

Development of a Large 3D printer for Manufacturing Form-Liner and Protective Skin of Concrete Structures

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Abstract

This study discusses research and development of large-sized 3D printers that can be applied to construction and civil engineering for various designs of protective casing on foam liner for concrete exteriors. The consistent use of concrete represents the current surroundings. However, concrete exteriors in Korea have not considered the regional characteristics, but the concrete has been poured solely for economical aspects for the last decade or two. There are many cases of poor installation and not enough design development projects to correct it. This study was conducted to apply various patterns, regional characteristics, and 3D printing for protective casing design for foam liner to create various designs for the concrete walls. Therefore, we started researching on a large 3D printer, and designed and developed this system. Considering the chronological process, the properties of concrete structures were identified, the application of designs for concrete in Korea and abroad and the 3D printing materials for the protective casing were surveyed and analyzed, and a stereotype was produced in the first year to study designs for the beauty of concrete surfaces. In the second year, images of regional characteristics were gathered, design ideas for regional promotion were derived, virtual images were produced along with design modeling to simulate the appearances, and verify the effect of application and promotion. Finally, in the third year, the 3D printer for concrete foam liner was constantly improved to analyze the 3D printing program and the various library elements to complete an actual large-sized 3D printer.

Keywords: 3D Printer, Concrete, Aesthetic, Form Liner, Protective Skin

1. Introduction

Currently, most of the domestic structures are not processed considering the formative aspect due to the economic aspect of the concrete structure and the difficult technical reasons that appear in production. However, by applying a very inexpensive material pattern, the aesthetic treatment technology of the concrete surface is applied to apply a very rudimentary degree as shown in Figure 1. [1],[2] However, as shown in Figure 2, in developed countries, various aspects of the concrete surface treatment technique are considered and applied, so the aesthetic treatment is considerably nature-friendly and has already been applied to a

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considerable level in consideration of regional characteristics. In this case, it has been manufactured by applying steel formwork, which requires considerable cost, and has not yet been applied in Korea. By utilizing the customized 3D printer developed in this project, it is possible to overcome such economic and technological limitations because high artistic molding processing is economically possible.[3]



Figure 1. Coarse aesthetic treatment of retaining walls / walls in Korea



Figure 2. U.S. Case of Untreated Concrete Wall (Highway 161, USA)

Existing concrete surfaces without special protection are directly exposed to deterioration such as weathering and erosion (Figure 3), but when the protective sheath is treated on concrete surfaces, deterioration and damage of concrete are reduced, thereby increasing the durability of the concrete to increase the durability of the structure. It reduces the life cycle cost (LCC) by prolonging life and reducing maintenance costs. The technology that increases the durability life of the structure can maximize the efficiency of investment in the national infrastructure in the long term, making it a very important technology in terms of economy, industry, and even aesthetics of each region.



Figure 3. Concrete aging and rebar corrosion

Although several types of 3D printer equipment are already commercialized, the construction field product of this convergence research requires large relief technology, so it is suitable for the application and development of customized 3D printer equipment and the synthetic manufacturing method of manufacturing materials. Hardware application development is essential. Currently, the related technology patent of Fused Deposition Modeling (FDM) 3D printer has expired and the technology has been released, so utilize it. Figure 4 shows an overseas case of building a model with a 3D printer. In order to develop a customized 3D printer for this study, new design and production are required in various parts of the equipment.

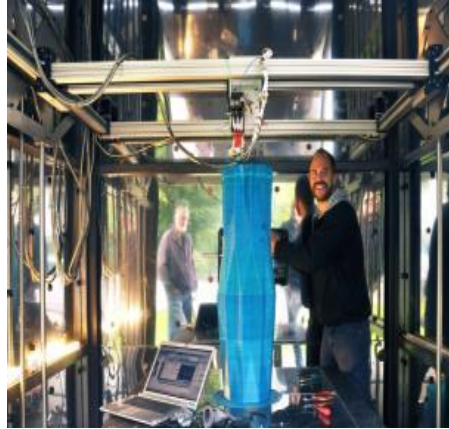


Figure 4. 3D printing building model production (DUS Architects, Netherlands) [4]

In this paper, we introduce a foam liner for creating aesthetic appearance of concrete surface and a protective shell for preventing deterioration of concrete, and summarize the design and manufacturing process of a customized 3D printer to produce it.

2. Foam Liner and Protective Shell

2.1 Foam Liner

If a concrete formwork as shown in Figure 5 is used for pouring and curing concrete, the concrete surface can only be produced in a monotonous plane. On the other hand, as shown in Figure 6, various mold reliefs can be realized on the concrete surface by demolding the form liner and formwork when demolding the formwork after curing the concrete by installing a foam liner that includes reliefs for relief processing. In this case, a 3D printer produces a semi-stereo-structured foam liner processed for engraving.

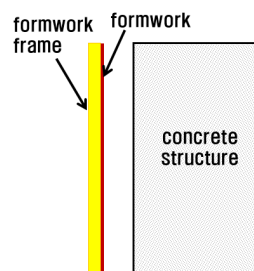


Figure 5. Application of ordinary formwork

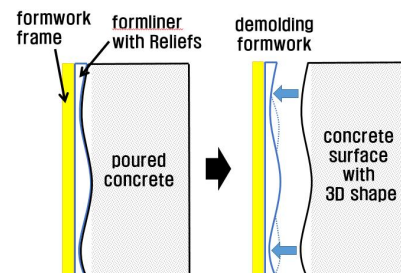


Figure 6. Three-dimensional modeling form liner and formwork application concept

2.2 Protective Jacket

As shown in Figure 7, air, moisture, and carbon dioxide penetrate the exposed concrete without a protective outer sheath, and deterioration occurs in the concrete. When a protective sheath is applied to a concrete surface, the durability or structure is extended by reducing the deterioration or damage of the concrete, thereby increasing the durability. Therefore, it reduces the life cycle cost (LCC), maximizing the effect on the construction investment cost.

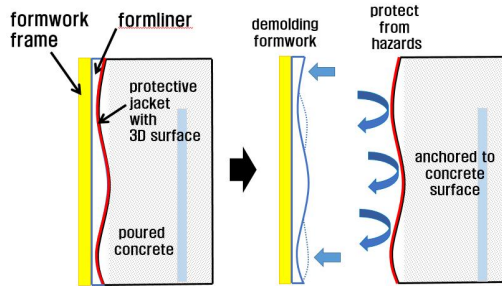


Figure. 7 Reduction of damage and deterioration due to envelope

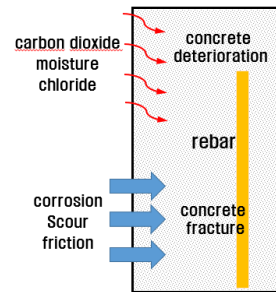


Figure. 8 Concrete damage and deterioration

As shown in Figure 8, the concrete protective sheath is mounted on the formwork, and when the concrete is cast and cured, the protective sheath (indicated by the red curve) is integrated with the concrete, and only the formwork is demolded. The protective sheathing must be designed and applied with a sturdy structure that can withstand the pressure of the hardened state before curing when pouring concrete. In addition, since it has to be integrated with concrete, it must be designed and manufactured to have a separate anchor structure to be permanently settled on concrete on the inner surface of the protective sheath.

3. Materials

ABS or PLA is generally used for the FDM production method. In addition, glass fiber reinforced composite materials (GFRP) combined with polyester and vinyl ester, chemical resistant resins, etc. may be used according to environmental exposure conditions. The following is a reorganization of the characteristics of materials used for 3D printing among the table contents of the Small and Medium Enterprise Technology Roadmap 2017-2019 Technology Road map for SME-Summary Report I, 3D Printing Materials Industry Roadmap [5].

Table 1. Materials are divided into four types as shown in the following table.

Material type	Material Name
Thermoplastic	PLA
	ABS
	PVA, HIPS
	Polycarbonate, Nylon , Polyphenylsulfone
	ULTEM, PEEK, PAEK Engineering Plastics
Powder	Polyamide
	Alumide
	Multi-color

Resin	UV Resin
	Paint Resin
	Resin
Metal	Titanium
	Stainless steel
	Bronze
	Brass, Silver, Gold
Ceramic	Glass, Alumina, Silica

First, it is a thermoplastic. It refers to plastic that melts in heat among plastics. The types of thermoplastics are PLA, PVA, HIPS, Polycarbonate, Nylon, and Polyphenylsulfone. Among these, PLA was difficult to perform in the initial stage in 3D printers, but it is currently used as an engineering plastic that exhibits tensile strength and compressive strength using other additives. It is an eco-friendly material that decomposes naturally. Therefore, it is known as a material that is not easy to store materials. ABS is also a widely used material, and it has a lot of problems due to odor and various harmful gases when melting. It is also used in 3D printers, but it has a high shrinkage, so it is a material with a lot of deformation.[6]

Second is the powder type (Powder). Polyamide is a material that is frequently used in nylon 12 and is used as a blend multi-color fine powder of aluminum powder of alumide gray and polyamide. Third is the liquid (Resin). High-precision UV resin is a photo-polymer liquid and is known as a photo-curable resin. This is of interest through functional liquids that can be used through self-light sources even at night by mixing fluorescent materials through functional application of various materials.

Fourth, there is a metal. Recently, the metal case is widely used in the production of special parts with Titanium, and is known as a 3DP material requiring light weight and strength. There is also a method of sintering the powder with a laser, and recently, a Fused Deposition Metal Modeling (FDMM) method of binding a powder to a polymer and stacking it with an FDM method has also been spotlighted. Materials such as stainless steel, bronze, brass, and silver are also showing considerable interest due to the competitiveness of 3D printing inexpensively through the FDMM method. Fifth is ceramic. As ceramics, materials such as glass, alumina, and silica are used as materials requiring special parts.[7]

4. 3D Printer Design

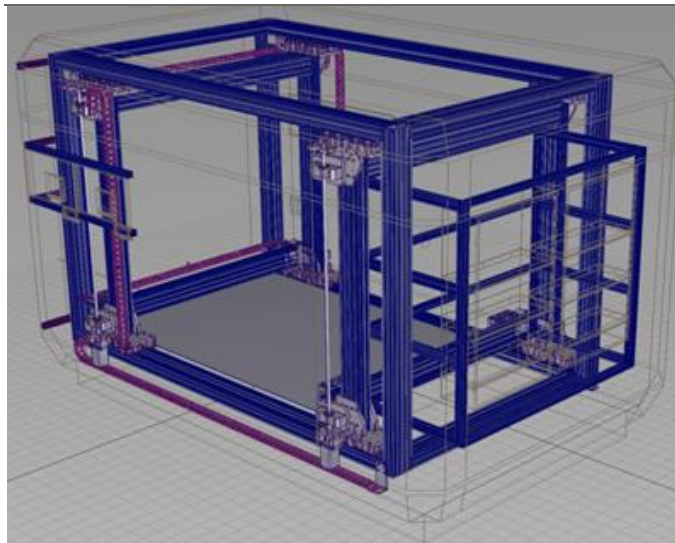
The 3D printer developed in this study was developed in the first and second order. The 3D printer is largely composed of hardware and software, and the hardware is composed of a structural frame, mechanics, electronics, and extruder that form the overall appearance of the printer and enable stable operation. The software consisted of CAD, CAM and firmware. In order to enlarge the 3D printer, it was designed by changing the size of various parts and changing the existing belt-type drive to Linear Guideways (LM) guide and block method.

4.1 Frame Design and Production

The large 3D printer is as shown in the table below. The external size (frame) is 2,680 mm × 1,460 mm × 1,660 mm. The maximum molding size is 1,830mm × 1,200mm × 1,200mm, and the output resolution is 0.01mm for the X and Y axes and 0.02mm for the Z axis.

Table 2. Requirement of the large 3D printer

Item	Specifications
Frame Size	2,680 mm × 1,460 mm × 1,660 mm
Working Size	1,830 mm × 960 mm × 960mm
Resolution	X 0.01 mm
	Y 0.01 mm
	Z 0.02 mm
Filament Diameter	1.75 mm

**Figure 9. 3D Printer Frame Schematic****Figure 10. Large 3D printer frame produced**

As shown in Figure 9 and 10, it was manufactured using aluminum 70 aluminum profile for construction materials. In consideration of the weight due to the enlargement of the head, a LM guide with a higher precision

was applied than before.

4.2 Design and Manufacture of Drive and Control Devices

With the Nema 47 series motor, the torque output and stepping motor were applied to withstand the weight of the X and Y axes and move quickly to stop. The main board used MKS GEN V1.4 version (Figure 11). It is equipped with a circuit that can use all 5 motors, and has installed a limit sensor and a bed heating port while following the Mega 2560 series, an existing educational 3D printer board. [8]

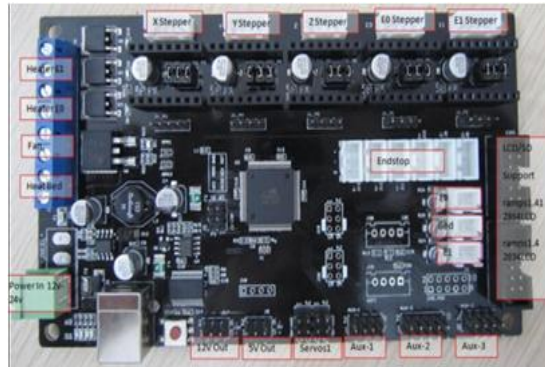


Figure 11. Motherboard (MKS GEN V1.4)

It is designed to run a separate slicer program in the computer by embedding the computer. For easy control, a full-touch monitor is installed to design the equipment for easy operation by the user (Figure 12).



Figure 12. Full-touch printing control monitor

For driving of power, a total of 8 Nema34 Stepper Motors were designed and applied, one on the Z axis, four on the Y axis, and two on the X axis. The M860 model was applied to the stepper driver at 7.8A, and the power supply was designed by applying 350W and DC60V for each motor due to the capacity of each motor. Figure 13 shows the wired state for the motion control stepper.

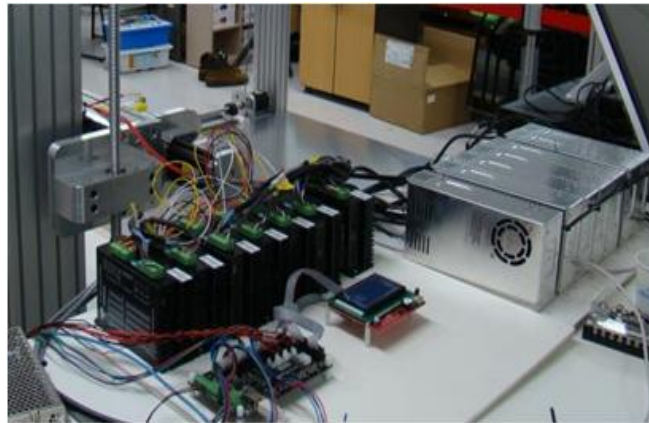


Figure 13. 3D motion control stepper driver

The controller, which was designed and manufactured in the LCD method, was upgraded, and it was designed and manufactured to be easy for the user to control, mainly on the touch pad and temperature controller, as shown in Figure 14. A temperature controller and a timer were placed directly under the monitor to facilitate temperature control, and the total heating bed area was large to produce and divided four heat beds, and each temperature controller and timer was set to operate stably. On the lower left side, emergency stop button and on-off button are located. On the right side, a full-touch controller of the MKS Pad7 version is designed separately with a keyboard. Using this controller, the whole slicer path can be simulated.



Figure 14. Dedicated controller design

4.3 Smart Head Design

In order to use a variety of materials at a lower cost, the head was designed to use pellets, which are raw materials, rather than using a regular filament (Figure 15 left) (Figure 15 right). The solid pellet is melted and the raw material is extruded from the nozzle, and the extruded raw material is laminated one by one by a predetermined thickness, so the bonding force between the laminates is determined according to the

characteristics of the molding material, production temperature, and nozzle movement speed.

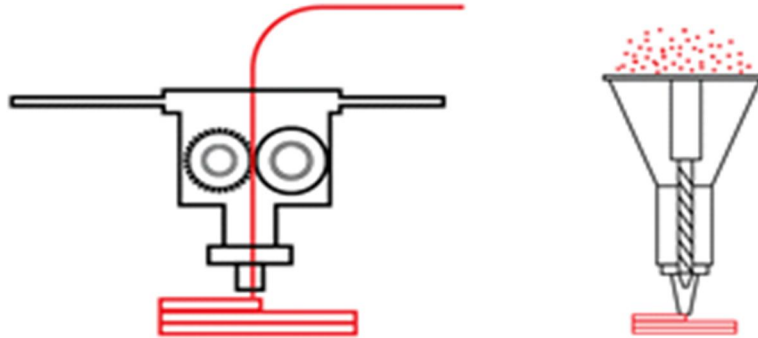


Figure 15. Printer head for filament (left), printer head for pellets (right)

As shown in Figure 16, the contents were largely applied with a hopper that is a raw material inlet, a grinder for allowing the raw material to fit into the pellet, and a gear type (10: 1) Nema27 motor that drives it. In addition, the white part inside is a hopper made of Teflon to block the heat conducting from the inner head so that melting of the raw material pellet does not occur in the initial hopper. Figure 17 shows the hopper and grinder at the top of the manufactured smart head.

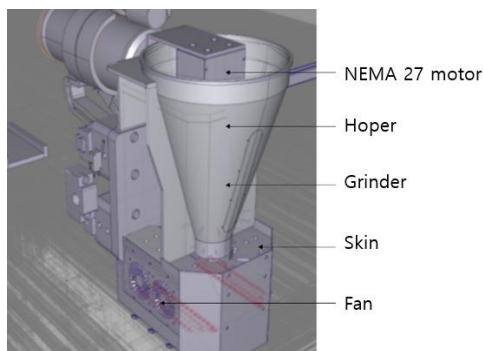


Figure 16. Smart head design



Figure 17. Grinding inside the hopper at the top of the smart head

The existing 3D printer senses the temperature to operate the fan to maintain the rated temperature, but the temperature control system designed and manufactured in this study utilizes the ambient temperature in consideration of the circulation of air to efficiently control the temperature. That is, the circuit was designed to allow gradual temperature control different from the sudden temperature control by utilizing the air temperature of the barrel surrounding the outside and the screw. As shown in Figure 18, the heat loss that occurs when the temperature of the corresponding part is changed from low temperature to high temperature or high temperature to low temperature due to the change in the circulation flow of the air according to the direction change of the fan is reduced. Figure 19 shows the parts used in the head, and Figure 20 shows the appearance of the head and the fans that hang around it. Figure 21 shows the discharge of pellets from this head. [9]

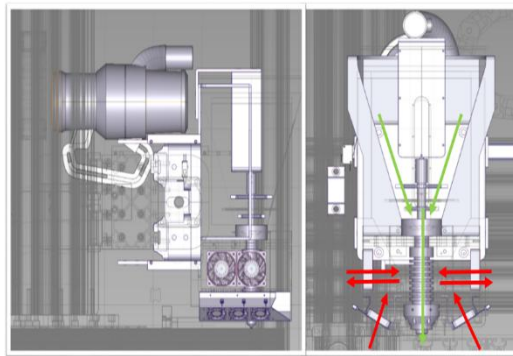


Figure 18. Smart Head Air Circulation System



Figure 19. Screw, heat rod, barrel, nozzle of the smart head



Figure 20. Large 3D printer smart head

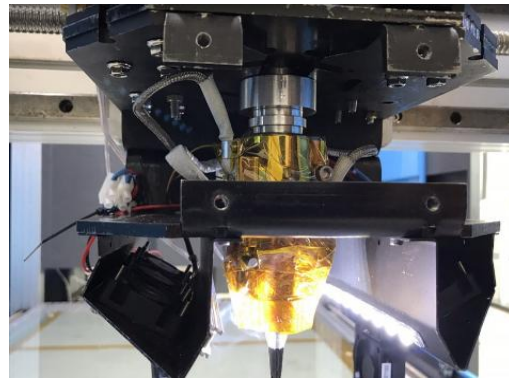


Figure 21. Large 3D printer pellet ejection

4.4 Exterior Design

Sliding doors were created on both sides to prevent safety accidents by closing the doors during 3D printing production, and when the production was completed, the doors were completely opened to facilitate transport of prints (Figure 22). In addition, a full-touch monitor is installed on both sides of this door, and it is connected to the camera showing the overall production status from the top, and it is connected to the camera showing the enlarged screen of the desired part through remote control, so you can check the production status. [10]

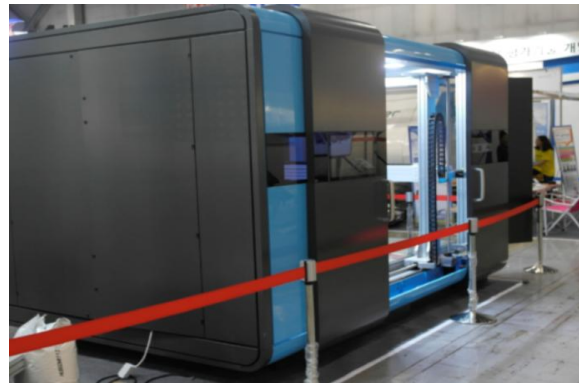


Figure 22. 3D printer exterior design

5. Production Result

5.1 Form Liner Production

Figure 23 shows the wave pattern modular form liner actually outputted on a large 3D printer. Combining various modules has the advantage of providing various design shapes. Figure 24 shows an example of applying a geometric design to a form liner.



Figure 23. Moire Modular Foam Liner Design



Figure 24. Geometric modular formliner design

5.2 Protective Outer Sheath

Figure 25 shows the construction of the anchor part for fixing the protective sheath to concrete after completion. Next, the anchor part plays a role of integrating the protective shell with the concrete after being poured and cured and buried inside the concrete. In order to disperse the settling load, the height of the anchor portion was changed, and the length of the anchor portion was lengthened to reduce the possibility of damage to the anchor.

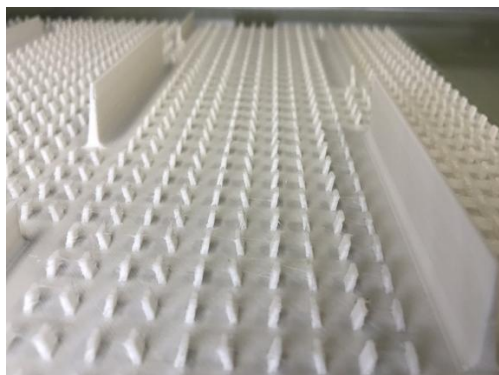


Figure 25. Manufactured protective sheath anchor

6. Conclusion and Expected Effect

In this study, a 3D printer was designed and manufactured as follows to produce a foam liner for creating aesthetic appearance of concrete and a protective shell for reducing deterioration of concrete.

- 1) A large 3D printer frame was designed and manufactured to a size of 2,680 mm × 1,460 mm × 1,660 mm. At present, the size of the production produced by domestic 3D printing technology did not exceed 50cm on one side, but this was greatly expanded to the 3D printer developed and researched in this study. By utilizing this, it is possible to produce a variety of large-sized sculptures, and it will be able to be sufficiently utilized in the field of sculpture art.
- 2) Designed and manufactured a head drive and control device equipped with a touch pad and temperature controller for ease of use.
- 3) We designed and manufactured a smart head that can use a variety of pellet materials at a lower cost and can effectively control the temperature inside the head by utilizing the situation of ambient temperature.
- 4) The exterior was designed and manufactured considering safety and workability.
- 5) The foam liner and protective sheath were successfully manufactured with the 3D printer. If the spread of this technology that can mass-produce concrete foam liners of various shapes and protective sheath products as a large-scale 3D printer spreads, it will significantly change the aesthetics of cities and roadsides, and will greatly contribute to the aesthetic enhancement of public infrastructure and buildings. It is expected.

We are planning to continue various empirical studies based on research on large 3D printers in the future. From the previous examination of the precision and applicability of the initially developed large-scale 3D printer, it was confirmed that there was considerable interest in the field of construction and civil engineering. In addition, the strength of the hardware and software developed by our research team was that it can apply engineering plastics required in the field and that it can be printed in large format. In the future, we hope to develop a more realistic system in the field of construction and civil engineering after testing by applying a large form liner.

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