for printing each layer [18]. The printing process of concrete structure was explained by Mehmet and Izabela in their paper in the form of a work-flow diagram as in Figure 3 and can be seen that the printing process is the same [18 & 19].

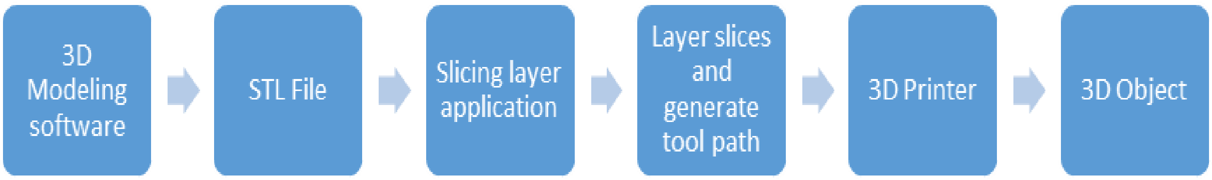
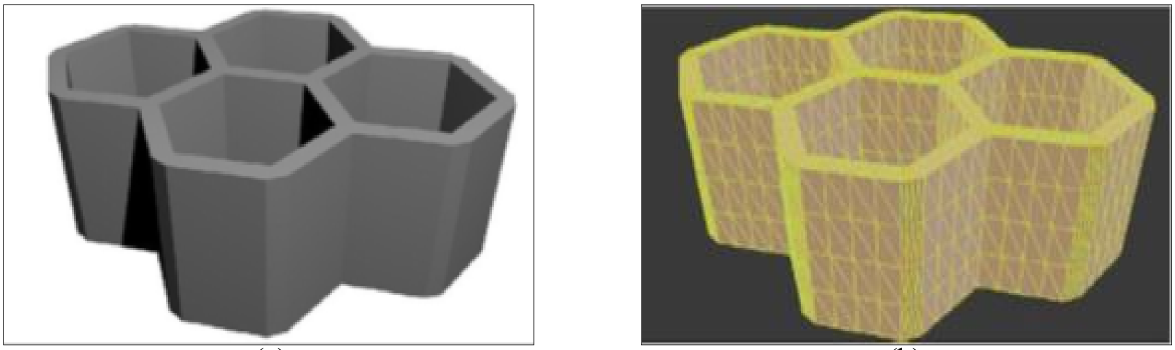


Fig. 3 - A typical workflow of the 3D concrete printing process.

The workflow can determine that the printing process is precisely the same as standard 3D printing, and the difference is only on the material used. So, converting the STL file, it can be done in the design software used in modelling. However, converting format is only available on 3D modelling design software. The transfer of model information via STL format needs that all boundary surfaces to be triangulated as pictured in Figure 4.



(a) (b)

Fig. 4 - Illustration of the honeycomb (a) using 3D modelling design software then the mesh; (b) is appear once finish converting from drawing (dwg.) file to STL file [18]

STL is a standard input format for 3D printing. It should emphasize that the model does not need to save in this format and orders can be produced directly from the template in its indigenous variant. It's about geometric computations in the geometric kernel of a 3D printer. The current processing and data formats for 3D geometric printing models originate in 3D computer graphics for screen rendering. Due to some issues and constraints when using digital printing models.

Since the additive manufacturing techniques is an advanced technology, the non-standard geometric forms with fresh geometric depictions directly linked to the physical material deposition method. Thus, it is possible to bypass the geometry processing that is suitable for screen rendering but hard for 3D printing [18]. Parallel planes cross the geometric model during the slicing stage to obtain the contour of each material layer. Figure 5 shows, this step can be carried out with a constant layer thickness (uniform slicing) or layer thickness variable (adaptive slicing). Adaptive slicing increases the surface quality of the critical features of the printed model while saving time in fields with acceptable rougher finish [20].

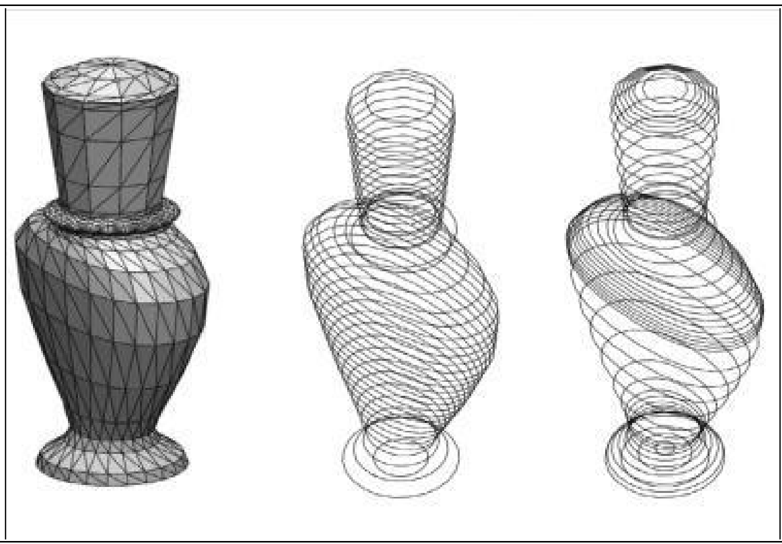


Fig. 5 – The illustration of slicing in the geometric model during the slicing stage as the printed layer [20]

In general, 3D printing software assumes that the geometric model is reduced to an unordered and unstructured set of triangles approximating the surface of the object. This representation is a standard de-facto industry, represented in the Stereo Lithography (STL) accessible file format. Therefore, an unordered and unstructured range of line segments on each cutting plane is also the first result of the slicing stage [21].

3. Review on Concrete Material for Printing Activities

Concrete is a composite material consisting mainly of a binding medium such as a mixture of portland cement and water containing embedded particles or aggregate fragments, usually a combination of fine and coarse aggregates. The characteristics of the end product in concrete manufacturing is not only relying on different constituent components but also on how they are proportioned and blended as well as on the techniques of deposition and curing the composite [22].

The paste is about 25% to 40% of the complete concrete quantity, whereby the total cement quantity is typically between 7% and 15% and the water between 14% and 21%. The air content in airborne concrete varies from approximately 4% to 8% of the quantity [23]. The material mixtures are designed empirically, often with the help of mixing test to obtain good strength and concrete properties. The mixing design aims to ensure that both fresh and hardened state has defined characteristics for the product. The main aspect of the mix design is the water-cement ratio (w/c). The rate of water-cement is essential as it determines the concrete's strength. If the water-cement ratio is too small, it can weaken the concrete workability [22,61-62].

There are a lot of different types of cement. In concrete, Portland cement is the most commonly used cement, hydraulic cement that sets and enhances the chemical reaction with water. Generally, as we understand, cement acts as the binder that connects the concrete components and it is essential to the composite's strength. Portland cement consists mainly from mineral parts (tricalcium silicate, dicalcium silicate, aluminium tricalcium, and aluminoferrite tetracalcium), each of which has its own hydration features. The American Society for Testing Materials, meanwhile, defines the sort of cement-base on its characteristics. By following the standard that has classified from the society, the standard of cement is ASTM C150, and it classifies as Table 2 below [24].

Table. 2 - Type of cement used in the industries based on their properties following cement standard ASTM C150 [24]

Type of Cement	Description
Type I	Normal
Type II	Moderate Sulfate Resistance
Type II (MH)	Moderate Heat of Hydration/ Moderate Sulfate Resistance
Type III	High Early Strength
Type IV	Low Heat Hydration
Type V	High Sulfate Resistance

As for aggregates, the following standard used is ASTM C125 & D8, and it defines aggregate as granular material of the mineral structure, such as sand, gravel, shell, slag or crushed stone. Used as a cementing medium for the formation of mortars or concrete, or alone as in base courses, railway ballast or other associated materials [25]. Generally, they can split into two groups, namely fine aggregates and coarse aggregates. Fine aggregate is the small size particles in the form of sand where it can pass through the sieve in the range of 4.75 mm and retain on 0.075 mm. Meanwhile, coarse aggregate is the coarse particle where it is in gravel form, and the particle size retained on 4.75 mm of sieve [26]. Table 3 below shows the size variation between fine aggregate and coarse aggregate. Although they classified by different sizes of aggregates, the primary purpose is the same, which is to fill the voids in the mixture and act as the workability agent.

Table. 3 - Type of aggregate which classified based on the size [26]

Fine Aggregate		Coarse Aggregate	
Coarse sand	(2 – 0.5) mm	Fine gravel	(4 – 8) mm
Medium sand	(0.5 – 0.25) mm	Medium gravel	(8 – 16) mm
Fine sand	(0.25 – 0.06) mm	Coarse gravel	(16 – 64) mm
Silt	(0.06 – 0.002) mm	Cobbles	(64 – 256) mm
Clay	< 0.002 mm	Boulders	>256 mm

Through the mix design of concrete for printing activities, the mix design must fulfil the hardened concrete quality requirements of fresh concrete. The quality of the concrete mixture must include the extrudability and buildability that are greatly affected by the workability and the open time [27]. Extrudability refers to the machine's capacity to deliver the concrete paste to a nozzle through a hopper and pumping machine where it has to be extruded as a continuous filament. Therefore, the particle size of aggregate and type of aggregate is important to ensure not only the workability of concrete mixture but also its capability for extruding from the machine. T.T. Le [27] reported that the particle size of the constituent materials for mix 1 and mix 2 was affecting the extrudability which lead to nozzle blocking even though more water and cement were added to make it flowable. Table 4 below shows the mix proportions made and Figure 6 shows the percentage of particle that is passing through the sieve used according to the sieve size.

Table. 4 - Five mix proportions made with different material for fresh concrete [27]

Material	Mix proportions (kg/m^3)				
	Mix 1	Mix 2	Mix 3	Mix 4	Mix 5
Sand	1612	1485	1362	1241	1123
Cement	376	446	513	579	643
Fly ash	107	127	147	165	184
Silica fume	54	64	73	83	92
Water	150	178	205	232	257

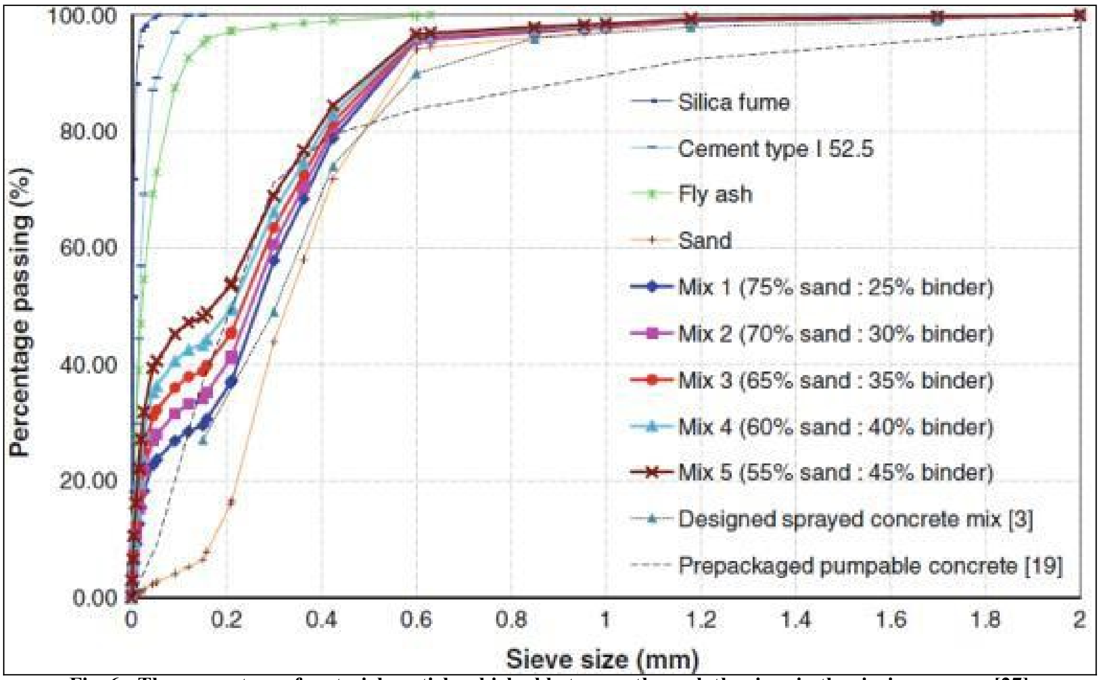


Fig. 6 - The percentage of material particle which able to pass through the sieve in the sieving process [27]

4. Challenging of Concrete Mixture in Deposition System and The Workability

After the concrete material is well-mixed, it is placed into the deposition system. Depend on the system design; there are a variety of methods which can be used to deliver the material for printing activities such as air pressure and mechanical pressure. By the air pressure, the high-pressure pump motor used and located outside the rig. Then a specific range of pressure will be fixed from the pressure gauge to apply a particular amount of air flowing inside the hose as the pressure onto the material. Meanwhile, the mechanical force is the system that is used extruder screw inside the hopper where the content will directly extrude from the system flowing through the nozzle and performing the printing activities.

Extrudability described as the ability of the fresh concrete flow through the delivery system of the printing machine which is from the hopper to the nozzle where the concrete need to be printed in a continuous filament. Nozzle design is one of the critical elements because it can affect the properties of a specific structure due to the direct relationship with concrete mixture properties in terms of flowability instead of workability for the concrete structure [19]. The nozzle size and design are essential because the capabilities of the machine in extruding the material for a variety of mixture proportions depending on it. Moreover, nozzle clog can affect the extrusion process if suitable size and design are not correctly determined. Not only that, nozzle orientation between the tool path should remain tangent to keep it from misdirection between the fresh layer to get an excellent physical concrete structure [16].

Moreover, the stability of the concrete structure also depends on the nozzle design. There are several shapes of nozzle used as the orifice such as circular, ellipse, square and rectangular. As freedom of printing activities, commonly the circular nozzle will have more freedom in doing printing activities without bothering in adjusting the printing angle for shape continuity at vertices or changes in the edge of the printed element. However, a study made by Kwon [28] says the surface finish created with a square orifice is better compared to an ellipse orifice and his statement supported by Anell [29]. Figure 7 below shows an example of nozzle design with side trowels, which enabled the concrete structure to be built with a better surface finish.

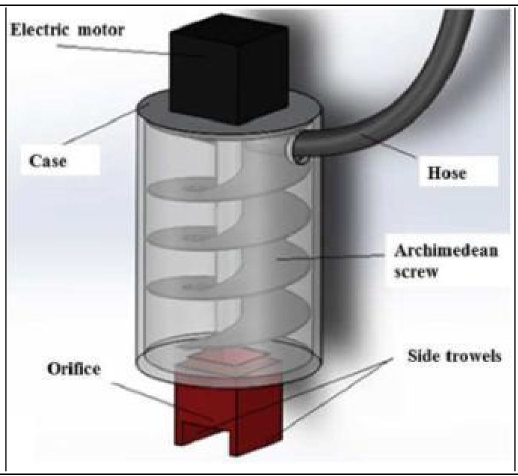


Fig. 7 – An illustration of nozzle design with side trowels for concrete printing [28]

However, the most important in 3D printing for concrete material is to determine the capabilities of the printing machine in extruding the material. Moreover, the concrete mixture proportion significantly influenced the workability but also comprised the extrudability and buildability concrete structure [27]. Meanwhile, the workability of the fresh concrete is affected by the cement/water (c/w) ratio. Thus, a correct proportion of the concrete mixture is needed to ensure the capabilities of the machine in extruding the material at maximum capacity with a high performance concrete mixture properties. Moreover, amount of c/w ratio give a result to mixture viscosity which is another factor that need to be considered for concrete printing. This is because the mixture viscosity not only effecting the capabilities in extrussion but also effecting the structural integrity (buildability) [57]. Therefore, a suitable amount of viscosity modify agent (VMA) or water reducer (superplasticizer) can help by increasing the contact behaviour between the adjacent extruder layers. A behaviour of discontuinity and segregation on printing path during extrusion process will be occured if insufficient quantity of material or insuffiecient mix design of concrete material which can lead blockage in the hose [58]. Therefore, this is the challanging situation in term of pumpability control and Figure 8 show the example of concrete layer that are splitting due to lack of pumpbility control.

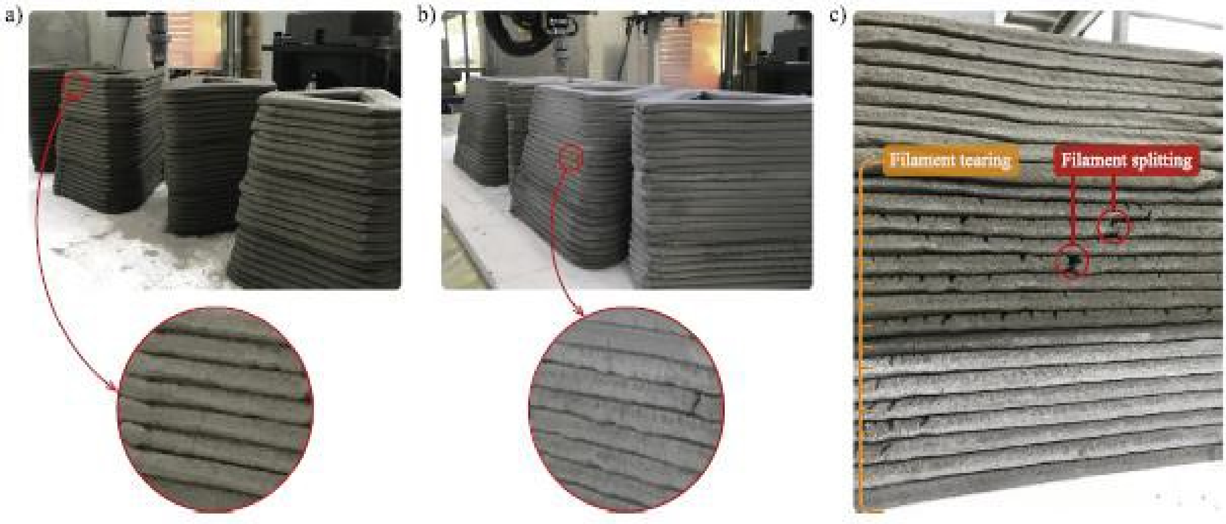


Fig. 8 - The concrete layer condition due to discontuinity and segregation during concrete printing: (a) Good quality of concrete layer; (b) Concrete layer showing the tearing sign caused by lack of paste volume; (c) Concrete layer spliting [58]

To evaluate the workability of the fresh concrete, usually conventional method such as the slump test, compacting factor and flow test will be used. However, T.T.Lee et al. [27] reported, by using the conventional method such as the slump test does not measure the fundamental physical properties of the concrete on concrete printing. Thus, he suggested to use the shear vane apparatus due to the advantages of measuring the workability of concrete at various points [30].

Therefore, from the discussion above can be assumed that to produce a good quality of concrete structure, nozzle design and mix proportion of concrete material is among the essential criteria in the printing parameter which need to be highlighted instead of the printing speed, pressure, and concrete viscosity.

5. Natural Fiber in Cement Composite

In definition, natural fibre is the fibre that is produced by natural resources either from plants, animals, and geological processes. Natural fibre has many uses in human life. Usually, they are used as a component of composite material where the orientation of fibres can impact the properties of the product. Natural fibre attracts many researchers and industrial practitioners in a variety of sectors, for example, cars, furnishings, packaging, and construction. Moreover, the characteristics of natural fibre are particularly high with low prices of natural fibre composites for multiple applications such as construction materials, particle boards, insulation panels, food and feed for humans, cosmetics, medicine, and other biopolymers and fine chemicals [20, 25, 27].

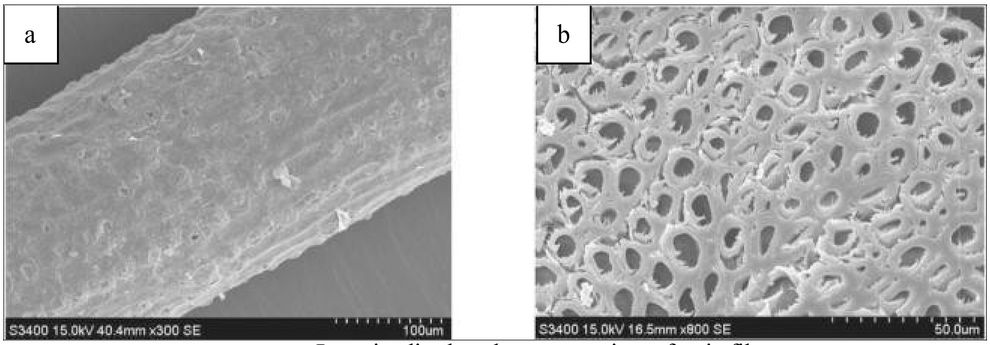
In the construction industry, there are research and development in the field of natural fibre composites owing to the benefits of natural fibre such as composite structure formability, abundant, renewable, cost-effective and environmentally friendly characteristics [31]. As we can see, building structure around was made by the concrete material. The main ingredient to construct the building is cement, and the additional element is the aggregate which consists of sand and rocks where those materials made are non-renewable sources which cannot be recycled. Due to this matter, by contributing millions of tonnes of the mineral waste but also carbon dioxide gas emissions, the construction industry is liable for the depletion of large quantities of non-renewable resources [4].

Therefore, the use of renewable resources such as natural fibre, to attain sustainable development, can assist in accomplishing a more sustainable pattern of building products. Because of their characteristics, natural fibre acts as an extra reinforcement in the concrete mixture. However, natural fibre characteristics differ due to varying humidity conditions, distinct fibre types and different test methods. Table 5 below shows the properties of selected natural fibre-based on mechanical properties in terms of tensile strength.

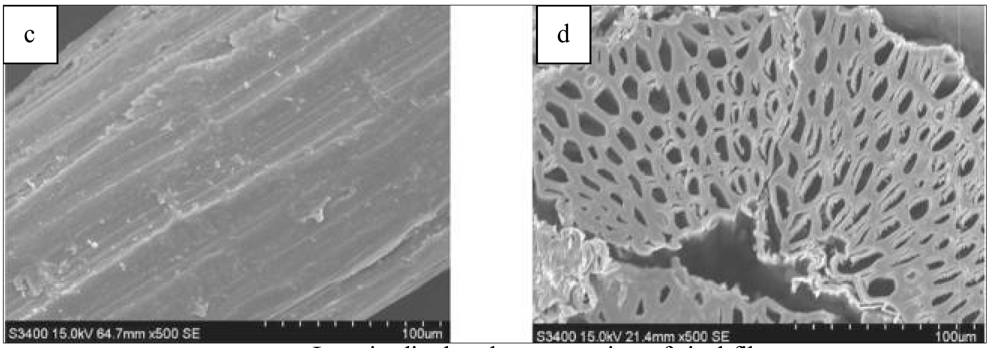
Table. 5 - Mechanical properties of natural fibre [31 & 32]

Grouping	Fibre Source	Tensile Strength (Mpa)	Young Modulus (Gpa)	Elongation at break (%)	Density (g/cm3)
Bast	Abaca	400	12	3-10	1.5
	Flax	345-1035	27.6	2.7-3.2	1.5
	Jute	393-773	26.5	1.5-1.8	1.3
	Hemp	690	70	1.6	1.48
	Kenaf	930	53	1.6	-
	Ramie	560	24.5	2.5	1.5
	Bamboo	140-230	11-17	-	0.6-1.1
Leaf	Sisal	511-635	9.4-22	2-2.5	1.5
	Curaua	500-1150	11.8	3.7-4.3	1.4
	Pineaple	400-627	1.44	14.5	0.8-1.6
Seed/fruit	Coir	175	4-6	30	1.2
	Oil palm	248	3.2	25	0.7-1.55

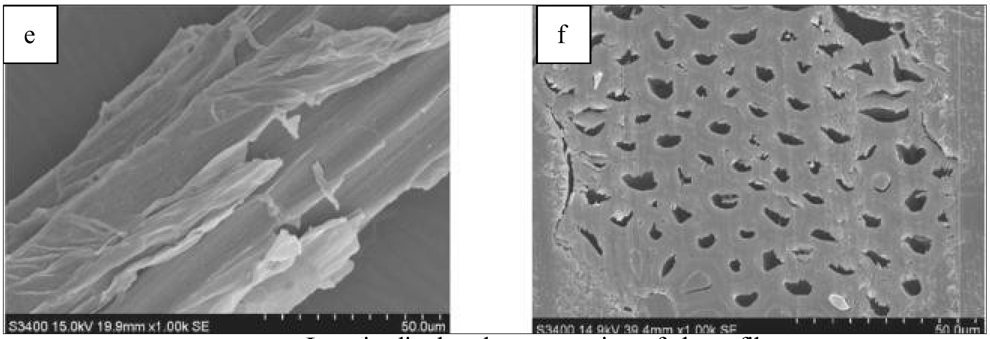
By knowing the characteristics of the fibre, it is beneficial to enhance natural fibre efficiency in composites. Natural fibre's characteristic values are significantly higher than human-made fibre, which is explained by the variations in the fibre composition during development owing to the environmental factor. The properties of natural fibre can be differed by following ways of process. The moisture content of hydrophilic fibre content is the problem for all types of cellulose fibres, where the moisture content of the fibre depends on the content of non-crystalline parts and the fibres' void [5]. It supported the report reviews by Geetanjali Das [6], A. Al-Maharma [7], and T. Alomayri [8]. The water absorption rate depends on the fibre length. The longer the fibre, the greater the absorption of water. Thus, this will cause micro-cracking problems and bad thermal stability for concrete structures. Figure 9 below shows an example of the image cross-sectional of the void of fibre.



Longitudinal and cross-section of coir fibre



Longitudinal and cross-section of sisal fibre



Longitudinal and cross-section of abaca fibre

Fig. 9 - SEM image of the void by the selected fibre of non-woody [33]

6. Composite Fiber – Cement Properties and Performance

6.1 Fresh Properties

6.1.1 Consistency

In terms of consistency, the study made by Mansur and Aziz [34] by using jute fibre shows that cement paste and mortar workability decreased with enhanced fibre length and content. Savastano [35] observed, the workability of strengthened cement composites reduced by the combination of eucalyptus pulp, coir or eucalyptus with sisal fibres. They recorded the same observation where the hydrophilic absorption of natural fibre impacts the outcome of cement's workability. The main factor influencing the loss of workability in natural fibre-reinforced cement mixtures is the fibre aspect ratio and volume fraction in mixtures. Fibre pre-treatment can act as remedy to reduced water-absorbing chemical fibre elements. Alternatively, workable natural fibre with improved cement mixtures could be produced by evaluating the water absorption characteristics of fibres in the mixture design.

6.1.2 Setting Time

From the observation made by A.Varshoee et al. [36] on his study using sugarcane bagasse fibre shows that the reinforced cement composites delayed in time setting and reduced heat of hydration. This occurrence is resulting in water-soluble sugars from alkaline lignin hydrolysis and partial solubilization of hemicellulose contained in these fibres. Same as [34 & 35] suspected, the short setting time in which they recorded, bamboo flakes reinforced portland cement matrix caused by high quantities of sugars in the fibre. The dissolution of these soluble sugars produces calcium compounds in the cement matrix. These compounds lower the cement hydration temperature and delay the formation of hydration products. A similar delay in the setting time of cement composites containing hemp fibres are also observed by Sedan [37]. Thus, attributed to the presence of pectins contained in these fibres, which acted as a calcium-silicate hydrate (CSH) growth inhibitor. Vaickelionis and Vaickelioniene [38] were giving an opinion that delay in hydration depends on the concentration of soluble sugars in mixtures, and could mitigate through the addition of pozzolan. The negative effect of plant-based natural fibres on cement hydration could also be reduced through the use of pre-treated fibres containing low amounts of lignin in cement composites. Furthermore, increased curing temperature, the addition of chemical accelerators and supplementary materials with a high surface area such as finely ground limestone powder to mixtures could also help in enhancing early age hydration.

6.2 Hardened Properties

6.2.1 Drying Shrinkage

Free and contained drying shrinkage issues frequently happen in hardened cement-based mixtures. Some studies showed that adding natural plant-based fibres to cement mortar could not reduce these issues. Study results by ToledoFilho [39] showed, by volume addition of short sisal and coconut fibres, cement mortar drying shrinkage enhanced by 2-3%. They also observed that drying shrinkage in sisal fibre composites was higher due to increased water absorption and less smooth sisal fibre than coconut fibre. High drying shrinkage also noted in their sisal fibre strengthened cement matrix survey [40]. This event is attributed to the increased porosity of samples induced by these fibres. Therefore, the drying shrinkage behaviour of plant-based natural fibre reinforced cement mortar mixtures seems to depend on fibre characteristics, fibre volume fraction, and the consequent effect on matrix pore structure.

6.2.2 Mechanical Strength

Generally, adding synthetic fibres to composites of cement enhances durability, flexibility and impact resistance. Excerpts from Ramakrishna and Sundararajan's [41] says the effect of resistance test outcomes shown in Figure 10. Results show that the impact strength of reinforced plant-based mortar plates was 3-18 times higher than that of unreinforced plates. All the slabs' impact strength improved as the volume fraction and duration of the reinforcing fibres increased. As the volume fraction and length of the reinforcing fibres increased, all plates enhanced impact strength.

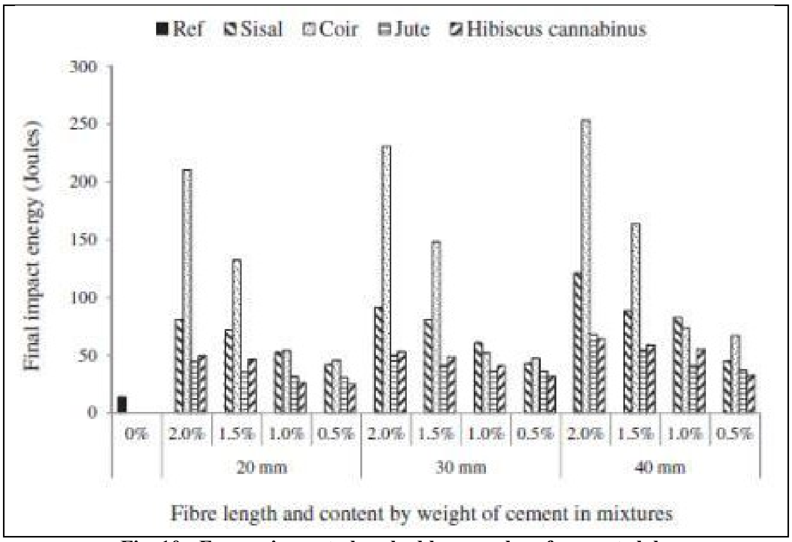


Fig. 10 - Energy impact absorbed by samples of cement slabs [38]

Munawar [42] reported coconut fibre is the hardest natural fibre and approximately 4-6 times greater than other natural fibres. Coir fibre's high flexibility is very useful in decreasing the fragility associated with composites based on cement. Research linked to this [43], it was also reported that the moisture content of samples impact the mechanical strength and failure mechanism of cement composites. The moisture content of samples influences the mechanical strength and failure mechanism of cement composites. From the beginning, it is apparent that for effective composite performance, moisture absorption by plant-based natural fibres should manage.

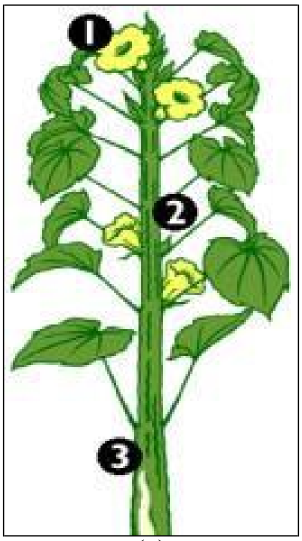
7. Natural Fiber as Reinforcement in Concrete for 3D Printing

As we know, due to the compressive strength of standard portland cement-based, the cement only display 20-60 MPa for general use and reduce around 3-10 MPa for simple pastes in terms of tensile and flexural strength. The concrete cement usually introduced in building operations for formworks to enhance the flexural strength of cement composite [33,34,44,45]. However, the use of steel reinforcement in concrete consuming labour expenses during building owing to operating time and material since the steel has to manually placed in building moulds.

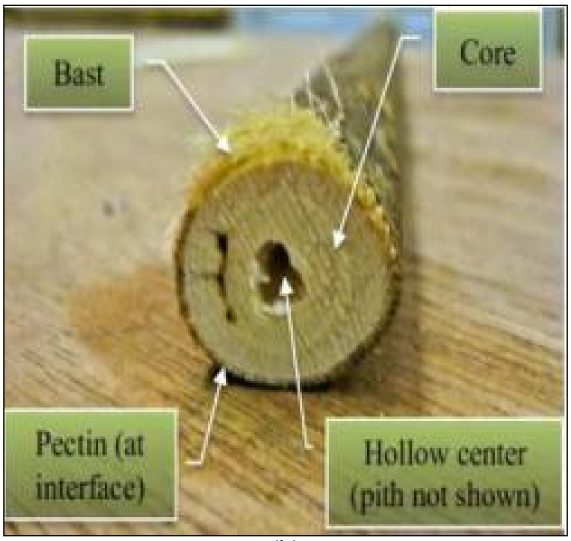
Therefore, a study on an extrusion method was carried out to fix this issue. From several reviews made by Manual Hambach and Dirk Volkmer [46], stated that the extrusion process in extruding fibre-reinforced cement paste had established since 1990. Through scientific research, it shows a positive result where the flexural strength and tensile properties increase up to 50 Mpa [35,36,47,48]. Using the extrusion process, it enables fibre alignment in the cement paste due to the pressure exerted on the cementitious paste through the extrusion nozzle. So that, the fibre-reinforced can achieve a maximum strength value. Thus, future research in concrete fibre reinforcement conducted by using 3D printing technology is to evaluate the particular structure properties, especially for kenaf fibre.

7.1 Characteristics of Kenaf Fiber

Kenaf fibres are emerging as a promising alternative material that will provide a boost to the construction industry. Kenaf is a member of the scientifically named hibiscus family (Hibiscus Cannabinus L) related to cotton and okra. As in Figure 11, kenaf plant consists of two fibres namely the bast which is the outer fibre and roughly comprises about 40% of the stalk's dry weight and the core which is the inner fibre [49,58 – 60].



(a)



(b)

Fig. 11 - (a) The illustration part of kenaf plant: (1) Flower of kenaf (2) Stalk-outer fibre (3) Stalk-inner fibre; (b) The cross-section of kenaf plant showing the physical characteristic of kenaf plant [50]

To separate the fibre, kenaf plant will undergo harvesting process using mechanical fibre separator which allows two fibres separate independently as the raw material for another product such as paper, particleboard, animal bedding, and bioremediation aids. As in Figure 11 shows the kenaf fibre after undergoing separation process [51].

(a)

(b)

Fig. 11 - The image of kenaf fibre after undergoes mechanical separation process: (a) Core fibres; (b) Bast fibres [51]

The essential tensile characteristics of kenaf fibres characterized by the previous study where the average tensile strength of kenaf fibres ranging from 157 MPa to 600 MPa. An average ultimate tensile strain and fibre elastic modulus ranging from 0.015 to 0.019 MPa and 12.800 Mpa to 34.200 MPa, respectively [52]. Meanwhile, The mechanical properties of the fibres depending on the location of the fibres. Fibres from the core of the stalk tend to be stronger and more rigid. Meanwhile, fibres from the ends of the stalk tend to be weaker and more flexible due to environmental exposure, insect deficiency, and damage. The research further stated that the stress-strain curve of the kenaf fibres is roughly linear to failure regardless of the location of fibre taken. Inspection shows that the tensile characteristics of kenaf fibres are similar to those of other natural fibres such as jute, flax, and bamboo. Whereby, the production of natural fibre at earlier used to strengthen the concrete [53].

8. Summary of Previous Research Work on Natural Fiber-Reinforced Cement Via 3-D Printing Technology

After reviewing the article from the previous researchers, it is well known that the fibre reinforcement with high modulus elasticity used in cement-based matrices can improve the physical strength. Meanwhile, fibre with low modulus elasticity such as plastic and cellulose can improve the energy absorption of the composite at the cracking stage. Holmer et al. [35] reported in his paper based on the review he made, the shorter fibre performed a significant impact on the ability of energy absorption. Manual Hamback [46] reported in his paper, he stated that short fibre reinforcement also influences the mechanical properties of the concrete mixture. The properties affected in terms of flexural and compressive strength during the extrusion process. Thus, during the extrusion process, the fibre alignment is more accessible and very efficient for portland cement paste.

Meanwhile, Zhou et al. [54] with his study confirmed where by using natural fibre composites in the concrete mixture is an effective way to develop the strength of concrete to be applied on resisting the high impact factor.

Through the development of 3D printing machine in construction industries, it is assumed that the technology is promising a lot of advantages for the sector. However, several requirements need to be confirmed before the technology can be used. For example, the project scale and the printing materials need to be clarified so the technology can perform their duty in maximum potential. The development of 3D printing technology is not only focused and available with the extrusion method. There is another method in additive manufacturing that can use as 3D printing technology for concrete material. Therefore, Table 6 is the summary and as a comparison among the previous researchers who have done with their studies in developing 3D printing using concrete material.

Table 6 - Comparison of 3-D printing technology used and product made among the previous researcher [15]

Researcher	Type of 3D printing technology	Products	Remarks
Hinczewski et al., 1998	Stereolithography	Ceramic part	- Possibility using stereolithography to obtain dense ceramic is proved with homogeneous microstructure. - The study made is to show the rheology of material with the influence of viscosity is effecting the mechanical properties of materials.
Khoshnevis et al., 2001	Contour crafting	Plaster part Ceramic part	- Contour crafting give an advantage to construction due to its speed and its abilty on performing printing the complex geometrical shape. - Various statistics shows the CC can help in reducing the amount of construction waste and harmful emmisions. - Using CC also resulting an efficiency of construction logistics and management.
Lim et al., 2012	Concrete printing	Concrete part	- Researcher reviewing and compared other researcher who study in concrete printing technology. - From his finding, every concrete printing method such as contour crafting and D-shape has their own strengths and weakness. - In term of material, author mentioned that there is a sensitivity on the material and process to ambient conditions which can hamper on-site applications.
Gibson et al., 2002	FDM and SLS	Space frame Rotunda IBM Pavilion	- In architechtural applications there is a complications in conventional which can be solve by rapid prototyping (RP). - Through the sample product shows the RP technology can be used more creatively than usual from the combination of models with different materials and process.

Kimitrov et al., 2006	3DP	Plaster model	- The capabilities of 3DP in printing complex geometric shape gives new paradigm in product design. - However, designer should need to find a suitable information to exploit the strengths of the technology.

9. Future Research

After reviewing all the paper that related with concrete printing in terms of material development, it can be seen that most researchers are studying the feasibility of fresh concrete by reducing the size of aggregate in order to follow machine capabilities in extruding the material and controlling the workability of the concrete by creating a concrete mixture with trial and error. The study in the area of natural fibre as reinforcement in concrete structure is limited. Thus, as in future research, the feasibility of kenaf fibre to be used as the reinforcement material in concrete structure by using printing technology can be made in determining the properties of the concrete.

10. Conclusion

As a conclusion, the revolutionary technology for construction industries from traditional method to the digital approach is one of the new eras following the advanced technology nowadays. The use of 3D printing as automation technology for construction activities making it more promising due to the technical advantages. The use of 3D printing in the construction industry depends a lot on the accuracy of the printing jobs, the availability of printing materials, the cost of the printing process and the time taken to print based on which relevant 3D printing technologies. However, the use of 3D printing also requires a few prerequisites such as the capabilities in a large-scale construction project, the degree of mass custom demand, and the life-cycle price of 3D printed house or building. Using 3D printing provides access to complicated geometries and thus offers the option of printing hierarchical structures with the ability to provide sturdy and material-efficient structures for future buildings. The use of natural fibre perhaps can enhance more strength of mechanical properties for the concrete structure due to the pressure given during printing activities. So, the green concrete type will be produced by using natural fibre as reinforcement, which is cheaper and can be recycled.

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