Development of 3D Printing as an Efficient Home Construction Alternative

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***Abstract*— Technological advances will always experience very fast changes, especially in 3D printing technology, which is currently widely used in various industrial realms. The presence of 3D printing machines really helps humans in visualizing an idea and the results of their thoughts into a very profitable replica. However, construction industry has not fully utilized 3D printing technology, and only a few countries have made it. The advantages of building a house with 3D printing technology include saving labor and time in house construction, as well as minimize the construction. The use of this 3D printing machine will be very useful in Indonesia because the number of populations is very large, and the need for housing will be directly proportional to population growth. The research aim is to build a 3D printer for housing construction at the size of 1m x 1m x 1m, and at this moment the research has successfully built the prototype machine and developed a software controller which is able to control motors using keyboard and mouse through web interface. As a continuation of this housing 3D printing project, the research is currently focusing on development of suitable concrete mixture formula consisting of Portland cement, micro-silica, rice husk ash, aggregate, superplasticizer, fly ash, and water.**

Keywords*— house construction, 3d printing machine, efficient

I. INTRODUCTION

3D printing was introduced by Dr Hideo Kodama from Japan in 1981 by using photopolymer to print three-dimensional objects, and in 1984, 3D printing was developed by Charles W. Hull, which is by developing the Stereolithography Apparatus (SLA) 3D Printer and then Charles W. Hull known as "The Father of 3D Printing" [1]. Along with the times, the progress of the 3D printing world continues to grow, and the breakthrough of 3D printing technology, namely in 2008 artificial legs were made using a 3D printer machine which became a new history. Advances in 3D printer technology have penetrated into various fields, such as medicine, manufacturing, automotive, and advances in 3D printing technology have also slowly penetrated into the world of construction. As an example WinSun Decoration Design Engineering Co China, succeeded in building 10 units of five story apartment at Suzhou Industrial Park in 2014 [2]

In the current era of industry 4.0, we are required to be able to keep up with the times, digitization and automation. This technological advancement also applies to the world of construction, so that from design, planning to the construction process, robots can be controlled via software. This is in accordance with the wishes of the Indonesia Minister of Communication and Information to facilitate and accelerate the construction of a million houses, which need to be supported by technology [3] using 3D printing technology.

Utilization of technological advances through 3D printing machines in the building construction in Indonesia has not developed significantly, therefore researchers are very interested in conducting research on the development of software and hardware for home 3D Printers to the needs of the low cost, effective and efficient for the building construction, and this is business opportunity in the future .

The development of house-building technology has also undergone many changes and progress, starting from crushed stone pairs, turning into wood pairs, then turning into red brick masonry, to the emergence of lightweight concrete innovations. The process of building houses generally uses a concrete construction as the frame, and bricks, or lightweight concrete as the walls, but this conventional work requires quite a long working time [4], besides that it requires a large amount of money. The reason for the high cost is use of labor required, for example in wall installation process, we needed 1 bricklayer, and 2 helpers were tasked with helping prepare the materials. If want the job to be done quickly, we have to increase the number of workers, so if there are many workers, it will increase the cost [5]. In addition, the waste generated from construction work can also be a problem for the environment.

Based on the real case of the conventional building construction process, so this can be a problem because with low productivity but high demand for housing needs, therefore we need to find solutions to be able to build construction saves time, less labor, and not many equipment, therefore there should be a new way using technological advances.

In order to be focused, this research tries to formulate problems that will become solutions, including how to develop a 3D printer machine in an effort to support the improvement of fast and environmentally friendly construction work. The purpose and benefit of this research is to develop a 3D printer machine for the construction it can improve and accelerate the process of carrying out construction work by taking into account its impact on the environment.

II. 3D PRINTING OF HOUSE-BUILDING

The home industry with 3D printing has been developed by developed countries [6], which is the result of a

collaboration between the American 3D printing company Apis Cor and Russian real estate developers who are able to build one housing unit within 24 hours, saving up to 70% of construction costs, where the cost required for a single house unit complete with exterior and interior construction such as roofing, insulation, finishing, and of course the foundation is $10,134, with a size of 37 m^2.

Another study [7], shows that from the construction of houses with 3D printing, the financing has decreased by around 45%, while in the processing time there is a tremendous decrease and the waste generated in the construction of houses with 3D printers is around 40%.

3D printing innovation and technology is a very promising technology because it can automate construction work and can save work time, minimize material wastage, reduce the need for human resources in construction and minimize work that is at risk of work accidents for construction workers.

In its operation, 3D printing requires experts in technology, because it involves many disciplines including civil engineering as a construction planner, mechanical engineering as a robot motor planner in the form of a printer and the last is a computer as a software planner for the 3D printing machine. The software used in the operation of the 3d printing machine that can be used for design and architecture is grasshopper modeling [8], with the advantage of using grasshopper modeling, namely shapes based on parametric data and patterns.

The approach of 3D concrete printing for the type of house that will be mass-produced, then in its implementation must be based on layered extrusion, high spatial resolution, and the use of coarse filaments. Using large size filaments will allow high productivity and use of concrete with coarse aggregate in accordance with applicable national and international standards. The concept of using 3D printers was first presented in 2016 in Munich, Germany, and since then researchers have continued to develop 3D printer technology through a further approach towards its application in construction practice in collaboration with various construction industry stakeholders [9],.

3D Printing with new concrete materials was first carried out in 2008 at Loughborough University, England [10]. Building construction using the 3D printing method was only implemented in 2014 by WinSun in China who printed 10 houses measuring 100 m2 each within 24 hours [11], and in 2015 WinSun built a six-story flat with a total area of 1100 m^2 While the office building listed in the Guinness World of Records as the first to be built with a 3D Printer is The Future Academy building in Dubai covering an area of 241 m2 with a height of 6 m, a length of 36 m, and a width of 12 m which was printed in 17 days and took 3 months to complete the interior.

III. 3D Printer Construction

The results of Dubalet et al,'s research show that the 3D Printing system suitable for the concrete extrusion process is categorized according referring to Fig. 1 for to the size of the printed object, layer thickness, printing environment, assembly strategy, use of supporting structures, and robotic complexity [12].

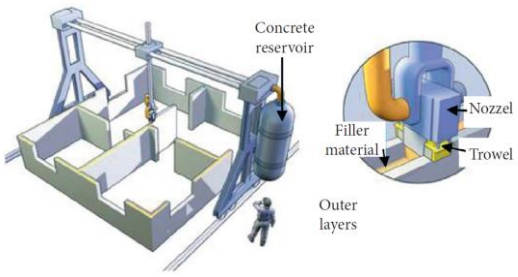

Fig. 1. 3-axis 3D printer

It was concluded that 3-axis Printers were the most common and most layers of several cm thick were produced. In addition, little research on component assembly and support structures was found.

Meanwhile, in a different research, Nerella et.al stated that the size of the 3D printer must be larger than the house to be printed using a new approach size, namely 3D Printing technology for on-site construction with the CONPrint3D system, and the working method of the CONPrint3D system refers to Fig. 2. CONPrint3D, is currently being developed at TU Dresden, Germany, which intends to bring 3D Printers directly to building sites. The main advantages of CONPrint3D technology are high geometric flexibility, use of commonly used construction machinery and low dependence on skilled labor [13] .

Fig. 2. CONPrint3D system

Gosselin et al. proposed a 3D Printing process for very high performance concrete. The proposed molding process is based on the Fused Deposition Modeling (FDM) method, in which the material is laid layer by layer through an extrusion nozzle mounted on a 6-axis robotic arm [14]. This process makes it possible to produce structures with complex geometries and large sizes without the use of temporary supports. This system is capable of producing walls measuring 1.36 m × 1.5 m × 0.17 m in approximately 12 hours (139 layers).

IV. 3D Printer Control Software

The 3D printer control software has the main task of controlling the printing process. The regulation of the process is carried out by providing control signals, in the form of digital signals, which must be given to the right points at the right time. This control signal regulates the actuator, which is a stepper motor, when to work (5 V) and when to stop (0 V). With its high capability in controlling stepper motor work precisely (up to sub millimeters), 3D printer control software can be used to print various shapes easily and quickly.

The precision of the stepper motor movement is controlled by the size or width of the pulse used (duty cycle). To adjust the pulse width, a microcontroller or computer is a very appropriate tool. With the ability to set the time up to microseconds and even nanoseconds, the microcontroller is able to adjust the pulse width flexibly and cheaply. The microcontroller is also powerful enough to operate non-stop during the printing process. With a good power supply and cooling system, it will be reliable and durable.

Another technology in the field of software related to 3D printers is a slicer or program to convert a three-dimensional model into a set of commands for a 3D printer. In this section, the command to determine the position where the concrete material in three-dimensional space (x, y, z) must be placed at the right time is compiled. This command must be set properly from the bottom one by one to the highest position to ensure the results obtained are in line with the desired expectations. Computers in this case can help the compilation process automatically and can even support simulations.

V. Alternative Concrete Material

The 3D Printing process requires the development of a new generation of materials to meet both manufacturing requirements (printability) and mechanical demands and long-lasting durability. Recent studies have shown the development of cementitious composites with different aggregate particle sizes [15]. In several studies, fibers have been included to stabilize the mixture in the fresh state or to minimize cracking due to shrinkage [16].

In the process of making a house using 3D printing, the important thing to consider in making the concrete mixture is the properties of the concrete itself such as workability, segregation and bleeding. The constituents of concrete are generally cement and fine aggregate (sand) and coarse aggregate (gravel), and water. To produce high quality concrete, additional materials such as fly ash, microsilica, and additives are usually used additive. There are several factors such as the quality of the material, the ratio of the ingredients, the water-cement factor, the composition, shape and size of the aggregate used, the conditions during manufacture and when hardening. The 3D printed house has plain concrete walls and for plain concrete walls, the vertical load supported is > 2,920 N/m, excluding its own weight [17].

In planning a house with a 3D printing machine, the type of concrete used is lightweight concrete, and the development of lightweight concrete mix designs used as structures has been widely carried out as a form of innovation from the development of the use of material limitations, and according to ASTM C1693-11 for light weight concrete types volume ranges from 400 kg/m to 1900 kg/m³, adjusted to the compressive strength class with a lightweight concrete weight ranging from 600 – 1600 kg/m³ [18]. Based on its specific gravity and compressive strength, lightweight concrete is classified into 3 groups, namely: first, Low Density Concretes, the designation is non-structural concrete such as separation/partition walls, the volume weight is 300 to 800 kg/m with a compressive strength of 0,35 to 7 MPa. Second, Moderate Strength Concretes are intended as walls that can carry loads on light structures, with a volume weight of 800 to 1.350 kg/m and a compressive strength of 7 to 17 MPa. Third, Structural Lightweight Concretes, this group can be used like normal concrete, with a volume weight of 1350 to 1900 kg/m3 and a compressive strength of >17 MPa.

An important process in concrete mixtures [19], is the mixing process because it must produce fresh concrete that is plastic, visually evenly distributed, has sufficient and homogeneous consistency, and because it is planned to be connected to a 3D printing machine, the mechanism the mixing uses the help of a tool, namely a batching plant with an automatic machine. In order for fresh concrete after being stirred and then printed through a concrete pump, the thing that needs to be considered is the timeliness in pouring the concrete mixture because this will affect the loss of plasticity before the fresh concrete is poured. The duration of time for the transfer from the concrete mixer to the pump must be considered, therefore the ease of work, segregation factors and concrete binding factors need to be the main consideration so that the plasticity of the concrete is according to the plan, and to maintain the plasticity of the concrete use admixture.

VI. Research Methods

The type of research used in this study is Research and Development, namely the research method used to produce certain products, and test the effectiveness of these products [20], and in this study there are three parallel product developments, first is the study of the comparison with the conventional construction work and the technology construction work use 3D printer machine, second is developing 3D Printer software using the Rapid Application Development (RAD) method, and lastly developing concrete mix materials using an experimental method, as well as designing a 3D Prototype printers . Referring to Fig. 3, it can be seen the plan about this research method.

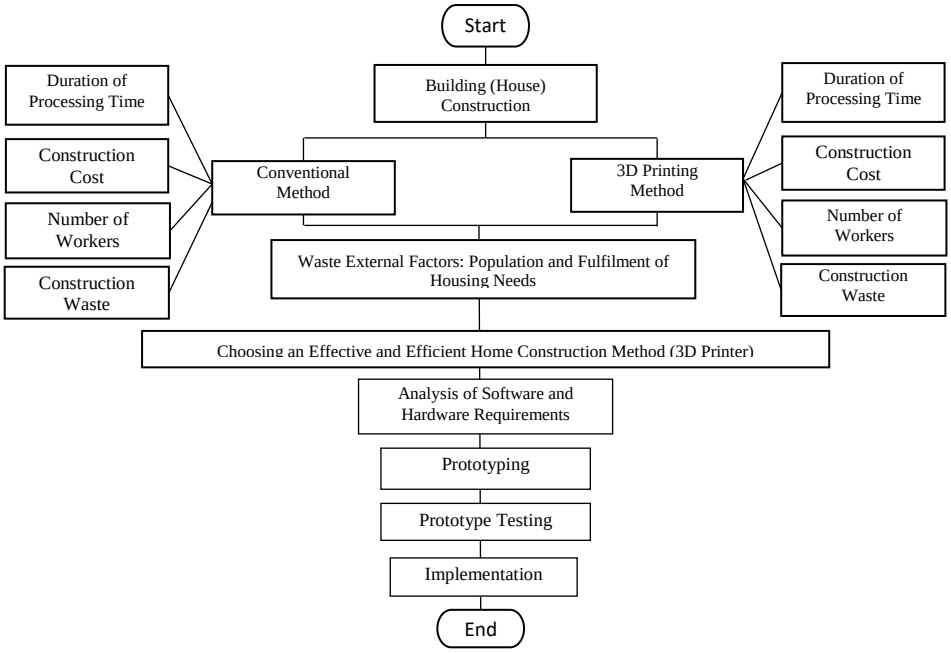

Fig. 3. Research method

VII. Results And Discussion

A. *Fulfilling Housing Needs Due to Population Growth*

The main factor that drives the development of 3D printer machines for the fulfillment of housing needs in Indonesia is the population increasing every year . Statistics recorded that the total population of Indonesia is 270.2 million people, with the distribution per island is 56.10% in Java, 21.68% in Sumatra, 7.36% in Sulawesi, 6.15 in Kalimantan, 5.54% in Bali and Nusa of Southeast and 3.17% in Maluku and Papua, this data shows that population growth has begun to spread evenly to various islands although it is still slow (humas Setkab.go.id, 2021). The increasing population of Indonesia will certainly have an impact on the fulfillment of housing needs, and the fulfillment of housing needs is an indicator of welfare for the Indonesian people. Housing needs from year to year always fluctuate, such as data on housing needs from the Central Statistics Agency of Republic of Indonesia from 2007-2017. Referring to Fig. 4, we can see that the number of families who do not have their own homes as of 2017 is 20.39 percent of about 63 million households or around 13,698,343 households.

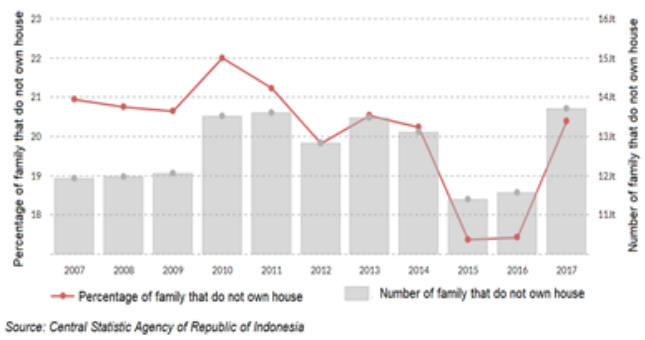

Fig. 4. Housing backlog in 2007-2017

In Fig. 4 we can see that the 11-year trend since 2007, backlog houses tend to fluctuate. Meanwhile, based on data from the Central Statistics Agency [21] shows that the percentage of households that have access to decent and affordable housing has decreased dramatically from 95.70% in 2018 to 56.51% in 2019. The president of Indonesia responded by targeting the building of a million houses and until the first quarter of 2021, have been realized 164,071 housing units for all (Kompas.com, 2021), and if the population growth rate is for example 1%, then per year there is an increase of 2.7 million residents, so the housing needs that need to be met are 625 000 housing units annual, and the total number of housing needs will increase if the backlog and rehabilitation of damaged houses are taken into account .

B. *Rapid Application Development (RAD)*

Printer controller software was developed using the Rapid Application Development (RAD) method. This method is appropriate to be used in software development in this research because it allows to speed up the completion time and at the same time open the interaction space for all parties involved in an intense and incremental manner. Faster time is needed because technological developments in this field are very fast and interaction space between related parties is mandatory because it involves cross-study programs with different disciplines, although they are still closely related.

The specifications of the printer controller software developed, based on the results of the requirements analysis stage [22], are as follows:

1. The software is able to control the printer to print flexibly, either automatically or point by point manually. This feature is very useful to support experiments related to the characteristics of materials and compositions to be used.
2. The software is able to control the printing process speed, can be programmed the time. This feature is also useful to support experiments related to the composition of mixtures of materials.

3. The software is capable of recording/documenting printing activities in the form of Documents, for example for subsequent processes such as repetition. This feature allows users to save, reopen, and make changes to documents.
4. For ease of operation, the software interface is made web-based via WiFi so that it supports laptops, tablets, and smartphones.

Referring to Fig. 5, the method of using the software developed in this research.

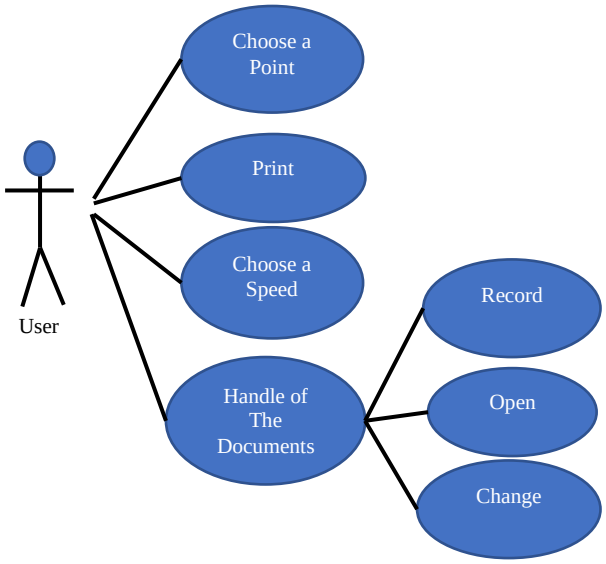

Fig. 5. Use case of 3D printing control software for house construction.

C. *Comparison of House Construction Conventional Methods with House Construction 3D Printing Methods*

In building a house, several things need to be considered such as the length of time for implementation, construction costs and the number of workers. Reinforcing structures in a house generally use reinforced concrete, and the manufacturing process cannot be carried out directly, but must be gradual, and for wall installation, based on the results of research conducted by Pramudiyanto et al. using lightweight concrete per m² is 25,966 minutes [23]. The duration of the work will be directly proportional to the costs that must be incurred, showing that, for the installation of red bricks the cost per m² is Rp. 69.122.53 /m², moderate if using lightweight concrete per m² Rp. 83,125.03 /m². The size of the house and the details and materials used determine the length of time the work will take (Sejasa.com, 2020), for a simple house it takes about 3-4 months, a medium-sized house about 4-6 months, with an average cost per m², of around Rp. 3,000,000, -, then for the construction of a 36 m², house, it costs Rp. 108,000,000,.

The results of a conventional house construction research conducted in the Bandung with a house size of 36 m², with a duration of work implementation of 16 weeks or about 3.5 months, with a total workforce of 3 builders, 5 workers, 1 foreman and the implementation cost is Rp. 149.034.000,- . Meanwhile, if we refer to the results of the work carried out by the WinSun Decoration Design Engineering Co China (Hager et al., 2016) company using a 3D printer machine and a larger house size, which is 4 m long, 10 m wide, and 10 m high, printed in a per layer way, and for one housing unit it is carried out for 24 hours with a total cost of 4,800 US$ or around Rp. 69,561,600,-.

D. *Construction Work Waste*

Construction activities such as the construction of houses generate a large amount of waste, construction waste is classified into two types, namely Consumable materials such as cement, sand, gravel, bricks, reinforcing iron, steel, and others. The second type is non-consumable materials such as scaffolding, formwork, and temporary retaining walls. This construction waste has a significant effect on the decline in environmental quality [24].

The increase in waste from construction work is caused by many things, [25] mainly due to economic development which is centralized in urban areas, causing urbanization and population growth. The increasing urbanization will affect the fulfillment of housing in the city area, so it can be said that the population growth rate is directly proportional to the waste generated from construction work. Construction work waste generated during the construction process can be in the form of excavated materials, construction materials such as concrete, wooden scaffolding, plastic wrapping materials or construction tools, cement paper, metal.

With regard to the need of fulfilling housing needs and comparing current existing conventional method of house construction to 3D printing method, as well as considering significant reduction of construction work waste, this research has successfully developed a prototype of 3D printer for construction, including the printer's controller software.

VIII. Recommendations

Based on the results of the analysis and fulfillment of housing needs which are directly proportional to the growth of Indonesia's population, the speed of construction time, the availability of experts for house construction, and the impact of pollution on the environment caused by construction activities, 3D printing machine technology for the construction world is very much needed [26] and therefore there is a need for a further study to procure a home-made 3D printing machine from both software and hardware.

IX. Conclusion

Based on the results of the analysis regarding the construction of a small house sizing 36 m^2 with the conventional method takes 3.5 months, needs 9 workers, and the total cost of Rp 149,034,000. On the other hand, the construction of a house sizing 40 m² by using a 3D printer, takes 24 hours, 1 operator and the required cost of Rp 69,561,600, this shows that the 3D printer is very efficient in saving time, labor and costs. When viewed from the waste of material used, 3D printer method significantly reduces construction waste, including consumable and non consumable materials, this construction waste greatly affects the decline in environmental quality. Therefore, the use of 3D printer machines for house construction is very suitable. The prototype of 3D printer for construction has been built, including the printer's controller software. Further research on finding suitable concrete mixture is on progress and in the future the full-scale housing 3D printer development has been planned.

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