DESIGN AND FABRICATION OF A 3D CONCRETE PRINTER

A Final Year Project Report

Presented to

SCHOOL OF MECHANICAL & MANUFACTURING ENGINEERING

Department of Mechanical Engineering

NUST

ISLAMABAD, PAKISTAN

In Partial Fulfillment
of the Requirements for the Degree of
Bachelors of Mechanical Engineering

by

Ibrahim Luqman
Muhammad Ashir Atif
Muhammad Arham
Syed Muhammad Asghar Abbas

June 2023

EXAMINATION COMMITTEE

We hereby recommend that the final year project report prepared under our supervision by:

IBRAHIM LUQMAN 321686.

MUHAMMAD ASHIR ATIF 297034.

MUHAMMAD ARHAM 284430.

SYED MUHAMMAD ASGHAR ABBAS 321737.

Titled: "DESIGN AND FABRICATION OF A 3D CONCRETE PRINTER" be accepted in partial fulfilment of the requirements for the award of BACHELOR'S IN MECHANICAL ENGINEERING degree with grade ___

Supervisor: Rehan Zahid, Assistant Professor FYP Supervisor	______________________ Dated:
Committee Member: Name, Title (faculty rank) Affiliation	______________________ Dated:
Committee Member: Name, Title (faculty rank) Affiliation	______________________ Dated:

______________________ ____________

(Head of Department) (Date)

COUNTERSIGNED

Dated: ________________ __________________________

(Dean / Principal)

ABSTRACT

The construction industry has seen significant technological advancements in recent years, with 3D printing being one of the most notable. 3D printing technology has the potential to revolutionize the construction industry, allowing for faster, more efficient, and more sustainable construction practices. In this thesis, we present the design and fabrication of a 3D concrete printer, which is capable of printing small-scale concrete structures.

The 3D concrete printer is designed to be affordable and easy to assemble, using off-the-shelf components and 3D printed parts. The printer is designed to be versatile, allowing for printing various shapes and sizes of concrete structures. The printer uses a custom-designed extruder, which is capable of printing concrete at high speeds while maintaining accuracy and precision.

The fabrication of the printer involved the construction of a sturdy frame and the integration of the extruder and control system. The printer was then tested and optimized to ensure its performance met the desired specifications.

The 3D concrete printer has the potential to transform the construction industry, allowing for faster and more efficient construction practices, reducing waste, and improving sustainability. This thesis presents a proof of concept for the design and fabrication of a 3D concrete printer, which can be further developed and optimized to suit specific construction needs.

ACKNOWLEDGMENTS

We would like to express our heartfelt appreciation to all those who have contributed to the completion of this thesis.

Firstly, we would like to extend our sincere gratitude to our thesis advisor Dr. Rehan Zahid and co-advisor Dr. Jawad Aslam for their invaluable guidance and support throughout the research process. Their expertise, insights, and constructive feedback have been instrumental in shaping our work.

We would also like to thank the faculty members of SMME and DME for their encouragement, guidance, and support in our academic pursuits.

We would like to express our appreciation to the staff members of CIM Lab and tribology lab for their assistance and resources that have facilitated our project.

We would like to extend our thanks to our family and friends and our fellow colleague Mr. Kashif Changez for their unwavering support, encouragement, and understanding throughout the process.

Finally, we would like to express our gratitude to the participants who participated in our study, for their valuable time, effort, and contributions, without which this project would not have been possible.

Thank you all for your support, encouragement, and contributions towards the completion of this thesis.

ORIGINALITY REPORT

TABLE OF CONTENTS

ABSTRACT.....2

ACKNOWLEDGMENTS.....3

ORIGINALITY REPORT.....4

LIST OF TABLES.....8

LIST OF FIGURES.....9

ABBREVIATIONS.....11

NOMENCLATURE.....12

CHAPTER 1: INTRODUCTION.....13

CHAPTER 2: LITERATURE REVIEW.....17

1. **Izabela Hager, et al. (2016)**..... 17
2. **Antony Thorpe, et al. (May, 2014)**..... 18
3. **Byung Wan Jo, et al. (2020)**..... 19
4. **Van Der Putten, et al. (July 2020)**..... 19
5. **Imane Krimi, et al. (June 2017)**..... 20
6. **Rabab Allouzi, et al. (April 2019)**..... 20
7. **Manju.R, et al. (August 2019)**..... 21

8. Behzad Nematollahi, et al. (2017) 21

9. Yasmin Tarhan, et al. (April 2019) 22

10. Amitkumar D. Raval, et al. (March 2020) 23

11. Guowei, et al. (April 2017) 23

12. Victor Molodin, et al. (April 2020) 24

Types of 3D concrete printers 24

Types of extrusion systems 26

Why is 3D concrete printer necessary in Pakistan: 28

Why are 3D concrete printers necessary? 30

What are the benefits of using gantry system in 3D concrete printing? 32

Material used in 3D concrete printers 34

CHAPTER 3: METHODOLOGY 37

Choosing the design 37

Articulated Robot 37

Gantry System: 37

Initial Design: 39

Base of the printer: 39

Motor Selection and Ball screw: 41

X-Axis Gantry 43

Z-Axis: 46

Oiling Mechanism: 48

Wiring diagram of the distribution box: 50

CHAPTER 4: RESULTS and DISCUSSIONS 52

CAD Drawings and Analysis 54

Base Plate: 54

Y-Axis Upper Bearing Plate 57

Vertical Plates: 60

Z-Axis Plate: 62

Extrusion System: 65

.... 69

CHAPTER 5: CONCLUSION AND RECOMMENDATION 70

REFRENCES 74

LIST OF TABLES

Table 1. Nomenclature..12

Table 2. Appendix I..72

LIST OF FIGURES

Figure 1: Design of base of gantry....**40**

Figure 2. Y axis components side view...**42**

Figure 3. Final design of Y-axis. **43**

Figure 4. X-axis gantry components side view **44**

Figure 5. X and Y axes gantry **46**

Figure 6. Aluminium plate design for Z axis...**47**

Figure 7. Reinforced final design for Z-axis..**48**

Figure 8. Oil Lubrication Mechanism..**50**

Figure 9. Wiring diagram of the distribution box: **51**

Figure 10. MS Base Plate...**54**

Figure 11. Equivalent Deformation of Base Plate..**55**

Figure 12. Equivalent Stress of Base Plate **55**

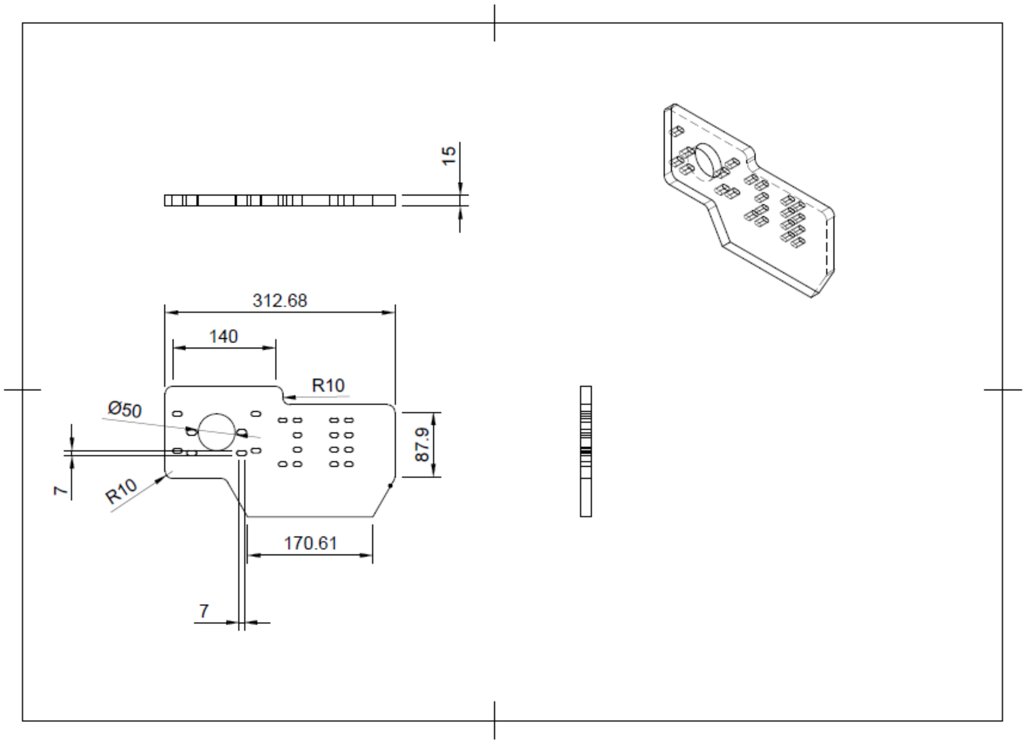


Figure 13. MS Base Plate..56

Figure 14: Y-axis Bearing Plate...58

Figure 15: Total Deformation..58

Figure 16: Equivalent Stress...59

Figure 17: Vertical Plates for X-Axis...60

Figure 18: Total Deformation..61

Figure 19: Equivalent Deformation 61

Figure 20: Z-Axis Plate...62

Figure 21: Total Deformation...63

Figure 22: Equivalent Stress..63

Figure 23. Z-axis plates CAD...64

Figure 24. Extrusion system..65

Figure 25. Extrusion system..69

ABBREVIATIONS

CNC: Computer Numerically Controlled

MS: Mild Steel

FDM: Fused Deposition Modeling

STL: Stereo Lithography

NOMENCLATURE

Table 1. Nomenclature

Component	Nomenclature
SHAC Linear Bearing	HGH 25 CA
Linear Rails	HGH 25
Ball screw	SFU 2510
Stepper Motor	Nema 34

CHAPTER 1: INTRODUCTION

The construction industry has been rapidly evolving over the past few years, with the introduction of innovative technologies that have significantly improved the efficiency and accuracy of construction processes. One of these technologies is 3D concrete printing, which allows for the fabrication of complex and customized architectural elements using additive manufacturing techniques. In this thesis, we present the design and fabrication of a 3D concrete printer that utilizes a CNC routing machine and extrusion system. The printer is designed to enable the creation of complex concrete structures with high precision and efficiency, which can significantly reduce the cost and time required for construction projects.

Problem Statement:

The traditional construction industry is associated with several challenges, including high labor costs, slow construction processes, and high material wastage. Additionally, traditional construction methods often result in limited design flexibility and require extensive resources to create complex structures. These challenges can be addressed by utilizing 3D printing technology, which offers increased precision, design flexibility, and reduced material wastage.

The construction industry has been struggling with the limitations of traditional construction methods for years. These methods are often inefficient, labor-intensive, and result in high material wastage, which significantly increases construction costs.

Additionally, traditional construction methods can lead to limited design flexibility and require extensive resources to create complex structures. As a result, there has been an increasing demand for innovative technologies that can address these challenges and improve the efficiency and accuracy of construction processes.

3D printing technology has emerged as a promising solution to the challenges associated with traditional construction methods. By utilizing additive manufacturing techniques, 3D printing can significantly reduce material wastage, increase design flexibility, and enable the creation of complex structures with high precision and efficiency. One of the most significant benefits of 3D printing technology is its ability to print customized architectural elements, which can significantly reduce the time and cost required for construction projects.

Motivation:

The motivation behind this project is to design and fabricate a 3D concrete printer that can address the limitations of traditional construction methods. By incorporating a CNC routing machine and extrusion system into the printer, we aim to increase the precision and flexibility of the printing process, while reducing material wastage and construction time. Additionally, the printer can enable the creation of complex structures that would be challenging or impossible to create using traditional construction methods.

The main motivation behind this project is to address the challenges associated with traditional construction methods and provide a viable solution to the construction industry.

By designing and fabricating a 3D concrete printer that incorporates a CNC routing machine and extrusion system, we aim to increase the precision and flexibility of the printing process, while reducing material wastage and construction time. Additionally, the printer can enable the creation of complex structures that would be challenging or impossible to create using traditional construction methods. Our goal is to provide the construction industry with innovative and efficient technology that can significantly improve the efficiency and accuracy of construction processes.

Objectives:

The objectives of this project are as follows:

To design a 3D concrete printer that can utilize a CNC routing machine and extrusion system to create complex concrete structures with high precision and efficiency.

To fabricate the 3D concrete printer using readily available and cost-effective materials.

To optimize the printer's performance by conducting experiments and testing to determine the ideal printing parameters.

To evaluate the printer's capabilities by printing a variety of complex concrete structures and comparing the results to traditional construction methods.

The first objective of this project is to design a 3D concrete printer that can utilize a CNC routing machine and extrusion system to create complex concrete structures with high precision and efficiency. The printer should be able to print a variety of complex shapes and designs with high accuracy and consistency.

The second objective is to fabricate the 3D concrete printer using readily available and cost-effective materials. It is important to ensure that the printer is constructed using materials that are affordable and easy to source, as this will make the technology accessible to a wider range of construction companies.

The third objective is to optimize the printer's performance by conducting experiments and testing to determine the ideal printing parameters. This will involve testing a range of printing parameters, such as extrusion speed and temperature, to determine the optimal settings for printing concrete structures with high precision and efficiency.

The fourth objective is to evaluate the printer's capabilities by printing a variety of complex concrete structures and comparing the results to traditional construction methods. This will involve printing structures such as columns, walls, and arches, and assessing their strength, durability, and overall quality. By comparing the results to traditional construction methods, we can demonstrate the advantages of 3D printing technology for the construction industry.

Overall, the objectives of this project are focused on designing and fabricating a 3D concrete printer that can address the challenges associated with traditional construction methods. By achieving these objectives, we aim to provide the construction industry with an innovative and efficient technology that can significantly improve the efficiency and accuracy of construction processes. In the following chapters, we will discuss the design and fabrication of the printer in detail, as well as the experiments and testing conducted to optimize its performance.

CHAPTER 2: LITERATURE REVIEW

3D concrete printing is a new and developing method in the construction industry. The main objectives of 3D printing are to reduce the need for formwork, save time, and use eco-friendly materials. There are two primary techniques in 3D printing, and contour crafting has the potential to transform the construction industry in the coming years. These technologies have the potential to usher in a new era of architecture that is better suited to the environment and integrated with engineering functionality.

Significant publications in this field are mentioned below:

1. Izabela Hager, et al. (2016)

The researchers conducted a study that delved into the history and overview of concrete printing technology, with highlighted case studies showcasing its application. In 1983, Charles W was credited with introducing the first 3D concrete printing technology, through the use of STL (stereo lithography) technology. Later, in 1988, S. Scott Crump introduced another technology, called FDM.

The study covered two case studies that demonstrated the practical application of concrete printing technology. In 2014, Dutch architects successfully built a house using concrete printing, with the different components printed individually. The construction process took around three months to complete. The second case study involved Winsum Company, which utilized their software to build a model house. Later, they used the same software to construct a five- story building using concrete printing technology. To date, this building remains the tallest construction built using concrete printing technology.

2. Antony Thorpe, et al. (May, 2014)

The researchers successfully created a concrete printing machine through the utilization of additive manufacturing (AM) technology. They put the machine to the test by printing a Wonder bench using concrete printing technology. The process involved designing a 3D CAD model for the bench, which was later transformed into STL (stereo lithography) format. After generating a printing path, a G-code was developed for the printing process, allowing for the construction of the bench. For the project, the team used a concrete mixture that consisted of both cement and gypsum materials.

The concrete used in the project had a density of 2400kg per cubic meter. Compared to regular concrete, the printed concrete was three times more durable in terms of compression and flexure, with a strength of approximately 100-110mpa. For printing operations, the team utilized a 9mm nozzle that was capable of printing 1.4kg of concrete per minute. The Wonder bench had a height of 0.8 meters and weighed one tonne. To ensure maximum strength, the team incorporated functional voids in the bench construction. They later post-tensioned the voids to make the bench stronger in tension as well.

3. Byung Wan Jo, et al. (2020)

The researchers utilized 3D concrete printing technology to print a hollow concrete wall. To ensure accuracy and performance, the team created a prototype model before developing the full-sized version. The prototype had dimensions of 1m x 1m x 1m. The study had three primary objectives, the first being 3D space motion control. The second objective was to analyze the properties of the concrete material used, while the third target was to optimize the material dispensing process.

Regarding material properties, the team utilized conventional concrete mixed with small-sized aggregates. For the dispensing process, a screw-type nozzle with a diameter of 50mm was used for extrusion purposes. To ensure quality and strength, the team conducted compressive strength tests on the printed models with different mixed designs. The average compressive strength obtained through these tests was approximately 61Mpa.

4. Van Der Putten, et al. (July 2020)

The researchers conducted an experiment on printed samples to test the level of chloride penetration compared to those constructed through conventional methods. The results showed that using the 3D concrete printing technique, there was more shrinkage, internal voids, and crack formation. This increased the amount of preferential penetration paths for chemical substances. Additionally, the penetration of chloride in the molded specimens was uniform throughout the entire sample height.

5. Imane Krimi, et al. (June 2017)

The researchers discussed two important parameters for evaluating the printability of binding materials such as cement, extrudability, and buildability. The team tested four different mixes to determine their extrudability and buildability. The extrusion process was affected by the granular distribution of the sand used. The study revealed that "SLI" sand had spread granular distribution, while "BB" sand had a tight granulometry. Buildability, on the other hand, refers to the early age resistance of the material being used.

The yield stress has a strong correlation to the properties discussed in the paper. To create a printable mix design, the team utilized these properties through several iterations. Upon completion, the mix was tested on a large-scale 3D printer, and no clogging was recorded during the printing process.

6. Rabab Allouzi, et al. (April 2019)

This paper recommends the incorporation of nanotechnology in 3D printing construction procedures for real structural engineering projects. To achieve this, the team suggests using graphene nanomaterials for the 3D printing of concrete structures. Graphene has garnered significant attention in recent times due to its remarkable properties, such as a tensile stress of 130GPa at 0.25 strain and a Young's Modulus of 1TPa.

Since traditional concrete is not suitable for 3D printing, this paper recommends using treated graphene oxide as a nanomaterial for 3D printing of concrete structures. This is because graphene oxide possesses exceptional properties such as tensile strength, compressive strength, and Young's modulus.

7. Manju.R, et al. (August 2019)

The researchers have conducted a study on the additive manufacturing (AM) process and have provided a detailed explanation of how 3D printers work using g-codes. In this process, the x, y, and z coordinates are given, and the printer is connected to a robotic arm setup with a nozzle across printers. Additionally, the team has provided details about the software used for slicing, which is a crucial element required by printers.

The article describes the step-by-step process of 3D printing where the structure is built based on a given program. The authors also presented some case studies of 3D printing projects conducted around the world. Finally, the team concluded by providing insight into the potential future scope of 3D printing technology.

8. Behzad Nematollahi, et al. (2017)

The primary focus of the study was on the techniques used for 3D printing, categorized into extrusion-based and powder-based methods. The authors further classified both techniques, and under extrusion-based printing, they mention concrete printing. They conducted an experiment where they created a bench measuring 2 meters in length, 0.9 meters in width, and 0.8 meters in height. The bench consisted of 128 layers with a thickness of 6mm, including 12 voids.

The study also explored the powder-based technique of 3D printing using geopolymer. The research team analyzed the strength of the structure based on its orientation and discovered that the orientation by X-axis resulted in 20% more green strength compared to the orientation by Z-axis. The percentage change between the strength in orientation by X-axis and orientation by Z-axis decreased to 12% and 5% for 1 and 7-day post-cured samples, respectively. Based on these findings, the team determined the optimal post-curing procedure.

9. Yasmin Tarhan, et al. (April 2019)

The article begins with a comprehensive explanation of the process from a CAD file to a 3D printed object. The authors also provide an overview of the evolution of 3D printers, starting from their origin to the present day. They conducted research on the properties of the concrete mix used for 3D printing and detailed properties such as extrudability, workability, and open time which should be sufficient to maintain extrudability. Additionally, they discussed the critical factors of contact strength between layers, aggregates, and water-cement ratio, which should be at least 0.25.

They also discussed the current challenges and opportunities for the world of construction to overcome the limitations of the past and embrace new technologies for large-scale development. They concluded by presenting solutions to make 3D concrete more efficient.

10. Amitkumar D. Raval, et al. (March 2020)

The study highlighted the risks and challenges associated with 3D printing technology, despite its many benefits, due to being in the initial stages and having several limitations. Additionally, the authors discussed environmental concerns related to this technology. They showcased the various processes involved in concrete printing and emphasized the importance of formulating computer models to implement this technology. With advancements in 3D computer graphics, it is now possible to fabricate digital models quickly and easily using commercially available tools.

The authors concluded that further investigation is required in the printing technique, particularly in selecting a new nozzle with an optimum size and shape. Additionally, they emphasized the need for a novel method of extrusion and a new method of delivery that can enhance the overall quality of the printing process.

11. Guowei, et al. (April 2017)

The main focus was to study the current methodologies of printing technology and evaluate methods for materials suitable for concrete printing. They began by explaining three large-scale 3D printing systems that have been successfully implemented in the construction industry. They also provided a summary of commonly used raw materials and the measures required to meet the critical requirements of the freeform construction process.

They suggested measuring methods to determine the fresh and hardened properties of concrete at an early stage. For the concrete mixture to be suitable for 3D printing, it must be easy-flowable and easy-extrudable, and any aggregate and coarse sand must be eliminated during the preparation process.

12. Victor Molodin, et al. (April 2020)

Using single stage polystyrene concrete as the material for fabricating objects using concrete printing technology they found that the labor consumption of formwork is significantly reduced, even for complex structures, by over 40%. This means that 3D printers will only require a small amount of work. Moreover, a wall printed using polystyrene concrete has numerous advantages, including a uniform distribution of polystyrene granules, which increases thermal resistance and ensures the specified strength characteristics of the erected wall. This results in an improvement in the thermal resistance quality of the wall and ensures that the wall has the strength characteristics that are required.

Types of 3D concrete printers

There are several types of 3D concrete printers available in the market, and they can be broadly categorized based on their printing mechanisms. While each printer has its own unique features, understanding their basic principles can help in choosing the right 3D concrete printer for a specific project.

1. Extrusion-based 3D Concrete Printers: These printers work by using a nozzle to extrude concrete in a layer-by-layer manner to create 3D objects. They are the most common and widely used printers in the construction industry. Extrusion-based 3D concrete printers can be further categorized based on their extrusion mechanisms, such as piston-driven, screw-driven, and auger-driven.
2. Piston-driven extrusion-based 3D concrete printers work by using a piston to force concrete through a nozzle. They are suitable for printing objects with high levels of precision and accuracy. Screw-driven extrusion-based 3D concrete printers, on the other hand, use a screw to push concrete through a nozzle, which makes them ideal for printing objects with high structural strength. Auger-driven extrusion-based 3D concrete printers use an auger to transport and extrude concrete. They are best suited for printing larger structures.
3. Powder Bed 3D Concrete Printers: These printers work by using a powder bed and a binder to create 3D objects. A binder is sprayed onto the powder bed, which binds the particles together, layer by layer, to form a solid object. Powder bed 3D concrete printers are ideal for printing objects with high levels of detail and intricacy, making them well-suited for architectural models and prototypes.

4. Stereolithography-based 3D Concrete Printers: This type of printer uses a light source to harden a liquid resin layer by layer, creating a solid object. Stereolithography-based 3D concrete printers are suitable for printing objects with high levels of accuracy and detail. They are commonly used for printing smaller structures and architectural models.
5. Inkjet-based 3D Concrete Printers: These printers use inkjet technology to deposit a binder onto a layer of powder to create a 3D object. They are well-suited for printing objects with intricate shapes and details, making them ideal for creating decorative structures.
6. Robotic 3D Concrete Printers: These printers use a robotic arm to deposit concrete, allowing for greater flexibility in terms of the shapes and sizes of objects that can be printed. They are ideal for printing large and complex structures, such as bridges and buildings.

Understanding the different types of 3D concrete printers and their printing mechanisms is essential in choosing the right printer for a specific project. Each type of printer has its own unique features and advantages and selecting the right one can help to ensure a successful outcome for any construction or architectural project.

Types of extrusion systems

Extrusion-based 3D concrete printers are the most commonly used printers in the construction industry. These printers work by using a nozzle to extrude concrete in a layer-by-layer manner to create 3D objects. The extruder is the most important component of an extrusion-based 3D concrete printer, and there are several types of extruders used in these printers.

1. Piston-driven extruders: Piston-driven extruders work by using a piston to force concrete through a nozzle. They are suitable for printing objects with high levels of precision and accuracy. This type of extruder is commonly used in smaller 3D concrete printers.
2. Screw-driven extruders: Screw-driven extruders use a screw to push concrete through a nozzle. This makes them ideal for printing objects with high structural strength. They are commonly used in larger 3D concrete printers.
3. Auger-driven extruders: Auger-driven extruders use an auger to transport and extrude concrete. They are best suited for printing larger structures, such as walls and pillars. This type of extruder is commonly used in industrial-scale 3D concrete printers.
4. Pressure-driven extruders: Pressure-driven extruders work by applying pressure to a hopper filled with concrete. The pressure forces the concrete through a nozzle, allowing for a consistent flow of material. This type of extruder is commonly used in 3D concrete printers that require a high throughput of material.

5. Peristaltic pumps: Peristaltic pumps use a series of rollers to squeeze concrete through a nozzle. This type of extruder is ideal for printing objects with high levels of accuracy and detail.
6. The choice of extruder depends on the specific needs and requirements of the project. The extruder must be capable of extruding concrete with a consistent flow rate, while also maintaining the desired level of precision and accuracy. By choosing the right type of extruder, it is possible to create 3D concrete objects with high levels of detail, strength, and durability.

Why is 3D concrete printer necessary in Pakistan:

3D concrete printing technology is a cutting-edge innovation that has the potential to revolutionize the construction industry in Pakistan. The country has been grappling with a severe shortage of affordable and quality housing, and this technology can be instrumental in addressing this issue by significantly reducing the cost and time required to build homes.

Here are some detailed reasons why 3D concrete printers are necessary in Pakistan:

1. Affordable Housing: The current housing situation in Pakistan is dire, with a huge demand-supply gap in affordable housing. 3D concrete printers have the potential to help bridge this gap by significantly reducing the cost of construction. This innovative technology allows for the rapid production of homes at a fraction of the cost of traditional construction methods. With 3D concrete printers, it is possible to create custom-designed, energy-efficient homes at affordable prices.

2. Faster Construction: Traditional construction methods are often time-consuming, labor-intensive, and prone to delays and cost overruns. 3D concrete printing technology can expedite the construction process by automating the building process. This innovation can reduce the time required to build homes and other structures, allowing for faster completion times and greater efficiency. The use of 3D concrete printers can also streamline the construction process and minimize the risks associated with traditional construction methods.
3. Reduced Waste: The construction industry is a significant contributor to environmental pollution, with large amounts of waste generated during the construction process. 3D concrete printers can help mitigate this problem by using precise amounts of concrete to build structures, resulting in less material waste. This technology also reduces the need for heavy machinery and other equipment, further reducing the environmental impact of construction. Therefore, the adoption of 3D concrete printing technology can help to create a more sustainable construction industry in Pakistan.
4. Improved Safety: Traditional construction methods can be hazardous and risky, especially for workers involved in manual labor. 3D concrete printers can improve safety on construction sites by automating the building process and reducing the need for workers to perform manual labor. This can minimize the risk of accidents and injuries on construction sites, making it a safer option for workers.

5. Innovation: Pakistan is a developing country that is eager to adopt innovative technologies to improve its infrastructure and support economic growth. 3D concrete printing technology is a cutting-edge innovation that has the potential to revolutionize the construction industry in the country. By investing in this technology, Pakistan can improve its infrastructure and support economic growth, while also addressing the pressing issue of affordable housing. The use of 3D concrete printing technology can also attract foreign investment and create new jobs in the construction industry.

In conclusion, 3D concrete printers are crucial for Pakistan as they can help to address the pressing need for affordable housing, improve construction efficiency, reduce waste, improve safety, and support economic growth through innovation. By adopting this technology, Pakistan can enjoy the many benefits of 3D concrete printing and make significant progress towards addressing the country's infrastructure challenges. The widespread use of 3D concrete printing technology can contribute to a better future for Pakistan by improving the standard of living for its citizens and creating a more sustainable construction industry.

Why are 3D concrete printers necessary?

3D concrete printing technology has become increasingly necessary in recent years due to its numerous benefits and applications in various industries. Here are some reasons why 3D concrete printers are necessary:

1. Cost Reduction: One of the primary benefits of 3D concrete printing technology is that it can significantly reduce the cost of construction. This is because it requires fewer materials and less labor compared to traditional construction methods. 3D printing allows for precise and efficient use of materials, which reduces waste and minimizes the need for costly manual labor.
2. Customization: 3D concrete printing technology allows for the creation of unique and intricate designs that are difficult or impossible to achieve with traditional construction methods. This level of customization can be particularly useful in architecture, where unique and creative designs are often required.
3. Speed: 3D concrete printing technology enables faster construction times compared to traditional methods. This is because the process is automated and requires minimal human intervention, reducing the time required for construction.
4. Efficiency: 3D concrete printing technology can produce complex shapes and geometries without the need for molds or formwork. This makes the process more efficient and reduces the amount of material needed.
5. Sustainability: 3D concrete printing technology is more environmentally friendly than traditional construction methods as it generates less waste and uses fewer resources. The technology also enables the use of sustainable materials, such as recycled materials, which contributes to a more sustainable construction industry.

6. Safety: The use of 3D concrete printing technology can significantly improve safety on construction sites. It reduces the need for manual labor, which minimizes the risk of accidents and injuries.
7. Scalability: 3D concrete printing technology is scalable, which means that it can be used for both small and large-scale construction projects. This makes it a versatile technology that can be used in a variety of applications.
8. Innovation: 3D concrete printing technology is a cutting-edge innovation that has the potential to transform the construction industry. It allows for new and innovative designs and structures that were previously impossible to create.

3D concrete printers are necessary due to their numerous benefits, including cost reduction, customization, speed, efficiency, sustainability, safety, scalability, and innovation. The adoption of 3D concrete printing technology has the potential to revolutionize the construction industry and make it more efficient, sustainable, and innovative. As technology continues to advance, it is likely to become an increasingly important tool in construction, architecture, and other industries.

What are the benefits of using gantry system in 3D concrete printing?

The gantry system is a key component of 3D concrete printing technology that plays an important role in the ability to create complex and customized concrete structures. There are several benefits of using a gantry system in 3D concrete printing, including improved precision, increased efficiency, and the ability to print larger structures.

One of the primary benefits of using a gantry system in 3D concrete printing is improved precision. The gantry system allows for precise control over the movement of the printer head, which is critical for creating complex shapes and designs. The ability to precisely control the movement of the printer head also enables the printing of intricate details, such as fine textures or patterns, which can be difficult or impossible to achieve with traditional construction methods.

Another benefit of using a gantry system in 3D concrete printing is increased efficiency. The use of a gantry system allows for faster printing speeds and reduces the amount of manual labor required. This results in faster construction times, which can be particularly advantageous for large-scale construction projects. The increased efficiency also reduces costs, making 3D concrete printing an attractive option for construction companies and developers.

In addition to improved precision and efficiency, the gantry system also enables the printing of larger structures. The ability to move the printer head along the gantry allows for the creation of structures that are larger than the printing bed itself. This makes it possible to print entire walls or even entire buildings using 3D concrete printing technology.

Another advantage of using a gantry system is that it can be used to print structures in difficult-to-reach areas. For example, a gantry system can be used to print concrete structures in areas with limited access, such as underground tunnels or bridges. This makes

3D concrete printing a versatile and flexible technology that can be used in a wide range of construction applications.

Finally, the use of a gantry system in 3D concrete printing also offers benefits in terms of sustainability. This technology generates less waste and uses fewer resources compared to traditional construction methods. The use of 3D concrete printing technology can also help to reduce the carbon footprint of construction projects by minimizing transportation and material waste.

In conclusion, the gantry system is a critical component of 3D concrete printing technology that offers numerous benefits, including improved precision, increased efficiency, and the ability to print larger structures. The use of a gantry system also offers advantages in terms of sustainability, making 3D concrete printing an attractive option for construction companies and developers looking for innovative and environmentally-friendly construction solutions.

Material used in 3D concrete printers

3D printing technology has revolutionized many industries in recent years, including the construction industry. One of the key applications of 3D printing in construction is the use of 3D concrete printers. These printers allow for the creation of complex and customized concrete structures in a cost-effective and efficient manner. In this article, we will take a closer look at the material used in 3D concrete printing and its properties.

The material used in 3D concrete printing is a specially formulated concrete mix that is designed to be extruded through a nozzle and deposited layer by layer to create a three-dimensional structure. This mix typically consists of a combination of cement, water, and aggregates such as sand or gravel. The exact composition of the concrete mix used in 3D printing can vary depending on the specific application and the requirements of the project. For example, if the 3D printed structure is intended for use in a marine environment, a more durable and corrosion-resistant concrete mix may be used.

One of the key advantages of 3D concrete printing technology is the ability to customize the material used in the printing process. This allows for the creation of structures with specific properties, such as increased strength or improved durability. Additives can be added to the concrete mix to enhance its properties. For example, fibers or polymer additives may be added to increase the tensile strength of the concrete or improve its flexibility. Other additives may be used to improve the workability of the mix or to control its setting time.

It is important to note that the properties of the material used in 3D concrete printing can vary depending on the specific mix and printing process used. As such, it is important to carefully select and test the material to ensure that it meets the requirements of the project and produces the desired results. The use of a specially formulated concrete mix is a critical component of 3D concrete printing technology and plays a key role in the ability to create complex and customized structures with this innovative technology.

Another advantage of 3D concrete printing technology is its ability to significantly reduce the amount of waste generated during the construction process. Traditional construction methods often result in a significant amount of waste material due to the need for cutting and shaping materials to fit the desired design. In contrast, 3D printing technology allows for precise and efficient use of materials, which reduces waste and minimizes the need for costly manual labour.

The use of 3D concrete printing technology also offers significant benefits in terms of sustainability. This technology generates less waste and uses fewer resources compared to traditional construction methods. The technology also enables the use of sustainable materials, such as recycled materials, which contributes to a more sustainable construction industry.

In conclusion, the material used in 3D concrete printing is a critical component of this innovative technology that is transforming the construction industry. The ability to customize the concrete mix and add additives to enhance its properties allows for the creation of complex and customized structures. The use of 3D concrete printing technology offers numerous benefits, including reduced cost, increased efficiency, and improved sustainability. As this technology continues to advance, it is likely to become an increasingly important tool in construction, architecture, and other industries.

CHAPTER 3: METHODOLOGY

Choosing the design

In lieu of the literature review, two types of designs were considered for the concrete 3D printer, namely:

- Articulated Robotic Arm Concrete 3D Printer.
- Gantry System Concrete 3D Printer.

Articulated Robot

This type of concrete 3D printer uses an articulated robotic arm to extrude concrete material layer by layer to create a 3D structure. The robotic arm is usually mounted on a fixed base and has several joints that allow it to move in various directions. The end of the arm is equipped with a nozzle that extrudes the concrete material.

One advantage of this type of printer is its versatility. The robotic arm can move in many different directions, allowing it to create complex shapes and structures. However, it is slower than other types of printers since the robotic arm needs to move to each location where the material needs to be deposited.

Gantry System:

A gantry system concrete 3D printer typically consists of a gantry structure that moves along rails, and a printing nozzle attached to the gantry. The gantry can move along both the x and y axes, and the printing nozzle moves up and down along the z-axis to create the 3D structure.

One advantage of this type of printer is its speed. The gantry can move quickly to each location where the material needs to be deposited, allowing for faster printing. However, it may be limited in terms of the shapes and structures it can create since it typically moves along a fixed path.

The design finalized for this project is Gantry System due its numerous advantages over the articulated robotic arm 3D printer such as:

- Speed: Gantry systems can typically move faster than articulated robotic arms. This is because the gantry system only needs to move along two axes, whereas the robotic arm needs to move in multiple directions to reach each location where the material needs to be deposited. As a result, gantry systems can be more efficient and print structures faster.
- Precision: Gantry systems are typically more precise than articulated robotic arms. This is because the gantry can move along a fixed path with high accuracy, whereas robotic arms may have some inaccuracies due to their multiple joints and movements. This precision can result in higher-quality printed structures.
- Stability: Gantry systems are often more stable than articulated robotic arms. This is because the gantry is typically fixed to a stable base, while robotic arms may have some movement and vibration when in use. This stability can result in more consistent prints, reducing the need for rework or adjustments.

- Flexibility: Gantry systems can be more flexible than articulated robotic arms in terms of the size of the structures they can print. This is because the gantry can be designed to move along a larger area, while robotic arms may have limitations due to their range of motion. As a result, gantry systems can be used to print larger structures with greater ease.

Initial Design:

In accordance with choosing the gantry system as our finalized design, we considered simplicity and ease of access, availability of required materials and the longevity of the parts in finalizing our design.

Base of the printer:

A concrete 3D printer requires a stable bed as an essential component as it provides a flat and stable surface for the concrete to be deposited on. A bed provides stability and support for the printed structure as it is being built. Without a bed, the structure would have nothing to rest on, and it could collapse or deform as it is being printed. The bed ensures that the structure remains stable and that the printed layers are deposited on top of each other correctly.

To start with the base of the printer, we used standard Aluminum extrusions in our design as they were robust, easily available in the market and served a number of advantages over metal plates such as slots for easy mounting of support material, and fittings such as corners for easy assemblage.

Since the length of each side of the base was chosen to be 2 meters, we added 8 additional extrusions in the base to provide more rigidity and stability to the base of the printer.

The whole assembly is supported on 4 base plates made of Mild Steel. The material was chosen keeping in view that the overall weight of the printer will be supported by these 4 plates, therefore a robust and reliable material was required. The plates not only provide feet for the printer, but they also house the ball screw, and motors for the Y-axis.

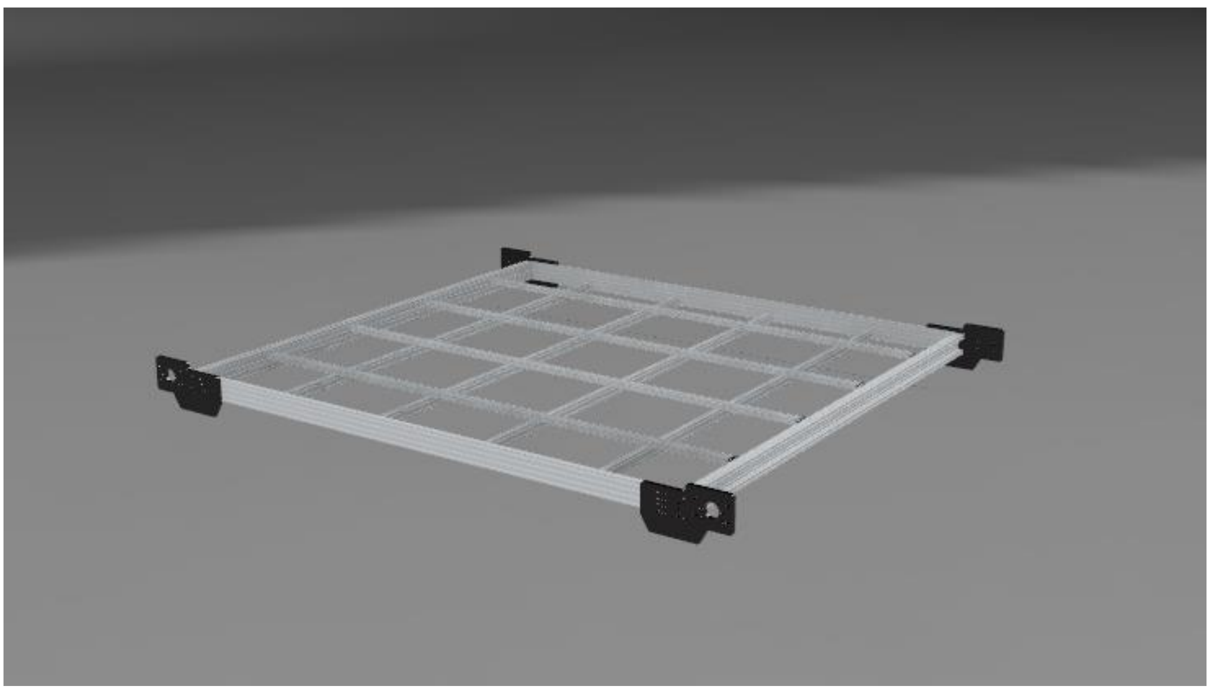


Figure 1: Design of base of gantry.

Motor Selection and Ball screw:

In order to drive the gantry system, we chose that ball screw, coupled with a stepper motor will provide the best results in terms of speed, reliability and mobility. A rack and pinion setup was also considered but since precise layer by layer deposition of material is a cruicial demand in a concrete 3D printer, the backlash associated with a rack and pinion setup of gears is not suitable. Therefore, ball screw sizing and motor sizing was done.

In order to drive the gantry, the following components are used:

- SHAC Linear Bearing HGH 25 CA
- SHAC HGH 25 Linear Rails
- SFU 2510 Ball screw
- Nema 34 Stepper Motor
- Flexible Coupling
- BK-17 and BF-17 Ball screw supports.

All of these components are mounted on the existing setup using nuts and bolts. The plates are designed in such a way as to house these components.

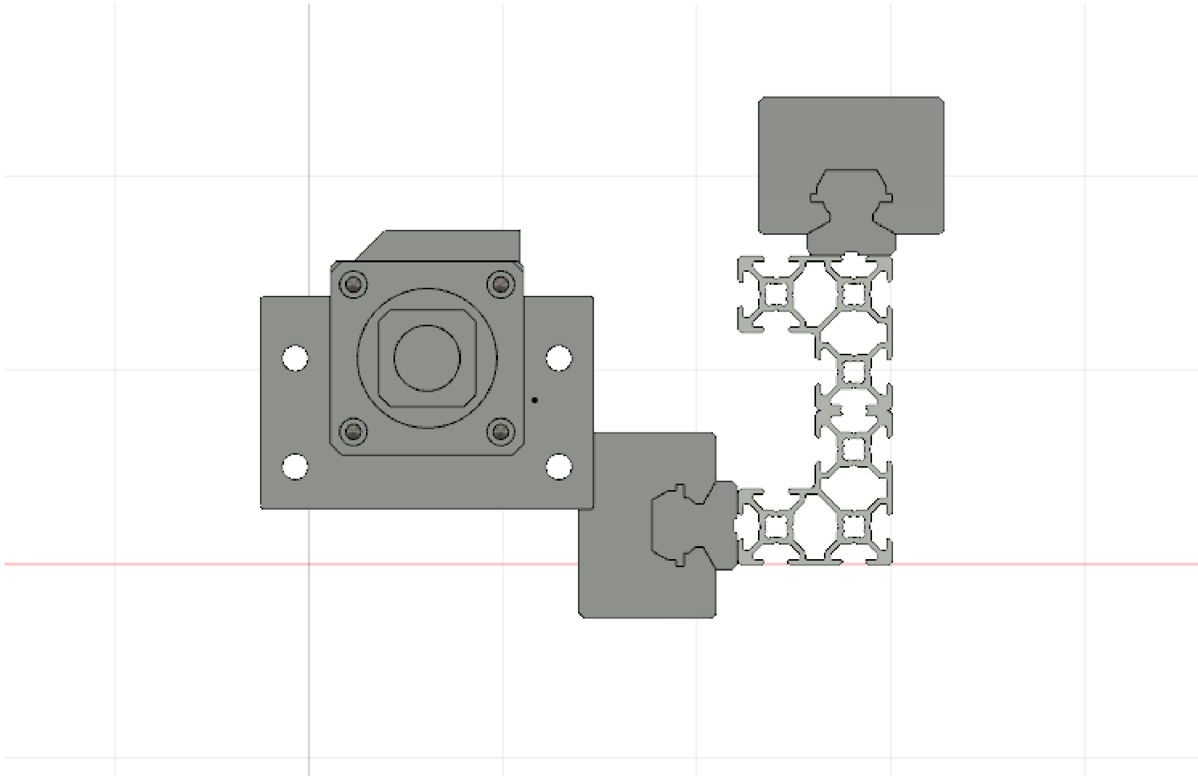


Figure 2. Y axis components side view

The parts were particularly assembled in this way to counter the torque and bending moments associated with the movement of the machine.

Moreover, two plates were designed to connect the moving nut of the ball screw with the 4 linear bearings on the guideway. These plates would also go on to attach with the X-axis Gantry.

Figure 3. Final design of Y-axis.

The Render of the final Design of Y-axis is given. It is powered by two NEMA-34 motors in by subduing a slave axis in order to make sure that we get the flexibility of having a simply supported structure for the next in line X-Axis.

X-Axis Gantry

For movement in the X-axis, a number of factors were to be considered. Since the width of the printer is 2m, and the travel required for the extruder in Z-axis is 50cm, the Gantry was needed to be raised at a height of more than 50cm from the bed of the printer in order to accommodate the 50cm travel of Extruder Nozzle.

Moreover, the problem of sagging of the Gantry beam also needed to be considered, as the added weight of rails and Z-axis sagged the beam.

Again, in order to achieve reliability and easy installation of all the components, Aluminium extrusions are used as the backbone beam of the X-axis gantry. To cater for the sagging, the beam is made using 2×4080 C Shaped beams and 2×2040 Extrusions.

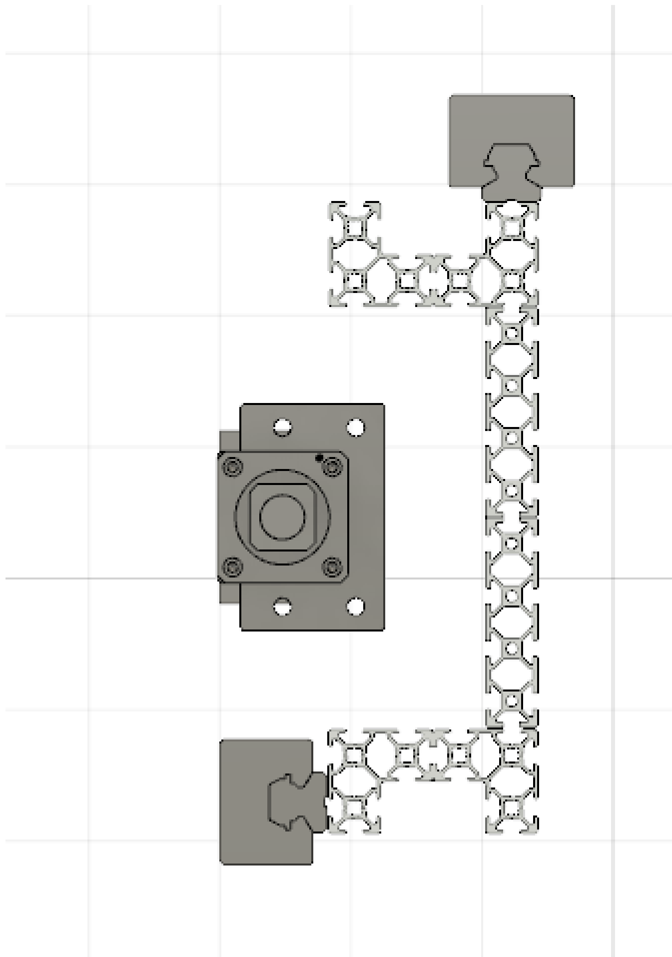


Figure 4. X-axis gantry components side view

Firstly, the X-axis gantry beam was reinforced using 2020 extrusions as the backbone of the whole beam. 2020 extrusions are a type of aluminum profile that is widely used in construction and industrial applications due to their strength, durability, and versatility. By using 2020 extrusions, the X-axis gantry beam is strengthened and made more robust.

Aluminum Plates:

The moving parts of the machinery, namely plates, are designed of aluminum. This choice was made because these parts needed to have the structural rigidity comparable with that of MS (mild steel) while being lighter in weight. This is important because the load restrictions of linear bearings come into effect. Linear bearings are used in the machinery to allow smooth movement along the X-axis gantry beam. However, they have load restrictions, and by using lighter aluminum parts, the overall weight of the machinery is reduced, ensuring that the load restrictions of the linear bearings are not exceeded.

In order to accommodate variable height levels of the whole gantry, the X-axis plates were made in a split-design configuration. This means that two plates were joined in between to form the support of the whole X-axis gantry. This split-design configuration allows for height adjustments to be made to the gantry without having to disassemble the entire structure.

Overall, this design allows for a strong and robust X-axis gantry beam, while also allowing for height adjustments and reducing the overall weight of the machinery to stay within the load restrictions of the linear bearings.

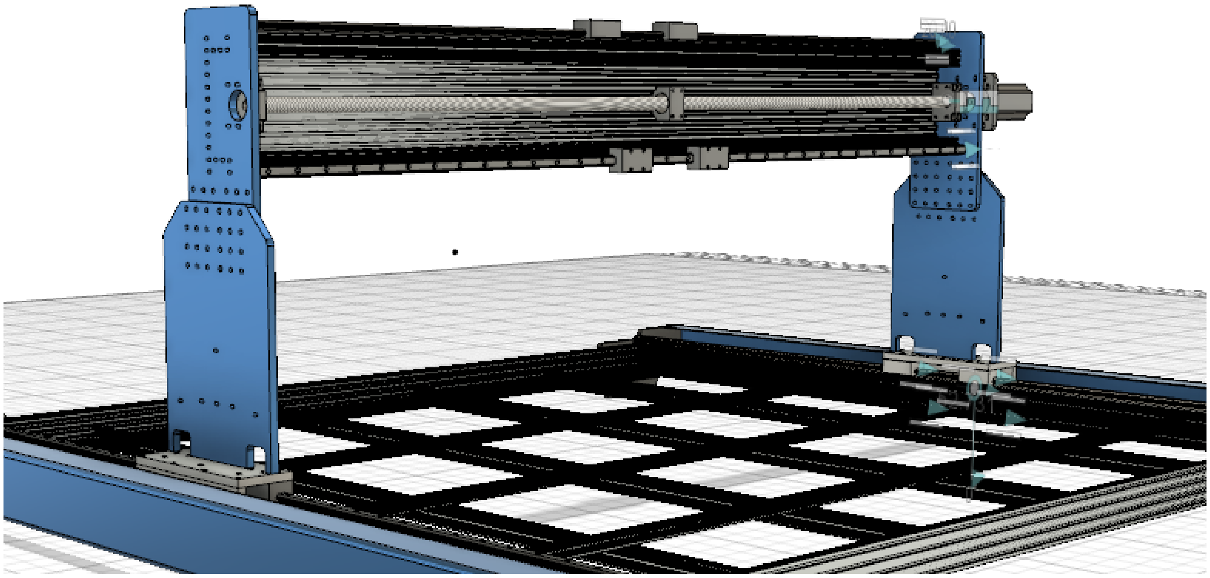


Figure 5. X and Y axes gantry

Z-Axis:

In CNC (Computer Numerical Control) machines, a ball screw is a type of linear actuator that is used to convert rotary motion into linear motion. It is used in conjunction with linear rails to provide precise movement of the machine's tool. The Z-axis controls the vertical movement of the machine's tool, allowing it to move up and down. The passage explains that the ball screw used in the Z-axis needed to be shorter in length as compared to the ball screws used in the other two axes (X and Y). This is because the travel distance required for the Z-axis is generally less than that of the X and Y axes.

To incorporate the ball screw and rails of the Z-axis, a single base plate was designed. All the components for the Z-axis were placed on this base plate, which provided a stable structure for the ball screw and rails. By using a single base plate, the design was simplified and assembly was made easier.

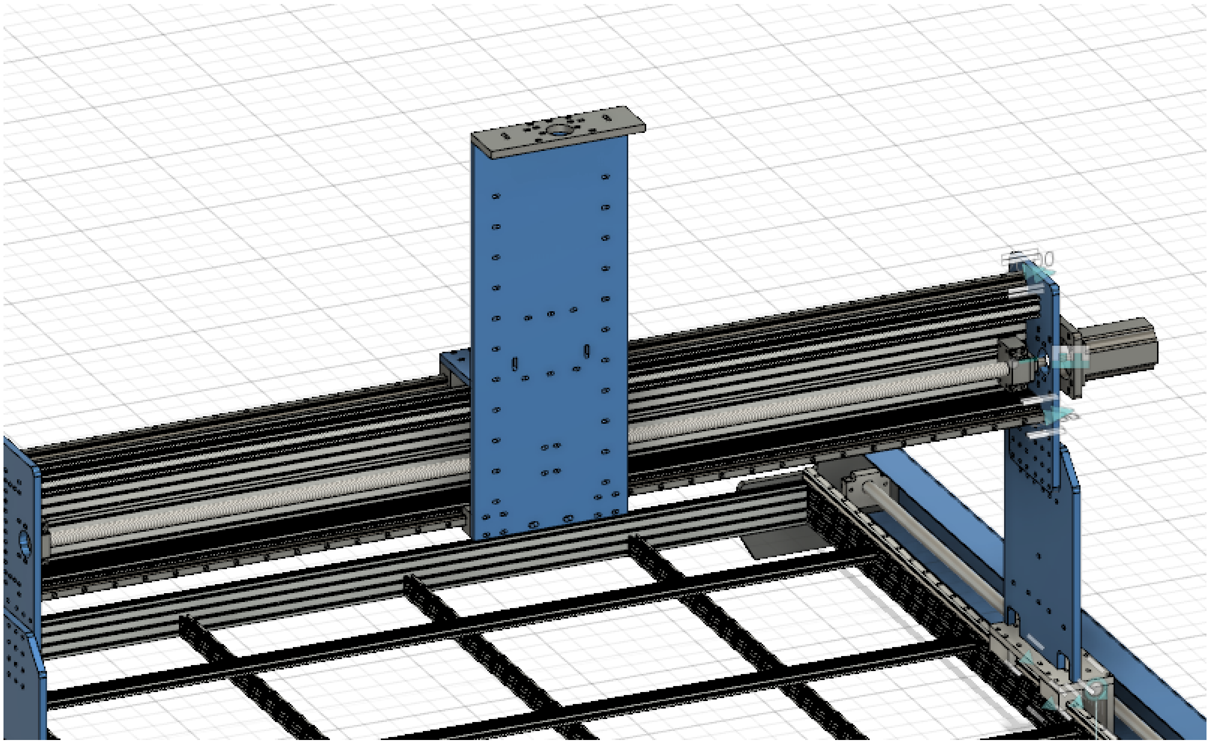


Figure 6. Aluminium plate design for Z axis

However, it is important to note that extrusion processes can lead to mechanical vibrations, which can negatively impact the precision of the CNC machine's movements. To address this issue, a rib was added to the back of the base plate to support it and diminish any mechanical vibrations that might arise during the extrusion process.

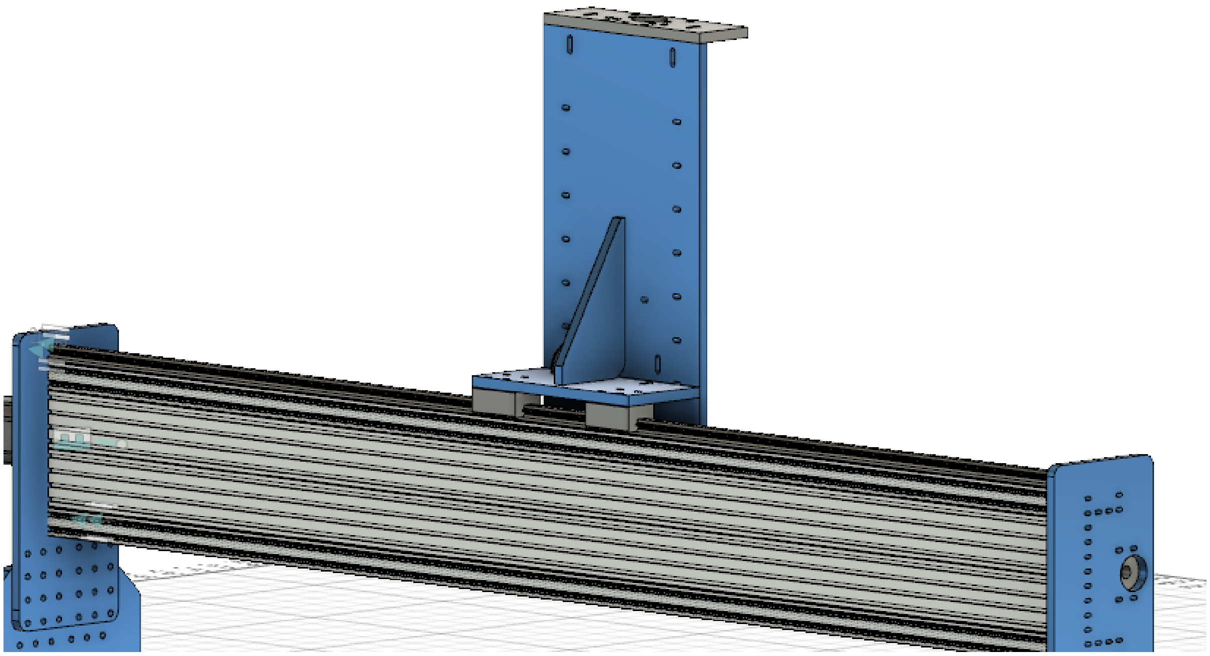


Figure 7. Reinforced final design for Z-axis

This design allows for precise vertical movement of the machine's tool, completing the overall design of a CNC router machine that can move in three axes (X, Y, and Z).

Oiling Mechanism:

In a CNC (Computer Numerical Control) router machine, the linear bearings and ball screws are critical components that allow for precise movement of the machine's tool. These components are constantly running equipment and require proper lubrication in order to be effective and precise in their movement. Without proper lubrication, the linear bearings and ball screws can wear out quickly and become less accurate, leading to reduced precision and performance of the CNC router.

To ensure that the linear bearings and ball screws are lubricated properly, a lubrication system is required. Traditionally, this system would consist of a grease pump, which would supply grease to the linear bearings and ball screws. However, this type of system can be expensive and harder to operate, especially in smaller CNC router machines.

In this case, we opted to use an electromagnetic oil pump with a 2L capacity, coupled with a complete distribution system that comprises pipes and flow regulators. This system is more cost-effective and easier to operate than a traditional grease pump system.

The electromagnetic oil pump is designed to automatically pump oil to the linear bearings and ball screws on a continuous basis, providing the necessary lubrication for smooth and precise movement. The distribution system comprises of pipes and flow regulators that attach the pump to all the 20 linear bearings and the 4 ball screws of the CNC router machine. The flow regulators ensure that the oil is distributed evenly to all the components and that the correct amount of oil is delivered to each bearing and screw.

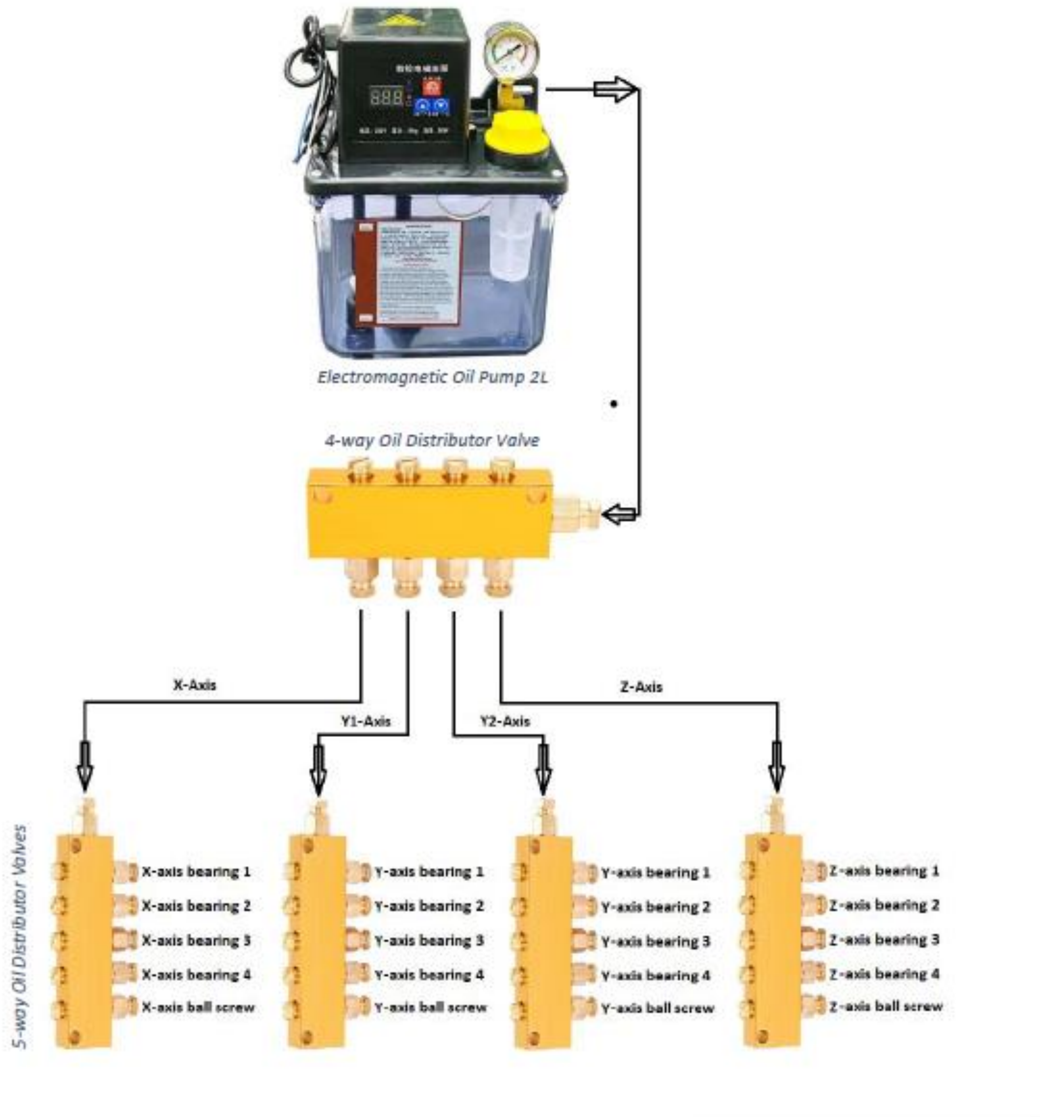


Figure 8. Oil Lubrication Mechanism

Wiring diagram of the distribution box:

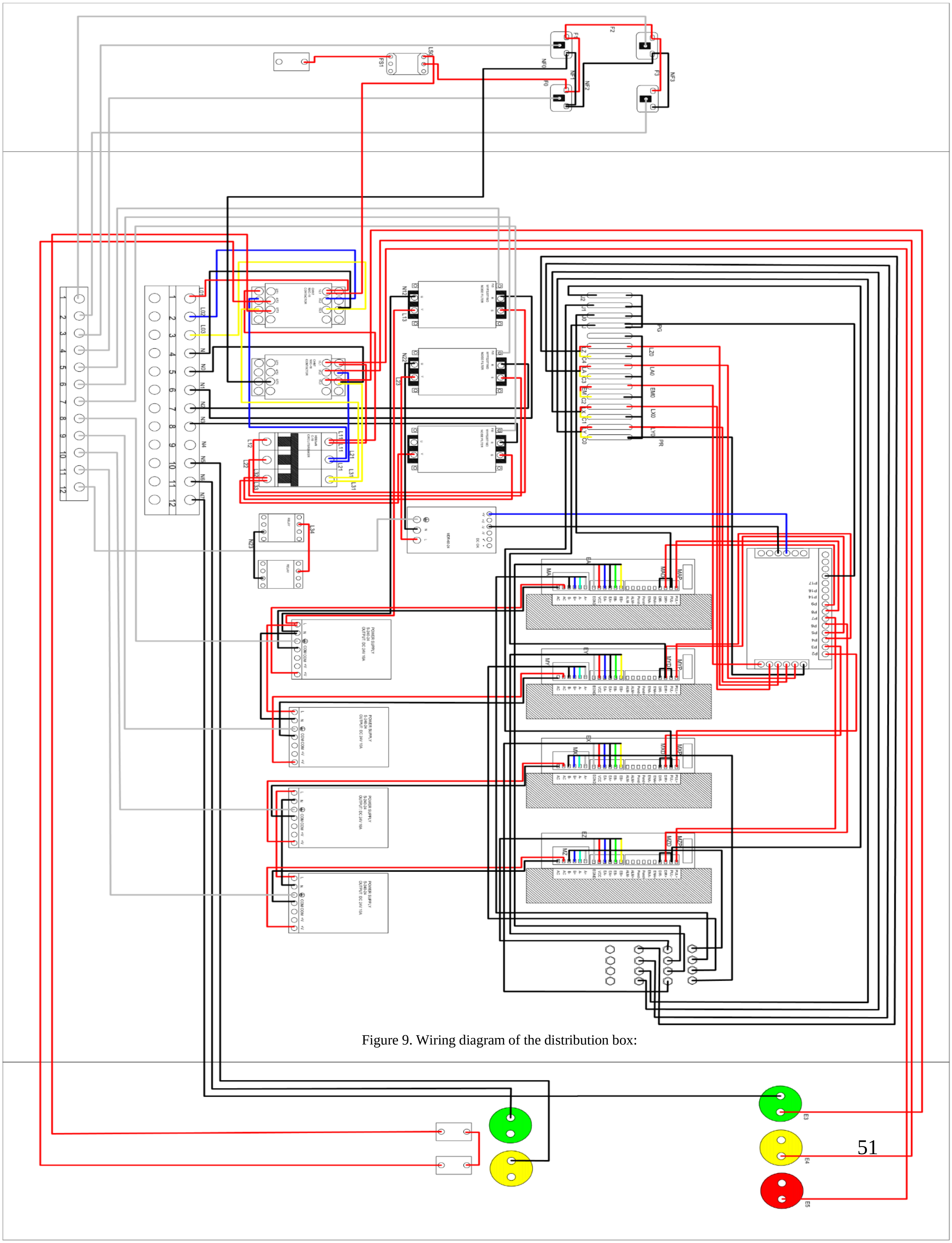


Figure 9. Wiring diagram of the distribution box:

CHAPTER 4: RESULTS AND DISCUSSIONS

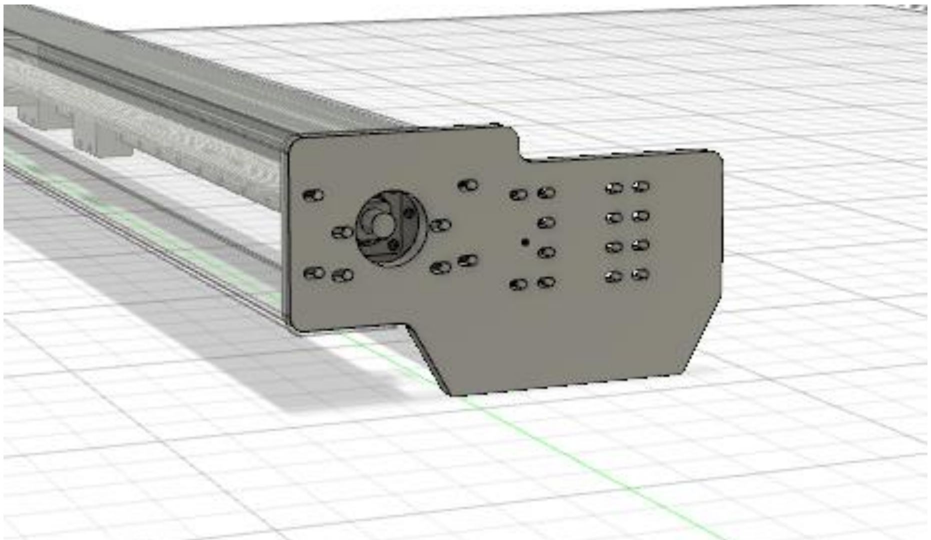
3D concrete printing has the potential to revolutionize the construction industry by offering several advantages over traditional construction methods. The use of 3D concrete printers allows for faster, more efficient, and more sustainable construction, while also enabling the creation of complex and customized shapes that would be difficult to achieve using traditional construction methods. In this paper, we have explored the history, technology, and applications of 3D concrete printing, as well as the challenges and limitations that need to be addressed to fully realize its potential.

The construction industry has seen significant technological advancements in recent years, with 3D printing being one of the most notable. 3D printing technology has the potential to revolutionize the construction industry, allowing for faster, more efficient, and more sustainable construction practices. The 3D concrete printer is designed to be affordable and easy to assemble, using off-the-shelf components and parts. The 3D concrete printer has the potential to transform the construction industry, allowing for faster and more efficient construction practices, reducing waste, and improving sustainability. The construction industry has been rapidly evolving over the past few years, with the introduction of innovative technologies that have significantly improved the efficiency and accuracy of construction processes. The printer is designed to enable the creation of complex concrete structures with high precision and efficiency, which can significantly reduce the cost and time required for construction projects. The traditional construction industry is associated with several challenges, including high labor costs, slow construction processes, and high material wastage. The construction industry has been struggling with the limitations of traditional construction methods for years. 3D printing technology has emerged as a promising solution to the challenges associated with traditional construction methods.

The main motivation behind this project is to address the challenges associated with traditional construction methods and provide a viable solution to the construction industry. The first objective of this project is to design a 3D concrete printer that can utilize a CNC routing machine and extrusion system using readily available and cost-effective materials, to create complex concrete structures with high precision and efficiency. The printer should be able to print a variety of complex shapes and designs with high accuracy and consistency. The second objective is to optimize the printer's performance by conducting experiments and testing to determine the ideal printing parameters. The third objective is to evaluate the printer's capabilities by printing a variety of complex concrete structures and comparing the results to traditional construction methods. By comparing the results to traditional construction methods, we can demonstrate the advantages of 3D printing technology for the construction industry. Overall, the objectives of this project are focused on designing and fabricating a 3D concrete printer that can address the challenges associated with traditional construction methods. 3D concrete printing is a new and developing method in the construction industry. The main objectives of 3D printing are to reduce the need for formwork, save time, and use eco-friendly materials.

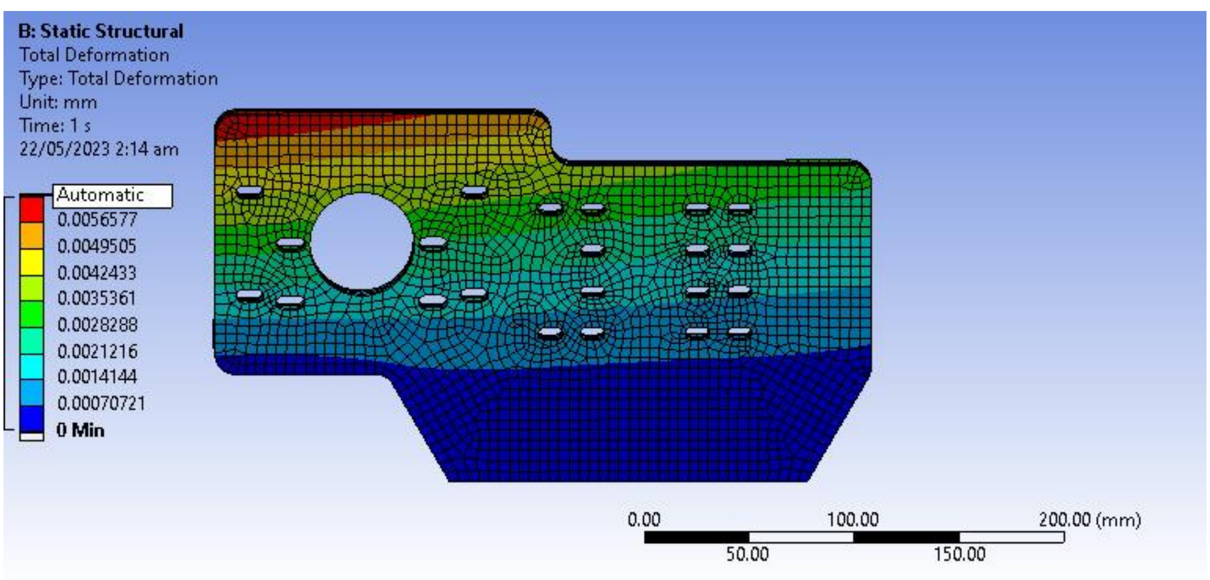
CAD Drawings and Analysis

BASE PLATE:



To support the whole load of the gantry, we designed plates of high-grade Mild Steel. The same plates support the NEMA-34 Motors for the base y-axis and the SHAC Ball screw 2510. These multipurpose plates also raise the height of the bed 4inches above the ground. The plates were cut using CNC Laser Metal cutting.

Figure 10. MS Base Plate



The static structural analysis of the plates, with load applied on the anchor points results in Von-mises stress of 2.664 MPa. Yield Strength of Mild Steel is 250MPa. Therefore the plates are well designed to account for additional material load which the bed of the printer will be subjected to.

Figure 11. Equivalent Deformation of Base Plate

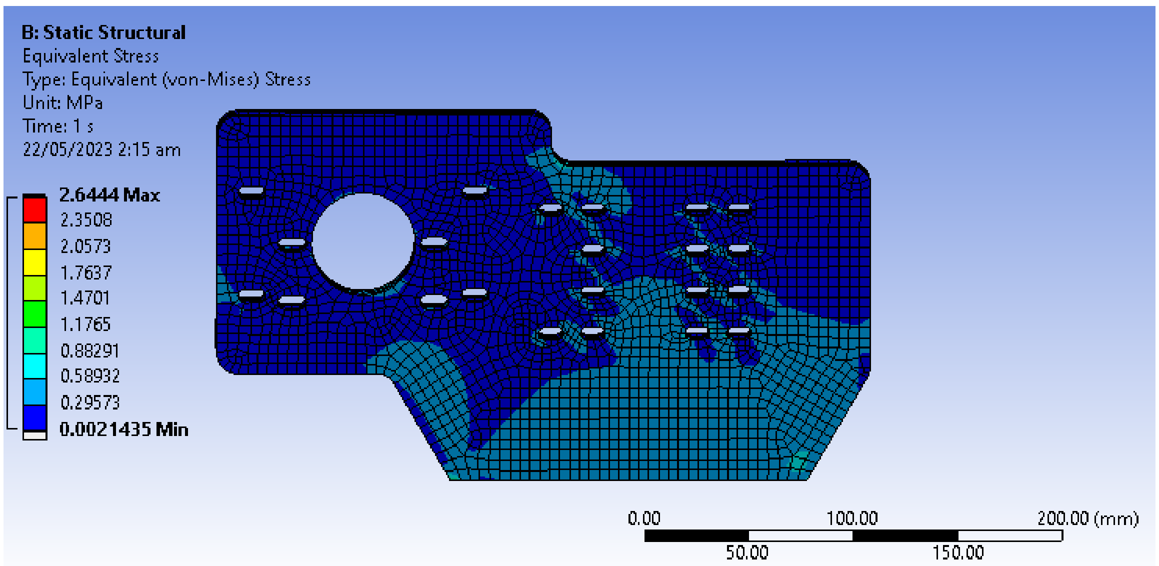


Figure 12. Equivalent Stress of Base Plate

2.664 MPa. Yield Strength of Mild Steel is 250MPa..

The static structural analysis of the plates, with load applied on the anchor points results in Von-mises stress of 2.664 MPa. Yield Strength of Mild Steel is 250MPa. Therefore the plates are well designed to account for additional material load which the bed of the printer will be subjected to.

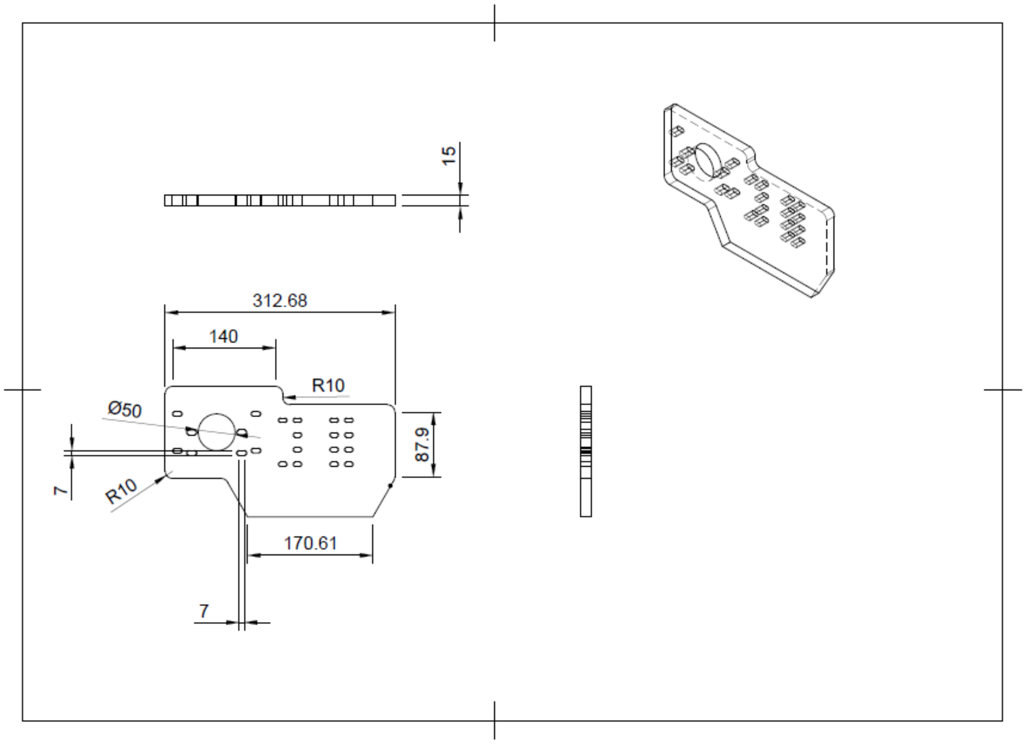
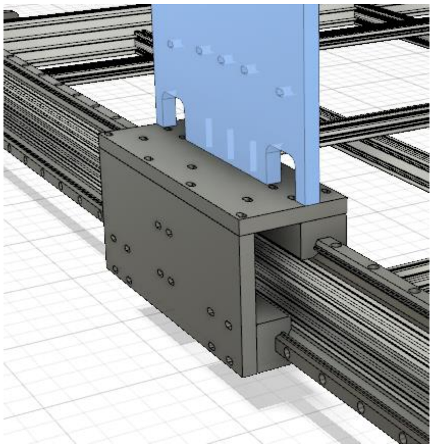
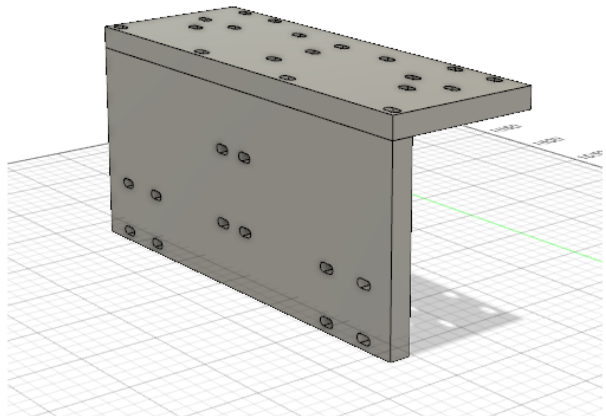


Figure 13. MS Base Plate

Y-AXIS UPPER BEARING PLATE





In order to connect the ball screw with the bearings, to account for smooth movement of the gantry and to support the whole load, the rails and bearings were assembled in a way to account for torsional and bending moments. The plates were designed of High-Grade industrial aluminum of 15mm thickness. The plates were CNC cut to ensure precision. The plates serve as a junction for the X-axis gantry and the Y axis bearings.

Figure 14: Y-axis Bearing Plate

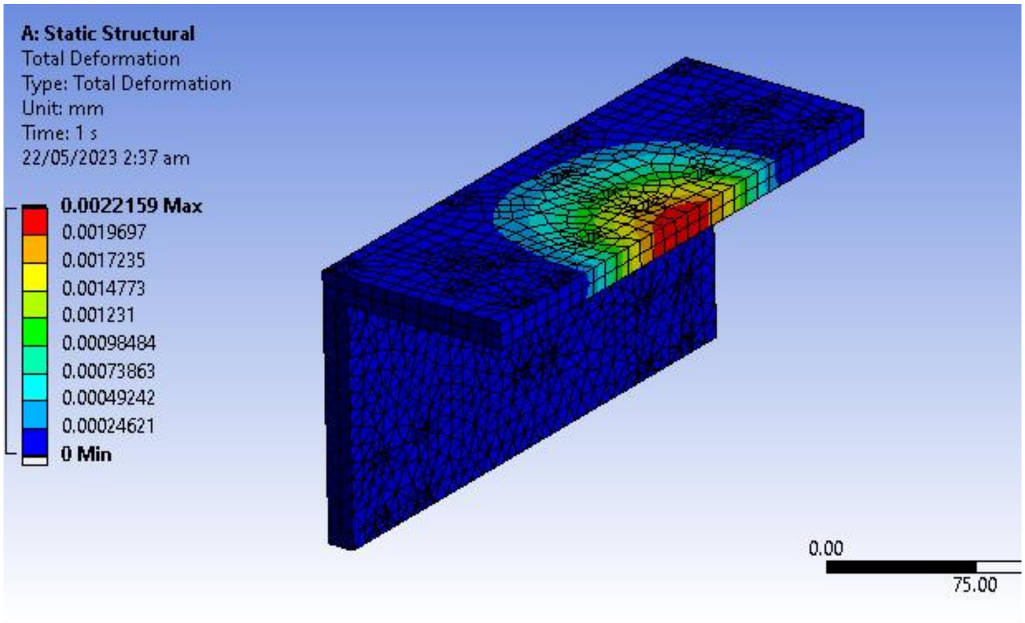


Figure 15: Total Deformation

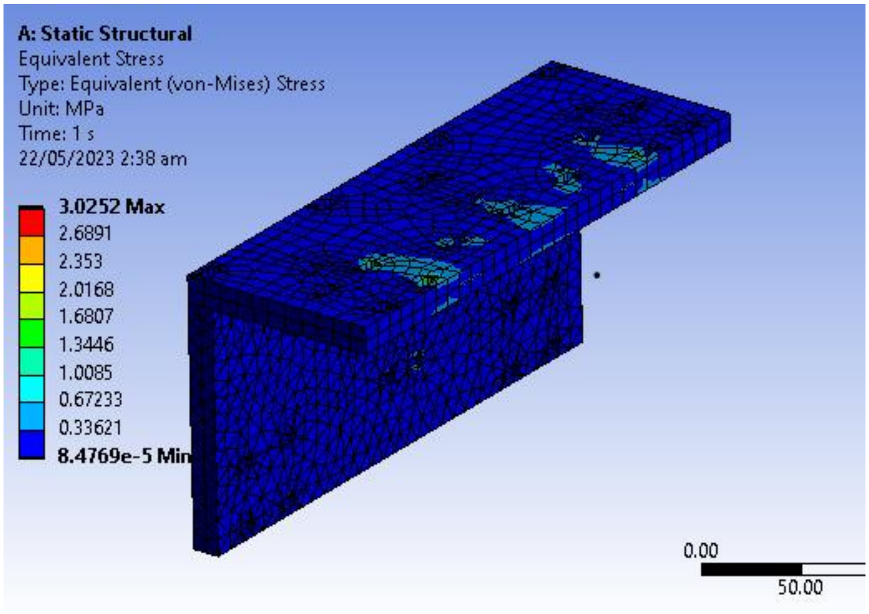
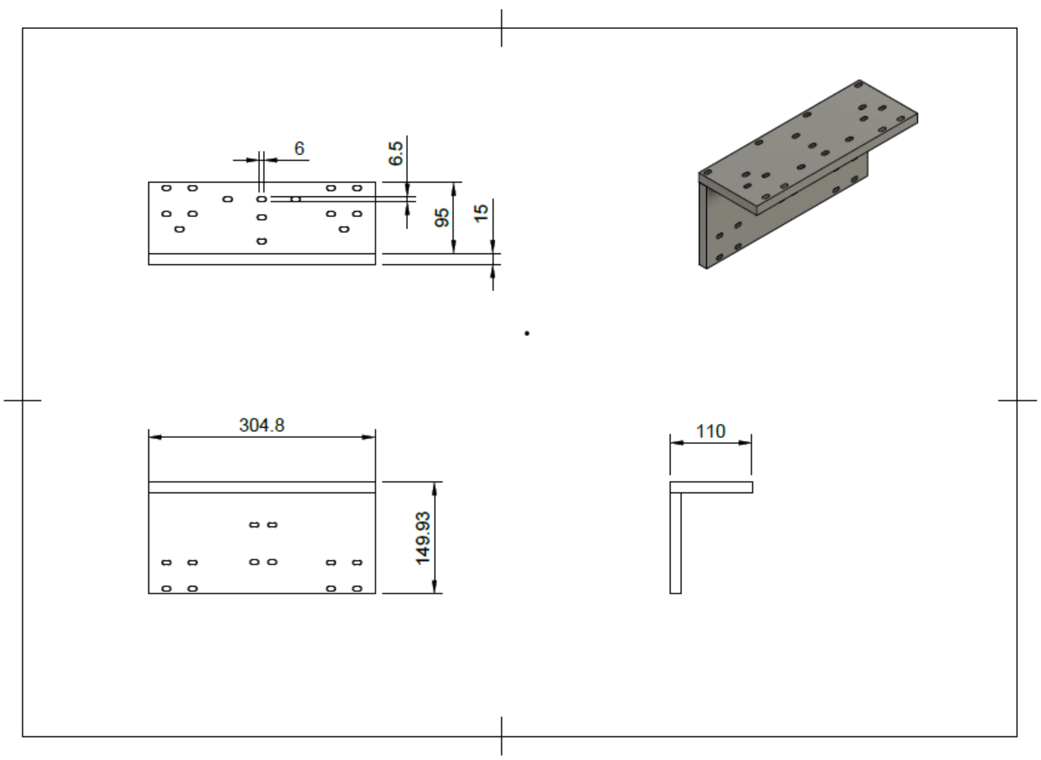


Figure 16: Equivalent Stress

The aluminum plates are subjected to a maximum Stress of 3.0252Mpa. The Yield Strength of Aluminum is 55Mpa. These plates, therefore, also have a factor of safety incorporated within themselves to account for the versatility of the CNC router machine.

Max Stress is 3.0252Mpa. Yield Strength of Aluminium is 55Mpa.



<u>**VERTICAL PLATES:**</u>

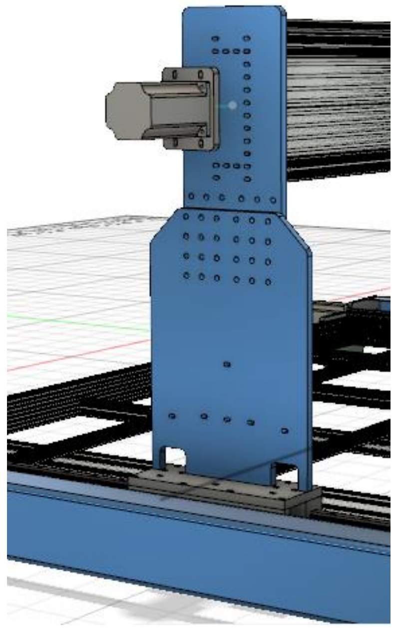


Figure 17: Vertical Plates for X-Axis

The vertical plates serve as the mounts for the X-axis ball screw and the NEMA-34 Motor. The plates have to bear the weight of all the components of X-axis and Z-axis of the CNC router machine such as the ball screws, rails and bearings. Along with the material that will be transferred onto the bed of the Printer while printing Concrete.

The overall 50cm height of the Z-axis was achieved by splitting these vertical plates into to, in order to incorporate the bending moments about the Z-axis, and to have the novelty of Variable height adjustments in the Z-axis.

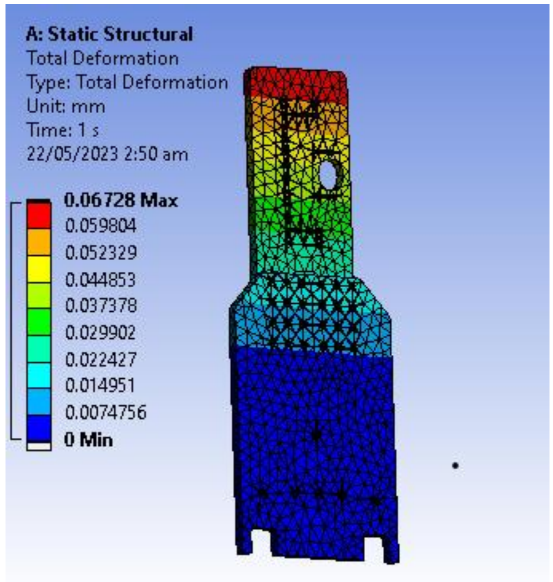


Figure 18: Total Deformation

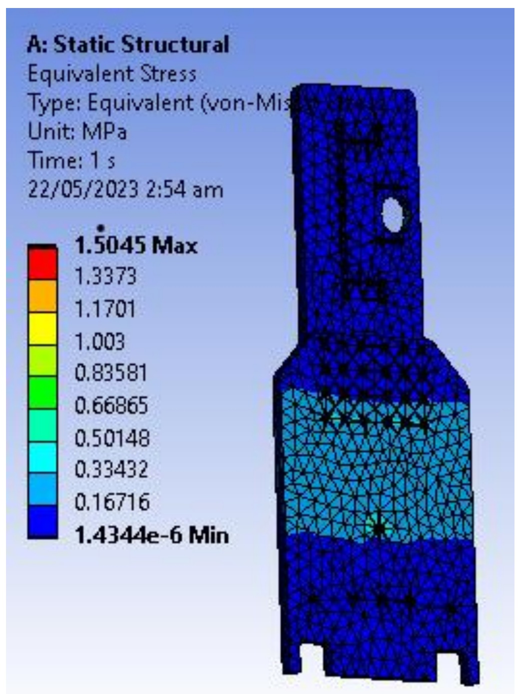


Figure 19: Equivalent Deformation

Z-AXIS PLATE:

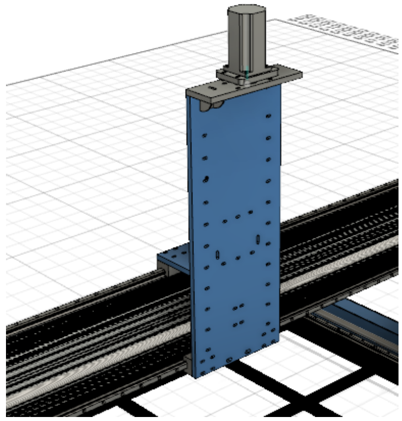
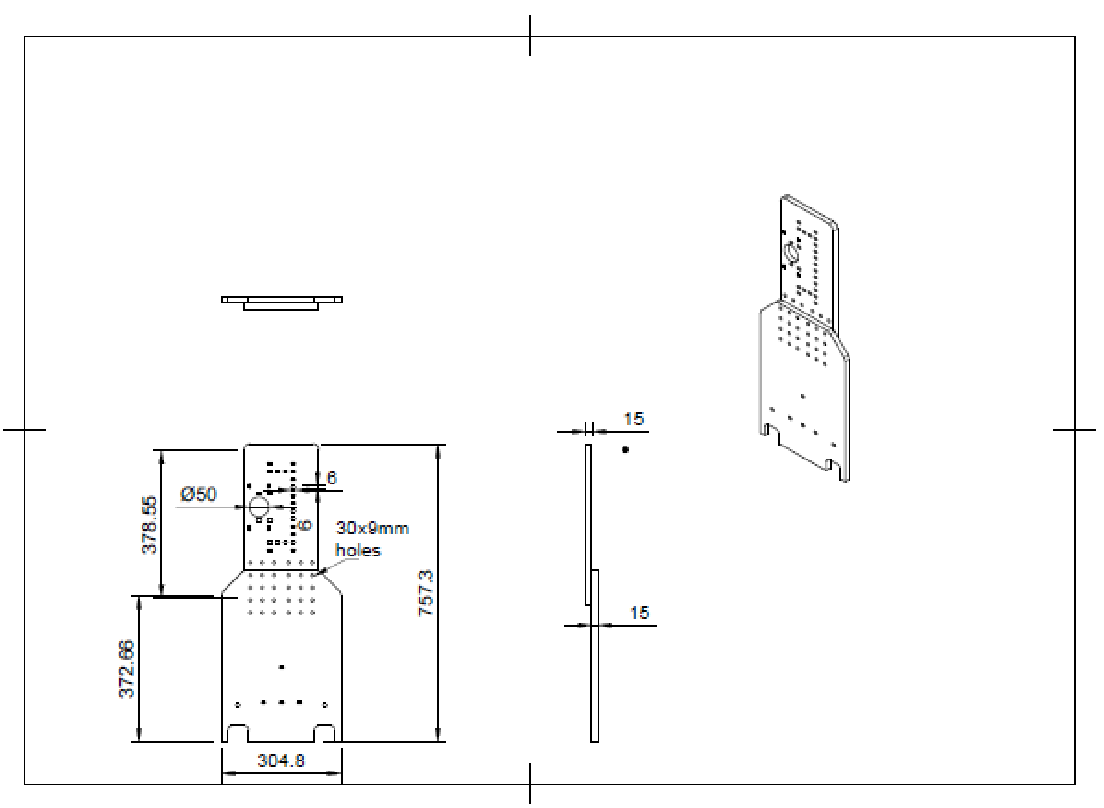


Figure 20: Z-Axis Plate

After being presented with the challenge of mounting the Z-axis rails and ball screw, the CNC machines used in industry have T-slot tables for easy adjustments. But due to cost effectiveness of getting High grade Aluminum plates of 15mm thickness, the platers were designed to match the equipment and to fit all the components on the aluminum plates.



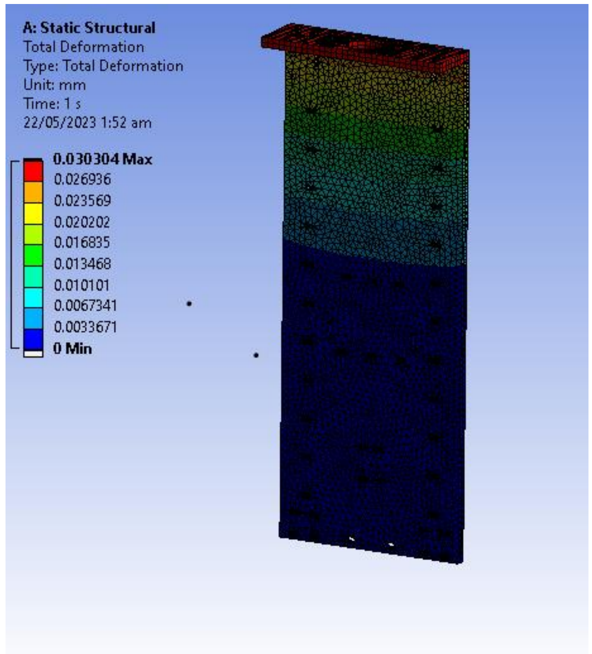


Figure 21: Total Deformation

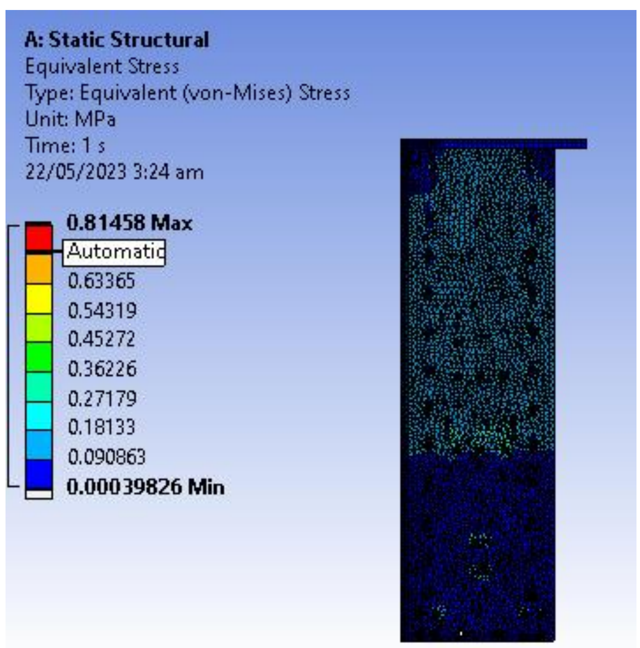


Figure 22: Equivalent Stress

The figures show the static structural analysis of the Z-axis plates. It was done after incorporating the weight of all the components attached to it. The finalized version has several benefits over the t-slot table such as incorporating the bearings and rails of 2 axis, and also providing anchor support for the Z-axis servo stepper NEMA-34 motor.

The values of von-mises stress are way under the yield strength of Aluminum. Approximately the plates are subjected to a maximum of 1Mpa of stress forces.

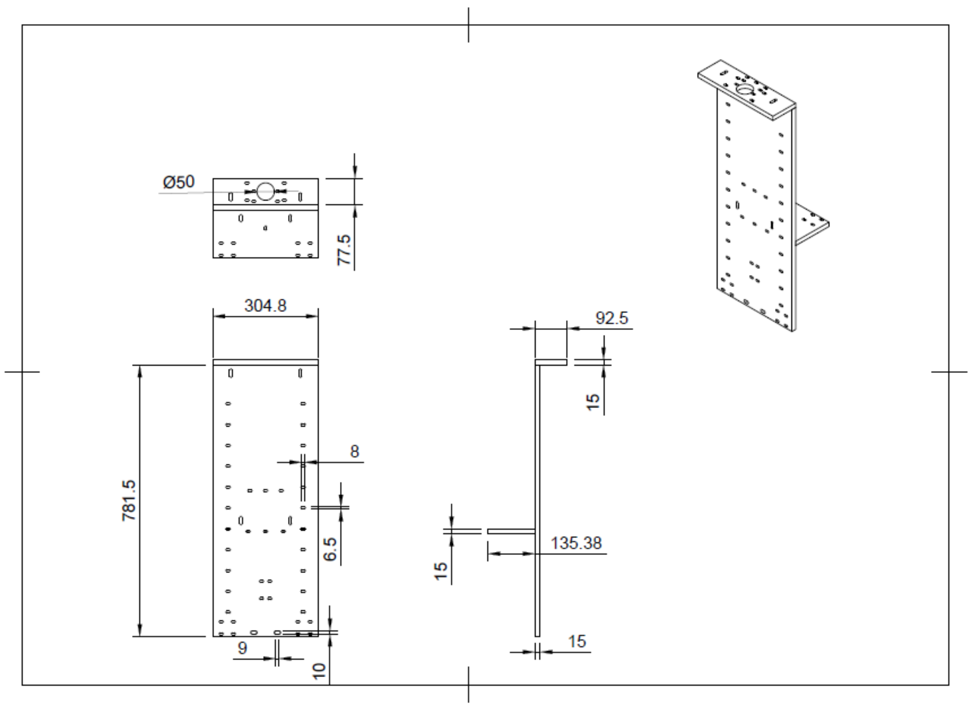


Figure 23. Z-axis plates CAD

Extrusion System:

Figure 24. Extrusion system

The extrusion system consists of a prime mover coupled with a reducer, which is attached by means of coupling to the screw. The screw is housed inside the hopper which can incorporate 5000cm3 of concrete at a given time. The prime mover is controlled by a VFD Drive which helps in controlling the rpm of the extrusion system.

The hopper is attached with a nozzle. The screw also consists of agitators which ensure continuous and thorough mixing of the concrete inside the hopper.

All the assemblage is fabricated of steel.

After considering the various benefits of 3D concrete printing technology, it is clear that this innovation has the potential to revolutionize the construction industry and address many of the challenges facing Pakistan and other countries around the world. By significantly reducing the cost and time required to build homes, 3D concrete printers can help to bridge the gap in affordable housing, which is a critical issue in many countries, including Pakistan.

Furthermore, the use of 3D concrete printers can expedite the construction process, streamline the process, reduce waste, and minimize the risks associated with traditional construction methods. This technology can create custom-designed, energy-efficient homes at affordable prices, while also attracting foreign investment and creating new jobs in the construction industry. Moreover, it has the potential to improve safety on construction sites and make a significant contribution to a more sustainable construction industry.

In addition, 3D concrete printing technology allows for the creation of unique and intricate designs that are difficult or impossible to achieve with traditional construction methods. This level of customization can be particularly useful in architecture, where unique and creative designs are often required. The technology enables faster construction times compared to traditional methods, making it a versatile technology that can be used in a variety of applications. Also, it is scalable, which means that it can be used for both small and large-scale construction projects.

Finally, the adoption of 3D concrete printing technology represents a cutting-edge innovation that has the potential to transform the construction industry. It allows for new and innovative designs and structures that were previously impossible to create. As technology continues to advance, it is likely to become an increasingly important tool in construction, architecture, and other industries.

The benefits of using 3D concrete printing technology are numerous and significant, ranging from cost reduction to customization, speed, efficiency, sustainability, safety, scalability, and innovation. As such, this technology has become increasingly necessary in recent years and has the potential to make a significant contribution to addressing the many challenges facing the construction industry and the world at large.

Despite the many advantages of 3D concrete printing, there are also some challenges and limitations that need to be addressed. For example, the technology is still relatively new and untested, which means that there may be some unknown risks or limitations that need to be addressed. In addition, the upfront costs of purchasing 3D concrete printers and training staff to use them can be high, which may make it difficult for smaller construction companies to adopt the technology.

To fully realize the potential of 3D concrete printing, it is important to continue research and development efforts to improve the technology and overcome its limitations. This includes improving the speed and accuracy of 3D concrete printers, developing new and more sustainable materials, and exploring new applications and use cases for the technology.

In conclusion, 3D concrete printing is a promising technology that has the potential to revolutionize the construction industry by offering faster, more efficient, and more sustainable construction practices, as well as enabling new possibilities for architectural design. While there are still challenges and limitations to be addressed, continued research and development efforts will help to unlock the full potential of this technology and drive innovation in the construction industry.

Figure 25. Extrusion system

CHAPTER 5: CONCLUSION AND RECOMMENDATION

In conclusion, the design and fabrication of a 3D concrete printer that incorporates a CNC routing machine and extrusion system has the potential to revolutionize the construction industry by providing innovative and efficient technology that can significantly improve the efficiency and accuracy of construction processes. Our motivation for this project was to address the challenges associated with traditional construction methods and provide a viable solution that can reduce material wastage and construction time.

The literature review conducted in this document highlights the various technological advancements and innovations that have been made in the field of 3D concrete printing. The review emphasizes the significance of 3D concrete printing in the construction industry and its potential to transform the way buildings are designed and constructed. The literature review also underscores the importance of utilizing cost-effective and environmentally sustainable materials in the 3D concrete printing process.

The introduction of this document sets the context for the design and fabrication of the 3D concrete printer, explaining the need for a more efficient and precise method of construction. The introduction outlines the objectives of the project, which include designing a 3D concrete printer that can create complex structures with high precision and efficiency, evaluating the printer's capabilities through testing and experimentation, and comparing the results of 3D printing to traditional construction methods.

The design and fabrication of the 3D concrete printer involved extensive research and experimentation to optimize the printer's performance. The printer was designed to incorporate a CNC routing machine and extrusion system to create complex concrete structures with high precision and flexibility. The printer was constructed using materials that are affordable and easy to source, making the technology accessible to a wider range of construction companies.

The testing and experimentation conducted to evaluate the printer's capabilities involved printing a variety of complex concrete structures and comparing the results to traditional construction methods. The results demonstrated that 3D printing technology has numerous advantages over traditional construction methods, including reduced material wastage, improved efficiency, and increased precision.

In conclusion, the design and fabrication of a 3D concrete printer that incorporates a CNC routing machine and extrusion system represents a significant technological advancement in the construction industry. The 3D printing technology has the potential to transform the way buildings are designed and constructed, and its benefits are numerous. By reducing material wastage, improving efficiency, and increasing precision, 3D printing technology can significantly improve the sustainability and cost-effectiveness of construction projects.

In future research, it would be interesting to explore the use of more environmentally sustainable materials in the 3D printing process, such as graphenenanomaterials. Additionally, further experimentation and testing could be conducted to optimize the printing parameters and performance of the printer. With continued research and development, 3D concrete printing technology has the potential to transform the construction industry and pave the way for a more sustainable and efficient future.

APPENDIX I: Components of cnc routing machine

Table 2. Appendix I

Sr. No.	Axis	Name
		Linear Guides
1	X & Y	Linear Guides + Screws Sets
2	Z	Linear Guides + Screws Set
		Aluminium Extrusions
3	XYZ	4080C Beams
4	XYZ	2040V Beams
5	Base	2080V Beams
		Motors
6	XYZ	NEMA 34 Step-servo
		Screws
7	Z	M3 x 10mm Black Screws-
8	X	M4 x 10mm black screws
9	Z	M5 x 8mm Low profile screws
10		M5 x 12mm Low profile screws
11		M5 x 15mm Low profile screws
12		M5 x 20mm Low profile screws
13		M5 x 40mm Low profile screws
14		M5 x 50mm Low profile screws
15		M5 x 55mm Low profile screws
16		M5 Tee Nuts
17		M5 Nylon Lock Nuts
18		M5 Drop in T Nuts
19	Y	M6 x 12mm Black Screws
20	XYZ	M6 x 16mm Cap Screws
21	XYZ	M6 Strength Slide T nuts
22		M6 High Duty Screws
		M5 Screws and Nuts
		Others
23		Aluminium spacers 6mm
24		Aluminium spacers 40mm
25		Black Angle Connectors
26		Anti-Backlash Nut Block + Screws and Nuts
27		Acme-Nut Block + Screws and Nuts
28		Double L Brackets
29		Triple L Brackets
30		Brass Tension Nut
		Job Knob

REFRENCES

[1] Izabela Hager, el at. Cracow University of Technology, Warszawska str.24, Cracow, Poland. International Conference on ecology and new building materials and Products, (ICEBMP). DOI: 2016

[2] Sungwoo Lim, el at. Department of civil & building engineering, Loughborough University, UK DOI: May 2014.

[3] Byung Wan Jo, el at. Department of Civil and Environmental Engineering, Hanyang University, Republic of Korea. DOI: 2020

[4] J. Van der putten, el at. Van tittelboom Mangel-vandepitte laboratory for Structural Engineering and Building Materials, Ghent University, Belgium. DOI: July 2020

[5] Imane Krimi, el at. Bouygues construction, Avenue De Horizon, Haute Borne. DOI: June 2017

[6] Rabab Allouzi, Assistant professor of civil Engineering, the university of Jordan, Amman, Jordan. DOI: April, 2019

[7] Manju R, et al. DOI: August 2019

[8] Bezhad Nematollahia, et al. Center for Sustainable Infrastructure, Swinburne University of Technology, Melbourne, Australia. DOI: 2017

[9] Yesim Tarhan, et al. Department of Civil Engineering, Ataturk University, Turkey. DOI: April 2019

[10] Amitkumar D.Raval, Ganpat university, Gujrat, Head of the Civil engineering department, U.V. Patel Engineering college, Ganpat university, Gujrat. DOI: March 2020

[11] Guowei, el at. College of Architecture and Civil Engineering, Beijing University of Technology, Beijing, China. DOI: April 2017

[12] Victor Molodim, el at. Head of the Department of Construction Technology and Organization, Russian Federation. DOI: April 2020