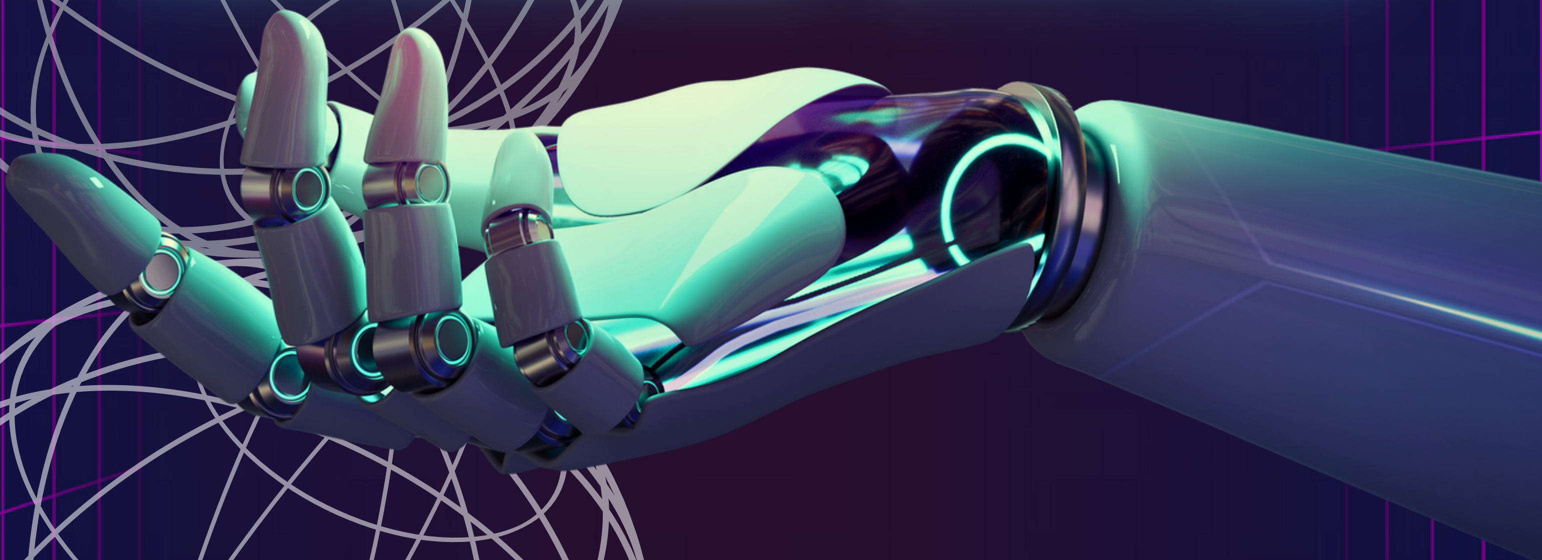
DIGITAL MANUFACTURING

MAGNETIC MECHANICAL KEYBOARD SWITCH



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Introduction

Background

Digital manufacturing is a new and upcoming approach that is dominating the current industrial revolution, with a high probability of being the leading manufacturing methodology in IR 5.0. The fundamental principles of digital manufacturing are to form coherently and cohesively an amalgamate of all manufacturing techniques through digitizing the required product and investing time into definitively analyzing each component through 3D CAD models, and lastly utilizing integrated additive and subtractive processes to bring the product efficiently and effectively to life. One inherent advantage is the boost in precision for the resulting product, which essentially inspires manufacturers and producers to rework their designs to better utilize the capabilities of this methodology.

As such, previously niche quirks that were previously limited to handcrafting, are now capable of being produced in large batches at an astounding accuracy. Customized computer peripherals are a recent example of this design revolution, as custom-made artistic, acoustically pleasing and aesthetically complex keyboards are desired by all millions of enthusiasts around the world. Traditionally, these keyboard "keycaps" were crafted with mundane aesthetics, often using injection molding, which would subtly sacrifice the quality of the keycaps but allow mass production. However, digital manufacturing allows designers to create complex visuals on the keycaps and allow for refined geometry and assembly with the keyboard to allow for a more pleasing "click" when pressed.

Innovation

Hence in regard to this niche component primarily utilized by enthusiasts, the pivotal and executive function is to manage the acoustic key pressing sounds, which often alternate depending on the material of the keycap, the spring and the keyboard frame/bed that produces a unique intensity and fluidity of the sound. However, through recent development, magnets embedded into the keycaps and the keyboard assembly can be utilized to further dampen the intensity of each key press and provide a quieter, more controlled experience. Hence, this report focuses on defining the manufacturing processes required to switch out the conventional spring and integrate a magnet into the key that aligns with the keyboard body to repel. The principle is feasible as it is utilized by Bluetooth speakers using magnetic- levitation "maglev", which is defined as strong magnets placed both in the base and the housings to provide an opposing force allowing the levitation of the speaker. However, in this scenario, the magnets dampen the keystrokes, providing a noise-free work environment with added customizability in the aesthetic and acoustic aspects of the keyboard.

Manufacturing Processes

Material and Process Selection

The following section outlines the material and process selection for each component in a single key cap. While the main innovation of using magnets instead of springs is outlined previously the product also comes with the ability of customization. This factor imposes constraints on the manufacturing process of the key cap. The components and their functions are listed below followed by the process of selection of both the material and manufacturing process.

Currently maglev keyboards are not manufactured in the mainstream. Some Dell laptops have this feature in certain models. Wooting, a keyboard manufacturer, provides keyboards with maglevs of which the cap is manufactured using polycarbonate, nylon for the housing, polyoxymethylene for the bottom housing. The bottom housing is translucent while the top housing is transparent ("Lekker switch Linear45 (L45)," 2023). A possible keyboard that might enter the market in 2024 is the flux keyboard but as production has not started it can only be speculated that transparent plastic such as polycarbonate will be used. ("Flux Keyboard," 2024)

Key cap

In addition to the maglevs, a unique selling point of the product is the customizability of the key caps according to user preference. As the target market itself is narrow and niche, to achieve this customizability in the manufacturing process only additive manufacturing (AM) processes were explored. Subtractive manufacturing processes were not considered due to the high initial cost and limited compatibility of plastics with subtractive manufacturing processes.

Key features that are required in the key cap,

- Good surface finish and quality
- Durability
- Customization
- Functional

Metal was not considered as the keyboard switches use magnets and as it is not compatible with the function of the key as it may disrupt the flux of the magnet. Therefore, only plastic options were considered in the material selection process. Possible plastics and other material that can be used in AM processes and their comparisons are outlined below. ("Guide to 3D printing materials: Types, applications, and properties," 2024)

Table 1 Material and Manufacturing Processes (MakeShaper. 2023 , Or, 2022, Jandyal et. al., 2022)

Material	Manufacturing process	Advantages	Disadvantages
ABS (acrylonitrile butadiene styrene	FDM	Tough Durable Less force in extrusion making it compatible for smaller parts Low cost	Heated bed and high temperatures are required for extrusion
PLA (polylactic acid)	FDM	Strong Rigid Biodegradable	Brittle Low heat resistance
PETG (polyethylene terephthalate glycol)	FDM	High transparency Can be used for waterproof applications. Can be used at lower printing temperatures than other materials	Low melting point
Nylon	FDM, SLS, Powder bed fusion	Lightweight Durable Strong	The thin section of final print tends to be flexible.

		Tough Heat, light and moisture resistance High resistance to impact	Sensitive to moisture Shrinks during the cooling process
TPU (thermoplastic polyurethane)	FDM, SLS	Resistant to impact Good vibration dampening Flexible	Low rigidity Absorbs moisture Printing speed is low
Composites (carbon fiber, kevlar, fiberglass)	FDM	Rigid Strong Tough	Only compatible with expensive 3d printers
Nylon composites	SLS	Higher strength and rigidity as they reinforced nylon	
Polypropylene	SLS	Ductile Chemically resistant Durable	

Table 2 Resin materials (P. M. 2023)

Material	Process	Advantages
Standard Resins	SLA	High resolution and surface finish
Clear Resin	SLA	Clear and transparent after post processing
Draft Resin	SLA	Can be printed very fast

		compared to other resins and FDM materials
Tough and Durable Resins	SLA	Strong Robust Can withstand compressive loads High impact resistance Comparable to ABS Resistant to chemicals
Rigid Resins	SLA	High strength and stiffness Thermally resistant Does not react chemically Can withstand loads
Polyurethane Resins	SLA	Durable Stable with respect to temperature Resistant to abrasion and wear
High Temp Resin	SLA	Resistant to temperature High precision
Flexible and Elastic Resins	SLA	Flexible Can significantly withstand cyclic loads Good compressive strength
Silicone 40A Resin	SLA	Has properties similar to cast silicone
Medical and dental resins	SLA	Biocompatible
Jewelry resins	SLA	Can be used for intricate detailing

ESD Resin	SLA	Safe in terms of electronic manufacturing workflows
Flame Retardant (FR) Resin	SLA	High resistance to heat Flame retardant Creep resistance
Alumina 4N Resin	SLA	Good thermal, electrical and mechanical properties

Typically, resins have common disadvantages such as their storage life and requirements. The resin cannot be exposed to light and needs proper storage and over time they degrade. When compared to other plastics, resins have lower mechanical properties. The cost of the resin is high and requires proper handling. When using the resin proper safety must be taken and there should be adequate ventilation.

Table 3 Advantages and Disadvantages of AM Processes (Jandyal et. al., 2022), ("What is directed energy deposition additive manufacturing and how does it work?," 2019)

AM process	Advantages	Disadvantages	Materials
Stereolithography (SLA)	High accuracy and surface finish Can produce complex parts Good thermal durability	Slow process High costs for equipment. Not suitable with components that have overhangs. A lot of post processing is required.	Photopolymer resins
Fused deposition modeling	Good surface finish Low investment cost Compatible for complex geometries No waste is generated	Slow process and quality is less compared to other AM processes	Thermoplastic polymers, polymer matrix composites, green ceramics, green metals, food pastes

Powder bed fusion	Low cost Can be used for large selection of materials	Post processing is needed Slow process Structural properties of the final product is not high	Metals, polymers
Selective laser sintering (SLS)	High accuracy and precision Suitable for mass production Complex parts can be manufactured	High cost Post processing is required Small holes are hard to manufacture	Thermoplastics, Nylon, glass, polypropylene, TPU
Binder jetting	Good resolution and surface furnish No supports	Limited range of materials Part strength is low Post processing is not required	Ceramics, Polymers Composites
Direct energy deposition	Larger and denser parts can be manufactured Can be used to repair parts Multiple materials can be used Less material waste	No supports are used so structures that have overhangs are not possible High cost Lower resolution	Metal, Ceramics Polymers

Justification and considerations

In order to achieve the desired features of the key cap, the most suitable AM method and material chosen is the use of photopolymer resins through SLA AM method. A tough or durable resin which are also called engineering resins are selected. The advantages of the process are compatible with the expectations of the product in terms of the surface finish and quality.

Cost - Although choosing SLA would result in higher costs per part, the tradeoff between cost and quality is difficult to meet. As the target market is niche, a higher cost is expected and thus it was not a deciding factor.

Feel of the key cap - By using a resin-based material the desired soft but rigid feel can be obtained. Users require certain characteristics from the keycap that are accomplished by selecting a resin based 3d print over other plastic materials

Profile - The profile of the cap is unique not just in regular mechanical keyboards, but this product must achieve the customisation factor. The resin and by using SLA this can be achieved at a higher quality. Additionally clear resins can be used for more degree of customisation

Chemical resistance - The chosen resin class resistant to chemicals and the keyboard will be subjected to cleaning materials.

Stability - As the key will be used constantly will substantially force over time, choosing an engineering resin will be compatible.

Color option - The resins do not have a diverse range in terms of colors and will need an alternative process for it.

Following is the specification for resin manufactured by formlabs under the type rigid resins of engineering resins

Table 4 Specifications (Formlabs, n.d)

Specifications	
Ultimate tensile strength (MPa)	75
Tensile Modulus(GPa)	4.1
Elongation(%)	5.6
Flexural modulus(GPa)	3.7
Impact property - Notched IZOD(J/m)	18.8
Heat Deflection temperature (C)	74

Housing and stem

For the housing and stem the most compatible material would be plastics. Metals would not work as they would interfere with the magnetic flux and result in higher costing in terms of not only the material but total energy. The standard to use in terms of keyboard housing and stems is plastics and for this particular product there is no reason to stray from this norm. In terms of plastics, thermoplastics can be used each with their advantages and disadvantages. The following are comparisons of popular materials used when manufacturing keyboard components.

Table 5 Material Choices for Stem and housing (Groover, 2010)

Material	Features	Applications
Polypropylene	Manufactured using injection molding light plastic and with a high strength to weight ratio. Polypropylene has a high melting point and can withstand large flexing cycles without failure	Automotive parts, houseware, fiber products
Polyoxymethylene	High in - Stiffness, toughness, resistance to wear.	Automotive components, door

	High melting point Low moisture absorption Insoluble Comparable to some metals	handles, hardware appliances, Machinery components
Acrylics	Transparent Limited resistance to scratches hen compared with glass	Optical instruments, aircraft windows,
ABS	Good mechanical properties	Automotive parts, Appliances, machines, pipes, and fittings
Nylon	Strong Elastic Tough Resistant to abrasions Retains mechanical properties at temperatures reaching 125C Absorbs water	Bearings, gears and high strength applications with low friction
Polycarbonate	High toughness Creep resistant High heat resistance Transparent Fire resistant	Machinery parts, pump impellers, safety helmets, compact disks
Polyethylene	Chemically inert Low cost Available as low-density polyethylene and high-density polyethylene	Bottles, frozen foods bags, sheets, film, pipes, housewares

Table 6 Specific Material properties (Groover, 2010)

Material	ABS	Nylon (Nylon 6,6)	Polyoxymethylene	Polycarbonate	Polyethylene
Modulus of elasticity (Mpa)	2100	425	3500	2500	140
Tensile Strength (Mpa)	50	20	70	65	15
Elongation(%)	10-30	100-300	25-75	110	100-500
Melting temperature (C)		327	180	230	115
Specific gravity	1.06	2.2	1.42	1.2	0.92

The manufacturing processes associated with thermoplastics are injection molding, Extrusion, Blow molding, Thermoforming, Compression molding, Rotational molding, Insert molding, and machining. However, processes such as extrusion, blow molding, rotational molding, thermoforming, and compression molding are not compatible in order to manufacture the housing and stem and will not be considered. They are normally used for either large components or in the case of hollow parts. Below are comparisons of possible processes that can be used.

Table 7 Manufacturing Processes Details (Groover, 2010), ("CNC machining has advantages for plastic part production," 2022)

Manufacturing process	Advantages	Disadvantages
Injection molding	Production cycle time is short Multiple moldings can be made at once Compatible for complex and intricate shapes Cost effective for mass production	Challenges in fabricating the mold in order to achieve the desired dimensions Shrinkage and defect can occur as polymers have high thermal expansion coefficients Defects - short shots, flashing, sink marks, weld lines
Injection molding with inserts	Can incorporate materials other than plastic More versatility in terms of properties Can handle complexities in the part designs	Higher costs High cycle time
Thermoforming	Cost effective Versatile Faster production Compatible with complex geometries	Limited material can be used Does not have high precision and surface finish compared to other methods High tooling costs
CNC machining	Cost effective when compared to molding in term of initial costs Shorter cycles Better surface finish	Large amount of waste High-cost equipment Not compatible with all languages Tool wear with certain plastics

The selected material for the housing is nylon and polyoxymethylene for the stem. The selected process would be injection molding. Injection molding is the preferred method as it is compatible with the selected materials and can give the high precision and details of the parts. The housing of the switch/key has many intricacies that need to be met.

Polyoxymethylene was chosen for the stem as the component plays a crucial role in the functional aspect of the key. Due to its mechanical properties, stiffness, strength, and resistance to wear it was the selected thermoplastic for the stem. As the housing would require less consideration in terms of mechanical properties compared to the stem, nylon was chosen for the housing. It is still advantageous in terms of cost effectiveness, weight, chemical resistance, impact resistance, and strength.

Magnets

Maglevs are typically designed by using Superconducting magnets, Electromagnets, and permanent magnets. Superconducting magnets are not used in consumer devices. Either electromagnets or permanent magnets can be used in this case. For simplicity, permanent magnets are used in order to levitate the keyboard key. These permanent magnets will not be manufactured but externally sourced with customization to obtain the flux and intricate dimensions needed.

Table 8 Type of Magnets (Hold, 2024)

Type	Features
Rare earth magnets (Samarium Cobalt. Neodymium Iron Boron)	Very strong magnets
Alnico magnets	Temperature stability High magnetic flux density High resistance to corrosion
Ceramic magnets	High resistance to corrosion Resistant to demagnetisation Cost effective

Table 9 Properties of the magnetic Materials ("Permanent magnets design guide | Magnetics design guidelines," 2024)

Type	Alnico	Ceramic Magnets	Rare Earth
Residual Induction (mT)	720-1300	230-410	830 - 1410
Coercive force (kA/m)	37-150	150-290	600 - 1000
Intrinsic coercive force (kA/m)	38-150	230-380	560 - 3260
Density (g/cm3)	6.9-7.3	4.9	0.27-0.30
Tensile Strength (Pa x 10^6)	28-450	34	35-81
Hardness (Rockwell C)	45-55	7Mohs	
Coefficient of thermal expansion (10^{-6} $per\ C$)	11-13	-	4.8-13
Curie temperature (C)	810-860	450	310 - 825
Max service temp. (C)	450-550	800	150 - 350

For the magnet, the chosen type would be a rare earth magnet. Rare earth magnets are generally more cost effective but due to its higher energy density (Dura Magnets, 2014) and higher residual induction it is the preferred type as the size of the magnet in each key is very small and will need to be strong in order to function as intended.

Detailed Drawing of Components

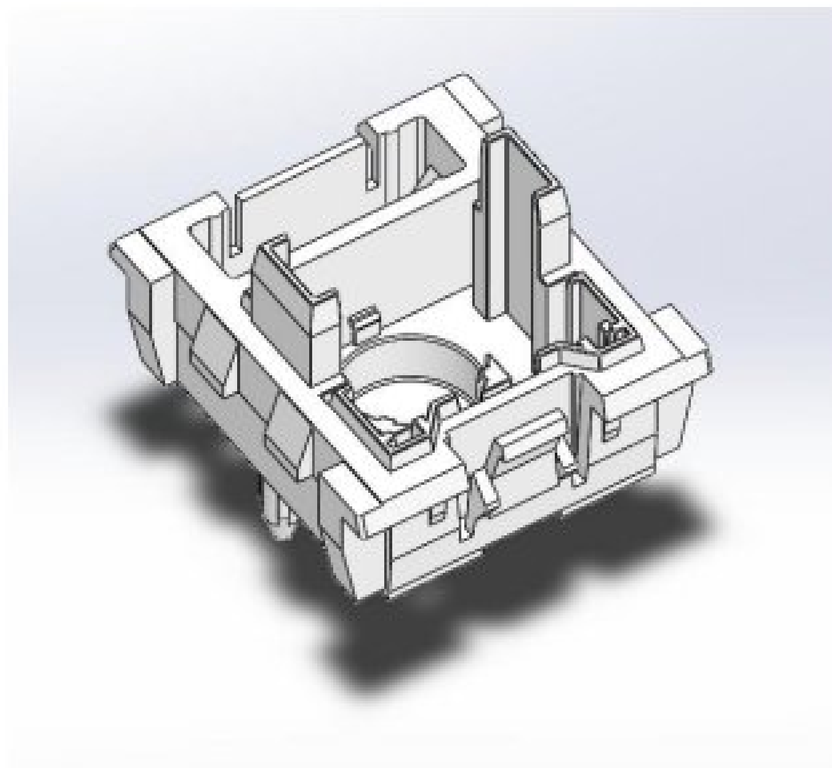

Figure 1 Housing

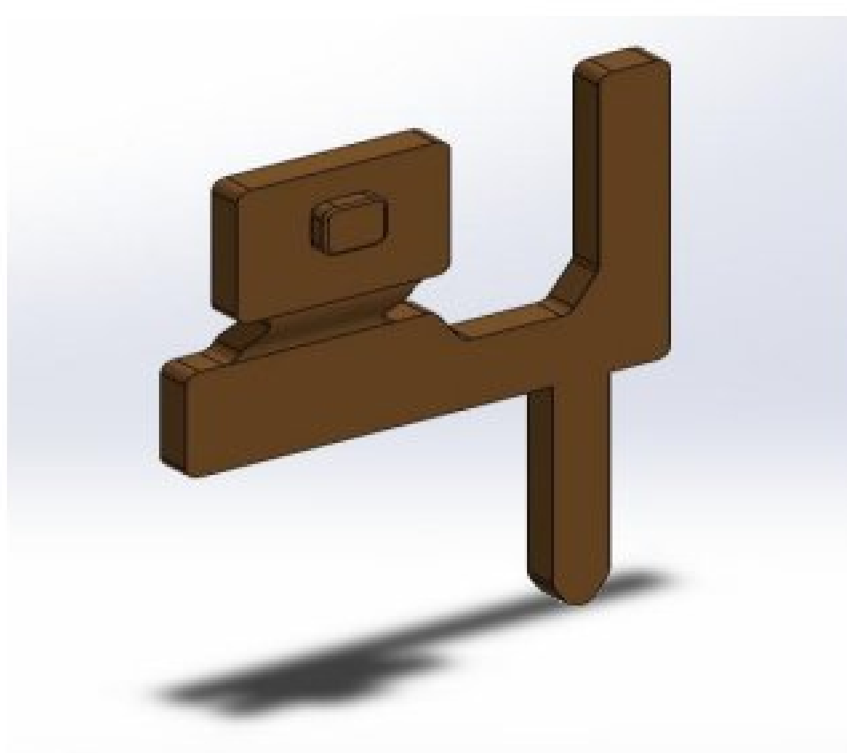

Figure 2 Thick Metal Contact

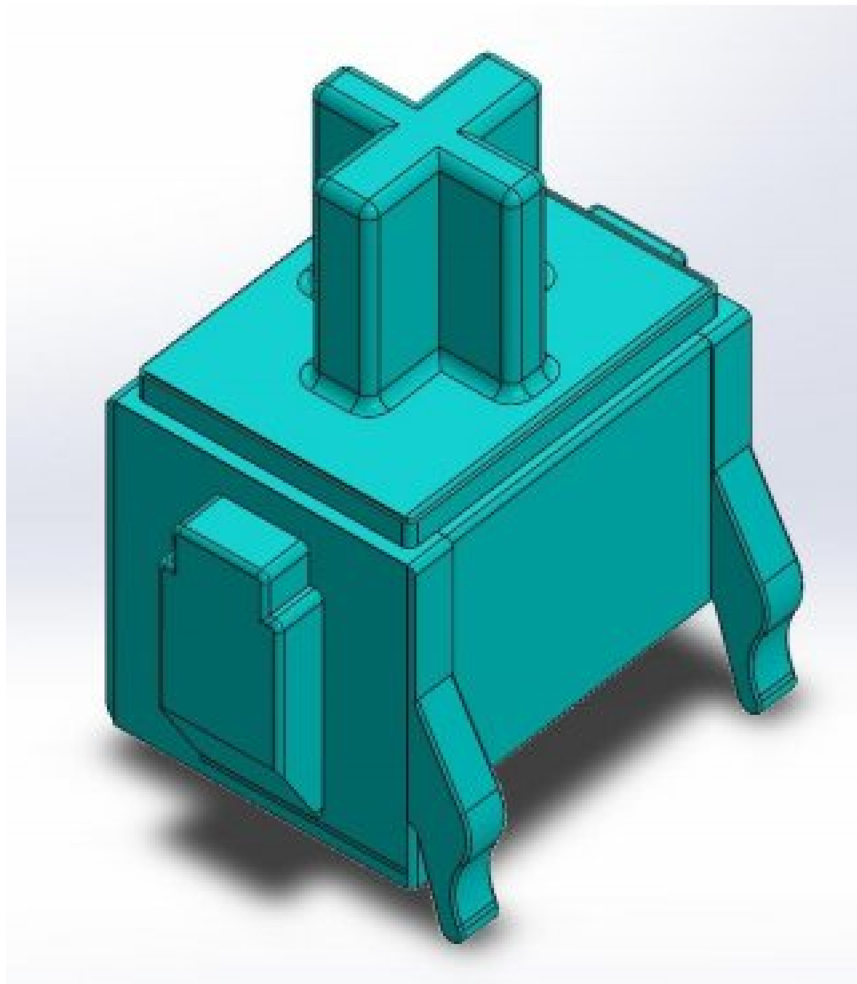

Figure 3 Stem

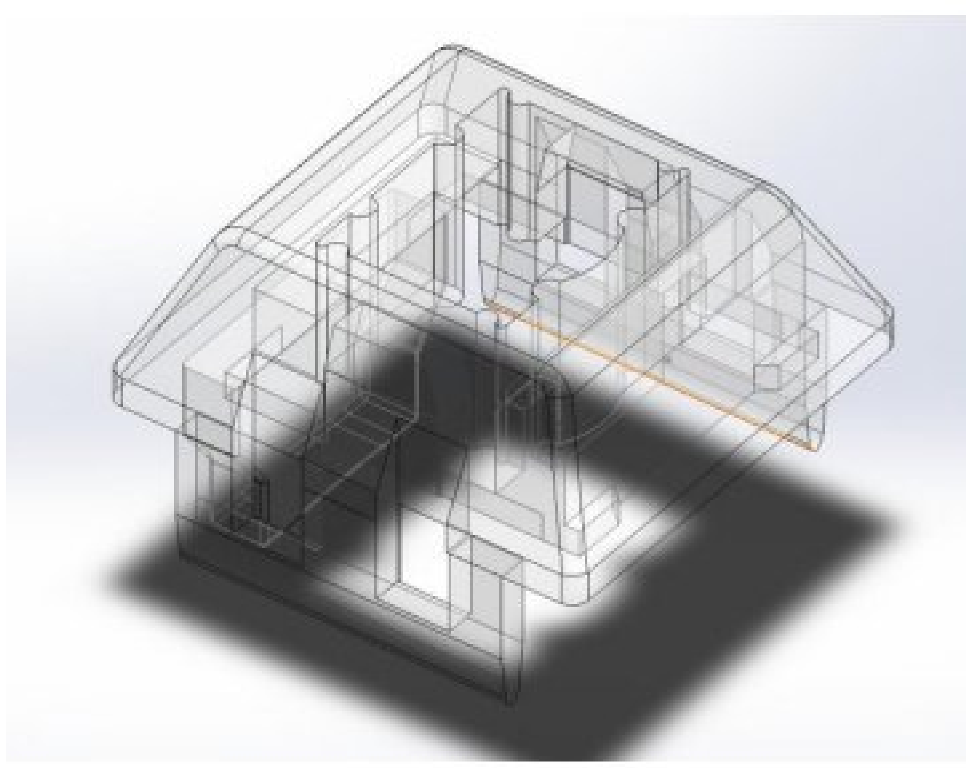

Figure 4 Lid (Top Housing)

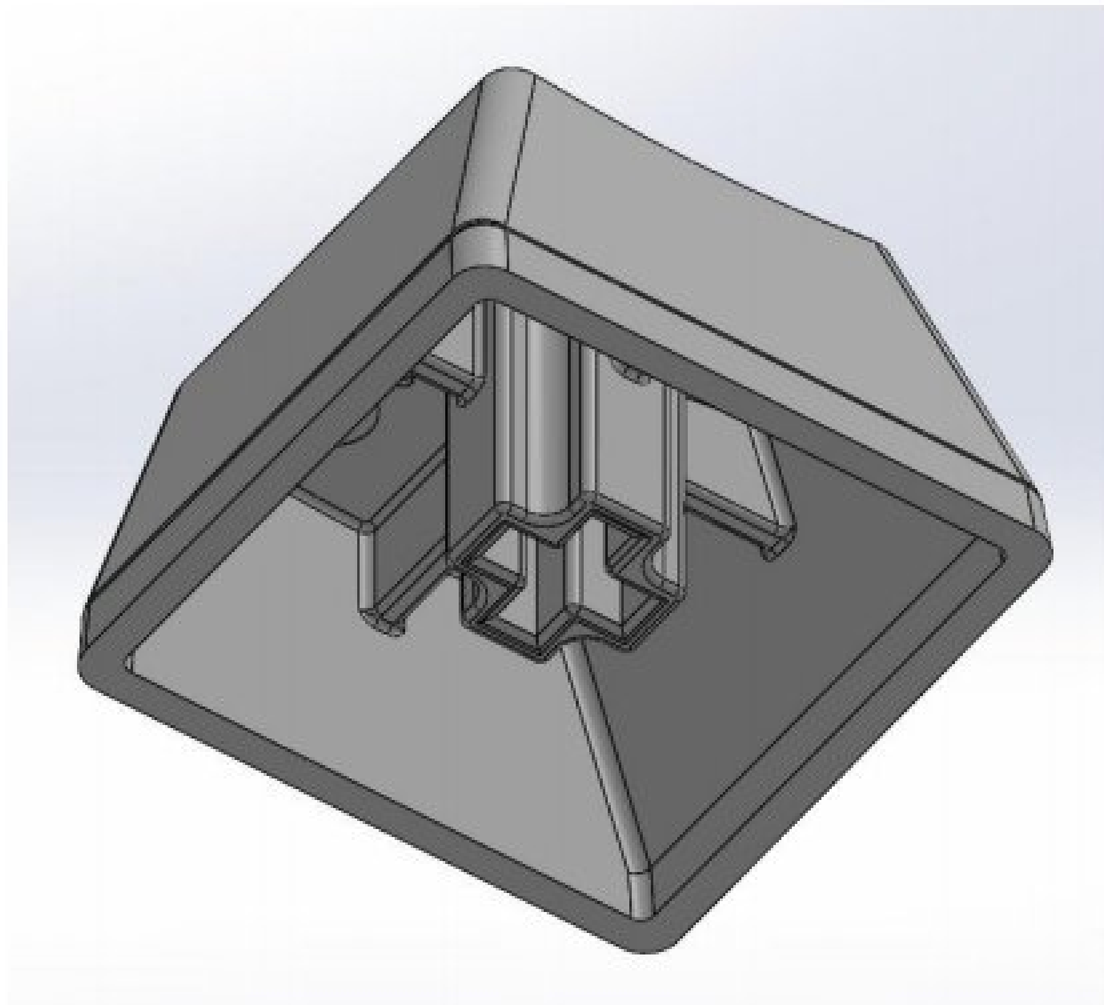

Figure 5 Standard MX Profile Keycap

Figure 6 Disc Magnet

*All detailed drawings for the main components and the full exploded view assembly are attached in the appendix.

Support System and Processes

Supply chain management

The manufacturing supply chain encompasses the entirety of the procedures employed by a company to transform raw materials into finished goods, which are then prepared for sale to consumers. These operations encompass the purchasing of raw materials, the manufacturing of products, the monitoring of quality, the distribution of goods, and the provision of after-sales support. A firm with a disjointed or ineffective supply chain is less likely to adapt to fluctuations in consumer demand, resulting in extended backorders or delayed delivery for customers. In the current fiercely competitive industry, where fast shipment is guaranteed, it is crucial to have efficient supply chain management at every level to ensure optimal manufacturing and minimal waste. In order to do this, several enterprises have altered their production strategies by transitioning from conventionally isolated activities to an integrated and comprehensive perspective of the supply chain. This is frequently achieved by utilizing contemporary technology and automation to obtain comprehensive insight into each individual stage. [2]

Supply chain in mechanical keyboard switches manufacturing

Mechanical keyboard switches are usually made from several components such as plastic housings, springs, and metal contacts. An efficient supply chain is essential especially when managing these different parts. The manufacturer of the switches often gets parts and the material from all over the world. The supply chain management (SCM) in this stage cares more about global sourcing and vendor management in order to find the trusted providers, negotiate contracts and to keep the quality high all along the manufacturing processes.

The inventory management is important to make sure that there is availability of the optimal quantity and specific variety of raw materials and components at the exact moment they are required. This strategy aims to reduce the expenses related to maintaining surplus inventory while also avoiding production delays caused by shortages. (Perks & Delport, 2023)

In addition, supply chain management requires a knowledge of and management of the industrial capacity. In order to achieve production targets without exceeding the available resources, this comprises planning how to make use of the workers, the facilities, and the machines. In order to maximize output while minimizing expenses and without straining resources, it is necessary to locate the sweet spot when production is operating at its maximum potential.

In order to properly manufacture mechanical keyboard switches, it is essential to reduce the amount of waste that occurs along the supply chain. Increasing both efficiency and environmental responsibility may be accomplished via the use of sustainable waste management strategies. Recycling materials from failed switches, implementing lean manufacturing to limit extra material consumption, enhancing quality control to lower the incidence of defective goods, using environmentally friendly packaging, and adopting energy-efficient manufacturing processes are some of the activities that fall under this category. These techniques not only contribute to the reduction of costs and the enhancement of operational efficiency, but they also fit with larger environmental goals.[4]

Quality control

Quality control, which is one of the most important supporting processes, occurs directly after the assembly process is finished. The quality control includes many processes that should be implied for each button to ensure that it meets the specification [1]. The process involved in quality control are as follows:

1. Visual Inspection: The visual inspection usually starts at an early stage to investigate the raw material involved in the manufacturing and to ensure that all the raw material meets the specifications. After the assembly is completed, the visual inspection takes place to check the physical appearance of the switch and check for any imperfections in the switch.

2. Electrical testing: the electrical testing is applied to each switch to ensure that it works correctly in terms of the distance it has to go when it is actuated and also to the time it takes to apply the command.

3. Force testing: This involves pressing the switch multiple times using different forces to know the maximum force that the switch can withstand

4. Durability testing: this involved applying repeated actuation to ensure that the switch can withstand repetitive pressings without experiencing any failures.

5. User testing : The last stages in the quality control process to give some users a keyboard that contains the switches to test it. This process is very crucial as it represents some insights into the practical performance of the switches. Users are asked to provide feedback on some features.

Data Analysis

Through the use of data analysis, it is possible to make predictions about the performance and durability of various switch designs. The ability of manufacturers to develop their designs in order to better suit the expectations of the market may be achieved via the analysis of past data on switch performance and user preferences. The simulation of various switch designs under a variety of settings is made possible by advanced data analysis, which assists in the identification of potential problems prior to the development of physical prototypes. Integrating data analytics into supply chain planning aids in risk mitigation by identifying potential risks and disruptions early. These insights allow for the development of data-informed contingency plans, resulting in a more resilient and adaptable supply chain that can withstand challenges [5]

Predictive analytics considers various factors, such as historical sales data, market trends, and external influences, to generate more accurate demand forecasts. Thus, this helps businesses anticipate customer needs and respond to changing market conditions effectively. (Falatouri et al., 2022)

Using machine learning for supply chain optimization in the specific domain of mechanical keyboard switch manufacturing can result in substantial advantages. Manufacturers can achieve more precise predictions of client requirements for various types of switches by using machine learning to improve demand forecasting. This enhances inventory control, minimizing the occurrence of overstock or inventory shortages, and decreasing warehousing expenses. Moreover, machine learning has the capability to optimize automated replenishment systems, guaranteeing effective stock management and prompt availability of switches. Furthermore, it improves supplier management by effectively recognizing potential hazards and optimizing the selection of suppliers to ensure reliability.[5]

Process sequence

I. Key cap

The first step in manufacturing keycaps is the design process using CAD softwares to come up with the digital design that will be used later for printing. The digital file includes shape and dimension. In the keycap profile, things begin to become a little more sophisticated than they were before. When we talk about the keycap profile, we are referring to the overall shape of the keycap. Some keycaps are flat, while others are rounded, and there are also many distinct shapes. It is possible to get a concave or sloped form over the full keycap set by using particular styles in which each row of keys has a varied height. You can take the look and feel of your keyboard to a whole new level by altering the form of your keycaps. This gives you plenty of creative freedom.

Figure 7 Side view of profile types (Harrington & Harrington, 2021)

Material selection comes after the design process. We have two main materials that are usually used to make the keycaps, which are ABS (Acrylonitrile Butadiene Styrene), PBT (Polybutylene Terephthalate), and resin. Each type has a different feel, sound, and look. ABS keycaps are the most prevalent and relatively inexpensive type of plastic. Due to the ease with which they may be injection molded, ABS keycaps are manufactured in large quantities. PBT plastic is not as widely used as ABS plastic, although it is often of a higher quality. On the other hand, resin offers great advantages when compared with ABS and PBT. Resin, when used in 3-D printing, can achieve higher resolution and finer details. Resin-based products have a smoother surface, which is very needed in the keycaps.

Additive manufacturing (AM) is used to make the keycaps. It is a layer-by-layer fabrication. The 3D printing technology used is stereolithography (SLA) because it is more suitable for the resins

The process of 3D printing is followed by post-processing procedures, which include cleaning and the removal of any excess material that may have been present while printing.

II. Magnet

The magnet is considered an improvement on the existing switch as it will replace the spring, which has some limitations. The process of creating magnets involves melting raw materials in an induction melting furnace in a vacuum or inert atmosphere. The alloy is reduced to a fine powder after melting; this powder has the potential for combustion when exposed to air and must be kept away from oxygen. In order to compact the powder, there are a number of different approaches, but they all include arranging the particles such that the magnetic areas face a specific direction. Axial or transverse pressing is the initial technique. In this procedure, punches are used to compress powder that has been deposited into a chamber within a press tool. Prior to compaction, which locks in the alignment, an aligning field is added. Because the powder particles are longer and thinner when transversely compressed, the resulting energy product is higher, and the alignment is better. As for the second option, isostatic pressing, which involves sealing a flexible container with powder, applying an aligning field, and then placing the container into the press, is a viable technique. The exterior of the sealed container is compressed uniformly on all sides by applying pressure. This technique produces the most energy while allowing for extremely large blocks (up to 100 x 100 x 250 mm) and keeping them in good alignment. [9]

After sintering, the magnet is machined in order to obtain the required measurements and shape. The machining can be done by grinding the sintered magnet so that it will become smooth and parallel

III. Housing components(Bottom housing, lid) and stem

One of the most important components in the switch is the stem, as it makes the switch linear and clicky. The stem and component housing usually follow the same manufacturing technology, which is injection molding. The manufacturing processes for both follows the same sequence.

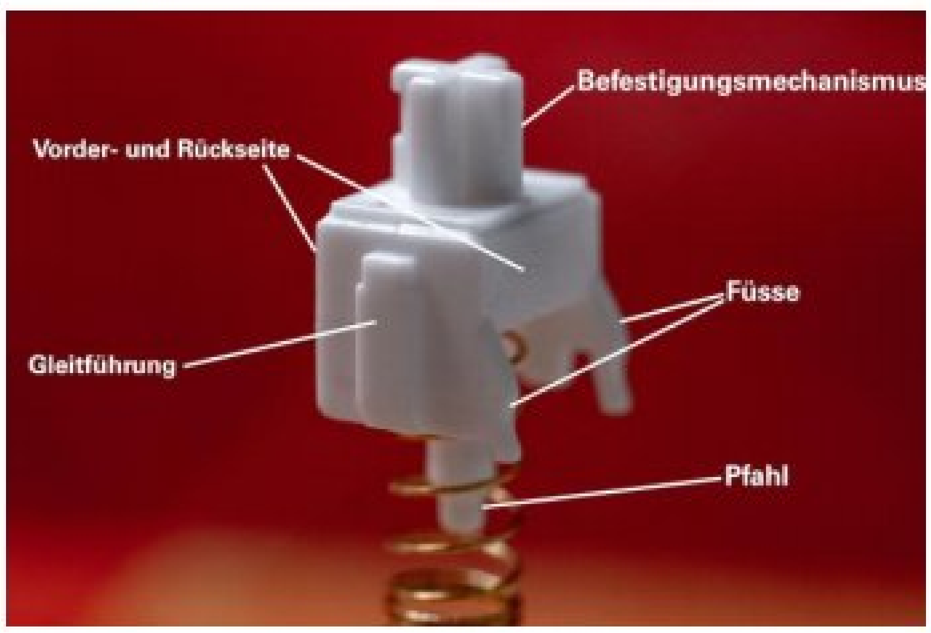

Figure 8 Stem. (Hofer, 2022).

The manufacturing sequence starts with the material selection, which will be polyoxymethylene for the stem and lid, and nylon for the top and bottom housing. Followed by creating 3D CAD designs that contain the shape and dimension of the stem and housing. It is preferred if a prototype is created after this process to check for any limitations that might appear in the physical product. After the 3D design modifications, the molds are created by using precise machining, in which a metal block is carved to the shape of the stem and housings. Precision and accuracy are highly needed for the mold.

Figure 9 injection molds for the housings. (Keebs, 2023).

Immediately following the creation of the molds, the molten plastic will be positioned inside the molds and then subjected to a significant amount of pressure. Once the plastic has reached the temperature for which it was designed, the finished product will be removed from the mold.

Tooling facilities and costs

Observing the manufacturing process as listed previously, the primary process for the keycap is SLA (Stereolithography, which utilizes a laser to cure a photopolymer resin into hardened plastic. Although the manufacturing could be done using other processes such as SLS (Selective Laser Sintering), producing similar results, SLA provides the highest resolution of parts with the best accuracy and has a very versatile material selection, hence the keycap material itself can be customized. The tools required to manufacture the keycap are an SLA printer, typically this can be done in-house or outsourced to a 3D printing-warehouse to streamline the production process as more than one keycap at a time can be printed. Below is the printing costs for a unit keycap.

Table 10 ("costs of SLA vs SLS 3D printing - Which offers better value?," 2023)

Estimated Printing Costs / Unit (RM)	***10 ~ 20***
Estimated Printing Costs / Keyboard (RM)	**200 ~ 250**

The costs listed above take into consideration the time required for printing, the labor cost, and the resin material cost to print a standard keycap. If, however, a more textured keycap is required, the cost is naturally higher. Examples of such keycaps can be seen below, done using the SLA process.

Figure 10 3D printed Custom Paw Keycap [7]

Figure 11 KeyCap Custom Hand Painted Keycap [8]

Following the keycap, most of the components are also made of plastic, hence it is possible to manufacture them through SLA printing, however it is not economical. For standardized parts such as housing, axis, lid etc. The best manufacturing method is injection molding, as these parts are hidden from the user and do not require an excellent surface finish. They must be functional and durable, as such injection molding will allow mass-production since all housings and keyboard sizes are typically standard or very well categorized, there isn't much need for customizability.

As injection molding is considered the equipment cost regarding mold quality is critical. If a high production volume is expected the mold quality must be durable enough to sustain hundreds of cycles of molding without losing any details and retaining design characteristics. Hence, considering the ideal mold type, it could be manufactured using CNC machining, 3D-printing or EDM (Electrical DIscharge Machines). Assuming a low volume mold is used, made using SLA process, furthermore, approximating the labor and time costs and factoring in the cost of the material, the estimated costs are as tabulated below.

Table 11 ("How to estimate injection molding cost?," 2024)

Factors	***Estimated Costs (RM)***
3D- Printed Mold	**200 ~ 400**
Material Cost / Kg	**10 ~ 15**
Labor/Services (per hr)	**40 ~ 50**

Assuming the process is outsourced, the labor and services cost will exceed the estimation as shipping and storage must be considered, however, to simplify the cost analysis, it is assumed that the manufacturing is done in house and the costs only include minimal labor and service. Furthermore, an injection molding machine is assumed, however if it is not available it would be economical to outsource the process to a manufacturing house as the injection molding machine is far too costly to consider in cost analysis for niche productions.

If a CNC process is used to manufacture a metallic mold as shown previously, the cost will differ greatly as the mold quality will surpass the required detail. Furthermore, the CNC tooling, maintenance, and operation cost would need to be approximated for the mold. Hence, as the mold is manufactured through machined aluminum, it can cost around 3000~ 4000 RM.
As the molds are manufactured through CNC process, the surface finish is excellent and does not need much post-processing, aside from cleaning due to metal chips.

Lastly the Mag-Lev Keyboard naturally requires magnets to support its mechanism. However, these magnets are not typically manufactured, rather they are bought in bulk in their natural state as they are ferromagnetic. This is followed by a process to align them with the spacing available and lastly, they are permanently magnetized. Though this process is time-consuming it results in the strong magnets that last long within the keyboard assembly. Although there is a possibility that within a few years' time the magnets will weaken and require replacement.

Currently the best choice for the magnet are neodymium strong strength magnets typically used to fix picture frames or for other odd works. These vary in size and typically are circular in shape, The magnets are small, but output a very strong magnetic force capable of holding objects far bigger in comparison. Overall, a neodymium magnet is not costly and can easily be bought from mass manufacturers for the price listed below

Estimated Costs/ 10 unit (RM)	***5 ~ 10***

Overall, in comparison to traditional spring-loaded keyboards, the cost of a singular customized mag-lev keyboard is far higher. However, the capability of the magnetic keys to produce a unique sound is deemed worth the extra costs. Similarly, digital manufacturing allows further customizability in this regard and allows users to fabricate keycaps according to the sounds they want, as well as any aesthetic they want to follow.

Functional Model

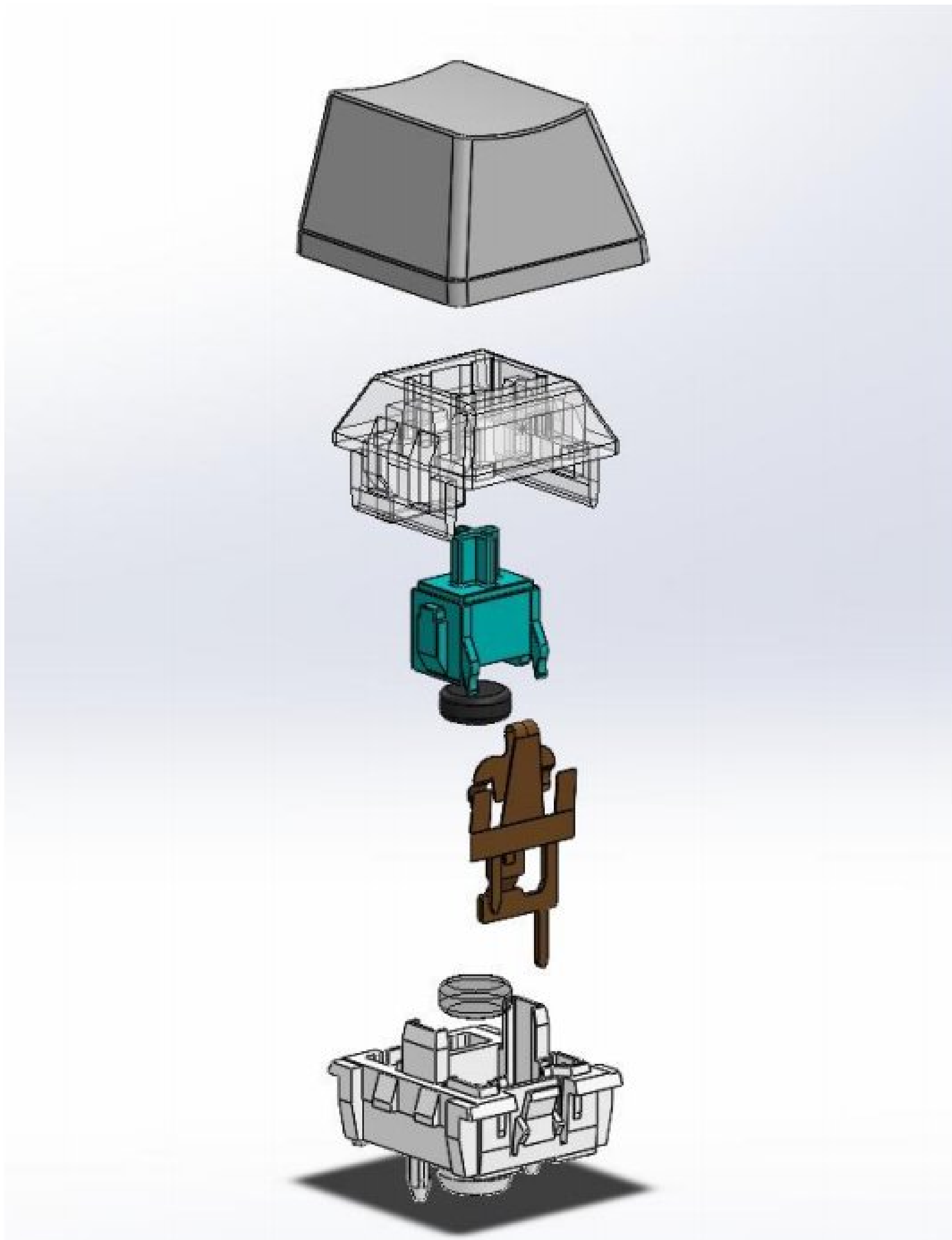

Figure 12 Full Exploded View

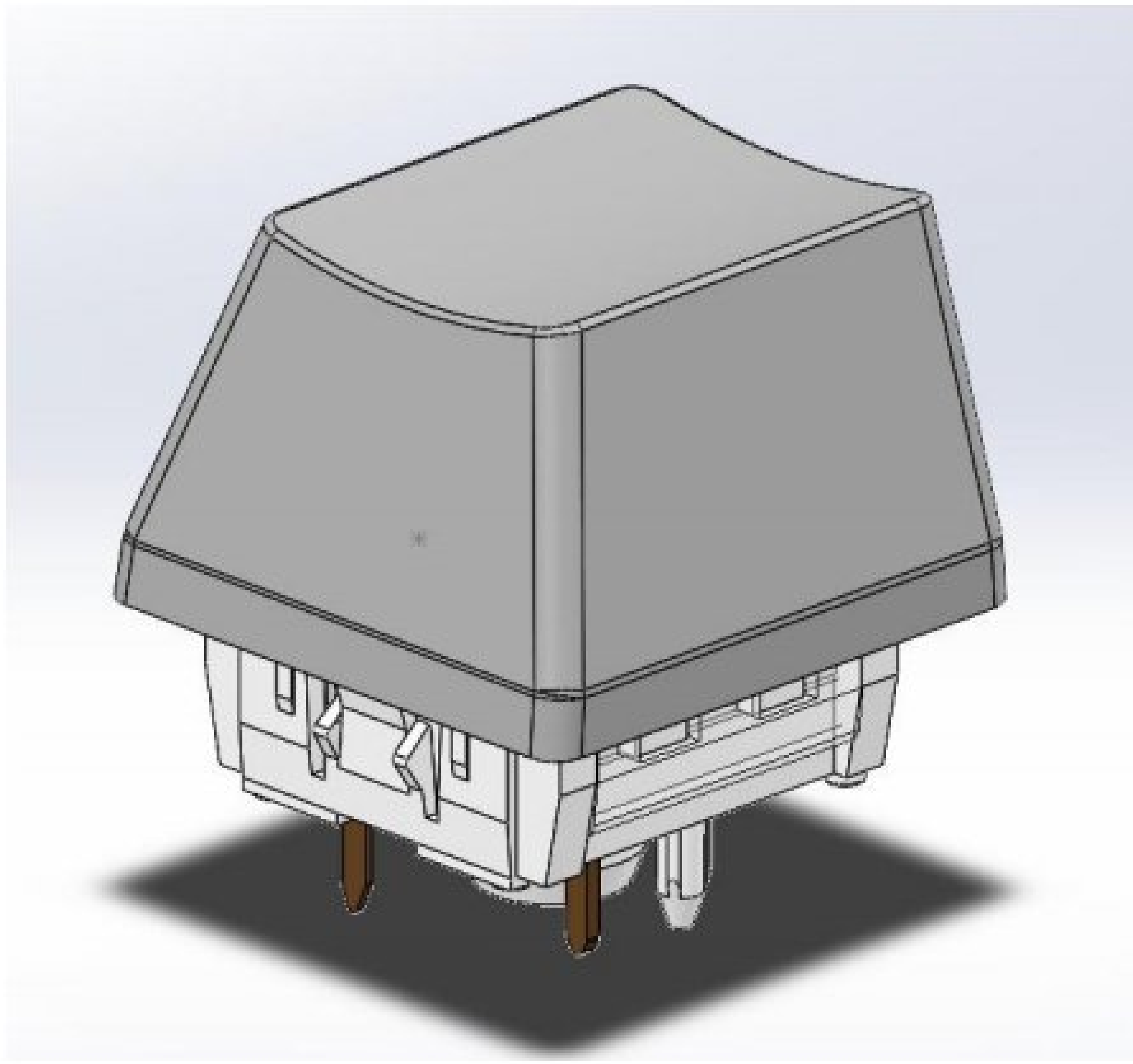

Figure 13 Fully Assembled Key

Note: Extended drawings are attached in the appendix, and an additional animation video is provided.

Discussion

The overall motive of this case-study and project was to analyze the integration of a new and innovative technique to apply customizability in objects used readily by many across the globe. Ways to include personalized aesthetics and acoustics provide individuals with an opportunity to express their preferences and to expose a niche market dominated by enthusiasts that propel towards technological advancement in their own industry using creative ways.

Innovation is a necessary part for the evolution of products. The introduction of the concept of using magnets in the production of keyboard switches has revolutionized the industry, opening the door to further innovation in the keyboard market. One might argue the point of replacing the conventional springs found in most mechanical keyboard switches nowadays; however, the use of the repulsive nature of same pole facing magnets allow for another level of user customizability and smoothness. An experience that is difficult to replicate for spring depressing switches. This innovation adds value to the product; increasing its functionality and satisfying hobbyists and video-game professionals who take the feel and responsiveness of their keystrokes seriously.

As aforementioned, this newly-developed type of keyboard switches depends on the repulsion of two disc magnets to depress the stem piece, hence the keycap. The disc magnet in the stem is secured by the combination of glue and stopper tabs designed to prevent the urge of the magnets to flip to their opposite polarity.

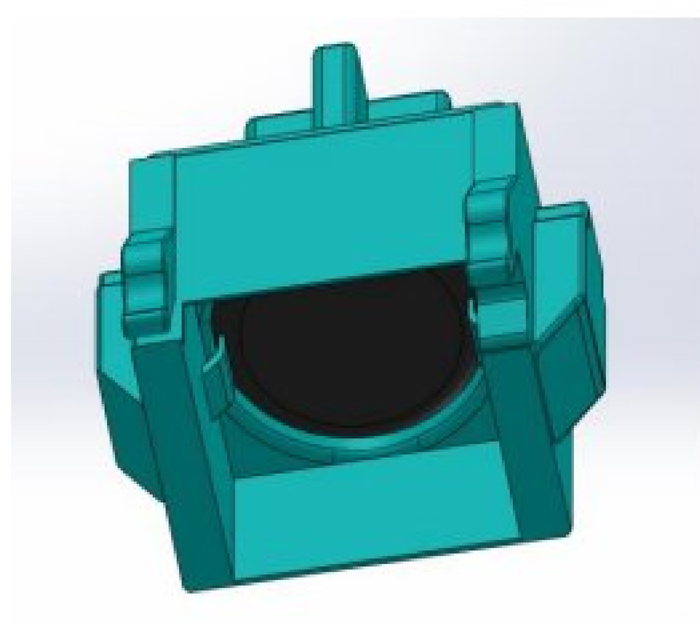

Figure 14 Magnet (black disc) secured inside stem (teal).

The other disc magnet is lodged in the housing, aligned with the stem movement axis. The model built for this project's case study uses the standard (thick and spring contact making the positive and negative poles) metal contacts to form a connection in the circuit, and hence register a key press. However, a hall effect sensor is used to better harvest the full potential of this design. The sensor is used to measure the magnetic flux density that varies as the magnets come closer or go further from each other during a key press. This sensor connects to the keyboard pcb and the analog signal can be used to allow the user to customize their desired actuation point or force in a key press. A "gamer", for instance, might want instantaneous registering of a keypress in some keys while others act normally. This has been backed by many recent hall effect magnetic switch keyboards that have been launched during the last year (2023).

According to Forbes newsletter website reporting on the launch of Keychrones' new HE Q1 keyboard; "the adjustable actuation points provided by magnetic switches allow for faster feedback, dynamic rapid triggering and a highly personalized typing sensation." (Sparrow, 2023)

Furthermore, replacing the normal permanent magnets in the housing with electromagnets allows it to adjust its magnetism by varying the electricity supplied to it. This grants consumers the incredible ability to customize the type of switch they wish to feel by simply selecting it from a software interface. While normally they would have to either buy a whole new set of key switches (and have to stick with it) if the keyboard is hot-swappable - allows for solderless switch replacement - or will have to simply replace the entire keyboard. Moreover, this sheds light on the environmental aspect of this innovation; reducing the production of plastic waste that is often non-recyclable by limiting the number of keyboards a person might need.

Digital manufacturing, which is also called Industry 4.0, signifies a change in some framework designed and manufactured by people as a product, being produced and distributed to the market. One of the main things that lies under digital manufacturing is modern technologies that are used, which include automation, artificial intelligence, additive manufacture (3D printing), and data analytics that help in an efficient operational process. But what exactly is the point of doing it this way, and why is it so crucial in today's competitive landscape?

In the first place, digital manufacturing is tailored to an exceptional degree of flexibility and personalization. A variety of limitations in terms of available product designs and customization is common with traditional manufacturing processes at the same time heavily based on standardized mass production. In digital manufacturing procedure, however, companies can adapt their production lines very easily in a bid to satisfy individual customer's approach. With such a high level of customization, not only will customer satisfaction rise but also new markets open up their doors.

In a business world that is moving fast, the ability to go from product ideas people wanted right up until the market shelf in good time determines success or failure. The availability of digital tools permits quick prototyping and iterations that make it easy for industries to evaluate and formulate their products faster than what used to be before. This type of agility is paramount for the survival of a business as successful products and market share are dependent on responding to competitive pressure and shifting consumer behavior.

In addition, digital production leads to cost productivity. Through the optimization of processes and eliminating waste, companies can save money while producing the same quality goods or even achieving a higher quality. Also, automation minimizes the reliance on manual labor; a reduction of labor costs and an upgrade in production are achieved at the end. The cost savings can then be allocated back to other innovation projects, thereby creating a continuous cycle of promotion that strengthens competitiveness in the long term.

Furthermore, digital manufacturing elevates the product quality and consistently enhances its reliability. The new process ecosystems that involve advanced analytics and monitoring systems enable companies to capture real-time insights into the production process at every stage, helping to identify problems before they can become serious. This preventative measure not only mitigates the defects' risks but also appreciatively changes to raise the final level of the product performance and sustainability. Therefore, customers can rely on the final product's quality and dependability when it is digitally made.

In summary, the idea of conducting digital manufacturing is simply its unprecedented ability to transform the way in which products are designed, manufactured, and circulated. Utilizing innovative technologies and data-driven knowledge, firms have made it possible to reduce the overall costs resulting from slower turnaround times or poor-quality manufactured products. In the end, what it all comes down to are sources of competitive advantages favoring better customer satisfaction and market sustainability in the fast-paced modern business environment.

Prototyping

Resin printing was chosen for the parts because it offers a higher resolution as the components are small and detailed. These steps were taken after the animation was finished in order to guarantee that there is no intersection between the various components.

Figure 15 Printed Parts

A resin-based printing process was used to create the stem, lid, and housing. The parts, however, had some issues related to tolerance because of the limitations of the printing process. To ensure that each part fits easily and that the movement of the stem is smooth, it is necessary to go through some post-processing procedures, such as sandpapering/filing.

Two magnets in the shape of circles were acquired in order to mimic the levitation. When pressing the switch, the two magnets need to be arranged in such a way that they will repel each other. This will result in a smooth and slightly resistant feeling against the finger when the switch is pressed.

Figure 16 Assembled Switch

Due to the fact that all of the components had to precisely fit into each other, the process of assembly was not an easy one. The first issue that we encountered was that the stem was unable to move because of the limited space available; however, after making some adjustments and processing the stem and the lid, we were able to move the stem. All of the components were able to be assembled into one another, and it was able to move without any obstructions. It has been demonstrated that the use of magnets is effective in terms of the ease of pressing, which is easy when pressed frequently and quickly returns to its initial position.

Conclusion

The case study explored in this project has certainly allowed for the discovery of new perspectives when it comes to the manufacturing of consumer products in niche markets. Specifically, the innovative ideas that bring about unique products, and the brilliant techniques that allow these innovations to come to life. Although many might consider a mag-lev keyboard to be a redundant invention, or perhaps a silly obsession with aesthetics, the reality is that it provides an extra layer of customizability to computer peripherals that hadn't ever been considered. It could be said that this application of digital manufacturing does not meaningfully impact society, or rather it doesn't shock the technological market as a global entity, however, as a niche innovation it fulfills the wishes of its users and developers to provide a custom and pleasing experience in our daily lives. The acoustics of a keyboard may be meaningless to a company with thousands of employees, but for those heavily invested into gaming, computer customization and overall digital work, it might make the difference.

Considering challenges faced in this project, the primary hurdle was to produce a viable prototype, as the 3D-model created was extremely precise, with a thickness of 2mm per side, which was not feasible for various commercial 3D printers due to its complex internal features. Furthermore, the lead time for the production did not meet deadlines. Hence, it was a tedious task to produce a physical prototype of the design to showcase its features.

Overall, the Mag-Lev key switch introduces a new feature in our daily digital peripherals, allowing further customizability of aesthetics and acoustics by incorporating a creative perspective on additive manufacturing technologies that inadvertently proves that societies require creative expression, and an iterative design process that allows interaction at each stage, is a system that is pivotal to creativity in our daily lives.

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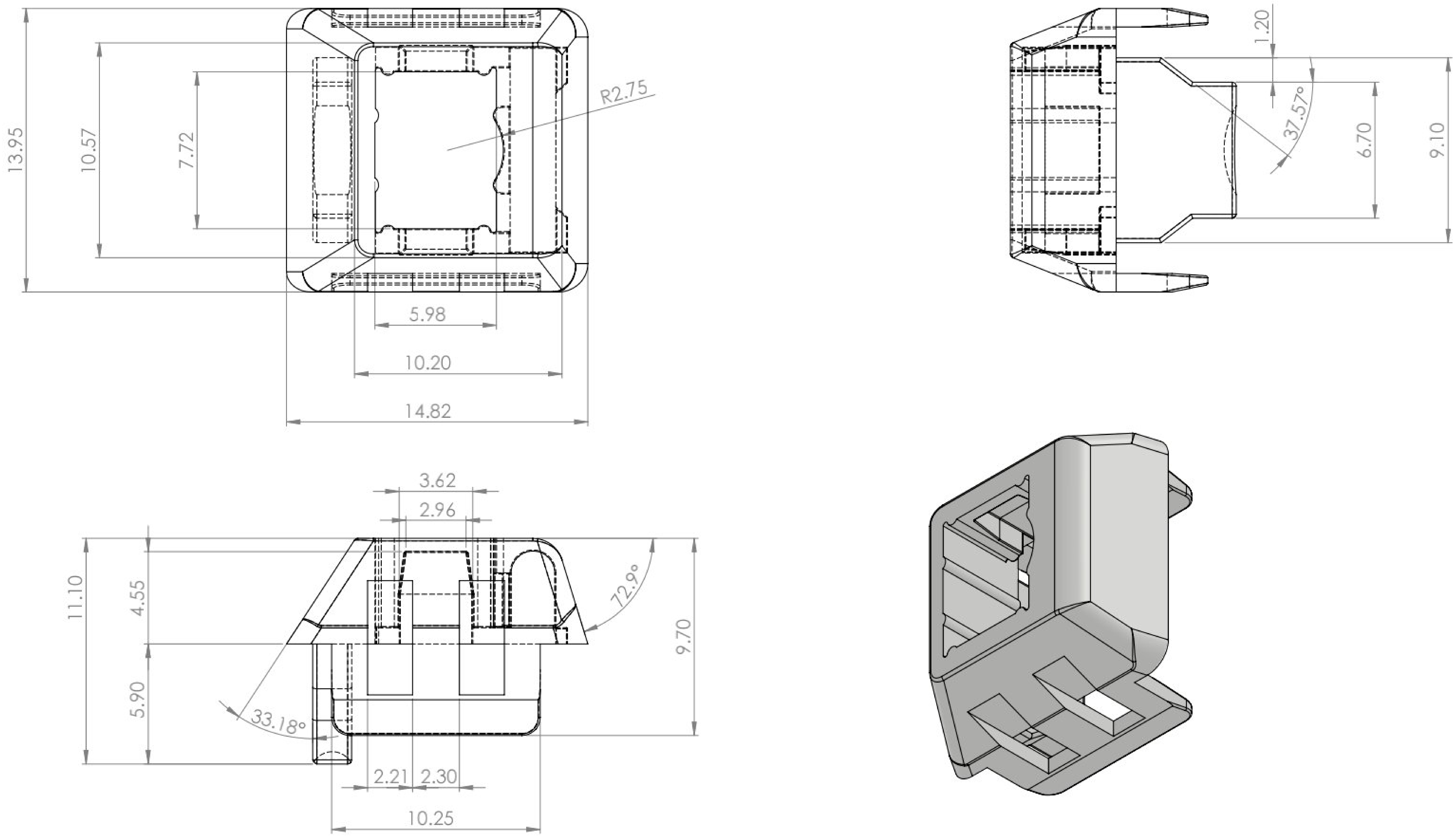
Appendix



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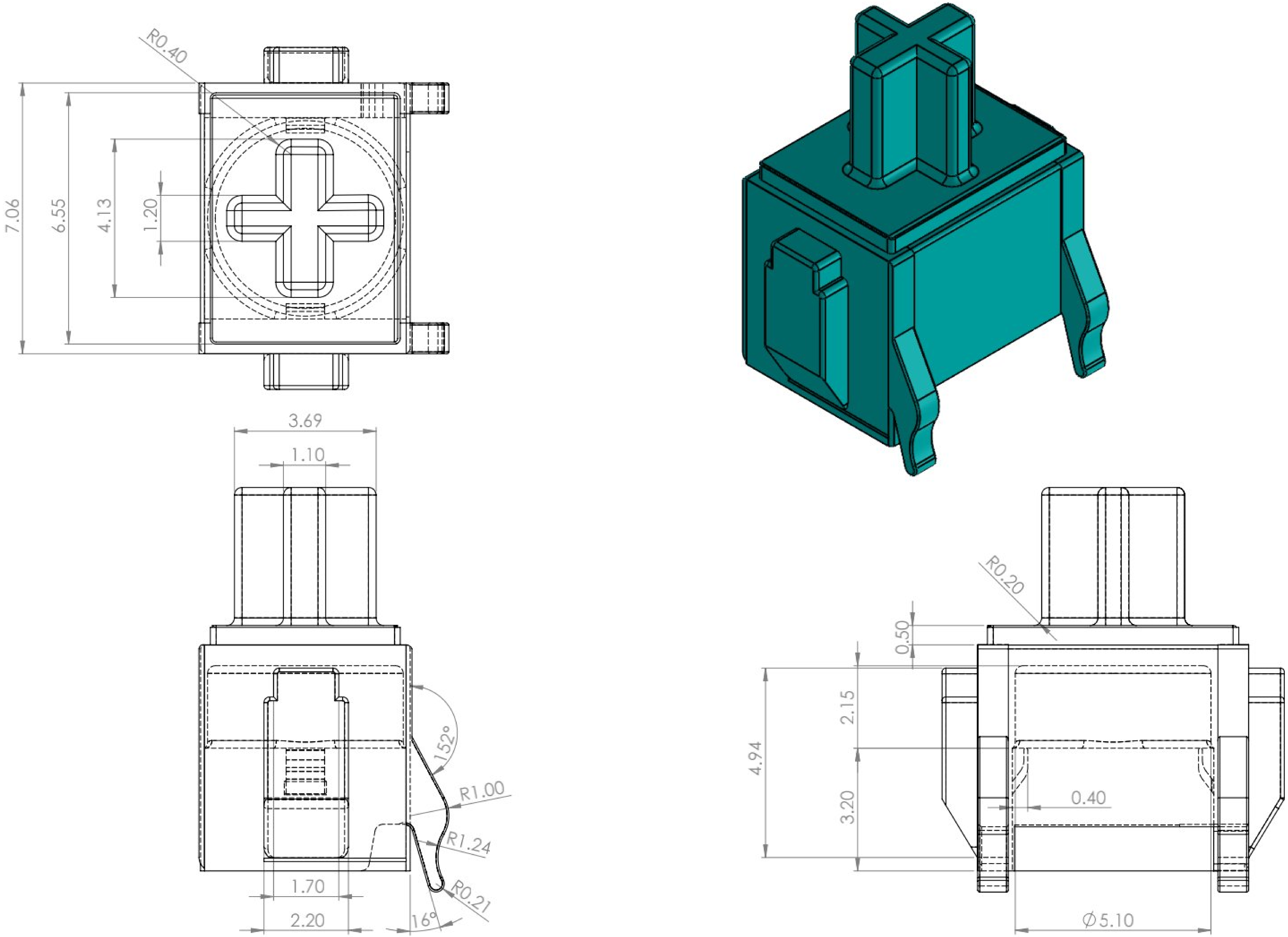

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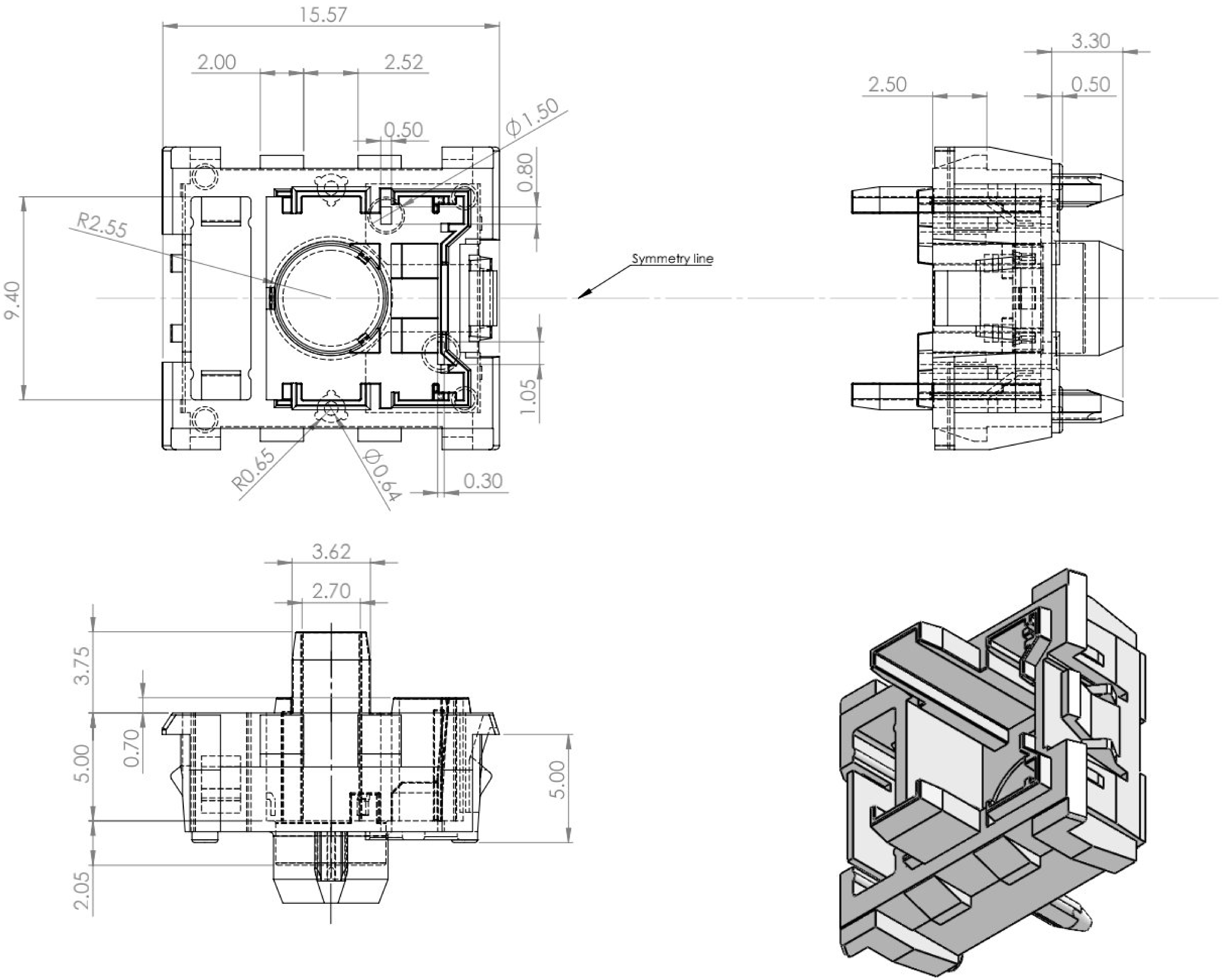

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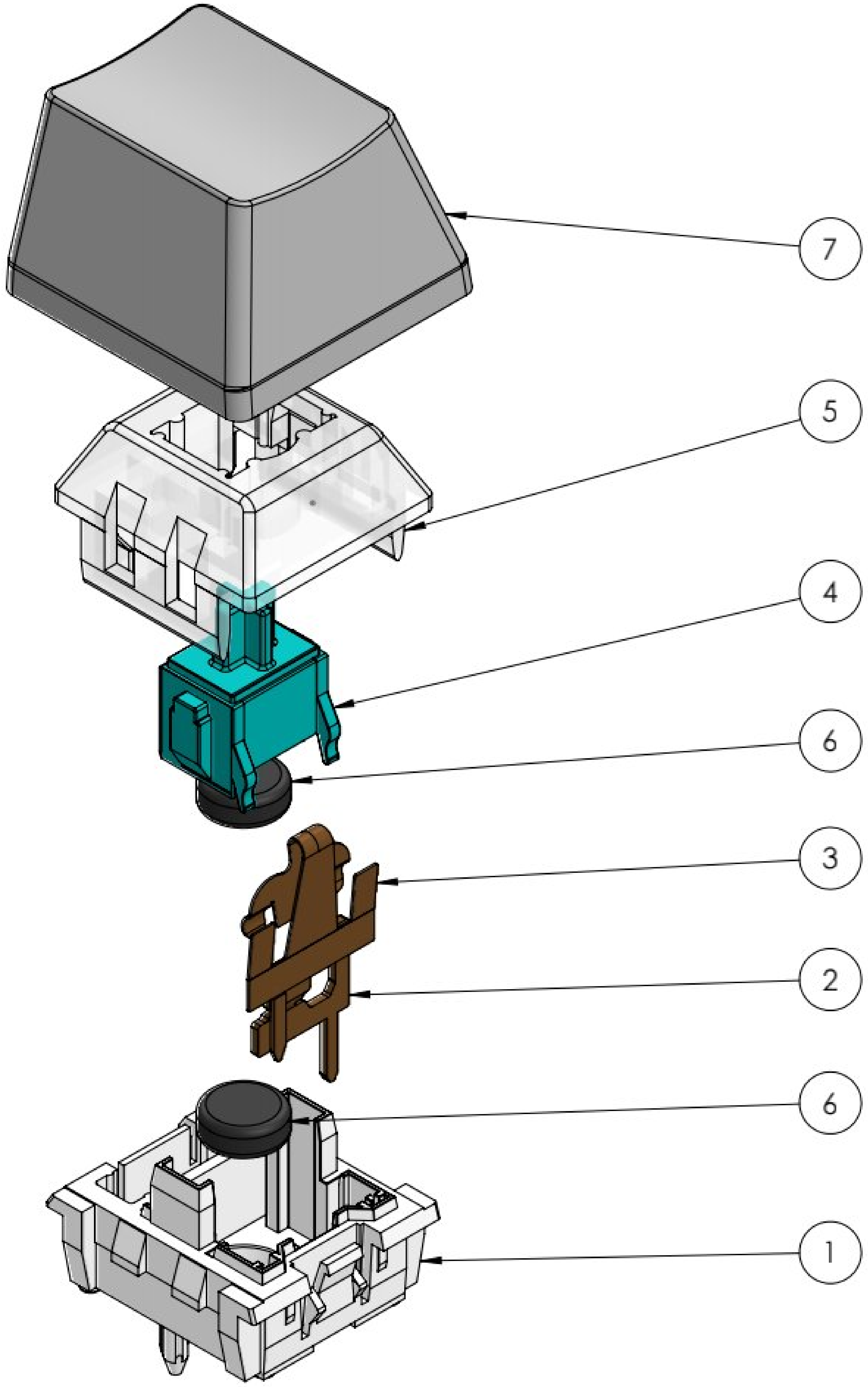

ITEM NO.	PART NAME	QTY.
1	Housing	1
2	Thick Contact	1
3	Spring Contact	1
4	Stem	1
5	Lid	1
6	Disc Magnet	2
7	MX Profile Keycap	1

UTM UNIVERSITI TEKNOLOGI MALAYSIA	UNIVERSITI TEKNOLOGI MALAYSIA SCHOOL OF MECHANICAL ENGINEERING	TITLE: EXPLODED VIEW	NAME: GROUP 9 SECTION: 01	DATE: 31-JAN-2024 SCALE: 3:1