Kaunas University of Technology

Faculty of Mechanical Engineering and Design

Development of Large Scale Printer Based on Material Extrusion Technology

Master’s Final Degree Project

Ignas Apieravičius

Project author

Assist. Prof. Dr. Tomas Kuncius

Supervisor

Kaunas, 2025

Kaunas University of Technology

Faculty of Mechanical Engineering and Design

Development of Large Scale Printer Based on Material Extrusion Technology

Master's Final Degree Project

Industrial Engineering and Management (6211EX018)

Ignas Apieravičius

Project author

Assist. Prof. Dr. Tomas Kuncius

Supervisor

Assoc. Prof. Dr. Darius Eidukynas

Reviewer

Kaunas, 2025

Kaunas University of Technology

Faculty of Mechanical Engineering and Design

Ignas Apieravičius

Development of Large Scale Printer Based on Material Extrusion Technology

Declaration of Academic Integrity

I confirm the following:

1. I have prepared the final degree project independently and honestly without any violations of the copyrights or other rights of others, following the provisions of the Law on Copyrights and Related Rights of the Republic of Lithuania, the Regulations on the Management and Transfer of Intellectual Property of Kaunas University of Technology (hereinafter – University) and the ethical requirements stipulated by the Code of Academic Ethics of the University;

2. All the data and research results provided in the final degree project are correct and obtained legally; none of the parts of this project are plagiarised from any printed or electronic sources; all the quotations and references provided in the text of the final degree project are indicated in the list of references;

3. I have not paid anyone any monetary funds for the final degree project or the parts thereof unless required by the law;

4. I understand that in the case of any discovery of the fact of dishonesty or violation of any rights of others, the academic penalties will be imposed on me under the procedure applied at the University; I will be expelled from the University and my final degree project can be submitted to the Office of the Ombudsperson for Academic Ethics and Procedures in the examination of a possible violation of academic ethics.

Ignas Apieravičius

Confirmed electronically

Kaunas University of Technology

Faculty of Mechanical Engineering and Design

Task of the Master's Final Degree Project

Given to the student – Ignas Apieravičius

1. Title of the Project

Development of Large Scale Printer Based on Material Extrusion Technology

(In English)

Didelių gabaritų spausdintuvo paremto medžiagų ekstrūzijos technologija kūrimas

(In Lithuanian)

2. Aim and Tasks of the Project

Aim: to develop a material extrusion technology printer for manufacturing large-format products.
Tasks:

1. to identify the main printer configuration and printing process requirements for a large-scale material extrusion technology printer;
2. to design a large-scale 3D printer based on material extrusion technology;
3. to investigate the Z-axis corner bracket under load using finite element analysis;
4. to evaluate the developed large-scale printer and determine printing process limitations;
5. to evaluate the design of the printer economic and environmental impact.

3. Main Requirements and Conditions

The constructed printer should have a build volume of around 1.5x1.5x2 meters. The 3D model should be created in the SolidWorks CAD software. Z-axis corner bracket strength should be analysed using SolidWorks simulations. The first print should be made using this machine. Economic and environmental overview must be made.

Project author	Ignas Apieravičius		07-03-2025
	(Name, Surname)	*(Signature)*	*(Date)*
Supervisor	Tomas Kuncius		07-03-2025
	(Name, Surname)	*(Signature)*	*(Date)*
Head of study field programs	Regita Bendikienė		07-03-2025
	(Name, Surname)	*(Signature)*	*(Date)*

Ignas Apieravičius. Development of Large-Scale Printer Based on Material Extrusion Technology. Master's Final Degree Project, supervisor Assist. Prof. Dr. Tomas Kuncius; Faculty of Mechanical Engineering and Design, Kaunas University of Technology.

Study field and area (study field group): Production and Manufacturing Engineering (E10), Engineering Sciences (E).

Keywords: 3D printer, large-format, pellets, extrusion, Cartesian.

Kaunas, 2025. 56 p.

Summary

This Master's degree project documents and describes the process of creating a large-format 3D printer for furniture and décor manufacturing. The main problem that this solved was the creation of an inexpensive, large 3D printer whose components are readily available. The project began with a theoretical overview of the existing printer market, a brief history and application. Several printing methods were analysed, and large-scale counterparts were presented. After the analysis of the printing technologies, the Cartesian FDM printing method and technology were chosen as the most suitable. The design began with the frame, kinematic system layout and general requirements for this machine. The extruder was chosen to use pellets as the primary material for manufacturing. For the kinematic system ball screws and linear rails are the main componenets. The required characteristics for it were: a large printing volume, comparatively low cost, ability to be used remotely, and pellets as a printing material. The printer was first designed in SolidWorks CAD and then assembled. The Z-axis corner bracket was simulated under extreme load in the virtual environment, and it was determined that it needs to be reinforced by welding the corners. After assembly, the printer was programmed using Klipper as firmware. Testing began and was successful, the printer worked as expected, bed levelled, and the extruder performed as needed. The overall cost of the printer was reduced by using differently manufactured parts, bent sheet metal, and off-the-shelf components. The overall cost did not exceed 5000 Euros, which was determined to be fair and in the allowable range. This project demonstrated that there is a possibility to create a custom large-format 3D printer without large investments. This project documentation might help readers develop their own large-format printing machine and avoid costly mistakes.

Ignas Apieravičius. Didelių gabaritų spausdintuvo paremto medžiagų ekstrūzijos technologija kūrimas. Magistro baigiamasis projektas, vadovas asist. dr. Tomas Kuncius; Kauno technologijos universitetas, Mechanikos inžinerijos ir dizaino fakultetas.

Studijų kryptis ir sritis (studijų krypčių grupė): Gamybos inžinerija (E10), Inžinerijos mokslai (E)

Reikšminiai žodžiai: 3D spausdintuvas, didelio formato, granules, ekstrūzija, Kartezinis.

Kaunas, 2025. 56 p.

Santrauka

Šis baigiamasis darbas aprašo ir dokumentuoja didelio formato 3D spausdintuvo modeliavimo ir gamybos procesą, skirtą baldų ir dekoro gamybai. Pagrindinis šio projekto tikslas buvo sukurti nebrangų, didelių gabaritų 3D spausdintuvą, naudojant nesunkiai prieinamas detales. Darbas buvo pradėtas nuo esamos 3D spausdintuvų rinkos, jų istorijos ir naudojimo apžvalgos. Išanalizuoti keletas spausdinimo metodų ir jų didžiagabaričių alternatyvų. Atlikus teorinę analizę buvo nuspręsta konstruoti kartezinį FDM spausdintuvą. Sekantis žingsnis buvo rėmo konstrukcijos ir kinematinės sistemos išvystymas, vadovaujantis bendraisiais spausdintuvo reikalavimais. Reikalavimai buvo: plastiko granulės turi būti prieinamos kaip spausdinimo medžiaga, didelis spausdinimo tūris, maža spausdintuvo kaina ir galimybė operuoti nuotoliu. Spausdintuvas sumodeliuotas SolidWorks CAD programoje, o vėliau surinktas fiziškai. Kinematinė sistema buvo sumodeliuota pritaikant linijinius bėgelius ir guolinius sraigtus kaip pagrindinę judėjimo sistemą. Z ašies rišamasis laikiklis buvo simuliuotas virtualioje SolidWorks aplinkoje apkraunant jį maksimaliomis jėgomis. Remiantis simuliacijos rezultatais, nuspręsta, kad, jį reikia sutvirtintinti. Norint sustiprinti jį, reikia suvirinti kraštus. Po mechaninio surinkimo, spausdintuvas buvo suprogramuotas naudojantis Klipper operacinę sistemą. Spausdintuvo testavimas buvo sėkmingas, spausdintuvas veikė kaip numatyta, plastikas liejosi kaip tikėtasi. Viso spausdintuvo kaina buvo sumažinta naudojant lengvai prieinamus komponentus ir detales, pagamintas iš lakštinio plieno. Bendra kaina neviršijo 5000 Eurų ir buvo priimta kaip atitinkama. Šis projektas pademonstravo, kad sukurti nestandartinį, didelių gabaritų spausdintuvą yra įmanoma. Šio projekto dokumentacija gali padėti skaitytojams sukonstruoti didžiagabaritį spausdintuvą ir išvengti brangių klaidų.

.

Table of Contents

List of Figures

List of Tables

List of Abbreviations and Terms

Abbreviations:

AM – Additive Manufacturing
DLP – Digital Light Processing
SLA – Stereolithography
SLS – Selective Laser Sintering
LCD – Liquid Crystal Display
FFF - Flament Fused Fabrication
FDM – Fused Deposition Modelling
CAD - Computer-Aided Design
UV - Ultraviolet Light
DLP - Direct Light Processing
SSS - Solid-State Sintering
PSU- Power Supply Unit
FEA- finite element analysis
AISI- American Iron and Steel Institute
PP- Polypropylene

Introduction

Additive manufacturing, also known as 3D printing, is a fast-developing manufacturing method to produce never-before-seen parts that were impossible to manufacture with traditional methods. It is a manufacturing method that produces parts by stacking two-dimensional layers on top of each other. This allows for the creation of geometries that are impossible to manufacture using traditional, subtractive manufacturing. With 3D printing, hollow structures or built-in features such as integrated cooling fins, mixing chambers are possible. This opens possibilities for the engineers to develop better, smaller and more feature-packed parts. This novelty in manufacturing has become abundant and readily available, companies have produced 3D printers at a low cost that are available to the masses. From its conception in the twentieth century to this day, it has improved substantially and the price of 3D printers has reduced drastically, this is due to open-source design, community improvements and third-party involvement in parts manufacturing for these machines. With availability and access, many users have started to implement this technology into their household manufacturing. Some design and create custom vases or brachets to hold other items. Some create more complicated sorting units for the garages, custom tooling or replacement parts. This is also achieved with the adaptation of computer-aided design software and model repository platforms. Users who can not use modelling software have access to the large selection of models created by other users, which encourages the use of 3D printing and its adaptation in many households. From this manufacturing and open-source community, many industries have benefited, such as automotive, medical, gardening and décor. As industries are evolving and different 3D printers are required to accomplish certain tasks, there is a growing market for large-format 3D printers. Industries such as décor or furnishing can heavily benefit from the adaptation of this technology. In these industries, single 3D printed furniture or large vases could open a portion of the market and be profitable. As there is a market from which it is possible to benefit, it is necessary to create machinery that can accomplish the task of large-format 3D printing. These industries can benefit from it by cutting costs by reducing material usage and creating complex geometries that were impossible to manufacture using traditional methods, it is possible to explore new designs and possibilities for the designers and engineers. This paper will describe the development of a large-format additive manufacturing printer based on extrusion technology. As creating furniture and décor requires custom-built machinery to print large objects, the benefit of developing this printer will open the possibility of making it. The large-format 3D printer is planned to be built with readily available industrial components with the intention of making it cost-effective and simple to operate.

Aim: to develop a material extrusion technology printer for manufacturing large-format products.
Tasks:

1. to identify the main printer configuration and printing process requirements for a large-scale material extrusion technology printer;
2. to design a large-scale 3D printer based on material extrusion technology;
3. to investigate the X-axis strength and stiffness using finite element analysis;
4. to identify the kinematic system parameters and limits;
5. to evaluate the design of the printer economic and environmental impact.

Hypothesis: a large-scale 3D printer can be built with commonly available industrial materials and be used to create furniture.

1. Review of 3D Printing Principles and Methods

Additive manufacturing (AM), also known as 3D printing, began its conceptualisation in the second half of the twentieth century, with its first recorded use in 1960 at the Battelle Memorial Institute. The first instance of 3D printing was performed by using two intersecting lasers to polymerise the resin material into a solid object. The first similar patent to this technology was called photomechanical machining and was issued by Wyn Swanson in 1971. The first rapid prototyping machine of similar technology using only one laser beam was developed by Hideo Kodama in the year 1980. For this advancement, a patent was issued, but it was unsuccessful. Further evolution of this technology was stereolithography (SLA). Later, in 1984, Charles Hull invented stereolithography, and two years later, it was patented, he also founded "3D Systems" and produced the first ever commercially available SLA printer. At a similar time, Carl Deckard invented the first selective laser sintering (SLS) 3D printer. The first fused filament fabrication (FFF) 3D printer was invented in 1989 by Lisa Crump and S. Scott [1]. With the development of additive manufacturing, the availability of rapid prototyping grew, and further development in this field followed shortly after. Further developments in computing and digital processing heavily influenced additive manufacturing development and further research. As the computational capacity increased and digital manufacturing became more integrated with traditional manufacturing, it was also implemented in additive manufacturing, which led to further improvements. In the mid-1990s, the additive manufacturing industry split into two categories, one for the general public as an easy-to-use prototyping machine and the other for high-end purpose-built engineering equipment. Further development of 3D printing technology was after the expiration of the fused deposition modelling (FDM) technology patent, when open-source communities started to form over this manufacturing method, one of the most well-known is RepRap [1]. These communities of individuals mainly focused on rapid improvement and development of self-replicating printers of the FDM 3D printers (Fig. 1) and sharing these improvements with others.

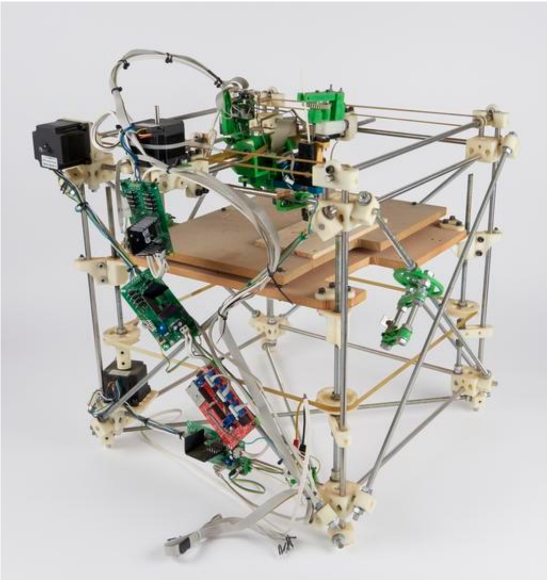


Fig. 1. 'Darwin' RepRap self-replicating 3D printer (Generation I) [2]

This led to rapid improvements in home-built 3D printers and solved many of the issues with early 3D machines. As the early machines for additive manufacturing were unreliable and difficult to use, the adoption of the open-source approach to problem-solving led to many improvements in the community. One of the most influential persons in the popularity of hobby-style 3D printers was Josef Prusa, by simplifying the construction of the FDM printer, outsourcing component production from the end user and offering full 3D printer kits his company "Prusa Research" made 3D printers (Fig. 2) available to the general public and companies at a low cost. As his designs were open-source, many other companies followed with their own designs, improving on it and reducing the cost further, making 3D printing available even more.

Fig. 2. Original Prusa i3 [3]

The latest disruption of the industry as of 2025 came from the company "Bambu Lab" with their ready-to-use, out-of-the-box 3D printers. With the offer of easy setup, simplified user interface and multi-material printing, it brought many new users to the industry and set a new expectation for the consumer of easy use and a user-friendly interface with multi-material printing. As of 2025, the household desktop 3D printers have become readily available and industrial 3D printers have improved substantially with an easy user interface and engineering material implementation. The hobby-style 3D printers became primary rapid prototyping tools for many companies, and the open-source approach to the industry further improves additive manufacturing machines and develops new software for a better user experience and final product.

With the improvements in the manufacturing sector, many industries heavily benefited and adopted this technology. First of which were the aerospace, medical and high-performance automotive industries. With the ability to create complex geometrical structures that were previously impossible to create with traditional manufacturing, such as milling, turning and machining. This method creates parts by stacking 2D layers on top of each other to create complex 3D parts by adding material to the part, whereas traditional manufacturing often subtracts material from a single piece billet. The main benefit of this technology is the possibility of creating built-in features in the part and simplifying the overall complexity of the part. It also allows the creation of new, optimised designs that were impossible to create previously. With the addition of material to the part rather than subtraction, it also saves material and reduces waste, which reduces the final cost of the product. As the AM heavily relies on software, a new streamlined workflow had to be created that consists of computer-aided design (CAD) and virtual part slicing into 2D layers to further create G-code that 3D printers can execute (Fig. 3). The workflow begins with a CAD model that is created in the virtual 3D environment and later converted to standard triangle language or standard tessellation language (STL) and further sliced to create a G-code [4]. The G-code is a text document that consists of coordinate movements for the machine, it is similar to milling machine control code, the file does not take much space and does not require high computing capacity from the machine executing it.

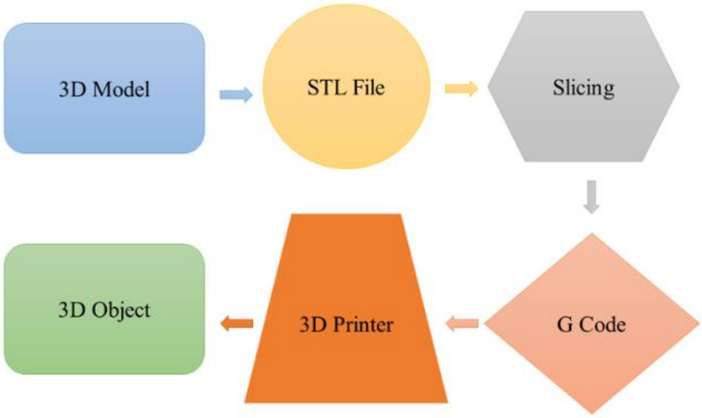


Fig. 3. 3D printing workflow [5]

The new manufacturing method allows engineers to envision and create parts that are better optimised and have features built in. Also, allows companies to reduce storage needed for final products as they can be manufactured on demand with no requirements for up-front manufacturing. But AM has some weaknesses as well, one of the most prominent in FFF being anisotropic properties in final products. This means that the part does not react to the applied load universally in all directions, as the part is created layer by layer the bondage between layers is the weakest point, and the load needed to break the part applied perpendicular to the layer orientation is significantly lower than applied directly to the layer orientation [6]. This property of the final part must be considered in the design phase by the engineers and worked around. With the new manufacturing method, new materials designed specifically for it have to be manufactured and engineered. As the FDM most commonly uses filament as its manufacturing material, it had to be created and designed specifically for this purpose. Many materials have been engineered to suit 3D printing applications. With the growing adoption of AM technology, new materials are created to suit specific purposes. For liquid crystal display printers and SLA printers, the production material used is specifically created photosensitive resin. And for the SLS printers, powdered materials are used, such as powdered nylon, aluminium and in high-end applications, powdered titanium. With the adoption of additive manufacturing, many new possibilities are available. 3D printing with the wide availability of the materials enables rapid prototyping, cost savings on final parts and reduced waste. As the FDM manufacturing technology uses plastic polymers, it enables the use of recycled plastics in filament form, further reducing material waste [7]. With the benefits provided by implementing additive manufacturing, many industries may benefit from it, one of them being the furnishing and décor industry [8]. As the design possibilities are virtually endless, designers can create never-before-seen before décor pieces. For the designers and engineers, it is possible to create heavily customised furnishing items, one-off designs and personalised furniture pieces with the same equipment, with on-demand manufacturing. As 3D printing offers previously impossible design capabilities and is more versatile and available to many more individuals, it has revolutionised desktop manufacturing and prototyping. With its availability and access to publicly shared STL files and integrated slicing and model-sharing repository ecosystems, it is becoming more widely adopted in households and businesses. As this manufacturing technology has become more popular, more things are modelled to suit it, more models are shared publicly and more designs are created for it, it is becoming the main manufacturing method for a variety of items.

1.1. 3D Printing Applications in Broader Industries

Parts produced using additive manufacturing technology often offer higher versatility, reduced material consumption and can be designed more intricately. This manufacturing type has shifted the prototyping and desktop manufacturing landscape. With 3D printing benefits of flexibility in parts manufacturing, reduced energy and material needs, it has become widely adopted. By allowing designers and engineers to create parts with better optimised topography, hollowed insides and newly envisioned shapes, this manufacturing method has found its way into many different fields.

As the technologies in the medical sector improve, some improvements come from different fields and are adopted. One of the fields that benefited from additive manufacturing implementation was medicine. Adaptation of 3D printing enabled customised cast creation for limbs that need to be immobilised. Using 3D scanned limbs and CAD software combined with additive manufacturing flexibility in producing complex shapes enables the creation of casts that are more comfortable and lightweight. These castings can be made with hollowed-out sections or in a honeycomb pattern, retaining their designed purpose and allowing air and water circulation for better comfort and hygiene (Fig. 4). The 3D printed brace is custom-made to best suit the patient and ensure functionality. The traditional plaster castings may cause unwanted side effects for the user, such as nerve dysfunction, muscle mass loss and skin irritation.

Fig. 4. 3D printed cast [9]

Due to hygiene restrictions under traditional casts, users may experience skin irritation and excessive sweating [10]. Most of these drawbacks can be solved by implementing 3D printing in cast manufacturing. The printed castings can be made in such a way that water passage can be unrestricted, which means that patients can take a bath with it and have better hygiene. It is also lighter in comparison to the traditional brace it is lighter, which reduces muscle strain and increases comfort for the user. Casts produced using additive manufacturing generally are lighter, offer better customisation, comfort, hygiene and patient satisfaction.

Additive manufacturing could also be used to improve water, wastewater and air treatment. Currently, the water treatment market is expanding into membrane technology to clear water. This technology uses membranes as a barrier for contaminants or other unwanted materials. This is done by separating water and unwanted materials by allowing water to seep through the membrane and leaving contaminants behind. This separation method is cheap and effective. 3D printing can improve membrane technology by introducing multi-hierarchical designs, which can make it even less expensive and more efficient. This improved design can enable water and oil separation and be used for water desalination, which may provide many people with clean drinking water [11]. Improvements in membrane production using additive manufacturing could reduce water treatment costs, make it more accessible and further increase clean drinking water availability worldwide.

As additive manufacturing is implemented in many fields, it has also been adopted by veterinarian science. Primarily, this technology is used to create prosthetics for small animals. With the adoption of AM, the animal care industry has implemented the streamlined fabrication of prosthetics with integrated manufacturing that comes with 3D printing. The streamlined fabrication of the artificial limb reduces lead times and cost, it also comes with the benefit of accessibility and better fitment. As the prosthetic is designed in CAD, it can be integrated with sensors that provide real-time monitoring and feedback to the veterinarians, leading to better care and more informed interventions [12]. This technology allows an ideal fit to the anatomy of the animal, which provides better mobility and comfort. Not only can prosthetic limbs be made using 3D printing, but also hip and knee replacements. This joint replacement is enabled by integrating high-precision scans and CAD into production, leading to more accurate customisation and improved fitment [13]. Additive manufacturing technologies have been adopted by veterinarians to ensure streamlined production and a perfect fit for prosthetic limbs and implants.

As 3D printing is becoming more available, many industries are adopting this technology to produce better and more efficient parts. The widespread integration of this manufacturing type leads to more advancements for different niches. With new advancements in AM technologies, industries find better ways to optimise and streamline production and design processes. With the optimisation, the price is often reduced and the benefits of this technology can reach more individuals. From water treatment to veterinarian and the medical industry, 3D printing has revolutionised how custom and individually tailored parts are produced. With further development in this field, it is likely that more and more industries will adopt and benefit from this technology.

1.2. Different 3D Printing Technologies and Capabilities

Additive manufacturing has improved substantially from its first inception and is now becoming one of the primary methods for complex parts manufacturing. The FFF, from its creation in early 1990, has improved and has now become one of the most common additive manufacturing methods globally and is used in many different fields. Also, other 3D printing methods have also improved and have seen many implementations in various fields and applications. The printing methods will be categorised by the material used, which could be powder in selective laser sintering, UV resin in liquid crystal display (LCD) and stereolithography or filament in FDM. These 3D printing methods are the most common and are widely adopted by the manufacturing industry.

1.2.1. Most Common FDM Manufacturing Methods

Fused deposition modelling is a 3D printing method where plastic polymer in filament form is pushed through a heated nozzle, melted and then deposited in a 2D layer. These 2D layers are stacked on top of each other in a controlled way to create a 3D part. The heated nozzle is heated by a heated element and monitored by a thermistor, all inserted in a heating block creating an assembly called a hot end. The nozzle is heated in a controlled way by the mainboard with a proportional integral derivative (PID) controller. The temperature set is slightly below the polymer melting point, which makes a semi-liquid state and the material is soft to be extruded through a nozzle and bonded to the previous layer [14]. The filament is pushed through the hot end by an assembly called an extruder. The extruder is a mechanical assembly comprised of gears, housing and a stepper motor, the gears are used to grip the filament mechanically and force it through the hot end and the stepper motor is a brushless direct current electric motor which is used to power the extruder. Stepper motors are also used to control the movements of the print head, they offer highly controlled movement at a competitive price. The whole printer, with all the heating and movement elements, is controlled by a computational unit called a control board. This board controls and monitors all the parameters in the printer, it sets the temperatures, reads the G-code and issues movements. The control board is programmed to suit specific kinematic systems, one of the most common being miscellaneous rectilinear, also called Cartesian. Other popular kinematic systems are core-xy and delta. The Cartesian system is most popular among hobby style 3D printers due to simple maintenance, simple design and low cost [15]. This motion system uses one motor to control one axis, these axis moves independently of the other (Fig. 5).

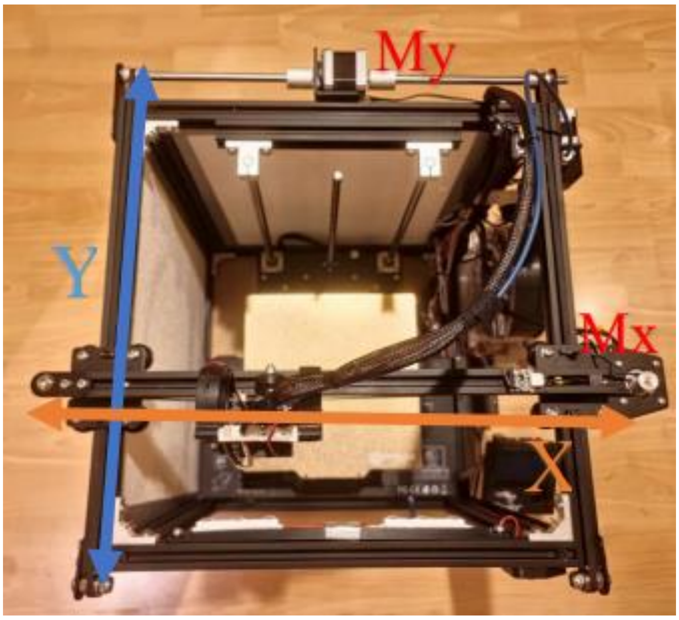


Fig. 5. Cartesian kinematic system

As shown in Figure 5, the x-axis movement is controlled by one motor and the other y-axis by a different motor. Another kinematic system previously reserved for high-end and professional printers is the core-xy system. This system controls both the x and y axes simultaneously by synchronous stepper motor movement (Fig 6.). Both stepper motors are used to control the hot end movement, making this system more complicated and requiring more knowledge to operate and set up the system.

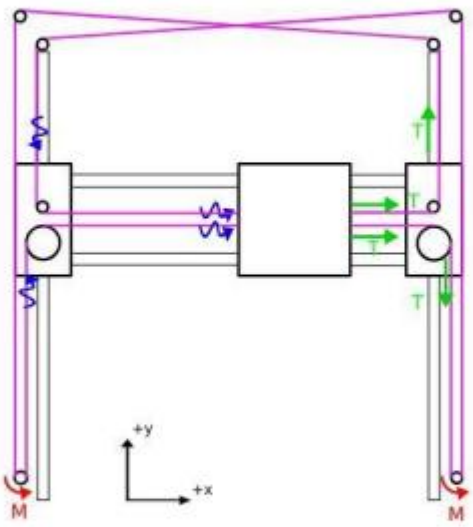


Fig. 6. Core-xy kinematic system diagram [16]

Since this system uses two motors to control movement, it is faster and can achieve higher printing speed compared to the Cartesian system. Another kinematic printer system is delta, this system uses three motors to move the hot end. The motion of this system consists of three motors, carriages and connecting rods attached to the effector that houses the hot end. The motors move carriages in a vertical motion that moves the effector in three dimensions via connecting rods. The synchronised movement of three motors in a vertical motion is translated into effector movement, the delta kinematic system is displayed in Figure 7.

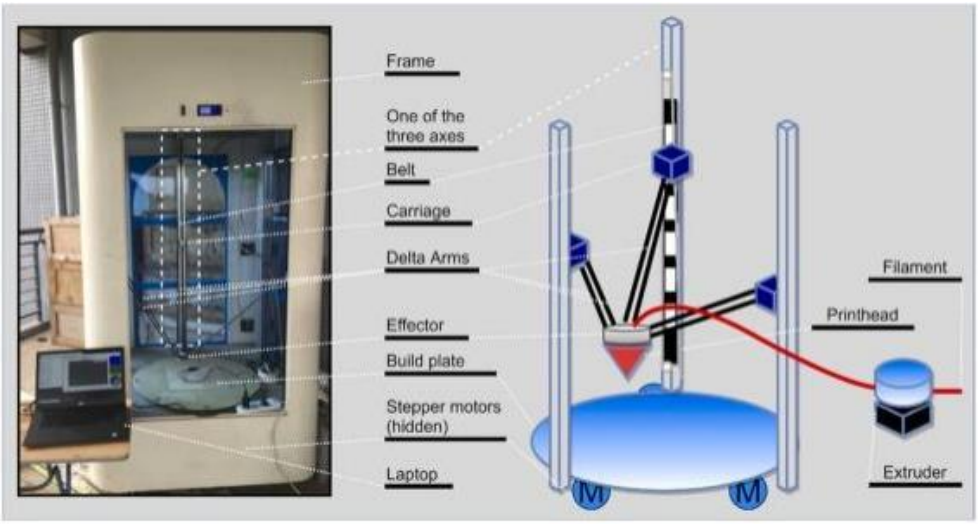


Fig. 7. Delta kinematic system [17]

This system is the most complex of all the ones mentioned previously. This system requires the most computational capacity and precise components. Delta is the least popular system for FDM printing due to its high complexity. Although it is complex, it offers the fastest printing speed and is precise. Many of the delta printers are modified to suit unconventional materials such as clay or chocolate. The FDM printing can be performed with various kinematic systems, which have their own benefits, but the main criteria for selecting one is its availability and intended use. As the affordable 3D printer market increases, each kinematic system is improved, new features are introduced, and the cost of owning a printer is reduced.

1.2.2. Most Common Resin Printing Methods

In the additive manufacturing industry, there is more than one printing technology, one being vat polymerisation. This method relies on UV light shining on photopolymerising polymer resin to harden it. Similar to FFF technology, this method builds parts by layer, but in contrast, it does it so upsidedown and builds parts from a vat of resin. The desired part is sliced into 2D layers that are projected as an image while printing. This is being done by submerging a build platform in a vat of resin under which is a UV light source that shines through a clear vat bottom onto the build plate two-dimensional image of a sliced parts layer. The whole layer is created at once, and when it is time to create another layer, the printer lifts the build plate by the next layer's height. After the printing is complete, the final part must go through extensive post-processing, which involves removing the supports, washing the part with isopropyl alcohol or water, and then curing the part in a UV light chamber. This post-process cleans the part of the remaining resin and fully hardens it. Some resin printing materials may require a heated UV light chamber to harden the part completely.

The most popular and the most available resin printing type is liquid crystal display (LCD) (Fig. 8), which is due to low cost and ease of use. This printing technology utilises the array of UV light-emitting diodes that shine through the LCD screen and harden the resin above them [18]. The light is perpendicular to the screen and is not distorted, the quality of the final part is determined by the resolution of the LCD screen and light intensity. The light intensity also determines how fast the layer hardens, thus determining the print speed.

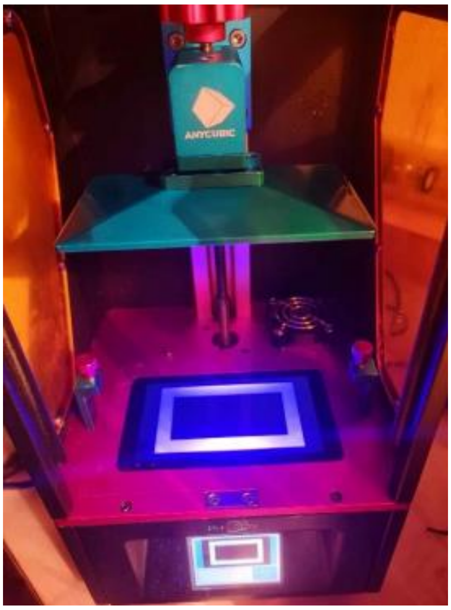


Fig. 8. LCD resin printer

This printing method is most common among 3D resin printing hobbyists due to its accessibility and low cost. This method has advanced to the point where the accuracy of 500 microns and pixel resolution from 14 by 19 microns [19], [20]. As it is much more accurate and can produce small details, it is adopted by miniature statue makers and jewellers.

Another resin additive manufacturing method using UV resin is digital light processing (DLP). This resing printing method utilises a projector that projects the image of a whole layer at once (Fig. 9). It is similar to LCD in hardening one layer simultaneously, but differs from it by utilising a different light source. The DLP printers use an array of micromirrors laid out on the semiconductor chip, the number of micromirrors determines the resolution and quality of the final part [18], [21]. This method is less common than LCD printing due to its higher complexity and increased cost.

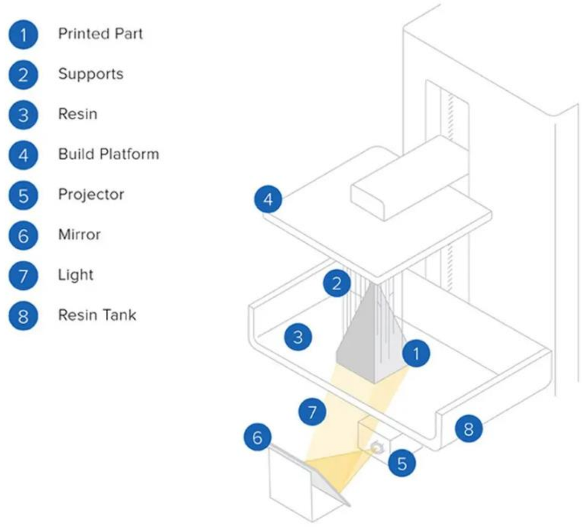


Fig. 9. DLP printer operating principle and layout of main components [21]

The least common resin printing technology is stereolithography (SLA). This method is different from DLP and LCD as it uses a UV light laser to harden the resin. The laser is focused in a single point and has to trace the outline and every detail of every layer (Fig. 10). This resin printing method is the slowest but can offer the highest quality of any other given method[22]. The quality of the parts produced with this method is determined by the laser spot size, z-axis height, accuracy of the x and y-axis movements and the laser power.

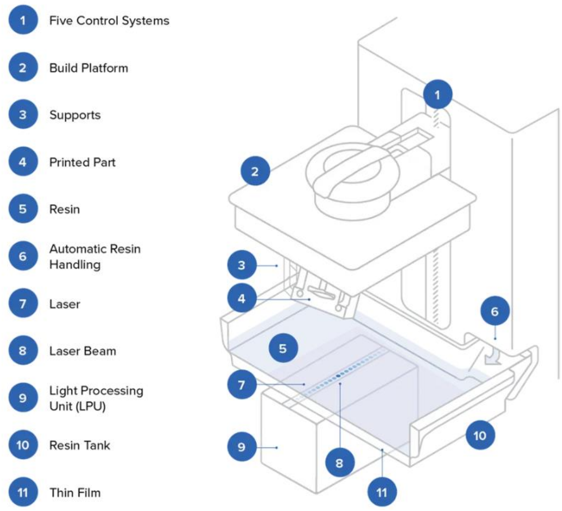


Fig. 10. SLA printer operating principle and layout of main components [21]

Additive manufacturing using vat polymerisation is one of the best 3D printing methods to create a highly detailed part with extraordinary precision. As this method is highly acurate and can produce small details, it is adopted by jewellers, figurine makers, dentists and people creating intricate and detailed products. These AM tools allow rapid prototyping at a small scale with highly controlled surface finishes and intricacies.

1.2.3. Most Common Powder Printing Methods

Additive manufacturing could also be performed by using selective laser sintering (SLS). This method is the most costly, requiring expensive and complex printers to create parts, but it offers the highest quality. It can also utilise all build volume by stacking parts in all three dimensions. This printing process uses a powerful laser to heat, trace an entire layer and fuse powdered material [23]. The laser fuses powder to the previously made layer, stacking two-dimensional layers one on top of each other (Fig. 11). It is good to note that this method can encapsulate powder within a part if there are no holes for the powder to escape. Compared to the previously mentioned printing methods, the SLS can produce supreme quality and can use metallic materials such as aluminium powder. In the year 1980, the first-ever printer utilising this technology was created by Carl Deckard and Joe Beaman, which they called powder bed fusion [24]. This technology was an early adaptation of using high-power lasers to fuse polymer powders. Later, this technology evolved into what is now known as selective laser sintering.

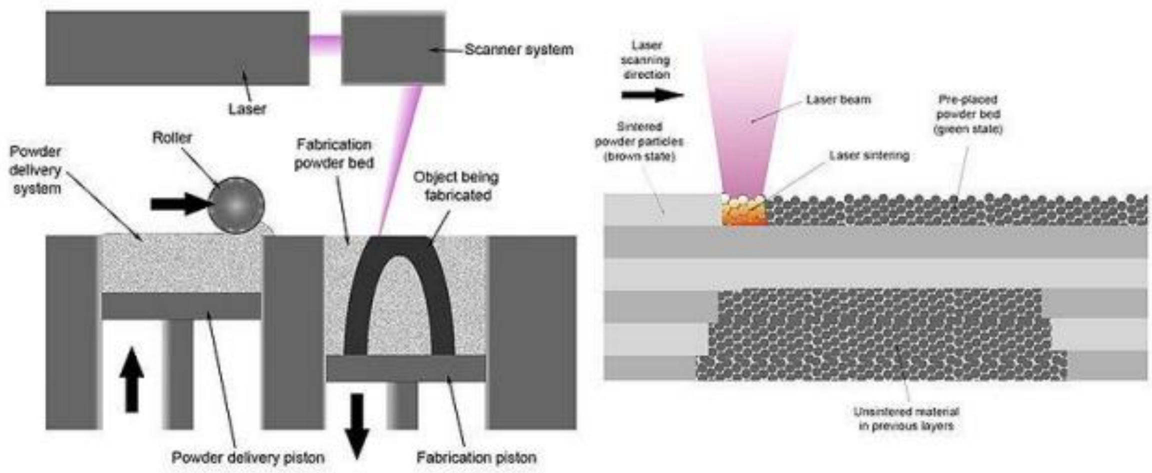


Fig. 11. SLS printer operating principle and layout of main components [25]

This printing method works by lowering the printing surface by a selected layer height, applying new powder with a roller and continuing the printing process by sintering another layer. Printing with this method offers another benefit: it does not require supports, in most cases, they are recommended but not necessary. The powder from previous layers acts as a support [26]. Selective laser sintering can come in two forms, which are direct and indirect sintering. The direct SLS process uses a powerful laser to sinter material powder together and bond them without any additional material [26]. The direct SLS can be further divided into categories, which are selective laser melting, solid-state sintering and liquid-phase sintering.

Selective laser melting utilises a high-power laser to sinter and bond selected material in powder form together. This method traces a 3D object with a laser layer by layer on a powder bed and fuses it into a solid part. This method can be used to create metal or even ceramic parts. This method is used in the automotive and aerospace industries because with it is possible to create accurate and complex parts from titanium, ceramics, tungsten and other metals. With this technology, almost solid metal parts can be made, but there are imperfections and microvoids in the part, making it slightly worse than a traditionally made part [27]. Selective laser melting could also be impacted by sintering the powder layer too quickly, causing internal stresses and deformations. The quality of the final part is impacted by factors such as laser power, powder packing, sintering speed, layer height and cooling.

Solid-state sintering is a process where a laser heats the powder just below its melting point, and diffusion bonding can occur. This is a process where solid powder particles fuse together by a small neck, the particles do not melt together but form a material corridor (Fig. 12). For a better final part, the powder is packed more tightly to reduce voids and make the part denser [27].

Fig. 12. Particles creating a neck between them [28]

With the increased part density, its mechanical properties increase. Typically, this process creates the porous parts, with more packing, less porous parts can be produced [26]. The final part quality and material properties are influenced by laser intensity, material used, material packing and printing settings.

The liquid-phase sintering is a SLS process where two materials are combined together and one of them is melted over another. This requires the use of two materials with different melting temperatures, where the lower melting temperature material is used as a binder for the higher melting temperature material [26]. For the process to be successful, materials that are not soluble should be chosen. The material with the higher melting temperature is the main component for the final part, and the one with the lower melting temperature is the binder material. If the materials are soluble, then they can create an alloy that can result in better mechanical properties, but lower dimensional accuracy [29]. The liquid-phase sintering is a complex process that requires extensive knowledge of materials and printing parameters.

The indirect selective laser sintering process is an SLS process where material powder is mixed with a fraction of binding resin that is later cured by the laser, and material powder is suspended within the resin. The powdered material is not fused or melted together, it is simply held together by a hardened resin [26]. The parts produced with this method have poor mechanical properties, which can be altered by post-processing these parts. The post-process can be done by sintering or infiltrating the final parts [30]. The post-processing by sintering the part is done by heating the part in a controlled environment that removes the resin and compacts the part. This enhances the mechanical properties but can result in dimensional inaccuracies and shrinkage. The infiltration process is where material with a low melting point is applied onto a printed part and melted. The melted material flows into the pores of a printed part, thus hardening it and making it denser [26]. This process in itself produces parts with poor mechanical properties that need further processing to improve them.

The SLS printing process is one of the most expensive and complex additive manufacturing processes that allows the creation of detailed, complex parts from various materials. This process is applied in various industries, but it is reserved for the most demanding applications. The parts produced with the SLS printing method can exceed any other method in final part mechanical properties and material variety. The method itself covers several sub-categories of SLS with different AM methods, but the same principles

1.3. Large Format 3D Printer Parameters

In the construction and design process for creating a large-format 3D printer for the furnishing industry, it is necessary to assess the already existing market of large-format AM. The analysis of the general market for large-scale 3D printing equipment could provide knowledge for upcoming designs. As the additive manufacturing industry improves, new technologies and methods of manufacturing large parts emerge. The latest improvement in large-format additive manufacturing was the adaptation of pellets as a primary material. Since the resin and selective laser sintering technologies require high-end technologies that are commercially unavailable, many companies and individuals have adopted FFF as the main large-format printing method.

The largest commercially available SLS 3D printer is Flight HT1001P (Fig. 13), produced in China by the Farsoon company, with a build volume of 1000x500x450mm [31]. With this build volume, it is possible to produce many complex parts, fully harnessing the benefits of SLS printing technology. This printer is built for large companies producing many complex parts and comes at a significant cost. Thus making this printer unavailable for many smaller companies or users. Building similar machine requires extensive resources and funding.

Fig. 13. Flight HT1001P SLS 3D printer [32]

The scarce availability of this machine and the costs associated with it are too high to consider this technology or machine viable for use in large common product manufacturing. As the machinery, material and operational costs directly influence the cost of the final product, the final parts should be made in bulk to offset the costs. As for furnishing, this method is too complicated and requires too many resources to be viable and the build volume is too small to create a furniture item. Another large format printer currently in use is ProtoFab SLA 2400 (Fig. 14). This large format 3D printer uses resin as a primary material with a build volume of 2400x800x800mm [33]. The use of resin as a material for furnishing may be viable, and the details produced by this printer could be a desirable feature for making furnishing. This could be used to create various décor objects and furniture. The printer and products made with it could serve as a means of manufacturing custom-ordered furnishings or highly desired parts. However, the costs of resin and the printer itself make it not viable.

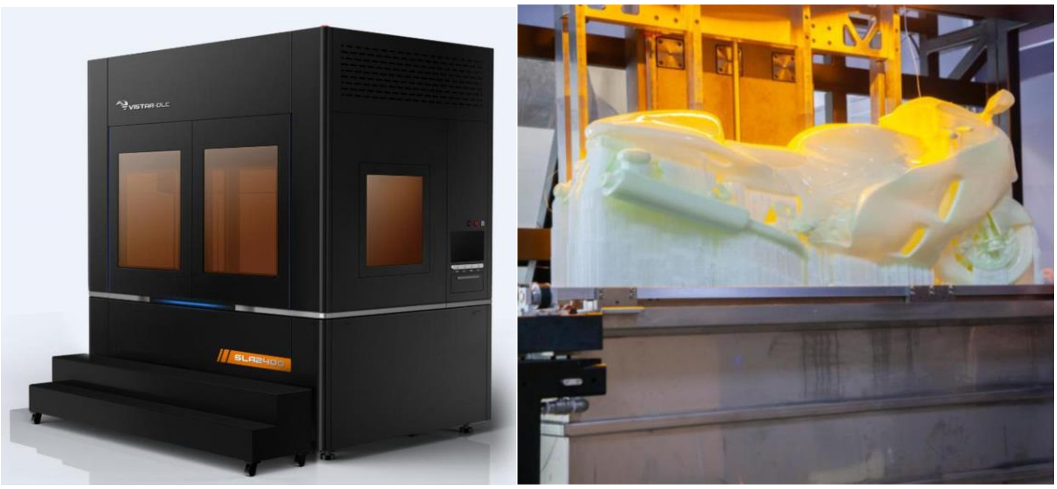


Fig. 14. ProtoFab SLA 240 and one-piece motorcycle printed with it [33]

The FDM printing method has been successfully used in creating furniture pieces. Furniture using this method was created with large format 3D printers, making the furniture in a single piece. It is enabled by the developments in FDM technology, already in use technologies in injection moulding and the general advanced industry. As injection moulding or plastic extrusion machines are the main methods to produce large amounts of parts for mass manufacturing, they use the extrusion technology to handle melted plastic, the technological knowledge is widely available in the industry. Also as the plastic pellets are an inexpensive and commonly available material due to their extended use in the wider industry. Thus making the FDM technology viable for furnishing item production. This is proven by companies such as “Model No” with the release of “Esker Chair” (Fig. 15) and other products.

Fig. 15. 3D printed „Esker“ chair by „Model No“ [34]

The company has reinvisioned the production of furniture by implementing 3D printing. As the additve manufacturing enables new design and production possibilities and developments reduces prices the more in demand these furniture pieces may become.

For the creation of single-piece furniture, large-format 3D printers are used. The companies that create products with large format 3D printers often construct these printers themselves from available industrial materials such as aluminium extrusions, linear motion systems and electronics. Often, these printers are similar to desktop 3D printers in their construction, some of them are based on CNC machines, as created by „Hyperion“ [35]. This company creates 3D printers based on CNC machines, as shown in Figure 16. This machine uses a welded steel frame with ball screws and linear rails for cartesian kinematics.

Fig. 16. Hyperion large format 3D printer [35]

As this is a commercial machine and the company is privately owned, the information regarding further motion elements and control software is not public. Another company that uses a large-format pellet 3D printer is „Braskem“, a European company that produces polyolefins. The company bought a 3D printer from „3D systems“, an additive manufacturing equipment manufacturer. The manufacturer also uses linear rails, stepper motors and ball screws for Cartesian motion, and as for control methods, the technology is not shared publicly.

From analysing other manufacturers that use or produce large format 3D printers, it is clear that the motion system should be robust Cartesian made from industrial materials such as linear rails and ball screws. For the extrusion system, it is understood that a single screw pellet extruder is used, due to its design and purpose to compress and melt plastic pellets and extrude them consistently [36]. Also, the benefit of using pellets as a primary material is reduced cost. The filament used in desktop 3D printers is made from pellets and costs roughly 10 times more than raw pellets due to the need to process it into filament. The reduced cost of printing from pellets makes it more economically advantageous. As for the size of the printer, it is wise to make it slightly larger than intended to have some spare build volume. As it is planned to construct a large-scale 3D printer for making furniture, the maximum build dimensions should not be smaller than the furniture pieces intended to be printed. And the largest foreseen furniture piece that is planned to be built is a sunbed. A sunbed is approximately 600x1900x1000 mm in size [37], [38]. The planned printer build dimensions should be roughly 1500x1500x2000 mm to print two sunbeds at the same time and have spare space. This space should be enough to print two sunbeds, four chairs, one table or other furnishing items at the same time. The Klipper software for controlling the printer is selected because it is open source, can support a variety of heating elements, has a wireless connection, and can be compiled for a Cartesian kinematic system [39].

1.4. Chapter Summary

Three additive manufacturing methods were analysed, and a brief history of 3D printing was presented. The most common and widespread additive manufacturing method is fused deposition modelling due to being open-source and commonly available. Resin and powder printing are more complicated and costly, for these reasons, they are not as popular as FDM, but can produce higher detailed and complicated parts. For the large format 3D printing and furniture manufacturing, a few companies were investigated. It was found that a robust Cartesian FDM pellet printing system is already proven and works. This system is planned to be built for the production of furnishing items. A single screw extruder will be used and Klipper firmware to control the printer. It has been decided that the printing dimensions should be roughly 1500x1500x2000 mm for larger single-piece furniture objects.

2. Designing a Large Format 3D Printer With Extrusion Technology

The making of a large-format 3D printer based on extrusion technology requires a technical understanding of kinematic systems and a general understanding of mechanical motion systems. The designing phase is comprised of 3D modelling in SolidWorks CAD software based on decision-making for the selected purpose of the component or subsystem. The whole design is focused on functionality and cost-effectiveness. Aiming to create a 3D printer that is available at a relatively low cost, that can perform furniture printing. The main requirements for a large-format 3D printer are:

- Build volume of around 1500x1500x2000 mm;
- Ability to use pellets as a main material
- Possibility to be operated remotely;
- Smooth movement of all axes;
- Automatic bed level and Z-axis calibration;
- Comparatively low production cost;
- Use of commonly available components.

2.1. General Requirements, Design and Decisions for the 3D Printer

The large-format 3D printer is being designed to produce single-piece furniture or large décor items. The printer needs to be able to print a single-piece sunbed and needs to have some print volume left for extra items or emergency manoeuvres. This makes the required printing area to be of around two meters by two meters and the height no less than one and a half meters. The extrusion system should be a single screw pellet extruder, this offers the ability to use pellets as a primary source material, reducing production costs and allowing wider material choice. The kinematic system should be cost-effective and simple. The main frame of the printer should be sturdy enough to support all the kinematic components and allow smooth operation. The main frame is also to be cost-effective and simple. For these requirements, a Cartesian kinematic system is chosen, previously described in the first chapter. The single screw extruder is chosen based on its cost, availability and flow. Flow in the extruder parameters describes how much material it can melt and extrude. The chosen extruder can flow 5 kilograms of plastic per hour and can be a ten-millimetre nozzle diameter, the nozzles are interchangeable, it is 70 centimetres in length and 45 millimetres in diameter. This offers more flow than is generally needed, giving the ability to produce parts faster. The chosen extruder is shown in Figure 17.

Fig. 17. Extruder

This extruder was purchased from an overseas supplier at a cost of 600 euros. It is equipped with three-zone heating, including pre-heating and melting zones with included thermocouples and heating elements. The heating elements are powered by 220V alternating current and controlled with bang-bang power modulation. This power modulation works by switching power on and off in quick succession, keeping the temperature at a selected range. The extruder will be mounted to the X-axis carrier plate and threaded to the adapting block. The extruder at the mounting end has an M45x2 left-hand thread that is used in extruder mounting. The adapting block is machined from an aluminium billet block using a CNC milling machine by a hired company. The control is being done by the main board. The main board will have several thermocouple connection ports that can monitor each zone and adjust the temperature as required. The extruder is mounted to the X-axis carriage plate, which is placed on four linear rail blocks that ride on two linear rails, this is done to acquire smooth and stable movement.

The linear movement components that are used in this project are only be two types of linear rails, aluminium extrusions and ball screws (Fig 18). The linear rails differ only by their size, one of them is HGR20 and the other is HGR25. The HGR means the product line of the component, and the number following it means the width of the linear rail. The two different size linear rails were chosen due to general weight and availability. The smaller HGR20 linear rail was used for the X-axis, and all other heavier HGR25 rails were used for all other axes (Fig. 18). As weight is not the primary concern for the Z-axis, the heavier rails offer better stability and modularity and interchangeability between the Z-axis and Y-axis. This allowed the purchase of materials in bulk and reduced overall expenses for the components of the kinematic system.

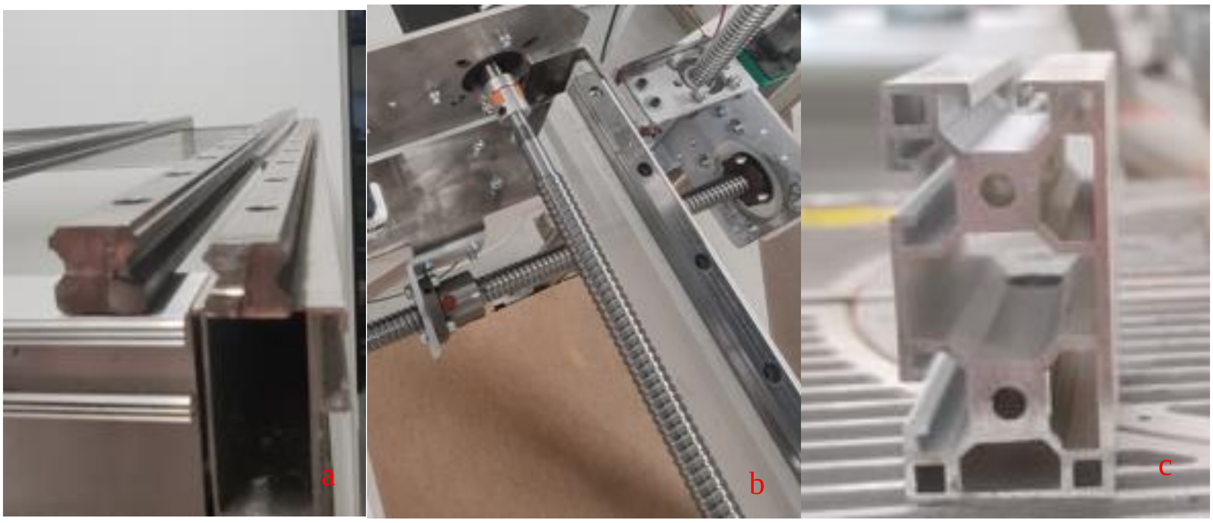


Fig. 18. A- HGR25 and HGR22 linear rails, B- Ball screw, C- Aluminium extrusion

The frame of the printer is to be constructed from aluminium extrusions. The aluminium extrusions are chosen to be 40x65 millimetres structural profiles commonly used in garage, greenhouse and shed construction. This profile is more cost-effective and more available than other types of aluminium profiles (Fig. 19). This aluminium profile is only used in frame construction, it is due to the fact that these profiles are second-hand and are in some places damaged. As for the motion system, damaged or bent profiles are unacceptable different profiles are desired to be used that are much stiffer and with no compromises in quality or price.

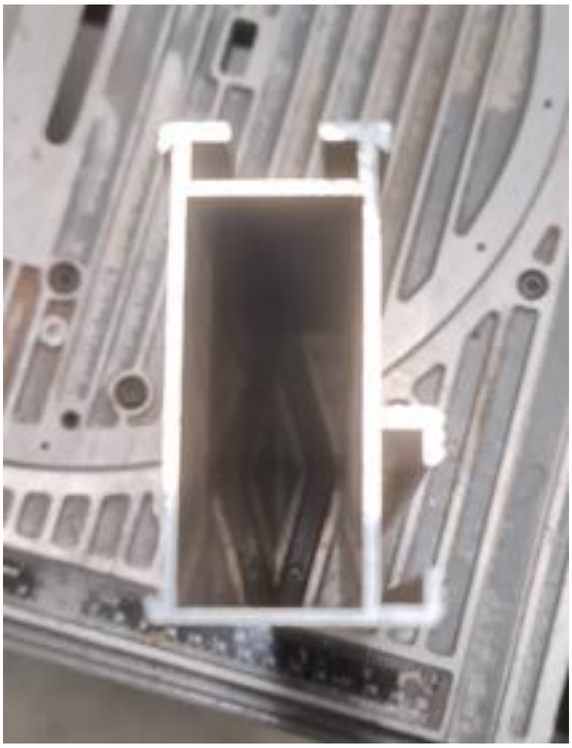


Fig. 19. Structural aluminium profile

The frame is planned to be assembled in a cuboid formation, creating a rigid frame on which every other component will be mounted. This formation is modelled and assembled in SolidWorks CAD software to create a 3D model (Fig. 20) on which further design will be done. The frame is braced with 45-degree aluminium extrusions to increase rigidity and limit flexing. The frame is fastened with 90-degree and 135-degree angle brackets. The bracing is necessary because of the profile type and its general use in different fields. As it was designed to be used in the greenhouse or garage construction, the wall panels or glass panels provided much-needed rigidity, which in this case is not possible. These profiles are not made to withstand heavy loads or dynamic loads, they were primarily used to fasten the wall panes together and provide mounting points for them, thus making frame bracing inevitable. The overall dimensions of this frame are modelled to be 1925x2175x3130 mm. These dimensions are chosen for extra spare volume, the Z-axis height is much higher due to the fact that the extruder is long and some more space is required to fully utilise ball screws and projected build volume. The 1925 mm width is constrained because the aluminium profiles that are used for the kinematics are this length, and since this length exceeds the projected build width, it poses no concerns and is beneficial for spare width. The extra length for the Y-axis is created because the Z-axis lifting mechanism requires extra length. The X and Y axis construction will be discussed more thoroughly further in this chapter.

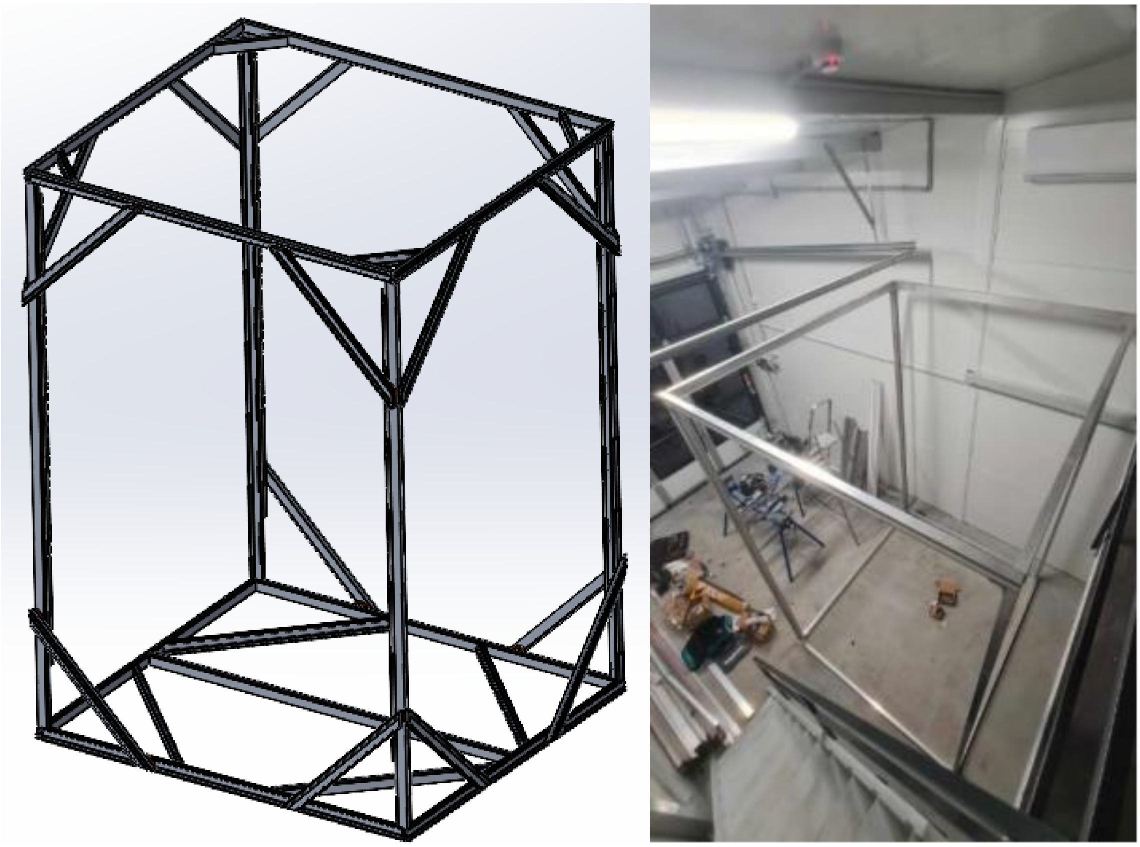


Fig. 20. Modelled printer frame and assembled one

This is the basis of any other adaptations and add-ons, including the kinematic system, extrusion system and build plate. The kinematic system begins with the Z-axis, this axis is designed to have four independent lifting motors at every corner of the machine. This is due to the ability to level each corner of the printer in relation to the build surface. The Z-axis motors will be placed at the top of the axis directly connected to the ball screw via coupling. The coupling is used to transmit rotation from the stepper motor to the ball screw and provide some misalignment compensation and dampen impacts created by quick changes in the rotation direction. The linear motion of this axis will be restrained by using linear rails and linear rail carriages. All components of the single Z-axis corner will be connected and assembled to the custom-made steel bracket (Fig. 21) that is designed to be laser-cut and bent. The material from which the plate is made of 5 millimetre stainless steel. This decision is made to reduce manufacturing costs and time. Also, the axis ball screw, which is the axis length limit, has to be lifted by 47 centimetres from the build plate (Fig. 21), because of the extruder length. The end of a ball screw is the end of an axis and in maximising the printing volume all of the screw must be utilised and it is done by lifting it. At the bottom end of a Z-axis, 3D-printed soft stops are installed to reduce the impact in case of a power outage or unforeseen emergencies. For the smooth rotation and resting of a ball screw thrust bearing is used and installed in 3D-printed housing. The printed housing is placed on top of the lifting profile and inside that 51101 thrust bearing is placed and inside that bearing ball screw end is placed.

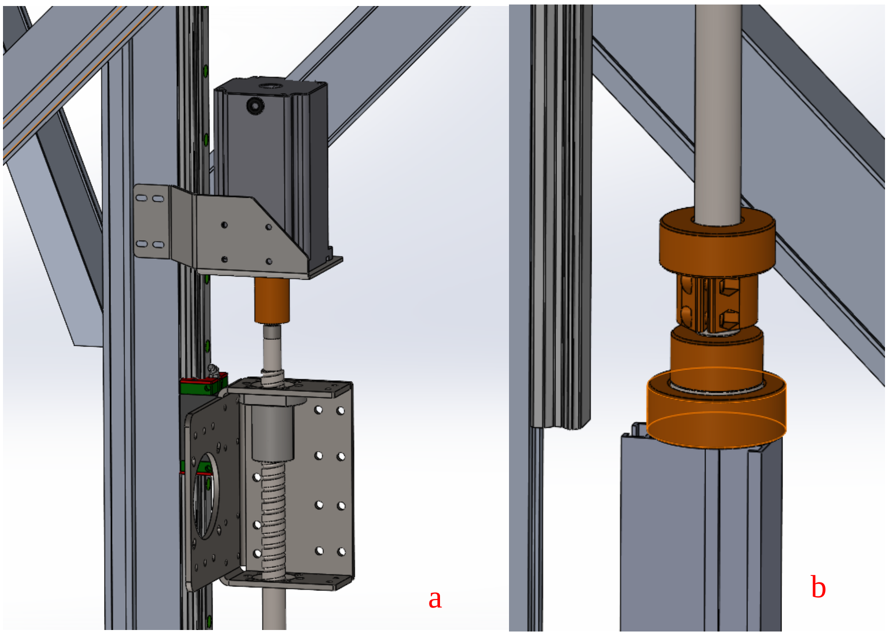


Fig. 21. A- Single Z-axis top motor corner and B- lifted ball screw end

The ball screw shaft used in this and all other axis is 2010, which means it is 20 millimetres in diameter and has a thread pitch of 10 millimetres. This ball screw was chosen due to availability. As these ball screws are available locally for a competitive price they were the best option to purchase and they were up to specification in desired length. The ball screw shaft is paired with the ball bearing screw and secured to the sheet metal bracket with nuts and bolts. The bracket is made from 5mm thickness stainless steel sheet metal and serves multiple purposes. The bracket is used to attack ball bearing screw, Y-axis aluminium profiles (Fig. 22), Y-axis stepper motor and Z-axis linear rail carriage block. The motors for all of the axes are chosen to be Nema 34 stepper motors, these motors are considered high torque and can produce up to 12Nm of torque and are operated at a maximum of 6 amperes of current and the operating voltage ranges from 18 to 110 volts. Overall, the printer will use eight stepper motors, four for the Z-axis, two for the Y-axis, one for the X-axis and one for the extruder. These motors produce a high amount of torque required to move all axes in their assigned directions. The motors were selected due to their cost effectiveness, in comparison to the Nema 23 stepper motor that produces only 3 Nm, the cost difference was less than 20 percent and the extra cost was deemed to be worth paying in regards to receiving four times higher torque. Also, these motors are compatible with TMC5160T Plus stepper drivers that are foreseen to control these stepper motors.

The X and Y axes will be constructed out of regular industrial aluminium profiles portrayed in Figure 22. These aluminium profiles are 40x80 millimetres and are commonly used in various industrial machinery or production lines. These profiles are also chosen due to their availability and cost. While conducting a search for components of the axis, it was discovered that these profiles were taken off from a scrapped industrial conveyor and sold at a minimal cost and are in near-perfect condition, the only damage that was discovered was cosmetic. These profiles are more than enough for a project like this, they were also chosen due to the ability to easily mount linear rails onto them using tee nuts (Fig. 22) that are designed to be used in aluminium profile slots, providing easy assembly and maintenance. These tee nuts can be added and removed from the profile without the need to remove the aluminium profile from the printer.

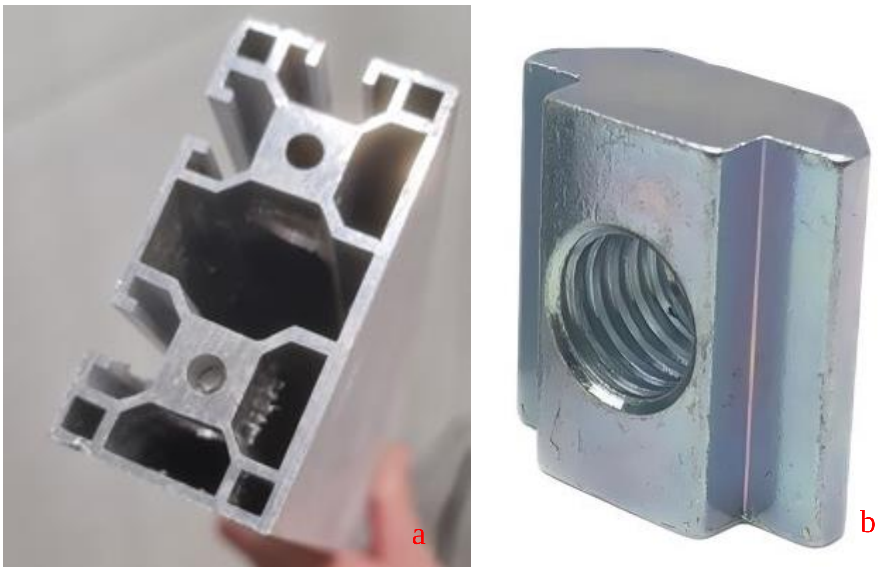


Fig. 22. A-Aluminium profile, B-Tee nut [40]

The Y-axis is from both sides of the printer left and right, provides movement back and forth and is powered by two Nema 34 stepper motors spinning two ball screws from each side. It is needed to have two stepper motors working in parallel due to the length of the X-axis, which sits on the Y-axis. The distance is too great to provide parallel movement between two sides, thus one side lags behind or in worse cases, does not move at all and could damage the components. Linear rails are mounted on top of aluminium extrusions. The X-axis provides movement from left to right and is also mounted on two aluminium extrusion and linear rails but is powered by one stepper motor spinning one ball screw. The X-axis motor is mounted on a single piece of sheet metal plate, the ball screw is fixed from both ends, from one end by a stepper motor and a coupling and from the other by a ball bearing and an end cap. The whole modelled 3D printer is displayed in Figure 23. For a full CAD drawing, view Appendix 1.

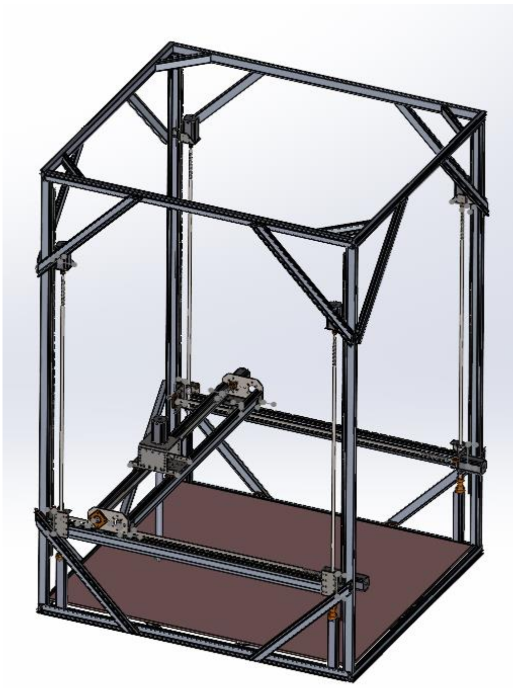


Fig. 23. Large format modelled 3D printer

This 3D printer model, with all the decisions made, is a basis for the construction of a full-scale large-format 3D printer made to produce decor items and furniture. This model does not include an electrical box or any other electronic components such as end buttons, stepper drivers and main board. The stepper drivers and the main board selected for this project are TMC5160T Plus stepper drivers and the Manta M8P V2 main board (Fig. 24). Selected stepper drivers offer a wide range of operating voltage from 8 to 60 that are in stepper motor operating voltage range and can operate at a stable 10.6 amperes of current with a peak current of 15 amperes. The Manta M8P V2 mainboard is selected due to the possibility of connecting eight stepper motor drivers at once and controlling them simultaneously. The printer will use eight stepper motors. The board offers wide compatibility for sensors, can monitor five thermistors and has a wireless connection, which improves and simplifies the user experience. Also, as this board is designed to be used for high-end desktop printers, it has many features and has a built-in Z-probe connection pin. The Z-probe offers automatic bed levelling that produces a topographic map of the build surface to which the extruder adapts and produces a perfect first layer.

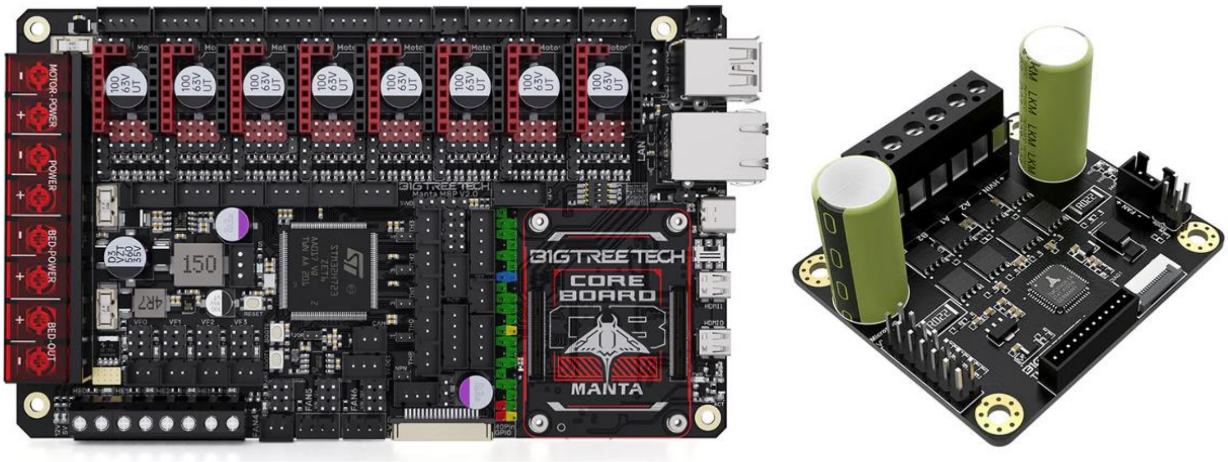


Fig. 24. Mnta M8P V2 And TMC5160T Plus [41]

The software that runs this machine is deemed to be Klipper. This software is open-source and has many needed features to make this printer operate [39]. It also has community-created features that can simplify programming, many of the code can be sourced from the forums and Klipper documentation. This control software has the benefit of being easily modifiable and can be adjusted via a wireless connection. The already-built community infrastructure around this firmware allows for easy modification and adaptation to the used equipment. It already has pre-built stepper driver profiles and options that are available freely in its documentation and community hubs. As the firmware is commonly used the information in regard to compiling it is common, and the software is updated regularly, introducing new optimisations and features.

The whole printer is foreseen to be created from commonly available and cost-effective materials. The frame is to be made from construction aluminium extrusion profiles and will be assembled in a cuboid shape. The Y-axis will have two motors from each side of the printer with ball screws to transfer motion. The Z-axis will be placed at each corner with an independent motor and ball screw. The X-axis will ride perpendicularly to the Y-axis on two linear rails and will be moved by a single stepper motor. Stepper motors will be Nema 34 with 12 Nm of torque and will be controlled by Manta M8P V2 mainboard and TMC5160T Plus stepper motor drivers.

2.2. The Construction Process of Large Format 3D Printer

After designing the virtual 3D printer, the construction process follows. The construction takes place in a rented working space, rent costs will later be calculated and added to the economic part of this paper. The printer is made as designed in SolidWorks. The creation of this machine consists of several distinct stages and steps. The individual steps will not be mentioned or discussed in this part due to the irrelevancy of commonly done tasks such as bolt tightening or wire hauling.

The build begins with the construction of the main frame. The main frame is constructed out of structural aluminium profiles and is first assembled in a cuboidal shape. After assembling the primary shape, the reinforcement crossbars are added for extra rigidity. The reinforcement consists of bracing every corner of the printer with the same aluminium profiles in a 45-degree angled crossbar. After the main frame is complete, the Z-axis motion system is installed (Fig. 25). The motion system is the same in every corner of the printer and is made in the same way. The lifting of the ball screw is done by cutting the construction profile into 35 centimetre segments and loosely tightening them perpendicular to the bottom beam of the main frame in every corner. The extra height to lift the Z-axis is further added by installing the bearing housing and the bearing itself. Then adding 3D printed parts that are designed to secure the end of a ball screw. The ball screw nut and stepper motor are installed onto the Z-axis mounting bracket and then to the ball screw. The mounting plate is attached to the Z-axis linear rail block and fixed, then the ball screw is aligned to the linear rail by adjusting and tightening the lifting segment and the stepper motor bracket. This is done to all four corners, as all the Z-axis subassemblies are the same.

Fig. 25. Assembled Z-axis one corner

The following axis to be assembled is the Y. This axis primarily uses 40x80 mm aluminium profiles and is constructed from both sides of the printer, but mirrored in orientation, on the Y-axis, the X-axis is to be mounted. The Y-axis aluminium extrusions are mounted to the Z-axis mounting brackets, to which stepper motors are also attached. On the extrusions, linear rails with carriages are installed, and Y-axis mounting plates are bolted to the carriages. The ball screw with the nut is installed and connected to the X-axis mounting plate. When both sides of the Y-axis are assembled (Fig. 26) the X-axis follows. The X-axis aluminium extrusions are placed on the Y-axis mounting brackets and bolted to them. Then linear rails with carriages are installed and similarly to the Y-axis, the ball screw with the nut is installed. The extruder mounting bracket is fastened to the X-axis linear rail carriages, and the stepper motor for the axis is added (Fig. 26). The extruder mounting plate is a plate on which the extruder is mounted, including the stepper motor and pellet supplying system. The mechanical and kinematics part of the printer is installed.

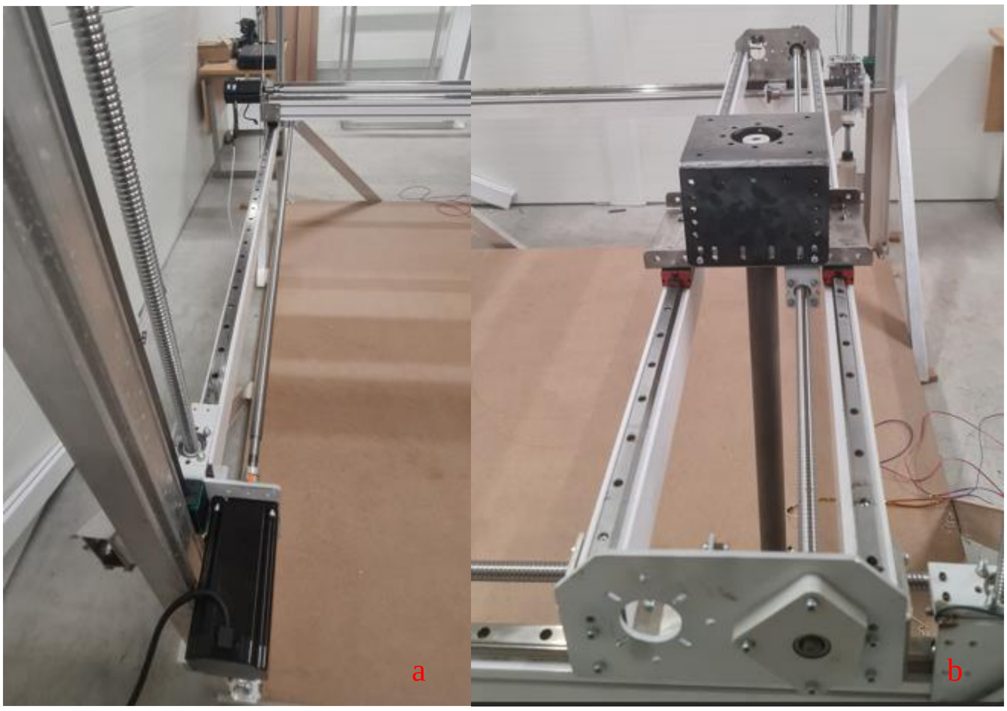


Fig. 26. A- Y-axis one side, B- X-axis with mounted extruder

The other part of the printer that needs installation is the electrical part. The electric part consists of stepper motor wiring, end-stop button wiring, and heating and monitoring wiring. All of this is controlled by the main board that is placed in the electrical box with the stepper motor drivers. The electrical box is decided to be placed at the top of the printer and fastened there permanently (Fig. 27). The electrical box does not house power supply units (PSU) for the stepper motors. The PSU are housed near the main electrical box, and each PSU provides power to only one axis.

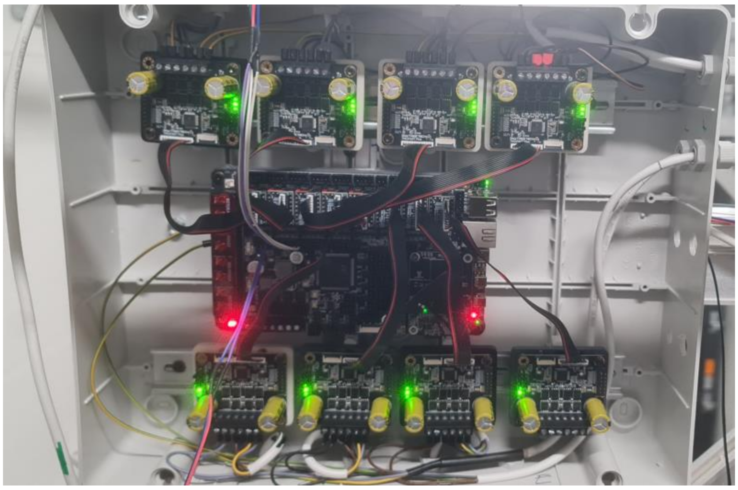


Fig. 27. Electrical box

With the assembly and complete wiring of an electrical box and all stepper motor drives the wiring for the endstop switches and stepper motors follows. The stepper motors are wired to each corresponding stepper motor driver and the cable is routed from the electrical box to the stepper motor with some cable to spare. The wires are routed alongside the main frame and secured by cable ties. After completing all the routing and establishing the power delivery to the stepper motors, the software adjustments follow. With the easy Klipper firmware adjustment, the printer is set to the homing positions and is ready to move. The printer kinematic system is fully assembled and displayed in Figure 28 with its corresponding axes. The printer is ready to move, the missing part are the extruder heating and the hopper that feeds it.

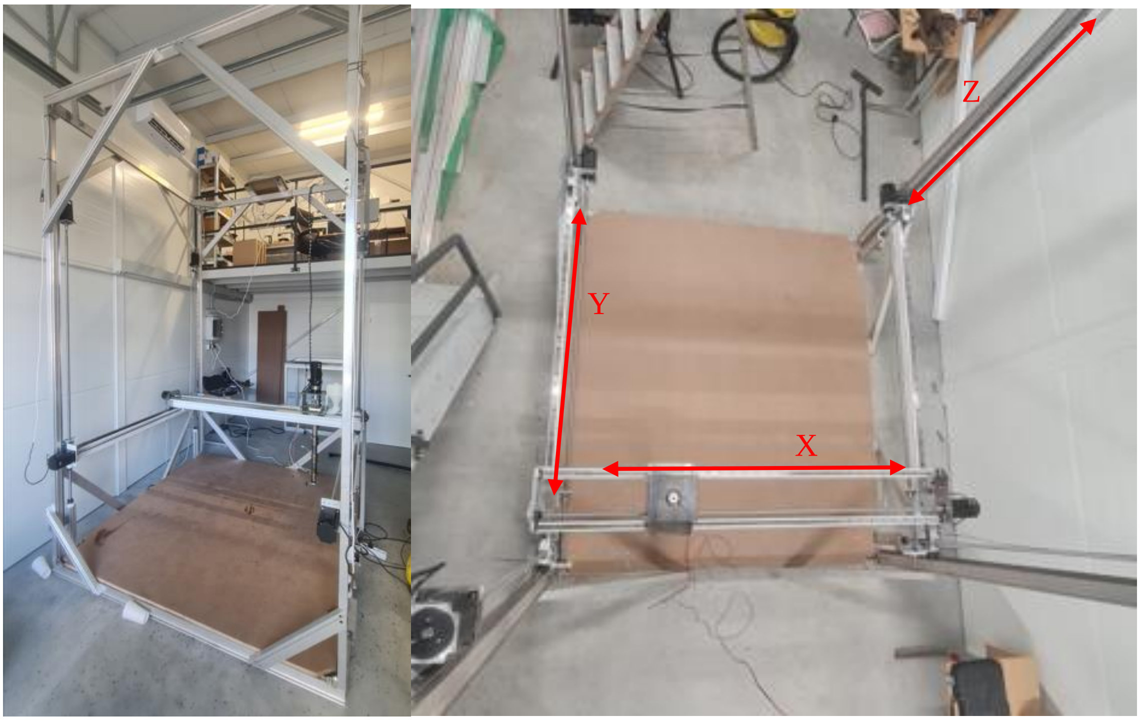


Fig. 28. Assembled printer and shown axes

With the assembly of the printer and the Klipper implementation, the printer moves successfully. Several commands were performed, homing, quad gantry levelling, rotational distance calibration and full movement execution. The printer was assembled in four months from the beginning, without counting the preparation and modelling time. The final print volume was set to be 1440x1600x2000 mm, this was set by limiting the volume in the software, which was implemented to leave some unused space for safety reasons. This was decided due to the concerns of inertial movement or in case of skipped steps by the stepper motor. The electronics were placed in an electrical box at the top of the printer, where access was easy. Some of the assembly mistakes were noticed during the first movements and calibrations. The nuts used were regular ones with no nylon, due to the vibrations produced by the movement of the printer. This was fixed by changing the regular nuts with the more vibration-resistant nuts with nylon inserts. The finalised and calibrated machine moved and behaved as expected. Movement commands were executed successfully and all axes can safely home. Maximum movement speed was discovered by increasing the movement speed until stepper motors started to skip steps, and the value was found to be 40 mm/s. The performed gantry levelling ensured the safe and aligned X and Y axis movement relative to the build plate. The gantry levelling is performed automatically, the Z-axis endstop is attached to the end of an extruder nozzle and moved to every corner of the build plate. When Z height is measured at every corner the gantry levels itself automatically. After that printer bed level is performed, which produces a bed mesh that resembles the printer bed and allows a uniform and stable first layer.

The following phases of this machine build are the extruder assembly and calibration. For the extruder assembly, three 230 V alternating current heaters are used, the heaters are placed on the extruder, and the thermocouples are attached to the extruder right above the heater. This is done because the thermocouples can not be placed between the extruder case and the heating element. If placed like this, this would result in false measurements and could interfere with the control unit. The extruder heating elements are assembled and later wrapped in heat-resistant material such as Rockwool and glass fibre. This is done to reduce heat loss, protect other elements from the extreme heat and make it safer. The hopper is also attached to the extruder, which will provide plastic pellets and surplus pellet feeding to ensure consistent extrusion. The final printer assembly parameters are shown in Table 1.

Table 1. Printer parameters

Parameter	**Value**
Printing dimensions	1440x1600x2000 mm
Printing material	Pellets
Heating zones	3
Wireless control	Yes
Automatic bed calibration	Yes
Automatic Quad Gantry Level	Yes
Max movement speed	40 mm/s
Enclosure	No
Heated bed	No

After this installation, the extruder motor with the reducer gearbox is mounted and wired to the main board. The gearbox used is 1:10 to increase the torque for the srew. The extruder assembly is complete (Fig. 29) and is ready to begin calibration and testing.

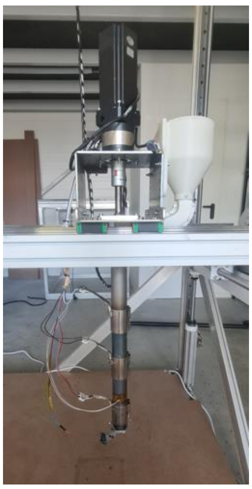


Fig. 29. Completed extruder assembly

The large-scale 3D printer is assembled. The following calibrations will be done to the extruder, rotational distance needs to be calibrated and optimal temperatures need to be configured and tested.

Also, custom slicer profiles have to be created. The custom slicer is chosen to be an „Orca slicer“ open-source 3D printer slicer that allows wide customisation and supports wireless file transfer. This slicer was chosen due to its built-in features, customisability and open-source design.

2.3. Chapter Summary

In this chapter, the general CAD model of the large-format 3D printer was presented. Decisions that led to this design were also explained and presented. Mechanical components and structural elements were chosen and described. Electrical components and a control board were shown and were chosen due to their features and design to support up to eight stepper drivers. All the control components were assembled in an electrical box and custom Klipper firmware was flashed. The assembly process was documented. The desired goal of 1440x1600x2000 build volume was reached and the quad gantry level was also performed. The used Klipper firmware allows wireless file uploads and control, the automatic bed level is functional and produces a bed mesh. All three axes move smoothly and behave as expected. The printer is functional and operational.

3. Investigating Z-axis Corner Deformation Under Load Using Finite Element Analysis

As the large-format 3D printer was designed, concerns were raised due to the strength of the corner parts created from the available 5 mm thick bent stainless steel. The concern was that when the printer is assembled and all the extruder parts and axes are in place, the corner bracket will bend from all the weight. The weight would consist of all the moving parts except the Z-axis and the pellets that would be fed to the extruder. This chapter analyses the stresses and deformations associated with the corner brackets.

3.1. Preparation For The Finite Element Analysis

The finite element analysis (FEA) is a virtual simulation of a given part or assembly that is designed in CAD software that is directly equivalent to the desired physical part. This testing method relies on predicting the simulated object behaviour based on mathematical calculations. It works by dividing the given object into elements, for example, generating a topology mesh that is later subjected to the virtual stresses. This allows engineers to design better parts by revealing optimisations, material savings and design flaws without expending many resources [42]. This precaution is to simulate and find weak points in the design and correct them before the final parts are manufactured.

The analysed part is the corner bracket of the Z-axis, this bracket serves several functions, it is used to mount the motor for the Y-axis, it supports the Y-axis aluminium extrusion and linear rail, it connects the Z-axis lead screw bolt that lifts or lowers the whole gantry corner. This plate is used in all four gantry corners and is designed in such a way that it is symmetrical (Fig. 30). The plate is made out of an AISI 304 (AISI meaning the American Iron and Steel Institute) stainless steel sheet that is 5 mm thick. It is manufactured by cutting out the flat pattern (Fig. 30) of this bracket from the steel sheet and bending it into the needed shape with the bending press. Thus, the bracket is made with precision and does not require any further form of processing.

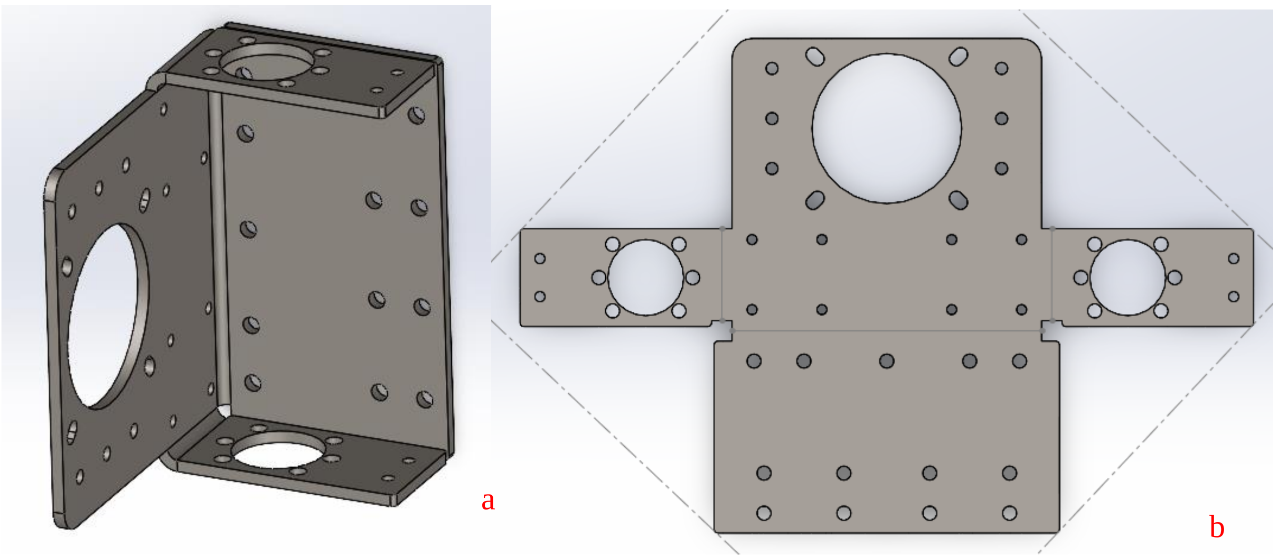


Fig. 30. A- Z-corner bracket, B- flat pattern

The main concern for the bracket's structural integrity is the lower flap, on which the Y-axis aluminium profile mounts. This part may experience severe bending in an emergency situation, and bending under load, when all the axes are fully loaded. This part is crucial for the smooth printer operation, with weak and easily deforming part, inaccuracies, and unwanted axial forces may occur.

The simulation is being conducted in the SolidWorks virtual environment it is done so, because all the parts were 3D modelled in this software, and it has built-in simulation tools. The load on which the simulation will be made is 60 kg, this weight is selected because the whole gantry weighs roughly 60 kg. This is done because in the case of an emergency, the whole weight could be placed on one axis. Also, in case of improper homing or bed mesh calibration, the motors could push the hotend into the build plate and create significant stresses and deformations. As this part has high significance, and in case it becomes unusable, the whole printer becomes inoperable and replacing this part could take up to a few weeks. Thus, this corner bracket needs to be able to withstand, in this case, extreme forces and not deform or break. As the whole gantry weighs roughly 60 kg, this translates into 588 N by multiplying the kilograms by the gravitational acceleration of 9.8 m/s^2. This value will be used for conducting a simulation.

3.2. Running the Simulation

For a proper simulation, several key elements should be defined: external loads, fixture points, mesh resolution and material used. Every element is necessary for the simulation without them, the software could not create any outcome. As the part is made from AISI 304 stainless steel, the material should be selected the same in the simulation, because it has a defined elastic modulus, tensile strength, yield strength and other necessary properties for the simulation. The fixture points are selected in the holes where the bracket is tightened to the linear rail carriage. External loads are placed on the face on which the Y-axis aluminium profile is placed and are equal to 588 N of force. The model mesh is selected to nearly as fine as possible (Fig. 31) for the fastest results and detailed deformation results. All of the settings are shown in Figure 31.

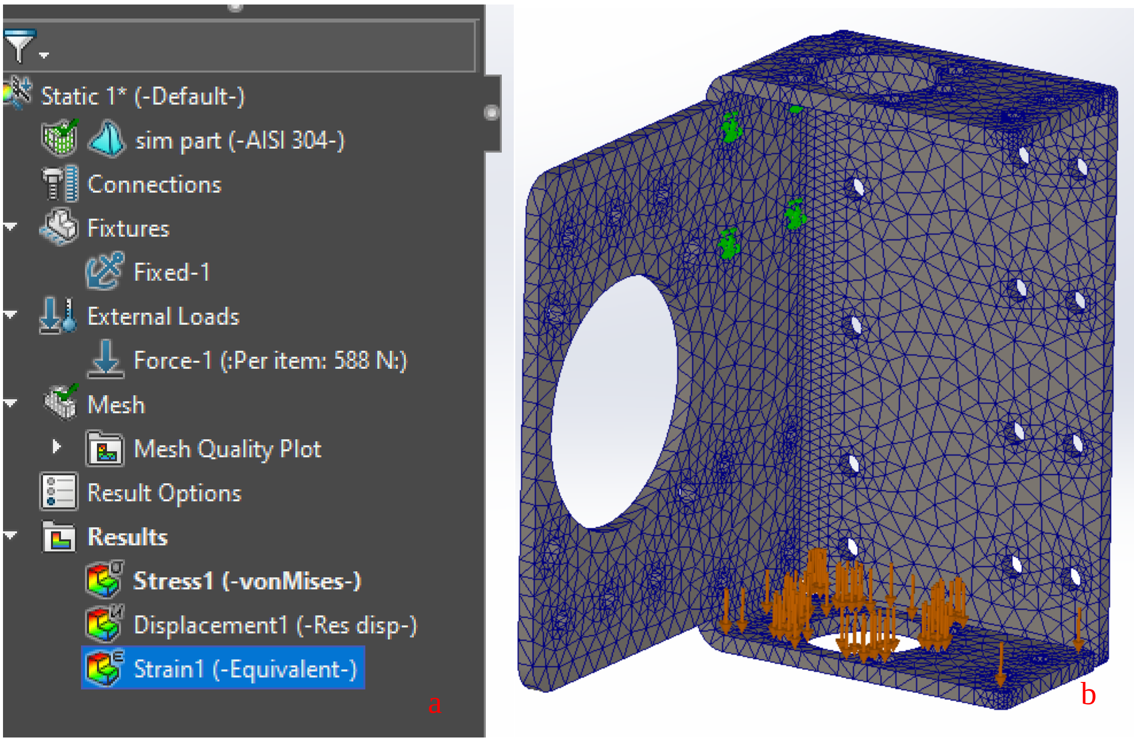


Fig. 31. A- settings for the simulation, B- generated mesh

The green arrows indicate the fixture points for the part. The orange arrows represent the load that will be placed on the lower flap of the bracket. The blue triangles represent the created mesh, it is shown that there is a higher mesh resolution around the features than on flat faces. This is done automatically to increase the resolution where it is needed more. On the flat faces, the forces would be distributed more evenly, which would be easier to calculate, this is done to optimise the computing and reduce load on the processor of the computer.

After running the simulation, it was discovered that the forces would bend the flap down about 5.5 millimetres, which is deemed too much. Also, the part would experience plastic deformation, which means the bending would be irreversible and would damage the part. The simulation results are shown in Figure 32. The results are chosen to represent the true scale of the deformations.

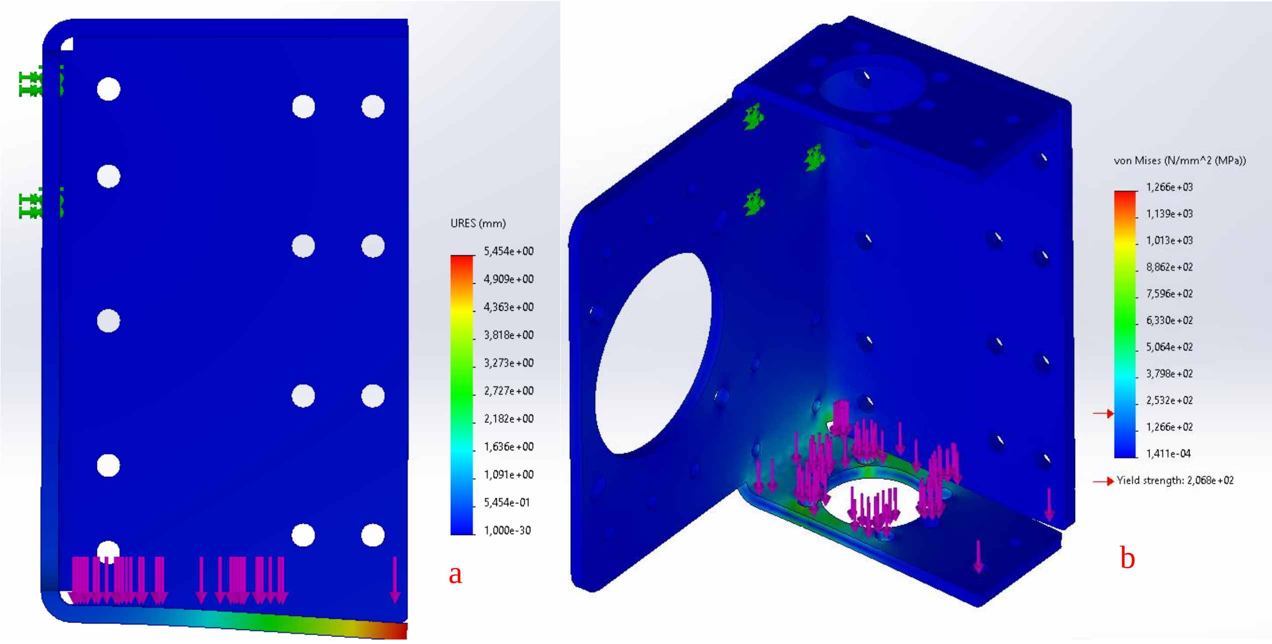


Fig. 32. Simulation results, A- deformation analysis, B- stress analysis

The simulation depicts deformation in Figure 32-A the deformation units are in millimetres, and the red zones are places where the highest deformation occurs. This deformation is deemed to be too much, it would result in making the printer inoperable. Figure 32-B shows the yield stresses and strength of the part. The yield strength of the material is 206.8 MPa, and if this value is exceeded, the plastic deformation occurs. The simulation predicts that some of the areas exceed stresses of more than 886,2 MPa, which is more than four times. This means that the maximum allowed stresses are exceeded, and the part deforms permanently. These stresses should not be exceeded.

After evaluation of the simulation results, the decision to introduce welding as a post-processing is made. This step is made because the already modelled parts fit together and are inexpensive, making a redesign would consume too many labour hours and would increase the cost of the part. The consideration to use another material or to make the part from billet aluminium was also made, but was deemed to be too costly. The welding would be done at the meeting points of the flaps and side reinforcements at a 90-degree angle. This should increase the resistance to bending and solve the deformation problem. Also, this would be cost-efficient and would not require the redesign of the part and the whole assembly. The changes made to the part are shown in Figure 33.

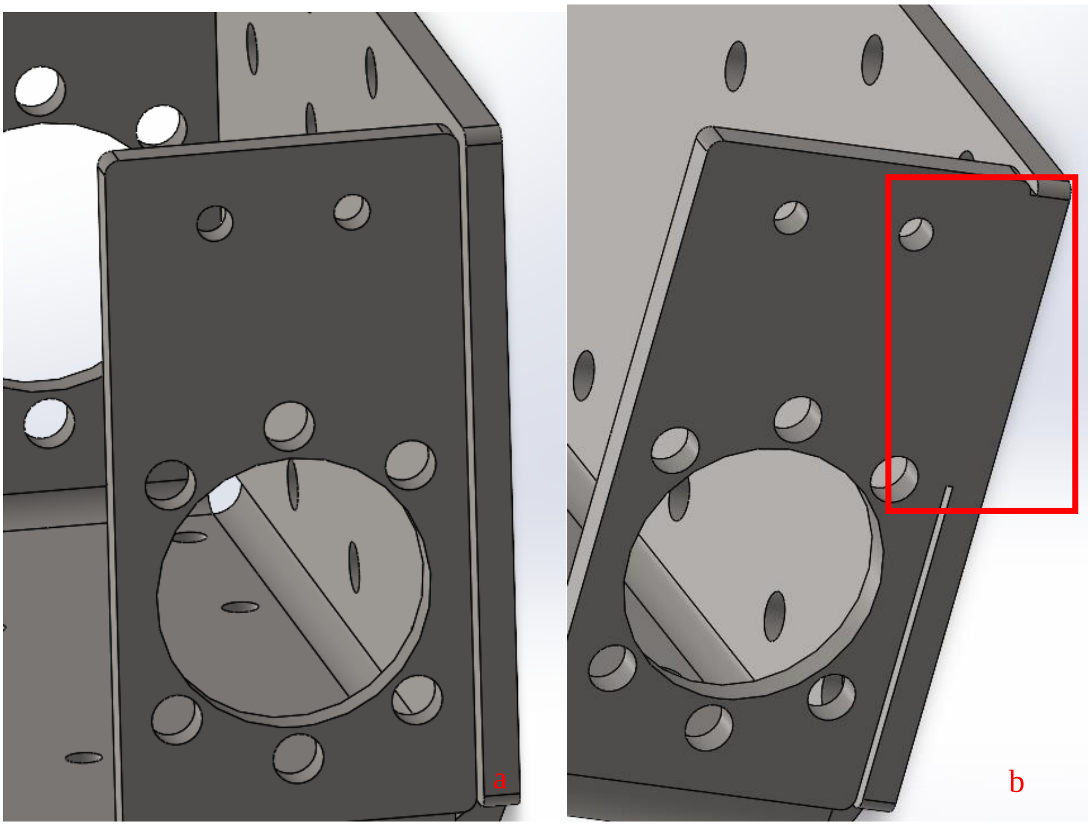


Fig. 33. Changes made to the part, A- before, B- after

The corner of the bracket is modelled so that it would represent the welded corner. The weld is created from the beginning of the flap and is 45 millimetres long, squared in red in Figure 33-B. All of the forces and the fixture points are the same as previously. The new mesh is generated according to the changes, but in the same resolution. The simulation is run again, and the results are depicted in Figure 34.

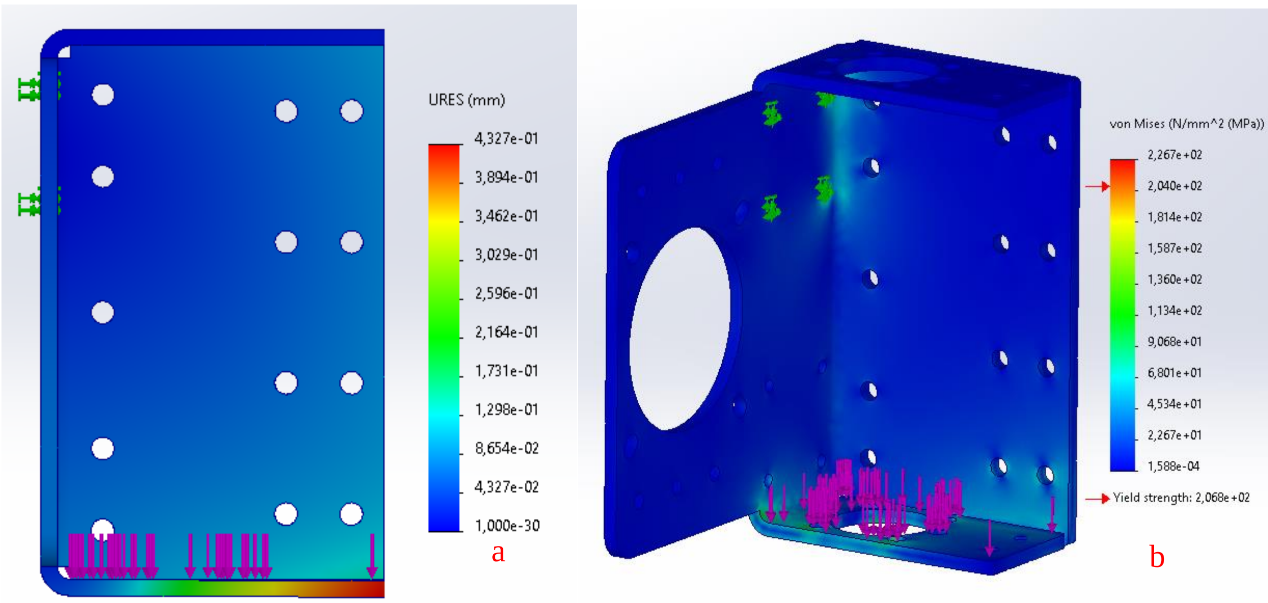


Fig. 34. Second simulation results, A- deformation analysis, B- stress analysis

From the repeated simulation, it is clear that the weld reinforced the part significantly. The maximum predicted deformation was 0,4 millimetres, which is deemed to be acceptable. The maximum predicted yield stresses have been reduced to a maximum of 226.7 MPa, which is slightly higher than the allowed yield strength. The plastic deformation in the emergency situation will occur near the holes for the ball screw nut mounting Figure 35.

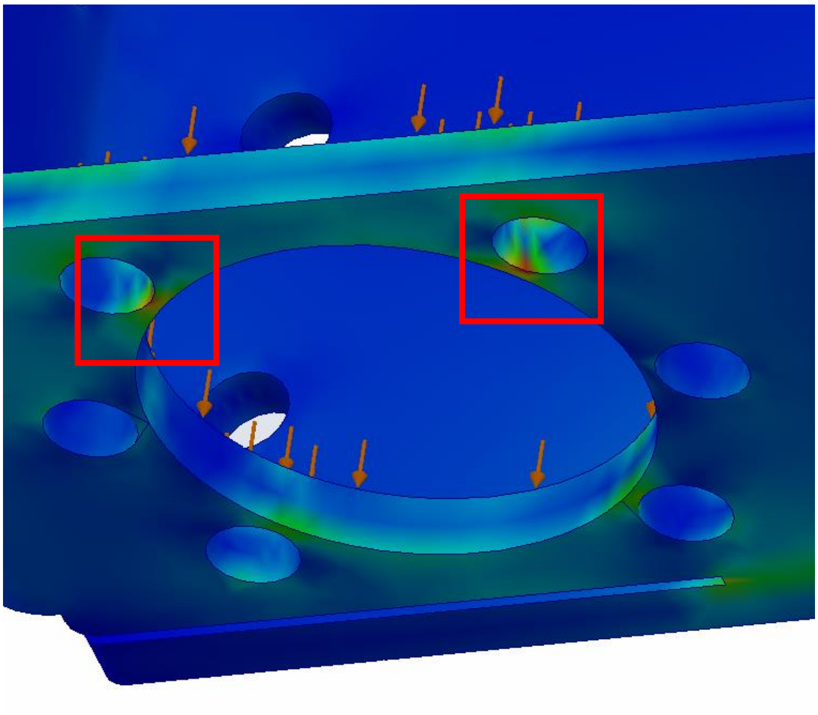


Fig. 35. Plastic deformation areas squared in red

As the nut will be mounted on the opposite side of the bracket, this poses no threat of severe structural impact to the part. As this simulation is done to ensure that the part withstands emergencies and severe malfunctions, it is deemed to be enough for this application. It is not expected for this part to operate in these conditions and experience forces of more than 588 N. In this application, changes were made to increase the yield strength of the part and to reduce its deformation under the extreme load by welding the flap to the reinforcement plate.

3.3. Chapter Summary

This simulation was made to determine if the Z-axis corner bracket will withstand the emergency situations in which the whole gantry load is placed on it, or it experiences a malfunction while homing or conducting a bed mesh. the simulation was executed with a load of 588 N of force acting on the lower flap of the bracket. The fixture points were selected to be holes on which the bracket is mounted to the linear rail carriage. After the primary simulation, the part was deemed to be insufficient for the emergencies it would bend more than 5 millimetres and undergo plastic deformation. To eliminate that, the decision to introduce the welding post-processing was made, and the corner of the flap would be welded to the side reinforcements. This eliminated the deformation problem, the yield strength was still exceeded, but was deemed to be acceptable as it occurs in irrelevant areas of the part.

4. Testing the Extrusion and Functionality of the Printer

The assembled printer must function as intended to be viable for furniture and décor production. The printer itself moves, homes and performs gantry-level, which is a mandatory procedure for successful printing. The extrusion process is more complicated and requires physical testing to calibrate and adjust the settings for the printer. The extrusion calibration process is done in two parts, Klipper calibration and slicer calibration. Klipper calibration ensures the input commands from the slicer are executed as intended, and the slicer calibration dictates how the extruder behaves in relation to the print moves.

4.1. Calibrating the Extruder

The Klipper, printer software, interpolates the slicer commands and acts as requested by the slicer. It is crucial to calibrate the printer software correctly for printing. The main parameters of the Klipper are rotation distance, nozzle diameter, filament diameter, sensor type and allowed temperatures. The rotation distance, in traditional printers, is calibrated by calculating the requested filament extrusion compared to the actual extruded filament. In this application, it is not possible due to the fact that the filament is not used. Printing is done by melting pellets, which do not have specific calculations to determine the rotation distance. The preliminary calculations were done by calculating the extruded volume. The extruded length was indirectly converted to the extrusion volume, and the theoretical volume was compared to the actual extruded volume and adjusted accordingly. After the rotation distance was figured out, other parameters were adjusted. The nozzle diameter was set to the actual 6 mm diameter, and the filament diameter was also set to 6 mm. This was implemented to have a one-to-one extrusion volume and for simpler calculations. As the nozzle diameter and filament diameter ratio dictate how much the extruder needs to turn to extrude the desired plastic volume, it is necessary to have a baseline parameters. The sensor type was set to be as used- NTC 100K, the same as used in household printers, then it was calibrated. The sensor is resistance-based. The resistance of the sensor element changes in correlation with the exposed temperature. And the allowed temperatures were set up to 300 degrees Celsius. This is the maximum required temperature to melt most of the plastics and is considered safe to not damage any extruder components and burn plastic. With the software set up, physical testing follows.

For testing, nylon pellets with 35% glass fibre were chosen. This decision was made because the material was available, and the nylon with glass fibre has desirable printing characteristics and is considered a primary printing material for future items. The extrusion temperature was set to 260 degrees Celsius, which is within the range of the recommended temperature. After 30 minutes, the extruder was fully heated, and the testing began. The extruder was commanded to extrude 300 mm of the filament at 10 mm/s several times to prime the extruder. After five attempts to extrude, nothing happened, and the extruder motor started to skip steps. The extrusion speed was lowered to allow better melting of the pellets. This technical adjustment did not work, and the motor kept on skipping steps. The extruder temperature was raised to 290 degrees, and the test was repeated at the same extrusion speed of 10 mm/s, the testing parameters are displayed in Table 2.

Table 2. Printing parameters

Parameter	Value
Extrusion speed	10 mm/s
Material	Nylon + 35GF
Temperature	260 C^{o}
Extrusion length	300 mm

While testing, the smoke started to come out of the nozzle, and the extruder skipped steps. It was clear that something was not working or there was a mistake in performing this extrusion testing. With this failed experiment, the extruder was turned off and allowed to cool down.

The possibilities for why it failed were:

- Faulty heat sensor
- Incompatible pellets
- Too low extruder torque
- Not working heaters

First, the extruder was disassembled and inspected, a discovery of melted heat sensor wires was made and the charred plastic acumilation in the nozzle and around the extruder screw (Fig. 36) was made.

Fig. 36. Charred plastic around extruder screw

To diagnose the problem, the extruder was heated to 250 degrees Celsius, and the temperature was checked with a laser thermometer. The registered temperature was slightly lower than intended. This is expected because the measurement was taken on the outside of the extruder barrel, and it is cooler due to the air cooling it. The faulty sensor and the heater cause were dismissed. The extruder torque could not be changed because the gearbox should be changed to a higher reducer ratio, which is not viable due to the waiting times and budget. The incompatible pellet possibility was thought to be the most likely. The nylon pellets absorb moisture and need to be dried before use, and the nylon, when melted, did not flow as needed. The high percentage of glass fibre made the material difficult to extrude. The previously observed smoke, coming out of the nozzle, was most likely steam from the moisture that was absorbed by the nylon. This preconditioning of the material is not available, the material itself was wrongfully chosen, and the decision to change materials was made.

The extruder and the nozzle were cleaned, and the sensor was swapped for a new one. The sensor was changed for future proofing, as it was disassembled, possible damage could be done to it, and it is better to change it. After cleaning the nozzle and the srew, the extruder was assembled back. The testing could continue, but for the second testing, different plastic pellets were decided to be used, the pellets are Polypropylene (PP). By performing the second physical extrusion testing, the Klipper software is adjusted. For the physical testing, PP pellets were chosen (Fig. 37), as this material has a low melting temperature range of 220 - 250 degrees Celsius and has a high melt flow ratio, which means this material flows well when melted. This material was also considered as a primary material for the item manufacturing, as it is commonly available and has desirable properties.

Fig. 37. PP pellets

The pellets were poured into the hopper, and the temperature of the extruder was set to 240 degrees Celsius. After 30 minutes, the extruder was fully heated and was ready to extrude. First, the extruder was primed, then the set value for the extrusion was set to be 300 mm of the filament at the 15 mm/s speed. The extruded length was compared to the requested length. As the filament and nozzle diameters are equal, the extruded length should be the same as theoretically requested. But after performing this test, it was found that the actual length was slightly longer than requested. Accordingly, the rotation distance was adjusted, and the test was repeated. After two attempts, the extruded length was the same as requested (Fig. 38).

Fig. 38. Successful extrusion

The extrusion calibration in Klipper software is complete. The extruder behaves as expected and operates normally. The mistakes were made in the testing, but they gave insight into the operation of the extruder and plastic behaviour. The appropriate measures were taken to figure out which fault was responsible for the extruder not working as intended. After solving the issue, the extruder worked without flaws.

4.2. Testing the Printer

The successful extrusion slicer profile creation is the following step. The chosen slicer is "Orca Slicer", this slicer is open source and has all the needed functionality built in. It is one of the most capable slicers with a wide customisability and features. The slicer is set to mimic the Klipper settings in nozzle and filament diameter. The printing speed is reduced significantly, because printing limits are still unknown, the speed for every printing move was set to 15 mm/s and the acceleration of 50 mm/s^2. The first model that is set to be printed is a simple cube (Fig. 39) of 150x150x150 mm. The cube is set to print in spiral vase mode, where only the outside wall is printed continuously. In this mode Z-axis rises gradually without creating seams. The temperature for the PP is set the same as in the extrusion testing, 240 degrees Celsius, the second test parameters are portrayed in Table 3. The build plate is not heated, so the temperature is not set.

Table 3. Second test printing parameters

Parameter	Value
Extrusion speed	15 mm/s
Movement acceleration	50 mm/s^2
Material	Polypropylene
Temperature	240 C^o
Extrusion length	300 mm

Cooling is not set because there are no fans mounted on the extruder. Almost every setting is changed accordingly, and the sliced file is uploaded to the printer wirelessly.

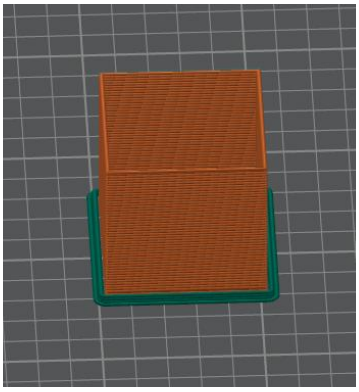


Fig. 39. Sliced cube

The printer performs the PRINT_START sequence, where it is programmed to home, commit the quad gantry level, and bed mesh. After this sequence, the printer rises from the bed and heats up to the set temperature. After 30 minutes, the extruder is heated, and the print begins. Z-axis height is adjusted manually in the Klipper web interface. The print begins, and it is displayed in Figure 40.

Fig. 40. The first print

The printer is working, plastic is extruded as expected. Further tuning is needed. Several settings need to be adjusted, and the Z-axis height needs to be calibrated. It is observed that the printing speed can be slightly increased, and the corner acceleration and deceleration can also be increased. But overall, the printer functions as intended. The printing of the cube failed after several minutes due to bed adhesion and severe warping, as portrayed in Figure 41 and Figure 42.

Fig. 41. Poor bed adhesion

Fig. 42. Severe warping

The first print is considered a success because the printer works, the starting sequence is executed with no problems, the extruder heats to the desired temperatures and does not skip steps. Further tuning is needed, the bed adhesion problem must be solved for good quality prints.

4.3. Chapter Summary

The extruder calibration was performed successfully in the second attempt. It was discovered that nylon with 35% glass fibre needs to be dried before extrusion. Polypropylene was used for further testing and was proven as a compatible material for this process. Slicer profile was configured according to the printer hardware and firmware. The first print was made and was deemed a success. Further slicer tuning is needed for better results.

5. Economic and Environmental Impact of the Project

Every project has its own cost, some come more expensive in time spent making it, some more in money. To complete the project, resources must be spent. In this case, the components and rent play a major role in making this printer. The costs, such as money spent on fuel and costs associated with labour hours, are not calculated due to the fact that this project was completed in the spare time and no salary was paid to anyone. As the project required many parts, available and custom-made components, the cost of this machine is one of the main limiting factors. As it is privately funded cost was aimed to be as little as possible.

5.1. Economic Evaluation of the Project

Components were first designed and assembled in CAD software to roughly estimate the final project cost. And the assembly time was estimated to be four months. Including all foreseeable costs, it was determined that the overall cost should be roughly around 10000 Euros. This was determined to be too much, and the decision to lower it was taken. First, the main frame aluminium profiles were changed from industrial 40x80 mm profiles to the structural aluminium profiles that were second-hand. The kinematic system was altered and the Z-axis height was lowered from the initially envisioned 3 metres to 2 metres. This was replaced so that the linear rails and ball screws were more commonly availabe and did not require custom order. The parts from machined aluminium were changed to bent stainless steel sheet metal. These decisions lower the expected material cost to roughly 6000 Euros. The rented workshop was chosen to be in Šiauliai at a 250 Euro monthly expense without including utilities. The cost of all 3D printer components is divided into different assembly units. For example, the extruder assembly, kinematic components, structural components, and electrical components. The costs does not include miscellaneous components such as screws, bolts, washers, electrical insulation and wire ends. It is safe to assume that these components do not exceed 150 Euros. The spreadsheet of the cost of the extruder components and equivalent price is shown below in Table 4. All of the costs for all of the components displayed in all of the tables are combined for the specific assembly, and the costs are rounded and shown combined for the same components.

Table 4. Extruder expenses spreadsheet

Extruder components	**Price in Euros**
Extruder set	600
Mounting brackets	60
Nema 34 Stepper motor	85
Insulating material	20
Reducer gearbox	130
Motor coupling	10
Thermocouple	5
CNC machined parts	50
TOTAL	**960**

This table comprises all the components that were purchased to build an extruder assembly. The extruder set includes the power relays, heating elements, extruder screw and unused heater controll modules. The combined extruder assembly cost is 960 Euros. Another separate assembly is the electrical components, including the control unit. The spreadsheet with all the costs associated with electrical components is displayed in Table 5. The combined cost of electrical components was 800 Euros, in the table cost is shown for each component.

Table 5. Electrical component expenses spreadsheet

Electrical components	**Price in Euros**
Main board Manta M8P V2	120
PSU	100
Electrical box	80
Electrical wire	120
TMC5160T Plus	170
Mounting rails	10
Tools	200
TOTAL	**800**

This table shows all the components associated with electrical wiring, routing and electrical assembly. These costs do not include heat shrink, tape, wire ends, or mounting fixtures. These costs are counted as miscellaneous and do not appear in this table. Further costs related to the printer are kinematic assemblies. These assemblies are grouped as one due to the fact that they share the same components that are displayed in Table 6. All of the axes use the same components, but in different numbers. The combined kinematic cost was 1990 Euros, in the table below cost for every component is displayed.

Table 6. Kinematic component expenses spreadsheet

Kinematic components	**Price in Euros**
Nema 34 stepper motor	595
MGN25 linear rails 2 m with carriages	390
MGN20 linear rails 2 m with carriages	120
2010 ball screw with nut	450
Motor couplings	40
Z-axis brackets	160
Bearings	45
T-nuts	160
Ball screw nut brackets	30
TOTAL	**1990**

These components are used in the kinematic assembly for all the axes. The Z-axis uses four stepper motors, ball screw with nut and MGN25 linear rails. The Y-axis uses two of each. And the X-axis uses one of each, but instead of MGN25 uses a smaller and lighter MGN20 linear rail with carriage. It was expected that the kinematic components would cost significantly more than other assembly components because of their quantity and required precision. And the last assembly that ties all of the previously mentioned components and that functions as a skeleton for this machine is the frame. The frame is assembled from different lengths of structural aluminium profiles. The profiles were purchased in bulk, and the specified length is not specified because these profiles were manually cut to the required length. The print bed is classified as a frame component. The frame components are few, and all of them cost 640 Euros and are shown in Table 7.

Table 7. Frame component expenses spreadsheet

Frame components	**Price in Euros**
Structural 40x65 mm aluminium profiles	300
Industrial 40x80 mm aluminium profile	160
Print bed	150
Corner brackets	30
TOTAL	**640**

The print bed is classified as a frame component because it serves not only as a platform on which the printing is done, but also as a stabiliser. The print bed is made from medium-density fibreboard (MDF) and is heavy, the weight at the bottom stiffens the printer. All of the main printer assemblies were shown in tables with their respective costs. The total overall cost of the printer is 4390 Euros without the rent and utilities. As for the workshop, the monthly cost was 250 Euros and in the wintertime extra 30 Euros for the heating and water. Since the majority of the assembly and working on this machine were at weekends and in the spare time, the utilities cost remained low. Overall, in the span of four months, when the printer was being constructed, the combined rent and utilities cost was 1145 Euros, which includes all of the costs associated with renting the workshop. So the combined cost of the printer, including rent, was 5535 Euros.

Another way the cost was reduced was the use of an acquired Bambulab printer and the personal 3D printers. The regular 3D printers were used to manufacture custom parts for the large-format printer by printing parts such as stepper motor mounting brackets, extruder hopper assembly (Fig. 31) and endstop switch mounts. The material used in printing these parts was “Flashforge” ASA, as it is heat resistant and can handle temperatures up to 88 degrees Celsius. To reduce the cost further, all of the assembly process was performed in-house with personal tools and no help from outside contractors or personnel. Only the custom sheet metal bent and CNC-machined parts were manufactured by other companies that have the tooling to make these parts.

Fig. 43. 3D printed hopper

Other cost-reducing measures were also made in the acquiring processes, such as buying in bulk and negotiating for a lower price. Overall, the cost of this large-format 3D printer was lower than expected and was within the budget. The low cost of this printer makes it viable for further development and exploitation. The low cost of the machine may make it attractive for others to purchase and create furnishings or other large-format 3D printed items.

5.2. Environmental Impact of the Project

As the plastic waste produced by single-use plastics poses a great threat to the global environment, it is encouraged to facilitate sustainable manufacturing practices. One of those practices would be to use a recycled plastic polymer to produce 3D-printed furniture and décor. It is now common to purchase a recycled 3D printing material for household printers. Manufacturers offer a wide variety of recycled filament for the printers, most common being recycled PET-G and PLA. These materials are often used to produce household items and single-use plastic products such as bottles of bags. But there are many more polymer materials that are not recycled due to costs or difficulty in doing so. Some of these materials are ABS and PP. These materials are often used in furniture, automotive and household applications. As these materials are commonly available and have a wide use in industrial applications, it is easy to obtain these materials in pellets or flakes from waste material. The availability to use these plastics for printing material makes it a viable option to produce furnishing from the waste material. This comes at a cost of reduced tensile and yield strength [43]. Where the pristine strength is not required, these materials can be used. With the addition of fibres such as glass or carbon, the rigidity could be increased for specific items where this is needed. It is expected that for the furniture produced with this printer, recycled PP will be used because of its reduced cost and common availability.

Another environment-preserving benefit of this project could be the printer itself. As this machine can produce a wide variety of parts and objects, it is not necessary to create specific tooling for the desired object. The printer can make any 3D printable large object and requires changes only to the software, but not the printer. Contrary to traditional manufacturing, where purpose-built tooling is required to produce desired parts. With no need for specific tooling, a lot of the material could be saved, further reducing environmental impact. The additive manufacturing technology produces less waste and is more optimised for complex geometries. By simply utilising this manufacturing technology, it is possible to produce less waste and save material on making specific tooling.

5.3. Chapter Summary

The printer was built without outside funding in the span of four months. The costs were tracked and monitored. Before the construction, changes to the printer were made to reduce the expected material cost from 10000 Euros to roughly 6000 Euros. Changes included a reduction in the printing volume, different part manufacturing methods, and structural changes. The final material cost for the printer was 4390 Euros. The workshop rent for the four months was 1145 Euros, resulting in a total printer assembly cost being 5535 Euros. The real cost was lower than expected. The environmental impact of this project should be positive, as the recycled material can be used, and the technology itself is more generally purposeful, not requiring custom tooling to produce large items.

Conclusions

1. The difference between the three printing methods(SLS, FDM, LCD) was described and explained. Different subcategories were also explained, benefits and drawbacks of each were described. Comparison between large-format 3D printers was made, and a decision to build a large-format FDM printer was made. The decision was made to create an extrusion-based large-format 3D printer with Cartesian kinematics.
2. Large-format 3D printer requirements were created according to the intended purpose of manufacturing furniture and décor. Build materials and decisions explaining the choice were presented. A full CAD model was created according to which the printer is assembled. Klipper firmware is selected to run this machine, the kinematic system is chosen to be Cartesian and the extruder is designed to use pellets. The mainboard is chosen to be Manta M8P V2 with the TMC5160T Plus stepper drivers for NEMA 34 stepper motors.
3. Finite element analysis was made for the Z-axis corner bracket in the SolidWorks virtual environment. It was discovered that it needs to forego post-processing, and the corners must be welded to ensure resistance to high loads and emergencies. The simulation was done with the expected maximum load of 588 N. According to the simulation, measures were taken to ensure the part withstands emergencies and does not permanently deform.
4. Extrusion calibration was performed with one failed attempt. It was discovered that nylon has to be dried before being used. In the first attempt, the extruder skipped steps and nylon pellets have charred and clogged the extruder screw. This occurred because nylon was not dried and flowed too poorly. Pellets were changed to polypropylene, and the calibration was successful. The first successful print was made, with further requirements for tuning and adjustments.
5. A financial forecast was performed for the overall cost of this project. The expected cost was deemed to be too high, and the cost-cutting decisions were made. The initial expected cost of 10000 Euros was reduced to 6000 Euros. The reduction in expenses was made by reducing the build volume, using more commonly available materials and changing parts manufacturing methods. The final printer cost was 4390 Euros, and 1145 Euros in rent and utilities, making the whole project cost of 5535 Euros. The environmental impact of this project should be positive, as the recycled material can be used, and the technology itself is more generally purposeful, not requiring custom tooling to produce large items.

Recommendations

While designing the large-format 3D printer, it is necessary to have a desired budget target and follow it. Decisions should be based on the intended final use of the printer and material availability. Use of industrial components is fine, and if possible, use stronger than intended components for the rigid and stiff frame. It is also wise to consider using belts and pulleys as a motion mechanism, it would increase the motion tolerances and reduce binding as it might be experienced using ball screws. The frame should be as stiff as possible because induced vibrations can cause excessive noise and printing inaccuracies. Software and slicer should be tailored to the mechanical assembly of the printer. Spare parts and power tools will ensure that the assembly of the printer goes smoothly and according to plan. Have lower expectations and understand that things do not go according to plan, critical thinking and patience are the key to success.

List of References

1. SU, AMANDA ; AL'AREF, SUBHI J.: History of 3D Printing. In: *3D Printing Applications in Cardiovascular Medicine*, Academic Press (2018), S. 1–10 — ISBN 9780128039175
2. INTERNET SOURCE „SCIENCE MUSEUM GROUP": https://collection.sciencemuseumgroup.org.uk/objects/co8357315/darwin-reprap-self-replicating-3d-printer-generation-i [viewed 2025-03-10]
3. INTERNET SOURCE „PRUSA 3D": https://blog.prusa3d.com/original-prusa-i3-mk2-release_4332/ [viewed 2025-03-10]
4. MOHSENI, YASAMAN ; MOHSENI, MINA ; SURESH, SINDUJA ; RIOTTO, MARCELLO ; JAGGESSAR, ALKA ; LITTLE, J. PAIGE ; WILLE, MARIE-LUISE ; YARLAGADDA, PRASAD KDV: Investigating impacts of FDM printing parameters and geometrical features on void formation in 3D printed automotive components. In: *Materials Today: Proceedings*, Elsevier (2023)
5. INTERNET SOURCE „RESEARCHGATE": https://www.researchgate.net/figure/Workflow-of-3D-Printing-Process_fig1_338600152 [viewed 2025-03-10]
6. DOSHI, MANAV ; MAHALE, AMEYA ; SINGH, SURAJ KUMAR ; DESHMUKH, SAMADHAN: Printing parameters and materials affecting mechanical properties of FDM-3D printed Parts: Perspective and prospects. In: *Materials Today: Proceedings* Bd. 50, Elsevier (2022), S. 2269–2275
7. PATEL, KAUTILYA S. ; SHAH, DHAVAL B. ; JOSHI, SHASHIKANT J. ; PATEL, KAUSHIK M.: Developments in 3D printing of carbon fiber reinforced polymer containing recycled plastic waste: A review. In: *Cleaner Materials* Bd. 9, Elsevier (2023), S. 100207
8. HAN, LEYU ; DU, WENFENG ; XIA, ZHUANG ; GAO, BOQING ; YANG, MIJIA: Generative Design and Integrated 3D Printing Manufacture of Cross Joints. In: *Materials* Bd. 15 (2022), Nr. 14
9. INTERNET SOURCE „THE MEDICAL FUTURIST": https://medicalfuturist.com/where-are-3d-printed-casts/
10. VAN LIESHOUT, ESTHER M.M. ; VERHOFSTAD, MICHAEL H.J. ; BEENS, LINDA M. ; VAN BEKKUM, JULIENNE J.J. ; WILLEMSEN, FLEUR ; JANZING, HEINRICH M.J. ; VAN VLEDDER, MARK G.: Personalized 3D-printed forearm braces as an alternative for a traditional plaster cast or splint; A systematic review. In: *Injury* Bd. 53, Elsevier (2022), S. S47–S52
11. NADAGOUDA, MALLIKARJUNA N. ; GINN, MEGAN ; RASTOGI, VANDITA: A review of 3D printing techniques for environmental applications. In: *Current Opinion in Chemical Engineering* Bd. 28, Elsevier (2020), S. 173–178
12. DAUNGSUPAWONG, HINPETCH ; WIWANITKIT, VIROJ: Application of 3D printing in veterinarian science. In: *Research in Veterinary Science* Bd. 186, W.B. Saunders (2025), S. 105571
13. SHAHRUBUDIN, N. ; LEE, T. C. ; RAMLAN, R.: An Overview on 3D Printing Technology: Technological, Materials, and Applications. In: *Procedia Manufacturing* Bd. 35, Elsevier (2019), S. 1286–1296
14. WOLF, JAN ; WERKLE, KIM TORBEN ; MÖHRING, HANS CHRISTIAN: Study on Dynamic Behaviour in FFF 3D-printing with Crossed Gantry Kinematic. In: *Procedia CIRP* Bd. 121, Elsevier (2024), S. 162–167
15. INTERNET SOURCE „TOP3DSHOP": https://top3dshop.com/blog/3d-printer-kinematics-explained [viewed 2025-03-12]
16. ZHANG, LIANGWEI ; LIN, JING ; SHAO, HAIDONG ; YANG, ZHE ; LIU, BIYU ; LI, CHUAN: An unsupervised end-to-end approach to fault detection in delta 3D printers using deep support

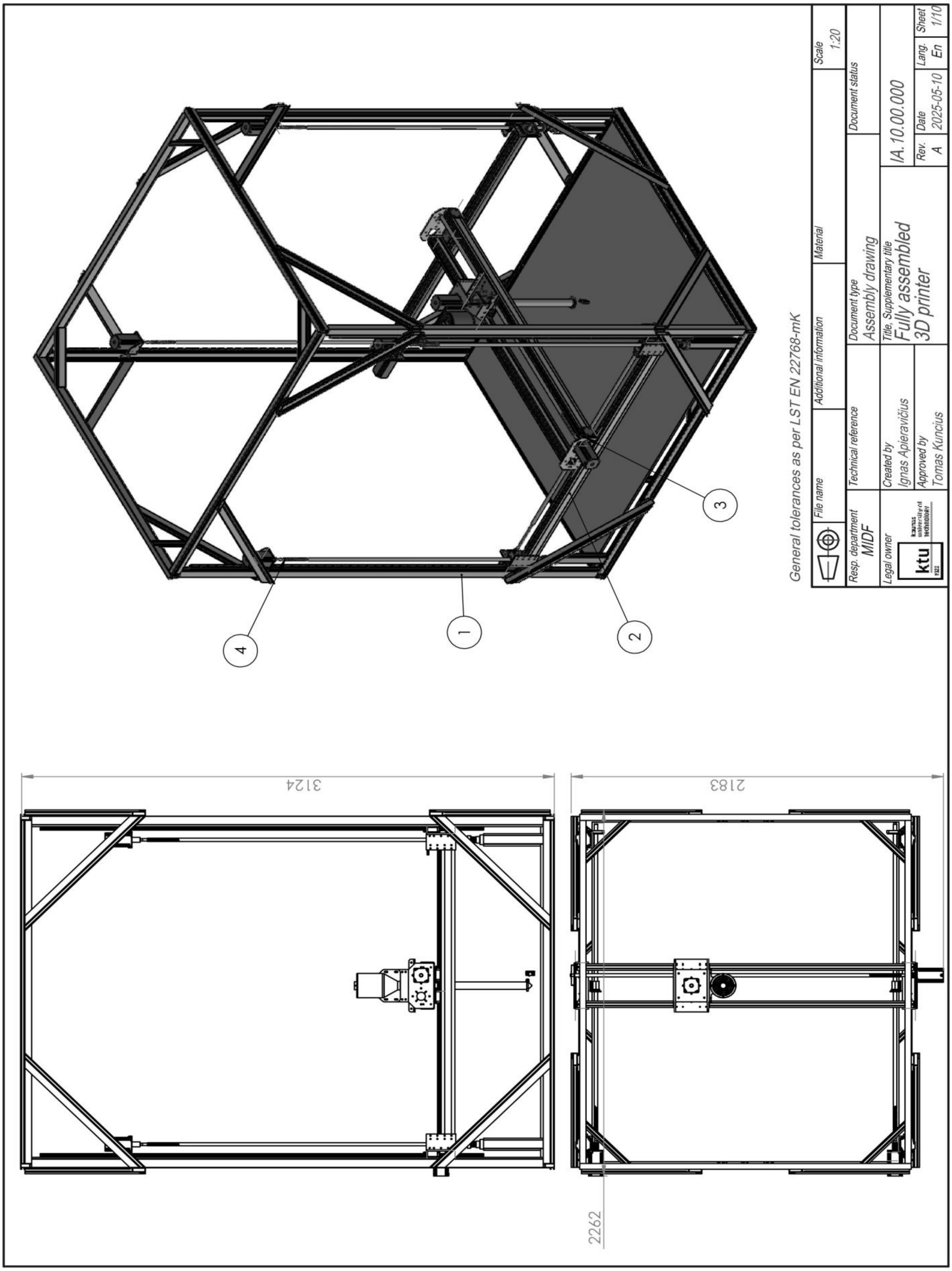
vector data description. In: *Journal of Manufacturing Systems* Bd. 72, Elsevier (2024), S. 214–228
17. TSOLAKIS, IOANNIS A. ; LYROS, IOANNIS ; CHRISTOPOULOU, ISIDORA ; TSOLAKIS, APOSTOLOS I. ; PAPADOPOULOS, MOSCHOS A.: Comparing the accuracy of 3 different liquid crystal display printers for dental model printing. In: *American Journal of Orthodontics and Dentofacial Orthopedics* Bd. 166, Mosby (2024), Nr. 1, S. 7–14
18. INTERNET SOURCE „ELEGOO“: https://eu.elegoo.com/collections/lcd-printers/products/saturn-4-ultra-16k-10inch-monochrome-lcd-resin-3d-printer [viewed 2025-03-12]
19. BATISTA, M. ; MORA-JIMENEZ, J. ; SALGUERO, J. ; VAZQUEZ-MARTINEZ, J.M.: Assessment of the Development Performance of Additive Manufacturing VPP Parts Using Digital Light Processing (DLP) and Liquid Crystal Display (LCD) Technologies. In: *Applied Sciences (Switzerland)* Bd. 14 (2024), Nr. 9
20. INTERNET SOURCE „FORMLABS“: https://formlabs.com/eu/blog/resin-3d-printer-comparison-sla-vs-dlp/?srsltid=AfmBOoo-AZF1z6WhkB0JA0S45MOx2uJeyaY2gfo36FA_TAbL2emSO6Vz [viewed 2025-03-12]
21. ZHANG, GUANGXU ; ZOU, BIN ; WANG, XINFENG ; YU, YANG ; CHEN, QINGHUA: Design, manufacturing and properties of controllable porosity of ceramic filters based on SLA-3D printing technology. In: *Ceramics International* Bd. 49, Elsevier (2023), Nr. 1, S. 1009–1019
22. SUN, SHAOJIE ; GAN, XINPENG ; WANG, ZHANHUA ; FU, DAIHUA ; PU, WULI ; XIA, HESHENG: Dynamic healable polyurethane for selective laser sintering. In: *Additive Manufacturing* Bd. 33, Elsevier (2020), S. 101176
23. SINGH, S. ; SHARMA, V. S. ; SACHDEVA, A.: Progress in selective laser sintering using metallic powders: A review. In: *Materials Science and Technology* Bd. 32 (2016), Nr. 8, S. 760–772
24. INTERNET SOURCE „LIVE SCIENCE“: https://www.livescience.com/38862-selective-laser-sintering.html [viewed 2025-04-05]
25. M. BHUVANESH KUMAR, P. SATHIYA, M. VARATHARAJULU ; NATARAJAN, J. ; CHEEPU, M. ; YANG, C.-H. (Hrsg.): *Advances in Additive Manufacturing Processes* : BENTHAM SCIENCE PUBLISHERS, 2021 — ISBN 9789815036336
26. YAP, C. Y. ; CHUA, C. K. ; DONG, Z. L. ; LIU, Z. H. ; ZHANG, D. Q. ; LOH, L. E. ; SING, S. L.: Review of selective laser melting: Materials and applications. In: *Applied Physics Reviews* Bd. 2 (2015), Nr. 4
27. SARKAR, JAYDEEP: Sputtering Target Manufacturing. In: *Sputtering Materials for VLSI and Thin Film Devices* : Elsevier, 2014, S. 197–289
28. DE ORO CALDERON, RAQUEL ; GIERL-MAYER, CHRISTIAN ; DANNINGER, HERBERT: Fundamentals of sintering: liquid phase sintering. In: *Encyclopedia of materials: metals and alloys* Bd. 3, Elsevier Amsterdam (2022), S. 481–492
29. SHAHZAD, KHURAM ; DECKERS, JAN ; KRUTH, JEAN PIERRE ; VLEUGELS, JEF: Additive manufacturing of alumina parts by indirect selective laser sintering and post processing. In: *Journal of Materials Processing Technology* Bd. 213, Elsevier (2013), Nr. 9, S. 1484–1494
30. INTERNET SOURCE „ANIWAA“: https://www.aniwaa.com/product/3d-printers/farsoon-flight-ht1001p-platform/ [viewed 2025-04-05]
31. INTERNET SOURCE „FARSOON“: https://www.farsoon-gl.com/products/flight-ht1001p/ [viewed 2025-04-05]
32. INTERNET SOURCE „PROTOFAB“: https://www.3dprotofab.com/protofabs-worlds-largest-sla-light-curing-3d-printer.html [viewed 2025-04-05]
33. INTERNET SOURCE „MODEL NO“: https://www.model-no.com [viewed 2025-04-11]

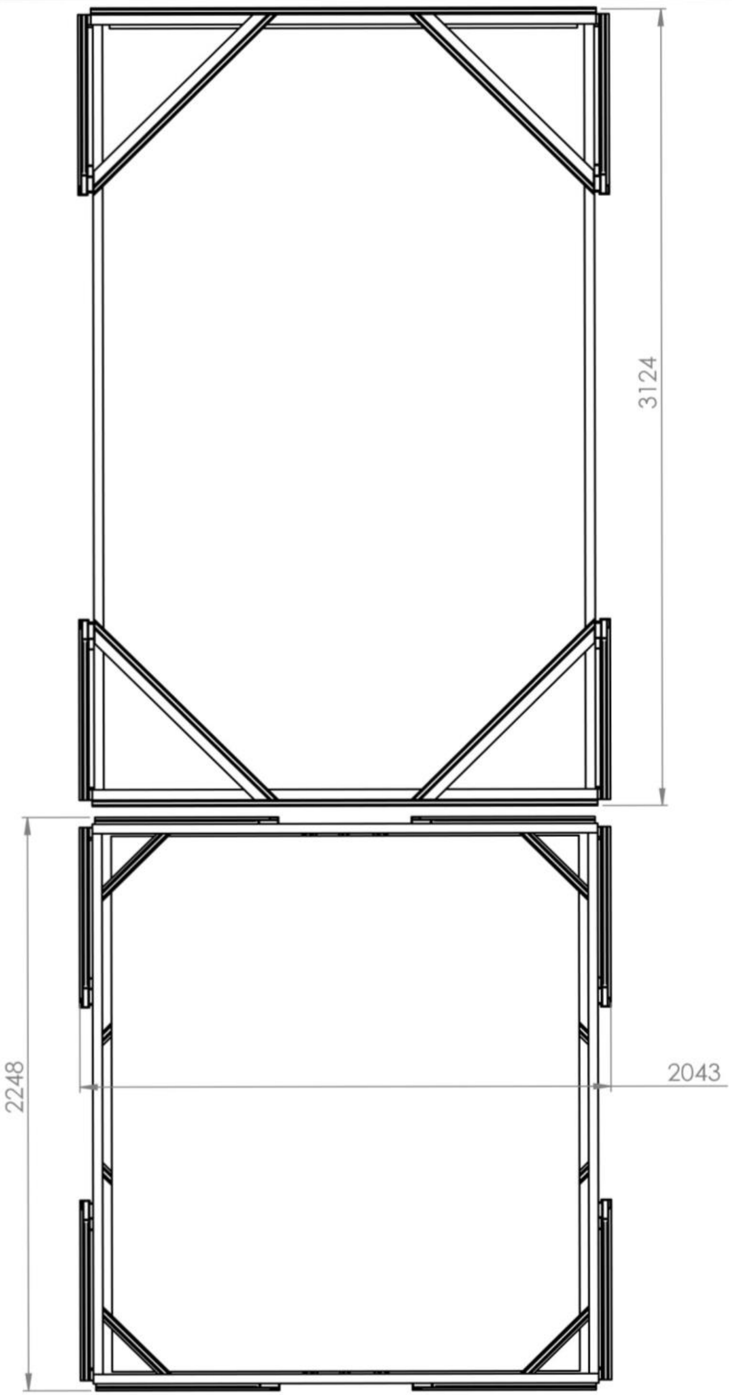
34. INTERNET SOURCE „HYPERION“: https://www.hyperionsystems.com.au/Hyperion-Systems-Blog/robotic-arms-and-gantry-systems-large-format-3d-printing-solutions [viewed 2025-04-11]
35. GOH, GUO DONG ; WONG, KIN KEONG ; TAN, NIGEL ; SEET, HANG LI ; NAI, MUI LING SHARON: Large-format additive manufacturing of polymers: a review of fabrication processes, materials, and design. In: *Virtual and Physical Prototyping* Bd. 19, Taylor & Francis (2024), Nr. 1
36. INTERNET SOURCE „ERMITAZAS“: https://www.ermitazas.lt/c/baldai-interjeras-tekstile/lauko-baldai/gultai-hamakai [viewed 2025-04-16]
37. INTERNET SOURCE „JYSK“: https://www.jysk.lt/sodas/gultai.html [viewed 2025-04-16]
38. HTTPS://WWW.KLIPPER3D.ORG/FEATURES.HTML: Internet source „Klipper“ [viewed 2025-05-19]
39. INTERNET SOURCE „KENENG“: https://www.kenenghardware.com/what-are-t-nuts-types-uses-and-installation/ [viewed 2025-05-19]
40. INTERNET SOURCE „BIQU“: https://biqu.equipment [viewed 2025-05-19]
41. INTERNET SOURCE „ANSYS“: https://www.ansys.com/simulation-topics/what-is-finite-element-analysis [viewed 2025-05-20]
42. WALKER, ROO ; KOREY, MATTHEW ; HUBBARD, AMBER M. ; CLARKSON, CAITLYN M. ; CORUM, TYLER ; SMITH, TYLER ; HERSHEY, CHRISTOPHER J. ; LINDAHL, JOHN ; U. A.: Recycling of CF-ABS machining waste for large format additive manufacturing. In: *Composites Part B: Engineering* Bd. 275, Elsevier (2024), S. 111291

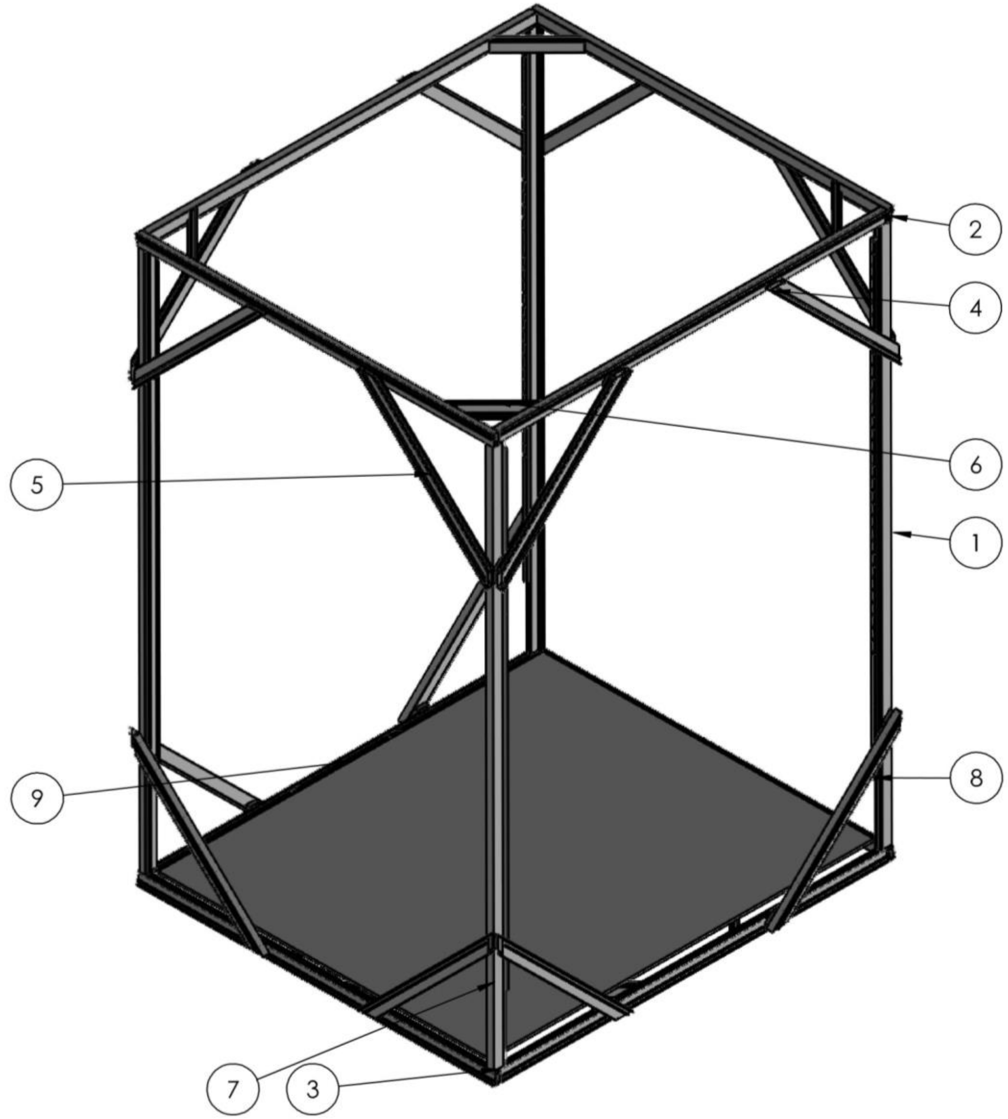
Appendices

Appendix No. 1 CAD Drawings

Appendix No. 1

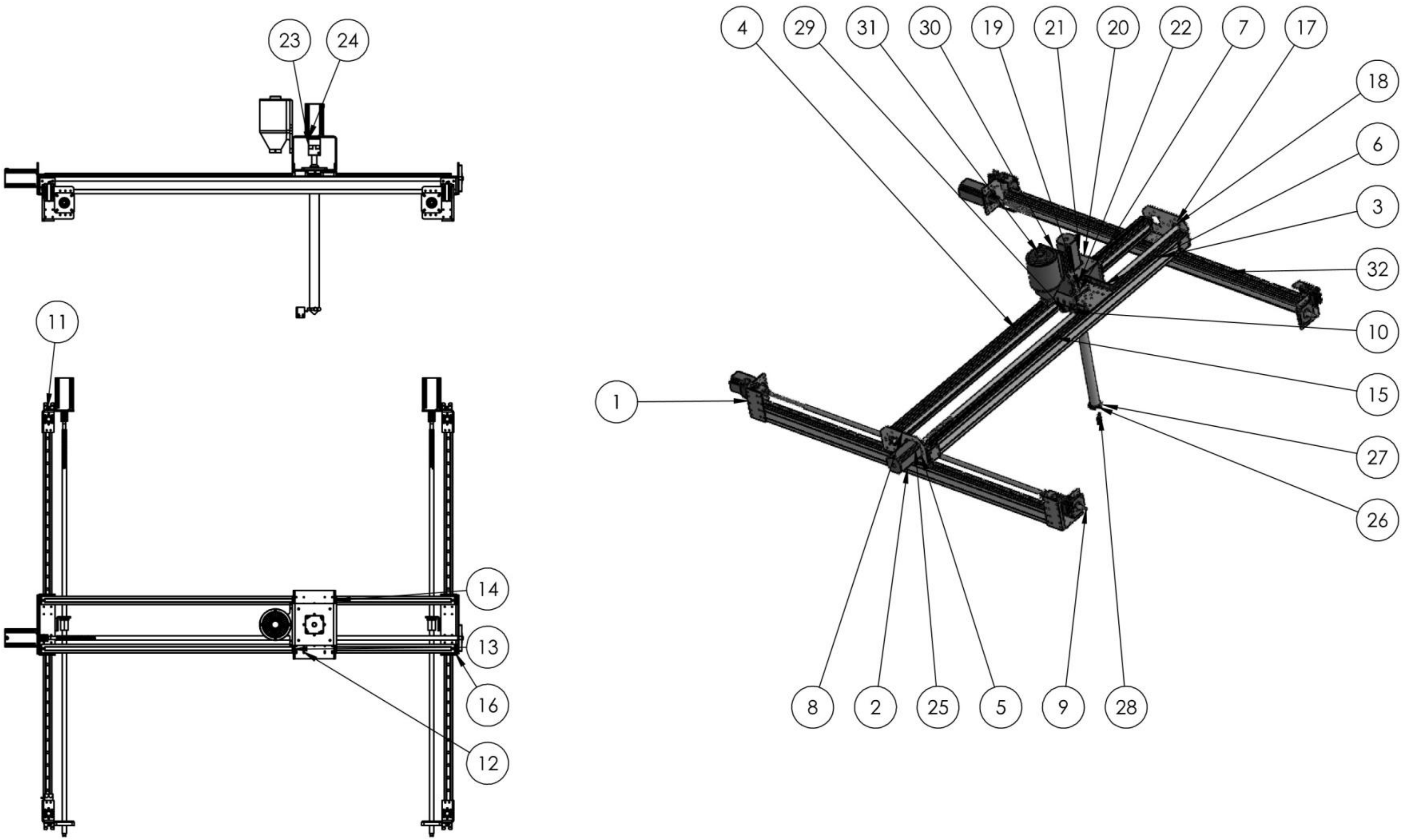






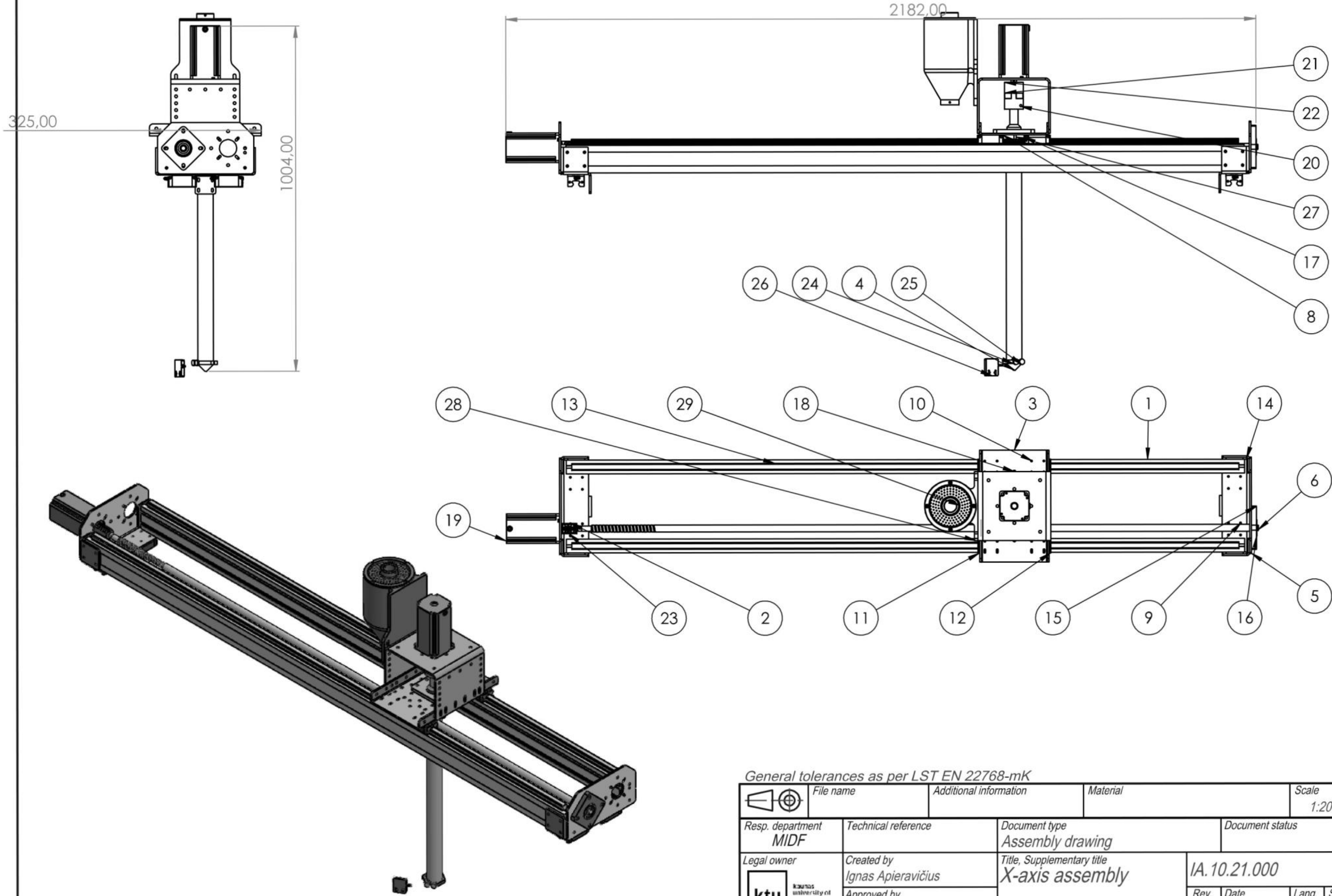
General tolerances as per LST EN 22768-mK

	File name	Additional information	Material	Scale 1:20
Resp. department MIDF	Technical reference	Document type Assembly drawing		Document status
Legal owner ktu kaunas university of technology 1922	Created by Ignas Apieravičius	Title, Supplementary title Frame	IA.10.10.000	
	Approved by Tomas Kuncius		Rev. A / Date 2025-05-10 / Lang. En / Sheet 2/10	



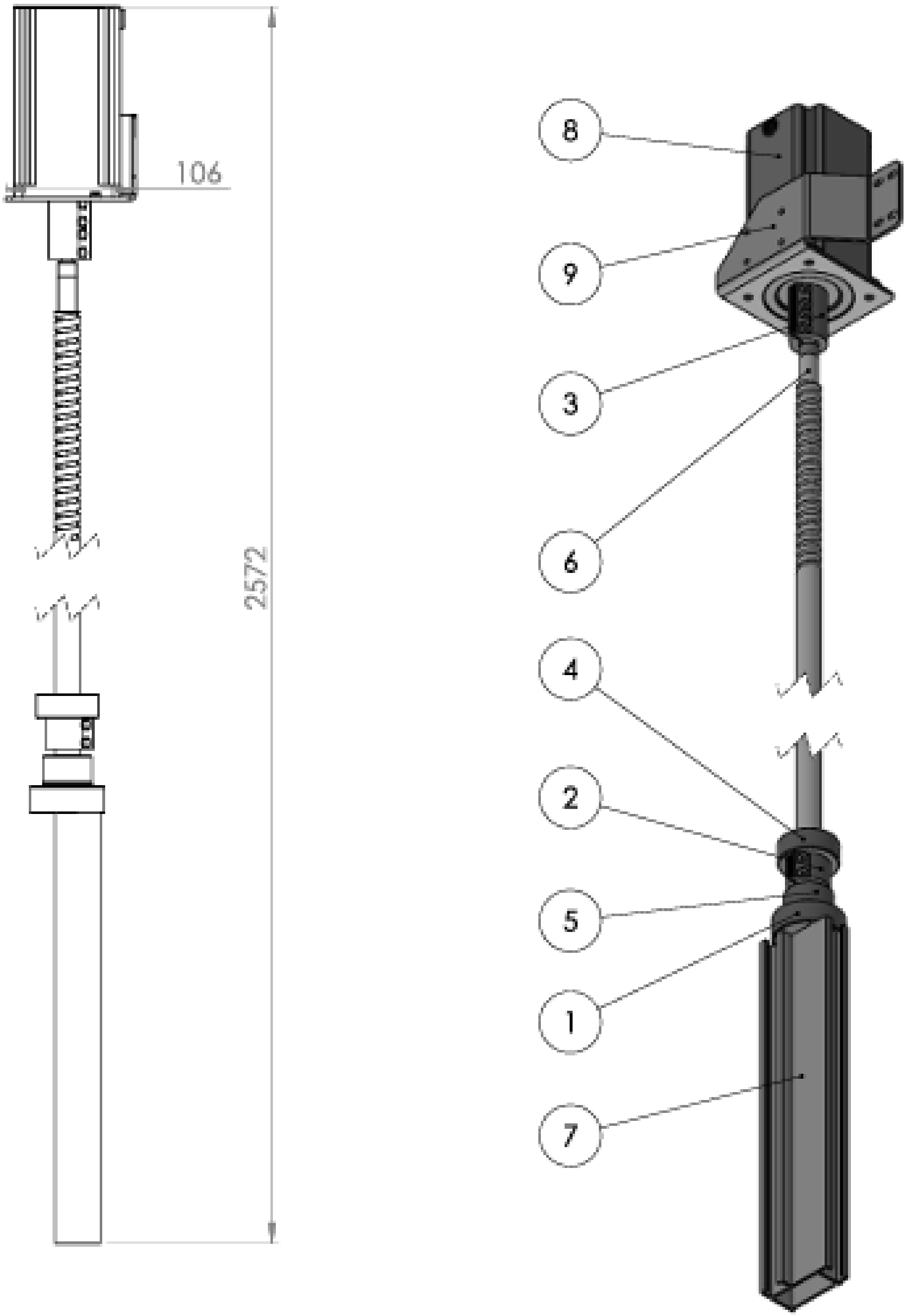
General tolerances as per LST EN 22768-mK

File name		Additional information	Material		Scale 1:20
Resp. department MIDF	Technical reference	Document type Assembly drawing		Document status	
Legal owner ktu kaunas university of technology 1922	Created by Ignas Apieravičius	Title, Supplementary title Gantry	IA.10.20.000		
	Approved by Tomas Kuncius		Rev. A	Date 2025-05-10	Lang. En / Sheet 3/10



General tolerances as per LST EN 22768-mK

File name	Additional information	Material		Scale 1:20
Resp. department MIDF	Technical reference	Document type Assembly drawing		Document status
Legal owner ktu kaunas university of technology 1922	Created by Ignas Apieravičius	Title, Supplementary title X-axis assembly	IA.10.21.000	
	Approved by Tomas Kuncius		Rev. A / Date 2025-05-10	Lang. En / Sheet 4/10



1. Unspecified tolerance limit according LST EN 22768-mK.
2. Unspecified radius of fillets R=0.5 mm.

	File name	Additional information	Material	Scale 1:20
Resp. department MIDF	Technical reference	Document type Assembly drawing	Document status	
Legal owner ktu kauno technologijos universitetas 1922	Created by Ignas Apieravičius	Title, Supplementary title Z-axis corner	IA.10.30.000	
	Approved by Tomas Kuncius		Rev. A · Date 2025-05-10 · Lang. En	Sheet 5/10

Appendix No. 2

Format	No.	Designation	Name	Qyt	Notes
			Documentation		
A3		IA.10.00.000	Assembly drawing		Printer
A3	1	IA.10.10.000	Assembly drawing		Frame
A3	2	IA.10.20.000	Assembly drawing		Gantry
A3	3	IA.10.21.000	Assembly drawing		X-axis
A4	4	IA.10.30.000	Assembly drawing		Z-axis

File name	Additional information	Material	Scale

Resp. department	Technical reference	Document type	Document status
MIDF		Specification	

Legal owner: ktu kauno technologijos universitetas 1922

Created by: Ignas Apieravičius

Approved by: Tomas Kuncius

Title, Supplementary title: Large format 3D printer

Rev.	Date	Lang.	Sheet
A	2025-05-10	En	6/10

Appendix No. 2

Format	No.	Designation	Name	Qyt	Notes
			Documentation		
A3	1	IA.10.10.000	Assembly drawing		Frame
	1	structural profile 65x40 L=3000		4	
	2	structural profile 65x40 L=1945		4	
	3	structural profile 65x40 L=2120		5	
	4	IA.10.10.001		16	
	5	structural profile 65x40 L=1000		14	
	6	structural profile 65x40 L=300		4	
	7	structural profile 65x40 L=1100		4	
	8	HGR25 L=2600	Linear rail	4	
	9	IA.10.10.002	Build plate	1	

File name	Additional information	Material	Scale

Resp. department	Technical reference	Document type	Document status
MIDF		Specification	

Legal owner	Created by	Title, Supplementary title	
kauno technologijos universitetas 1922	Ignas Apieravičius	Frame	
	Approved by: Tomas Kuncius		Rev.: A; Date: 2025-05-10; Lang.: En; Sheet: 7/10

Appendix No. 2

Format	No.	Designation	Name	Qyt	Notes
A3	2	IA.10.20.000	Assembly drawing		Gantry
	1	IA.10.20.001	Z-axis corner plate	4	
	2	80x40 L=1850		2	
	3	SFU-2010-ball nut		7	
	4	80x40 L=1950		2	
	5	IA.10.21.001	Y-axis screw bracket	2	
	6	IA.10.21.002	Extruder barrel	1	
	7	Extruder		1	
	8	IA.10.21.003	X-axis motor bracket	2	
	9	SFU-2010		3	
	10	IA.10.20.002	X-axis screw bracket	3	
	11	HGH25 L=2000	Linear rail	8	
	12	HGH20 L-1960		4	
	13	Plastic^HGH20		8	
	14	Rubber^HGH20		8	
	15	HGR20-1940		2	
	16	IA.10.21.004	X-axis spacer	4	
	17	IA.10.20.003	Extruder screw bracket	3	
	18	Bearing 6204ZZ 20X47		3	
	19	IA.10.21.005	Extruder screw plate	1	
	20	IA.10.21.006	Extruder motor mount	1	
	21	NEMA34 STEP MOTOR.step		4	
	22	Coupler *1		1	
	23	Coupler *2		1	
	24	Coupler *1		1	
	25	IA.10.20.004		3	
	26	IA.10.21.011	Z stop bracket	1	
	27	IA.10.21.007	Extruder screw	2	
	28	IA.10.20.005	X-axis bracket	2	
	29	IA.10.21.008	Hopper lid	1	
	30	IA.10.21.009	Hopper body	1	
	31	IA.10.21.010	Hopper snout	1	
	32	HGR25 L=1840	PART--DESC	2	

	File name	Additional information	Material	Scale
Resp. department: MIDF	Technical reference	Document type: Specification		Document status
Legal owner: ktu kauno technologijos universitetas 1922	Created by: Ignas Apieravičius	Title, Supplementary title: Gantry		
	Approved by: Tomas Kuncius		Rev.: A	Date: 2025-05-10 · Lang.: En · Sheet: 8/10

Appendix No. 2

Format	No.	Designation	Name	Qyt	Notes
			Documentation		
A3	3	IA.10.21.000	Assembly drawing		X-axis
	1	80x40 L=1950		2	
	2	IA.10.21.001	Y-axis screw bracket	2	
	3	IA.10.21.002	Extruder barrel	1	
	4	Extruder		1	
	5	IA.10.21.003	X-axis motor bracket	2	
	6	SFU-2010		1	
	7	SFU-2010-ball nut		1	
	8	IA.10.20.002		1	
	9	HGH25 L=2000	Linear rail	4	
	10	HGH20 L-1960		4	
	11	HGH20 carriage		8	
	12	HGH20 L=1750		8	
	13	HGR20-1940		2	
	14	IA.10.21.004	X-axis spacer	4	
	15	IA.10.20.003	Extruder screw bracket	1	
	16	Bearing 6204ZZ 20X47		1	
	17	IA.10.21.005	Extruder screw bracket	1	
	18	IA.10.21.006	Extruder motor mount	1	
	19	NEMA34 STEP MOTOR.step		2	
	20	Coupler *1		1	
	21	Coupler *2		1	
	22	Coupler *1		1	
	23	IA.10.20.004	Coupler	1	
	24	IA.10.21.011	Nozzle button	1	
	25	IA.10.21.007	Nozzle bracket	2	
	26	IA.10.20.005	Magnet	1	
	27	IA.10.21.008	Hopper lid	1	
	28	IA.10.21.009	Hopper body	1	
	29	IA.10.21.010	Hopper snout	1	

File name | *Additional information* | *Material* | *Scale*

Resp. department MIDF | *Technical reference* | *Document type* Specification | *Document status*

Legal owner ktu kauno technologijos universitetas 1922 | *Created by* Ignas Apieravičius | *Approved by* Tomas Kuncius | *Title, Supplementary title* X-axis | *Rev.* A | *Date* 2025-05-10 | *Lang.* En | *Sheet* 9/10

Format	No.	Designation	Name	Qyt	Notes
			Documentation		
A4	4	IA.10.30.000	Assembly drawing		Z-axis
	1	IA.10.30.004	Screw resting stop	1	
	2	IA.10.30.001	Hard stop	1	
	3	IA.10.20.004	Coupler	1	
	4	IA.10.30.002	Soft stop	1	
	5	IA.10.30.003	Screw insert	1	
	6	SFU-2010		1	
	7	structural profile 65x40 L=350		1	
	8	NEMA34 STEP MOTOR.step		1	
	9	IA.10.30.005	Z-axis motor mount	1	

File name	Additional information	Material	Scale

Resp. department	Technical reference	Document type	Document status
MIDF		Specification	

Legal owner	Created by	Title, Supplementary title	Rev.	Date	Lang.	Sheet
ktu kauno technologijos universitetas 1922	Ignas Apieravičius	Z-axis				
	Approved by: Tomas Kuncius		A	2025-05-10	En	10/10