REPLICATION AND PART VALIDATION OF MELAKA HISTORICAL ARTIFACT (PEMURAS) MADE USING SELECTIVE LASER SINTERING (SLS)

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BACHELOR OF MANUFACTURING ENGINEERING TECHNOLOGY
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Faculty of Industrial and Manufacturing Technology and Engineering

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A thesis submitted in fulfilment of the requirements for the degree of Bachelor of Manufacturing Engineering Technology (Product Design) with Honours

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Date	:	10/1/2024

DEDICATION

To my supervisor, Ts.Dr. Syahibudil Ikhwan Abdul Kudus,

To my second supervisor, Encik Mohd Rafi Omar,

To the department of Museum, Perbadanan Muzium Melaka (PERZIM)

To my members of project team , Nur Arif Asyraf

ACKNOWLEDGEMENTS

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ABSTRACT

The purpose of this study is to replicate the melaka historical artifacts made using selective laser sintering(SLS). This research was applied a Non-contact it is a reverse engineering (RE) and powder-based is additive manufacturing(AM) systems to execute this project. The main issues highlighted in this study is replicate the melaka historical artifacts to preserve its original condition. In this issue also to compare the dimensional accuracy of prototype product with the original product of historical artifact. Furthermore, the primary research and secondary research was collected to execute this project. This case study demonstrates the most effective restoration and reproduction techniques for the historical artefact. The data was collected by STL file from captured the scanned object from previous experiment, will go thru pre-processing, post-processing and conversion steps before its fabricate using additive manufacturing system by using method process Selective Laser Sintering (SLS). However, PolyWorks, Solidwork and Materialise Magic software was used to includes filling in holes, removing useless parts, and smoothing the surface. Direct STL file creation from scanned data is helpful to reduce time and mistakes in the modelling process. The quality of the STL data from the T-SCAN scanners was verified by Materialise Magic and Buildstar sofwares to analyse CAD-Part, Part-Part and visual inspection. This research will be focusing on laser sintering process as it will be used in fabrication process. Furthermore, the purpose of this study is to identify the dimensional accuracy of historical Pemuras using reverse engineering (RE) and additive manufacturing (AM). This is to compare the dimensional accuracy of original product and prototype product.

ABSTRAK

Tujuan kajian ini adalah untuk meniru artifak sejarah Melaka yang dibuat menggunakan pensinteran laser terpilih (SLS). Penyelidikan ini menggunakan sistem Non-contact ia adalah kejuruteraan terbalik (RE) dan berasaskan serbuk adalah sistem pembuatan aditif(AM) untuk melaksanakan projek ini. Isu utama yang diketengahkan dalam kajian ini ialah meniru artifak sejarah Melaka untuk mengekalkan keadaan asalnya. Dalam isu ini juga untuk membandingkan ketepatan dimensi produk prototaip dengan produk asal artifak sejarah. Tambahan pula, penyelidikan primer dan penyelidikan sekunder telah dikumpulkan untuk melaksanakan projek ini. Kajian kes ini menunjukkan teknik pemulihan dan pembiakan yang paling berkesan untuk artifak sejarah. Data dikumpul oleh fail STL daripada objek yang diimbas daripada eksperimen sebelumnya, akan melalui langkah pra-pemprosesan, pasca-pemprosesan dan penukaran sebelum ia dibuat menggunakan sistem pembuatan aditif dengan menggunakan proses kaedah Selective Laser Sintering (SLS). Walau bagaimanapun, perisian PolyWorks, Solidwork dan Materialize Magic digunakan untuk memasukkan mengisi lubang, mengeluarkan bahagian yang tidak berguna dan melicinkan permukaan. Penciptaan fail STL terus daripada data yang diimbas membantu mengurangkan masa dan kesilapan dalam proses pemodelan. Kualiti data STL daripada pengimbas T-SCAN telah disahkan oleh perisian Materialize Magic dan Buildstar untuk menganalisis CAD-Part, Part-Part dan pemeriksaan visual. Penyelidikan ini akan memfokuskan kepada proses pensinteran laser kerana ia akan digunakan dalam proses fabrikasi. Selain itu, tujuan kajian ini adalah untuk mengenal pasti ketepatan dimensi Pemuras sejarah menggunakan kejuruteraan terbalik (RE) dan pembuatan aditif (AM). Ini adalah untuk membandingkan ketepatan dimensi produk asal dan produk prototaip..

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LIST OF SYMBOLS AND ABBREVIATIONS

BDP	-	Bachelor Degree
AM	-	Additive Manufacturing
RE	-	Reverse Engineering
RP	-	Rapid Prototyping
CAD	-	Computer Aided Design
SLA	-	Stereolithography
SLS	-	Selective Laser Sintering
3D	-	Three Dimensional
2D	-	Two Dimensional
FDM	-	Fusion Deposition Modelling

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CHAPTER 1

INTRODUCTION

1.1 Research Background

The purpose of this research project is to replication and part validation of Melaka historical artifact (Pemuras) made using Selective Laser Sintering (SLS) and study the dimensional accuracy of a historical artifact of Pemuras and identify the built quality of the prototype version of the artifact printed via additive manufacturing (AM) by method Selective Laser Sintering (SLS). Hence, since the aggrandizing demand of high precision digital reproduction, both reverse engineering (RE) and additive manufacturing (AM) is a perfect combination technology that plays an essential role in replicating historical artifacts.

However, Additive manufacturing (AM) the process is to create a three-dimensional item by employing a computer-controlled programmed to construct successive layers of material. There are two types of 3D printing technologies direct and indirect 3D printing. The primary distinction resides in whether the design is directly produced by 3D printing (direct) or whether 3D printing was used to create the model (indirect).

Thus, cultural relics are increasingly being preserved by 3D printing and scanning in museums and by archaeologists. The preservation of rare, old, or fragile historical artefacts is facilitated by the creation of digital twins via 3D scanning and printing. Modern technology has made 3D capture of historical artefacts, sculptures, weapons, and other pieces of art accessible to curators, academics, and archaeologists. These technical breakthroughs can also help restore damaged cultural treasures and monuments.

3D scanning is the process of looking at a real-world item or environment to get information about its shape and possibly how it looks(Younan, 2015). The information that was gathered can then be used to make digital 3D models. Most of the time, a 3D camera is used to make a 3D model. This 3D model is made up of a polygon mesh or point cloud, which is a collection of geometric samples on the subject's surface. The point cloud digital model of an item can be made using three-dimensional (3D) scanning technology without having to touch the object (Song et al., 2022). The form of the subject can then be guessed from these points. This is called reconstruction energy unaccounted for due to consumer pilferages, faulty energy meters and incorrect billing.

1.2 Problem Statement

The historical artefact is very important to people because it gives them information about the past and gives them order in their lives. Meanwhile, a lot of historical items have been destroyed or lost because of the natural disaster. There are many ways to rebuild or fix up a historical item, but the method used needs to consider the materials used to fabricate historical artifact. Further, certain of the artifacts have complicated shapes or structures, which would make it hard for the conservators to complete tasks on them as well. Additionally, the more time it takes to restore an artefact, the more complicated it is.

Today, technologies like Reverse Engineering (RE), Computer Aided Design (CAD), and Additive Manufacturing (AM) are used a lot to make copies of broken historical artefacts. Additive manufacturing is processing gives designers a lot of design freedom and makes it possible to make parts with complicated shapes that would be impossible to make with other methods (Babuska et al., 2020). However, optimizing the digital model for 3D is important that once the digital model is obtained through 3D scanning, it needs to be prepared and optimized for 3D printing. This involves tasks such as mesh repair, surface smoothing, and ensuring the model is suitable for the chosen 3D technology and 3D techniques to preserve cultural and historical heritage (Richetti et al., 2022)

Furthermore, the experiment will be conducted using non-contact reverse engineering and a Laser Sintering Machine to replicate a local historical artefact. The objects geometry will be duplicated using non-contact RE, a 3D scanner and the component will be manufactured using a Laser Sintering machine. The final expected outcome of this project is that the surface quality of the manufactured part and the dimension of part will be comparable to that of the original part.

1.3 Research Objective

From the problem statement explained above, several objectives need to be completed at the end of this project. The main objectives of this project are:

1. To develop the CAD data from point cloud using Polywork, Solidwork and Materialise Magic softwares.

2. To fabricate pemuras using Laser Sintering

3. To analyse the dimensional accuracy of Pemuras prototype Part to CAD , Part to Part and Visual inspection.

1.4 Scope of Research

1.4.1 The scope of this research are as follows:

1. To carry out literature search and reviews

2. To carry out cad data by using Polywork sofware
3. To familiarize Reverse Engineering (RE), Addactive Manufacturig (AM) and Computer Aided Design (CAD)
4. To fabricate a prototype by using Selective Laser Sintering Machine (SLS)
5. To carry out a comparison of dimensional precision between the historical artifact object and prototypes.

1.5 Summary

This chapter discusses the history of the project and outlines its three main goals. Since historical artifacts are often fragile and perish quickly, it is best to build and copy them to preserve their original condition and appearance as much as possible. To make it easier to understand the requirements of this project, the objectives and scope of the project have been defined. To meet the projects goals, historical artifacts will serve as experimental subjects. Regarding the strength of dimensional analysis, comparisons between historical artifacts and prototypes will be recorded the dimensional accuracy of surface finish. Chapter 2 will focus on a literature review on Additive Manufacturing (AM), Reverse Engineering (RE), background information on historical artifacts, and computer-aided design data (CAD).

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

In today's world, a historical artifact is an object that was created by humans and has historical significance. Artifacts can be anything from tools and weapons to jewelry and pottery. Artifacts are essential to our understanding of history because they allow to make a direct connection to times gone by. They have the potential to enlighten us regarding the ways in which people lived, worked, and thought in various times and locations. The variety of the human experience can be better appreciated with the assistance of artefacts. Next, there are many ways to preserve its original condition and appearance as much as possible as these can often be fragile and easily damaged. 3D scanning technologies is important method to enable the capture and storage of the shape of physical objects as digital files. Thus, 3D printing technologies also the important way to replicas of historical artifacts that have been lost or destroyed. This can be beneficial for preservation purposes, as it allows future generations to see these artifacts even if the originals are no longer available

2.1.1 Historical of Malacca

In the history of shipping and trade, the Straits of Malacca are a well-known sea area. It is in the middle of Indonesia's island of Sumatra and the Malay Peninsula. It is the center of trade in Asia. As a trade route, the Strait of Malacca is the subject of many studies. People from both sides and people who pass through it meet, which leads to cultural events and trade on the water. Meetings happen often in the port areas along the Strait of Malacca, which has led to the growth of many ports with all kinds of activities in the area. (Nur M.S., 2018)

The story of the city of Melaka (Malacca) begins with the fascinating legendary tale of the Hindu prince Parameswara. The chronicle was envisaged in The Malay Annals (fondly known as Sulalatus Salatin or Genealogy of Kings), that gives a history of the origin of the Malay sultanate spanning from the ancient empire of Srivijaya to the time Melaka was founded. Melaka was the richest entrepot in Southeast Asia. Melaka's history transcends all the way back to the 14th century, from its humble beginnings as a fishing village to its rise as the center of the spice trade known as "Venice of the East". (Pike, 2012)

Melaka's strategic location and reputation among merchants from Arabia, China, India and Japan led to the colonization by the Portuguese, Dutch, British and Japanese empires. Nevertheless, each colonization has certainly left their mark in the historical city of Melaka. Melaka Town and the historic cities of the Malacca Strait have developed through 500 years of commerce and cultural exchanges between East and West in the Malacca Strait. The Asian and European influences have provided the towns with a distinct multicultural legacy that is both tangible and intangible. Melaka, with its government buildings, churches, squares, and defenses, exemplifies the early stages of this history,

In the 15th century, spices were more expensive in Europe, prompting Europeans to seek out their sources. The Portuguese and Spanish attempted to sail to the regions of origin of herbs and seasonings. In 1511, the Portuguese invaded and conquered the kingdom of Malacca. The Netherlands, the United Kingdom, and other nations followed. According to Gusti Asian, the Portuguese established the port of Malacca as a trading center in the sixteenth century, and commodities, products, and services also arrived from the west coast of Sumatra. Prior to their introduction, Islam was the predominant religion practiced by merchants and sailors in the strait. As a result, the Portuguese influenced Islam in the region. (Nur M.S., 2018)

Thus, in April 1511 Afonso de Albuquerque, who was the Portuguese expedition leader together with his armada, arrived in Malacca to sever its Islamic and Venetian trade. The Portuguese launched their first attack on 25 July 1511, but this was met with failure. Albuquerque then launched another attack on 15 August 1511, which proved successful as Malacca was captured on that day. The Portuguese constructed a fortress called A Famosa using rocks and stones taken from Muslim graves, mosques, and other buildings. Several churches and convents, a bishop's palace, and administrative buildings such as the governor's palace were built. The Portuguese imposed higher taxes on Chinese traders and restricted their ownership of land.

Figure 2.1: Malacca Sultanate Palace

Figure 2.2: Malacca and the Global Economy

2.1.2 Historical Artifact

A historical artefact represents something that has been generated or modified by people and is usually interesting from an archaeological or cultural point of view. These artefacts are very important for learning about and keeping our past and culture. They are physical proof of the ways people lived in the past, the things they created, and the art they developed. Researchers, students, and historians need historical artefacts because they are the most reliable evidence of what happened in the past (DAVIS KOLB, 2017). Scholars who want to learn more about a culture can learn a lot from artefacts. Archaeologists dig up places where people from the past lived and use the things they find to learn about the past. Many ancient societies did not have a written language or actively write down their history, so artefacts are sometimes the only way to learn about how the people lived.

Archaeologists found the figurine in 1908, about a week into excavations at Willendorf II, an Austrian site along the Danube River, roughly 50 miles from Vienna. Throughout the 1900s and 2000s, several other digs occurred there, with ever-improving methods, which unearthed two less-famous Venus figurines and hundreds of stone tools. Across Europe, nearly

200 similar statuettes have surfaced from sites between 23,000 and 40,000 years old.(Bridget Alex, 2020). Its important to keep things that happened in the past so that it can remember and protecting the artefacts is so important to kept for future generations.

Next, artefacts have given us important information about how people lived in ancient Egypt. Ancient Egyptians thought there was a life after death, so they buried their dead with things they would need to live on. Because of this, ancient Egyptian tombs are full of artefacts that tell us about the society. The tomb of King Tut might be the most well-known. In 1922, British archaeologist Howard Carter found the body of the Egyptian Pharaoh Tutankhamen, also known as King Tut. The body of King Tut had not been opened since he was buried around 1323 B.C.E. On the walls of the tomb were pictures of King Tut's funeral and trip to the afterlife. The tomb also had more than 5,000 artefacts, like perfumes and oils, jewellery, statues, and even toys from Tut's childhood. Carter led a group of researchers as they made a list of the things in King Tut's tomb. This work took archaeologists more than a decade, but the artefacts continue to help scholars learn more about how people lived in Egypt during the time of King Tut.

Restoration means looking back in time to see how an object would have looked when it was first made. Treatments are done to get the thing back to how it would have been made when it was first made. Depending on the artefact, this could mean taking off layers of paint, adding materials to the item, or replacing parts that aren't from the same time period. Preservation something means thinking about the future and taking methods to keep the object in the precise state it is in this moment. Even if the item has small amounts of damage, it may need to be treated to stop it from getting worse and keep it in its current state.(B.R.Howard, 2019).

Figure 2.3: Olmec Colossal Heads (Mexico)

Figure 2.4: King Tut’s Funerary Mask (Egypt)

2.1.3 Historical of Gun

A gun is a handgun designed to release projectiles, such as bullets, by the rapid expansion of high-pressure gas produced by chemical reactions within a confined space. Typically, firearms have been used for self-defense, hunting, target shooting, law enforcement, and military purposes. They are available in a variety of forms, including pistols, rifles, shotguns, and machine guns, each of which has its own characteristics and intended applications.That started in China in the 10th century, the gun has a long and complicated history that may be traced back to that country. The earliest firearms were crude implements composed of bamboo tubes that had been stuffed with gunpowder and pellets.

As early as the 11th century, they were put to use in combat, and by the 13th century, they had evolved into more complex weapons, with metal barrels and improved firing mechanisms (Jeff Harder & Sharise Cunningham, 2021). Next, In the 14th century, firearms made their way to Europe and almost immediately became an essential component of military strategy. By the 16th century, firearms had already established themselves as the preeminent weapon of choice on the battlefield, and their use had a significant impact on the growth of military strategy (Billy Shebar, 2014)

The cartridge and the percussion cap were both innovations that occurred in the 19th century that significantly impacted the guns industry. These newly developed technologies not only made it much simpler to use and reload firearms, but they also led to the invention of a broad array of new firearms, such as pistols, shotguns, and rifles. (Jim Supica, 2016)

Other than that, the invention of smokeless powder and mechanisms for automatic shooting in the 20th century led to the creation of weapons that were both more powerful and more technically advanced than those previously available. These newly developed firearms were put to use in both of the World Wars, and since then, they have been a significant factor in the majority of important wars that have taken place.

A gun's main parts are the barrel, the action, the magazine or cylinder for keeping bullets, the trigger, and the grip or stock for holding and aiming. When a gun is fired, a firing pin or striker hits the trigger of a cartridge to light the propellant powder inside. High-pressure gas is made when something burns quickly. This gas pushes the projectile or shot through the tube and towards the target. It is important to remember that different countries and areas have different laws and rules about how to use and own guns. The goal of rules about gun ownership, possession, and use is to find a balance between the right to bear arms and keeping people safe and stopping crime. It is important to follow the laws and rules that are in place and to put a high value on responsible gun ownership and safety.

At the beginning of the 16th century, Portuguese soldiers frequently carried the espingarda weapon. The Malay people have adapted the technology behind the weapon, and now it is called as a "istinggar," "setinggar," or "istinggar Minangkabau" ("fire pistol in West Sumatra"). After some time had passed, the Dutch taught the Malay people how to modify flintlock guns. Snaphaan is the name given to it by the Dutch, whereas "gun" is the term used by the Malays. It is also considered sensible by some. Up to the 19th century, this rather simple handgun was employed in armed conflict. After the middle of the 19th century, they also used rifles made by the English company Enfield. This demonstrates that the Malay people are skilled at adjusting to new technologies and making effective use of them during times of armed conflict.

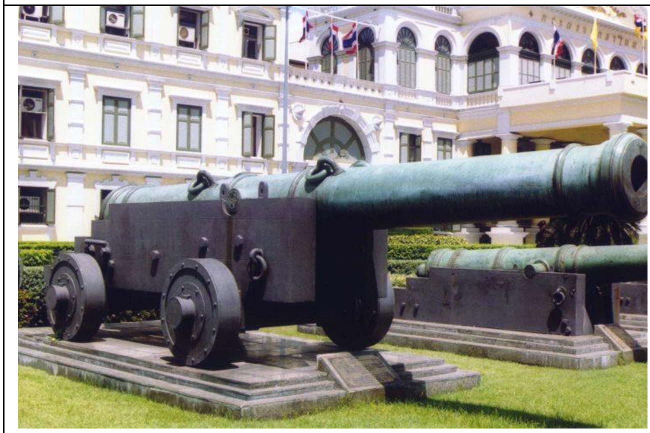
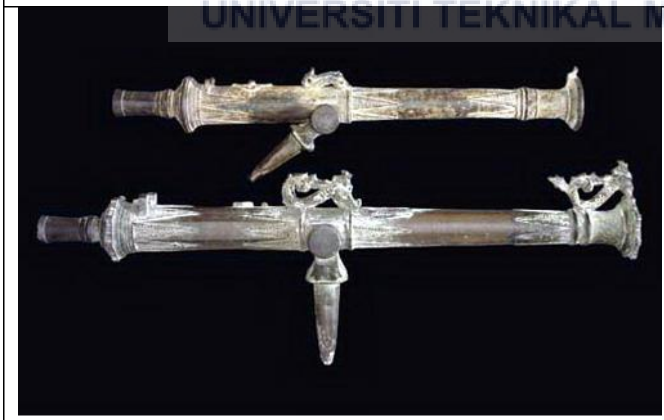
Next, the Cannon. The was placed on top of the city walls was often where massive guns designed for long-range battle. Other than that, Lela. This sort of cannon is smaller than a typical cannon; it is constructed of copper; and it comes in a variety of sizes. The term "swivel gun" is used to describe this type of cannon in English. It is a transportable cannon that can be fired from elephants as well as boats. Next, Rentaka. It has the appearance of a lela but is built of iron instead. It may be carried around easily, is not heavy, and is more compact than lela.

Typically, it will be carved with a Malay symbol that seems like a bamboo stalk but is actually shaped like a triangle.

However, Istinggar is the most renowned firearm of the 19th century.This is the forerunner of the contemporary shotgun, which possesses locking mechanisms. Matchlock Rifle is another name for the Istinggar, which is a type of musket. This istinggar is particularly significant in weight and length. It has a cylinder chamber that is vacant and can be used for gunpowder. Furthermore, Pemuras is a category of rifle known as a blunderbuss that is shorter than a blunderbuss. It is possible to say that it is the ancestor of the shotgun by comparing it to modern times and technology. It was traditionally utilised in ships for travel over shorter distances and was fitted with European studs. The end of the squeezer is typically carved to resemble the mouth of an animal, such as a tiger or a snake. This is the opening through which the gunpowder, sometimes known as lead bullets, was loaded.

Lastly, Terakol. It was common for pirates and Malay Sea traders to carry a shorter pistol known as a terakol or tarkol (in Turkish). A Terakol serves as the inspiration for this compact and lightweight pistol.It is the precursor to the modern handgun and was designed for rapid-fire combat in close quarters with the adversary. It does not require the use of a fuse to ignite the gunpowder because it uses wheel lock technology instead. Flintlock technology was eventually used in its place. These weaponries demonstrate that the Malay nation is a great one and that its people are skilled at adapting technology for use in armed battle to protect the nation's territory (Diyana AR, 2016).

Table 2.1: List of historical weapon artifact in Malaysia

Diagram	Name of artifact weapon
	Meriam besar Sri Patani
	Lela Naga
	Rentaka

	Istinggar
	Pemuras
	Terakol

2.1.4 History of Pemuras Gun

The Malay weapons consist of the celebrated kris, with its flame-shaped wavy blade the sword, regarded. However, more as an ornament the parang, which is both knife and weapon the steel-headed spear, which cost us so many lives in the Perak war matchlocks, blunderbusses, and lelahs, long heavy brass guns used for the defense of the stockades behind which the Malays usually fight. Isabella L. Bird says in her book The Golden Chersonese and the Way Thither that the main weapons of the Malay people are daggers, swords (which Bird says are rarely used and are more like decorations), parangs (which are also used as weapons and in daily life), and an iron-edged spear, which she says killed many people during the Silver War. Birds also noticed the appearance of Matchlocks, Blunderbusses, and Lelahs in addition to traditional weapons of war. (Sons, 1883)

Pemuras is a form of front-loading gun that has a funnel-shaped muzzle and a short barrel with a big caliber. Blunderbuss is another name for this type of gun. In comparison to the barrel of a shotgun, which is typically more than 90 centimeters in length, the blunderbuss typically has a barrel that is just 41 centimeters long. It is believed that the Dutch were the ones who introduced the blunderbuss to the archipelago somewhere in the middle of the 17th century. The blunderbuss is mostly employed for close quarters combat. These particular projectiles are known as scattershot bullets. Tin, nails, and sheet metal are all examples of ammunition. The British soldiers' diaries from the War of Naning indicated that the Malay soldiers were particularly skilled at utilizing this blunderbuss. As a result, the British were forced to dispatch their men against Dol Said multiple times, and the War of Naning itself took place over the course of several series. (pecintawarisanmelayu, 2017)(Haslina Bujang, 2018).

The Malay people of Borneo, and particularly the inhabitants of Brunei and Sulu, are the ones who consistently make use of blunderbusses. The bullets in this strainer are made of lead. A revolver is a type of gun that may also be used as a rifle, and it was initially designed for self-defense. In comparison to the western world, the Blunderbuss gun has a significant amount of notoriety within the Malay society. This gun, as opposed to the istinggar or Flintlock Musket, is featured in the events of the Malayan conflict a greater number of times. This is because in the past, the Malay people were known for their perseverance at sea and as travelers. It is common knowledge that pirates, traders, and sailors all make use of blunderbuss weapons. This is due to the fact that with only one shot from close range, it is able to inflict damage on several foes, making it an ideal weapon for battle that is both swift and aggressive. (wikipedia, 2021)

After Malacca fell to the Portuguese in 1511, thousands of Malay weapons such as Rentaka (grenade launcher), Terakol (pistol), Lela (short cannon),Pemuras (Blunderbuss), Istinggar (Long Rifle), Istikol (Short rifle) and Meriam (Cannon) were stolen and taken by the Portuguese from Malacca as war booty. Next, Malay people used the term 'bedil' (rie) to refer to all types of firearms. Numerous names for rie can be found in historical texts and Malay chronicles, including lela, lela rentaka, ekor lotong, jinjal, tahan turut, meriam, jala rembang, istinggar, pemuras, senapang terkul, senapang kopak, etc.(. et al., 2016) This technology was later developed in Europe.

2.1.5 The Stadthuys museum

The Stadthuys, constructed between 1641 and 1660, is Melaka's most impressive remnant from the Dutch period with its characteristic Dutch colonial elements, this building is often cited as the oldest surviving Dutch structure in the East. City hall and the Governor's mansion were both located there. The Governor Museum, the Admiral Cheng Ho Gallery, the Museum of Democratic Rule, and the History and Ethnography Museum are all located here(Worden, 2001). In reality, Stadthuys is an exact replica of the Stadhuis, which served as the municipal building in the Dutch town of Hoorn, which is located in the Frisian region.

Today, Stadthuys is a part of a massive museum complex, and it is also home to the History and Ethnography Museum, which is regarded as one of the most important museums in all of Malacca. Many Portuguese homes and schools were fixed up, but the many churches were not because they were used for other things. Simon Stevin (1548-1620) thought that the city should keep getting bigger as it grew. A Dutch engineer. In 1776, the Tax Office was finished on the Jonkerstraat (Jalan Hang Jabat). A first, second, and third Burgerstraat (Cross streets), a Visstraat (Fishstreet), and a Goudsmidstraat (Gold smithstreet) were also built.

In 1982, the Dutch architecture company of Laurens Vis renovated the Stadthuys. The town's main feature is the hill, which was used to keep an eye on what was happening in the nearby area. During the time of the Portuguese, a church was built on top of the hill, and the house of the Governor stood in the park at the base of the hill. During the time the Portuguese controlled Melaka, they built a fort around the hill that was centered on the square (The Dutch Settlement and Its Development in the Historic City of Melaka, 2016).

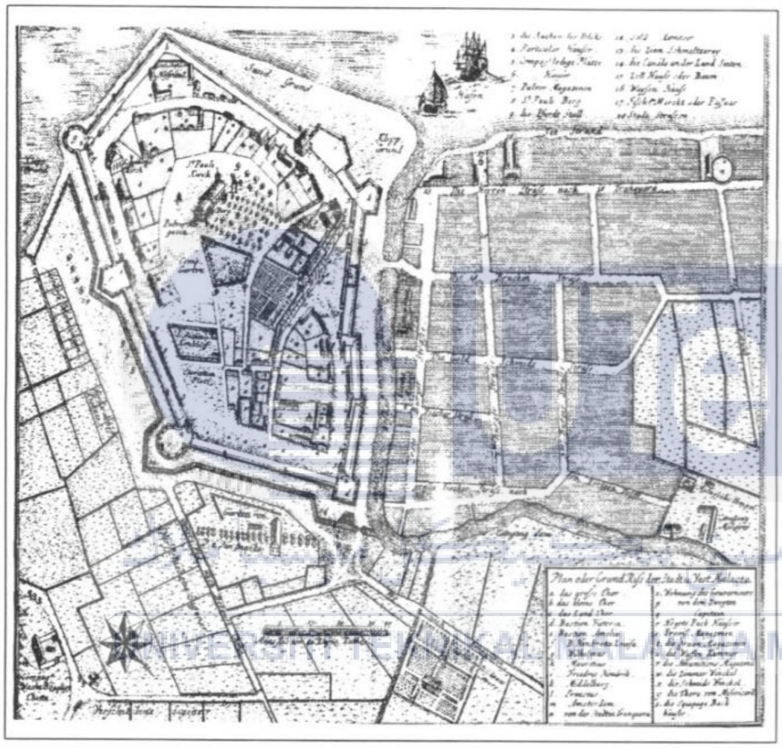


Figure 2.5: A map of Dutch Melaka, complete with walls and all.

Figure 2.6: The Stadthuys is the oldest Dutch building in the East

2.2 Reverse Engineering (RE)

2.2.1 Definition of reverse engineering

Reverse engineering mimics critical features of an existing object to create its accurate or enhanced virtual/physical models. Its goal is to build CAD models from measured data using 3D surfaces and geometric features that describe the shape of a physical part. A process of reverse engineering is considered sustainable if it requires fewer complex gadgets, fewer computations, and fewer specialized human abilities. Because of new technologies, product design is more complicated and creative now than it was in the past. With reverse engineering, manufacturers could make a copy of a current part by writing down its dimensions and features. In addition, the process of reverse engineering can be carried out using either into contact (probe-based) and non-contact (laser-based) method (Saiga et al., 2021).

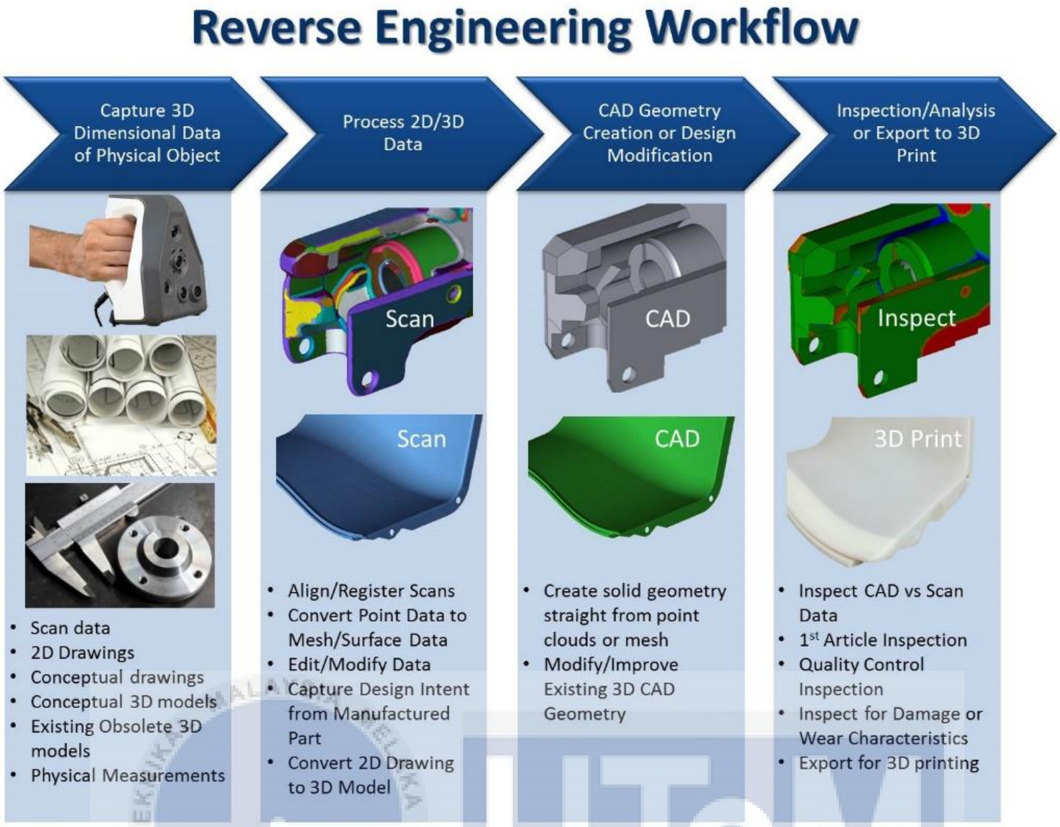


Figure 2.7: Reverse Engineering Workflow

2.2.2 Reverse Engineering Process

Surface triangulation is one example of a conceptual model that may be generated using RE from a physical model. The first step in RE was to create digital representations of physical objects or their components through digitizing or scanning. A "point cloud" is the term for this type of visualization. Point clouds are collections of points that have dispersed 3D locations. Model reconstruction with 3D scanning requires the use of RE software. Next, scanning an object or component with a 3D scanner is a method for accurately recording its dimension and shape in three dimensions. Other than that, the RE method does help in the restoration of the historical relic as well as keep the sources of data without harming the relic itself.

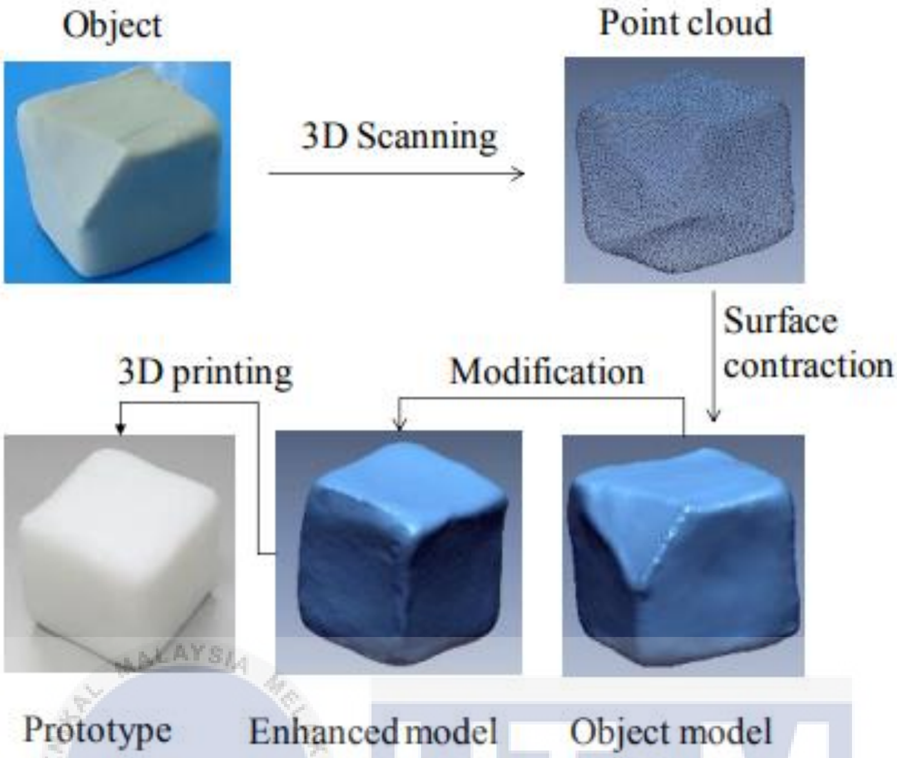


Figure 2.8: Conventional reverse engineering

2.2.3 Contact and Non-contact Method

Coordinate measuring machines (CMMs) and robotic arms are used in contact measurement techniques to guide a probe that touches the item in order to collect data(Buonamici et al., 2018). There is a total of two types of contact methods defined in the previous studies which are touch triggered probe and analog probe. Several tests have shown that the information is collected by directly touching the surface of the object with a stylus. Most of the time, it is used with a CCM or a machine tool, as well as a flexible arm. Point-to-point digitizing is used to get the info. The size of the sphere on the end of the stylus is instantly considered in the data that is collected. This method is faster than either analogue or drag probe the probe is always in contact with the object's surface or shape, and it collects a huge amount of data during the scanning process. This contrasts with touch-triggered probes, which only work when they hit the object.

Instead, sensors like digital cameras are used in non-contact approaches to observe the environment. The main benefit of non-contact devices or systems is that they can quickly collect a lot of data without having to touch the item or part being measured. When scanning, almost all non-contact methods make a lot of raw point cloud or voxel data. It is important to remember that non-contact measuring tools are usually less be less accurate and could be influenced by the properties of the object's surface. Then it uses the time to figure out how far away it is. Other than that, each scan is made up of millions of point cloud readings at scan points. But each scan is line-of-sight, so it might take a lot of scans to make a full digital 3D model of an object or a big area.

Table 2.2: Comparison table of Contact and Non-contact

No	Description	Contact RE	Non-contact RE
1	Speed	Slow (depends on CMM’s speed, i.e., 1/sec) and human fir the handled type.	Extremely fast (up to 10000/sec or more)
2	Accuracy	Good	Less accurate (need more point clouds)

3	Point cloud volume	Low (hundred or thousand points)	Extremely high (hundred thousand of points)
4	Surface effect	No problem	Object to be scanned may need to be painted
5	Effect of ambient lighting	No problem	Ambient lighting needs to be under controlled.
6	Portability	The only system attached to the articulated arm is portable.	Portable on most cases
7	Scanned object	Not suitable for soft object or materials	No problem

2.2.4 Computer Aided Design (CAD)

Computer-aided design, or CAD, is the use of computer tools to help with modeling, analyzing, reviewing, and documenting designs. But the benefits of CAD can be increased when combined with artificial intelligence (AI), extended reality, and manufacturing. CAD software enables designers to construct 2D and 3D models of objects, which can be utilized for a variety of purposes Documentation, Simulation, Manufacturing. CAD models can be used to generate technical drawings, which are utilized to convey design information to manufacturers and other stakeholders. Next, CAD models can simulate the behavior of products in real-world environments. This can be used to evaluate product performance and identify potential improvement areas. Thus, CAD models can be utilized to generate manufacturing to produce complex parts easily. This can enhance the manufacturing process's efficiency and rapidly (Regassa Hunde & Debebe Woldeyohannes, 2022).

Currently, computer-aided design technologies are extensively utilized in a variety of fields for design assistance. Computer-aided design technology provides information regarding the geometric, electrical, thermal, dynamic, and static behavior of specific product types. Computer-aided design systems should obtain rules and behaviors that allow users to focus on the design and function of the product, small characteristics of a large object, maintaining the data integrity, and sequencing it to know the step of subsystems complete with the ease, without considering the operation of the product.

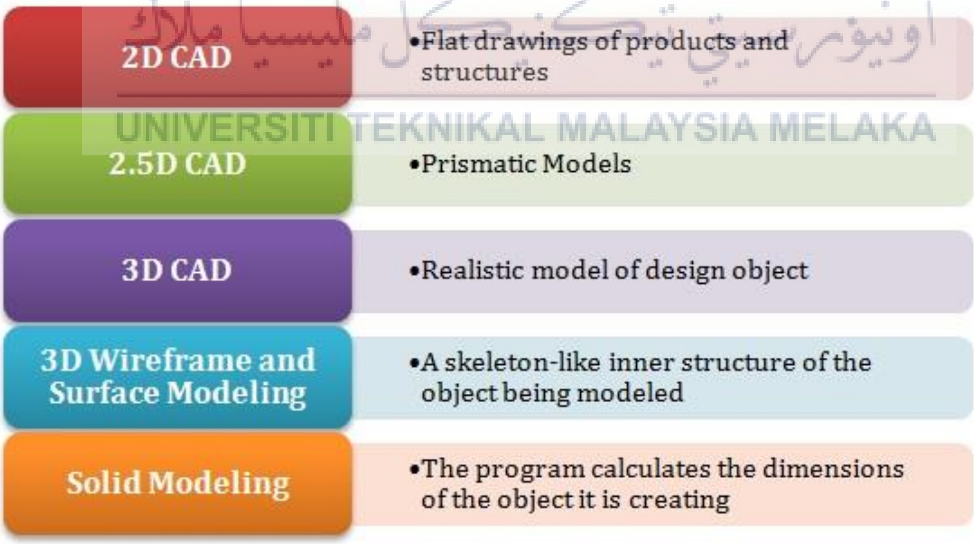


Figure 2.9: Types of CAD software programs exist in the market

(Sarah Rose Miller, 2019)

2.2.5 Point cloud Data

The surface of an object is often represented as a point cloud, which is a collection of data points in a three-dimensional coordinate system. Every point that makes up a point cloud possesses its own unique set of X, Y, and Z coordinates, in addition to other characteristics like as colour, intensity, or range. Several different types of technology, such as 3D scanners, lidar, and photogrammetry, are able to be utilized in the production of point clouds. Point clouds have a wide range of applications, the most frequent of which being 3D modelling and computer-aided design (CAD). Nevertheless, point clouds are an effective method for describing three-dimensional data. They are not difficult to generate or process, and they are versatile enough to be employed in the production of a wide range of outputs, such as three-dimensional models, visualisations, and measurements. It can be challenging to handle and analyse point clouds since the datasets they include might be quite expensive and complicated. In addition to this, it may be challenging to visualise and engage with them.

In addition, despite the difficulties, point clouds are an effective method for representing three-dimensional data. They are gaining popularity in an ever-expanding range of applications, and it is anticipated that they will play an even more significant role in the years to come. However, Point clouds are groups of points that exist in three-dimensional space, and point cloud functions are the tools that are utilised to carry out a number of processes involving point clouds. Point cloud registration is the initial step. Point cloud alignment is the process of aligning two or more-point clouds so that they precisely overlap one another. Multiple scans of the same item can be combined into a single, more accurate point cloud if this technique is utilised.

Next, Point cloud segmentation. This refers to the process of segmenting a point cloud into various regions based on certain criteria, such as the colour of the points, the surface normal of the points, or the distance from a given reference point. This can be used to distinguish between various items or features that are contained within a point cloud. The final step is the classification of point clouds. Labelling each individual point that makes up a point cloud is the next step in the process. It is possible to utilise this to determine the many kinds of items or characteristics that are present in a point cloud, such as trees, cars, and pedestrians, for example.

2.2.6 Standard Triangulation Language (STL)

The file format known as STL was developed by 3D Systems specifically for use with their stereolithography computer-aided design (CAD) software. Standard Tessellation Language is another name for Standard Triangle Language, which is another name for STL (StereoLithography). Rapid prototyping and computer-aided manufacturing, often known as additive manufacturing or 3D printing, both make extensive use of this file format, which is supported by a large number of additional software application. The only thing that is represented in an STL file is the surface geometry of a three-dimensional object there is no indication of its colour, texture, or any of the other usual CAD model properties. (3D PROTOTYPE DESIGNER, 2013)

Other than that, The ASCII and binary formats of data are both specified by the STL format. Because binary files take up less space, you'll most likely come across them. (Fabbers.com, 2020; Paul Bourke, 1999).The format was originally designed for stereolithography, a type of three-dimensional printing that was popular in the late 1980s for the purpose of rapid prototyping. In 1988, 3D Systems published the first documentation of STL, which was titled Stereo Lithography Interface Specification. The STL file format became the industry standard for rapid prototyping in the 1990s after gaining widespread use throughout that decade.(Library of Congress, 2019) (Paul Bourke, 1999)

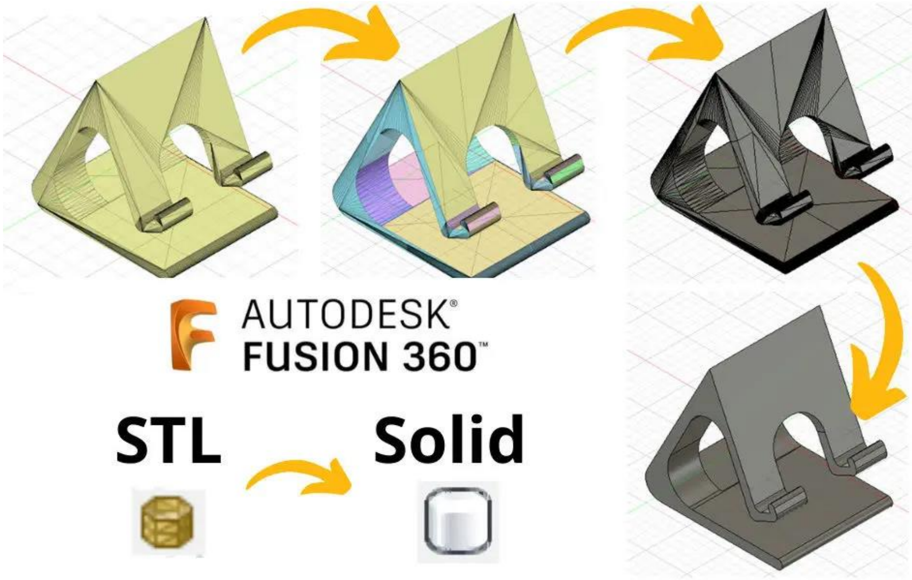


Figure 2.10: Standard Triangle Language (STL) file format

2.3 Addictive Manufacturing (AM)

2.3.1 Definition of Addictive Manufacturing

In additive manufacturing (AM), polymers and their composite powder materials are the most popular products on the market. Most of the time, these are used in the selective laser sintering (SLS) process. SLS is a powder bed fusion AM method that uses a 3D computer-aided design model to make solid 3D parts by selectively fusing layers of powdered raw materials (Shi et al., 2021). Additive Manufacturing generally commences with a digital 3D model made with Computer-Aided Design (CAD) tools or by 3D scanning. The 3D model is cut into thin layers with small cross-sections. These layers are then put together one by one to make the end result.

Additive Manufacturing offers several advantages over traditional manufacturing methods. It enables the production of highly complex geometries, customization, rapid prototyping, and the ability to create parts with internal structures or intricate details. It also reduces material waste since only the necessary material is used. In addition, In additive manufacturing (AM), the most common products on the market are polymers and their composite powder materials. These are mostly used in selective laser sintering (SLS) technology. SLS is a powder bed fusion AM process that makes solid 3D parts straight from a 3D computer-aided design model by selectively fusing successive layers of powdered raw materials(Shi et al., 2021). Typically, the process of Additive Manufacturing begins with a digital 3D model created with Computer-Aided Design (CAD) software or obtained via 3D scanning. The 3D model is sliced into narrow cross-sectional layers, which are then successively assembled to form the final object.

Additive Manufacturing offers several advantages over traditional manufacturing methods. It enables the production of highly complex geometries, customization, rapid prototyping, and the ability to create parts with internal structures or intricate details. It also reduces material waste since only the necessary material is used. In addition, Additive manufacturing (AM) is becoming increasingly popular due to advances in materials, printer technology, and process optimisation, making it a catalyst for production innovation.

2.3.2 Classification Process of Addictive Manufacturing

Additive Manufacturing can be classified into several categories based on the underlying technology and the materials used. Additive Manufacturing (AM), also known as 3D printing, is a broad category of procedures that produce three-dimensional objects by layering material. There are numerous methods to categorize the various additive manufacturing processes and classification is based on the materials used, while another is based on the layer deposition technique processes.

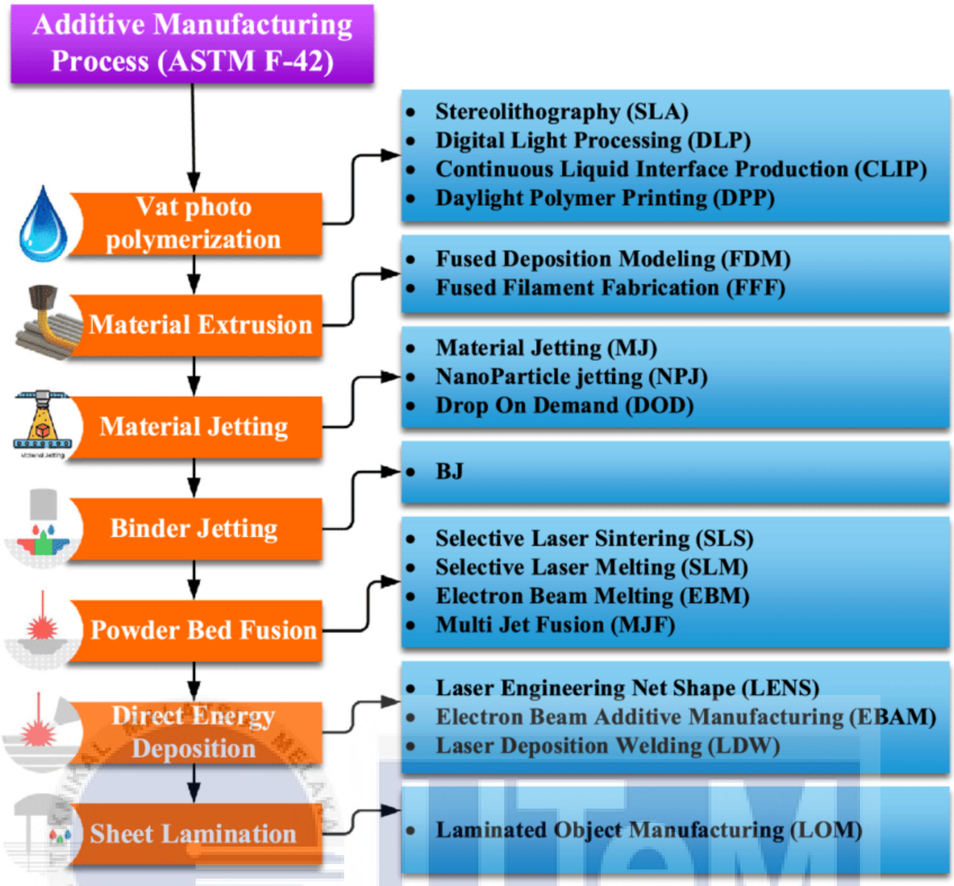


Figure 2.11: Classification of Additive Manufacturing process

(Eyob Messele Sefene Bahir Dar University, 2022)

2.3.2.1 Powder bed fusion

Powder bed fusion, also known as PBF, is a type of additive manufacturing that functions on the same fundamental premise as other forms of additive manufacturing, namely, that components are produced by adding material rather than removing it. The first step in the PBF process is the construction of a three-dimensional CAD model, which is then mathematically "sliced" into several separate layers.

After that, each layer is bonded on top of the one that came before it in order. Because PBF techniques involve spreading powdered material over layers that have already been linked, the manufacturing is discrete rather than continuous. This is because the powdered material is ready for processing on the next layer. The optimal thickness of each layer of spread powder is dependent on the processing conditions and material used

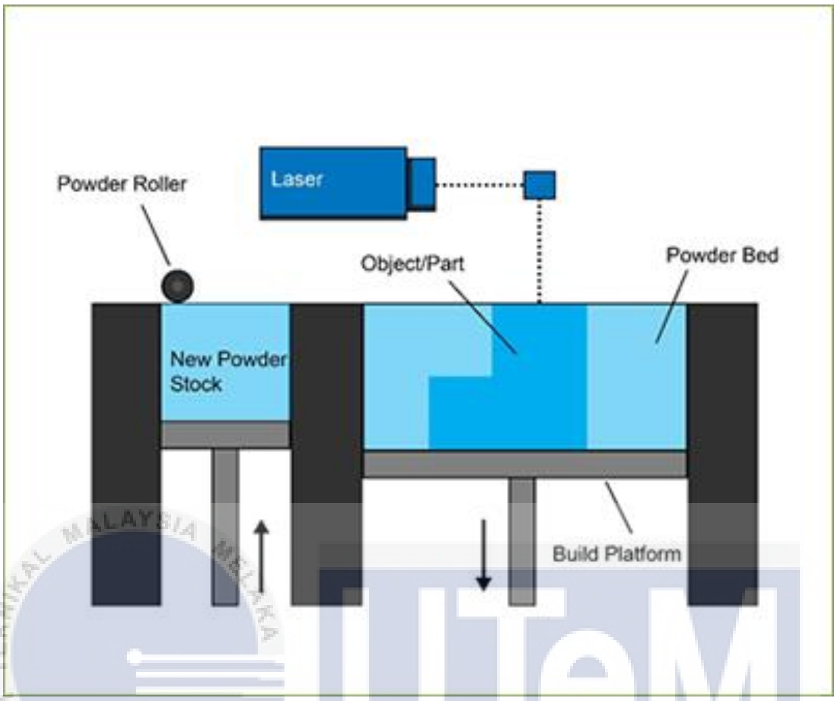


Figure 2.12: Powder Bed Fusion Process

(Loughborough (The Dutch Settlement and Its Development in the Historic City of Melaka, 2016)University, n.d.)

2.3.2.2 Material Jetting

The model is constructed one layer at a time using material that is blasted onto the build surface or platform, where it hardens and becomes part of the sculpture. A nozzle that travels along the build platform in a horizontal direction deposits material as it works. Machines range widely in both their level of intricacy and how they control the deposition of material. After that, layers of the material are exposed to ultraviolet (UV) light in order to cure or harden them. As a result, polymers and waxes are appropriate materials that are frequently utilised because of their viscous nature and their capacity to create drops.

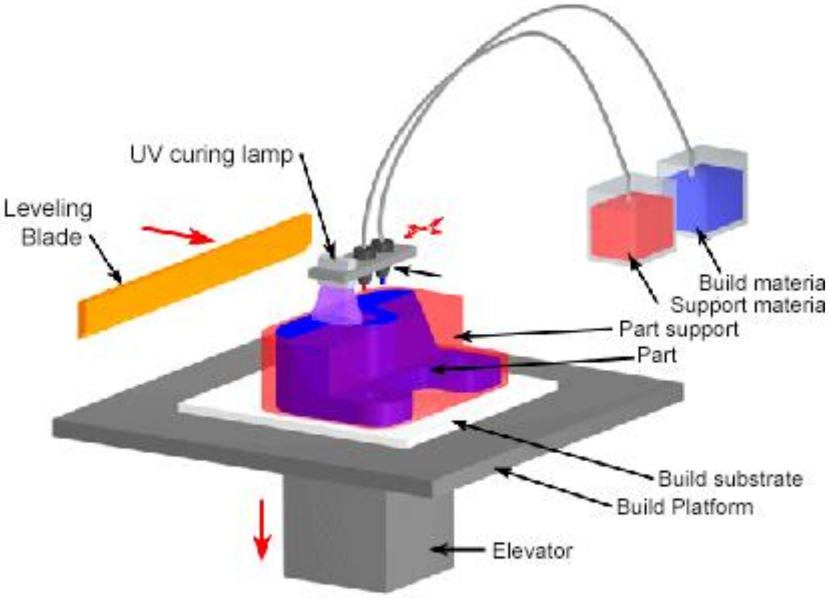


Figure 2.13: Material Jetting Process

(Loughbrouh University, n.d.)

2.3.2.3 Binder jetting

Binder jetting is a technique for securing particles with the help of a liquid binder and creating a layer by spraying the binder on top of the powder. After distributing the powder layer across a build platform and depositing binders selectively in each layer based on the information in the CAD model, the procedure is repeated until the desired geometry is achieved. Casting patterns, raw sintered goods, and high-volume objects such as metals, sand, polymers, hybrids, and ceramics can be made using a technique called binder jetting. The binder jetting process is uncomplicated, rapid and its very low cost of entry and the relatively low cost of the materials it uses, binder jetting is one of the more cost-effective methods of additive manufacturing(Spatial Team Tue May 11, 2021).

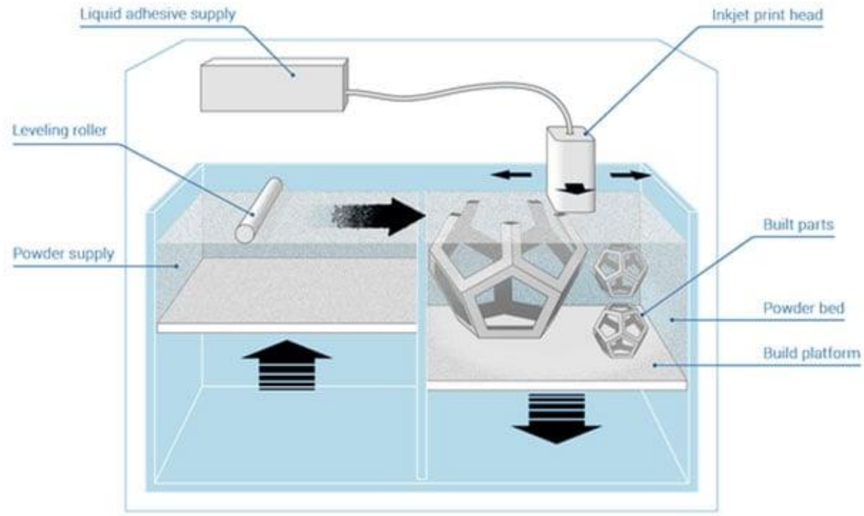


Figure 2.14: Binder Jetting Process(3Dnatives, 2022)

2.3.2.4 Material extrusion

The additive manufacturing techniques that fall into the material extrusion category are those that construct a three-dimensional item by forcing material through a nozzle while simultaneously applying heat to the material in order to soften it but not completely melt it. The heated material is made to flow out of the nozzle in the form of an extrusion and is then deposited on the build platform in a layer-by-layer fashion in accordance with the path that was derived from the CAD data. One of the most common techniques for producing hobbyist-quality 3D prints is a technique known as Fused Filament Fabrication (FFF), which involves the extrusion of material. In the late 1980s, S. Scott Crump came up with the idea for the proprietary term fused deposition modelling, or FDM for short. The Stratasys firm did not start commercializing the technology until 1990. (3DEXPERIENCE Platform, 2018).

A design of experiments (DoE) method with four factors is taken by adjusting print parameters such as layer height, print speed, extrusion rate, and nozzle diameter in order to explore their impact on the geometry of produced filament. These print parameters include layer height, print speed, and extrusion rate. The filament geometry can then be used further to produce consistently aligned three-dimensional structures, which enables analysis of how the inter-filament void volume and structure varies on the different printing parameters. (Jang et al., 2021)

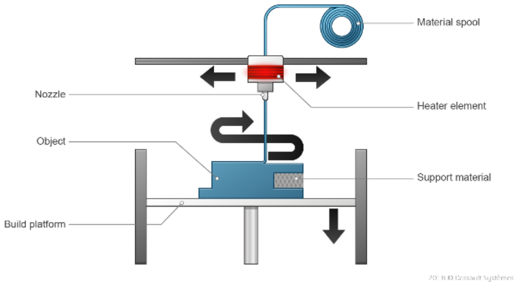


Figure 2.15: Material extrusion process

2.3.3 Selective Laser Sintering (SLS)

Selective Laser Sintering (SLS) is a common additive manufacturing process used to produce three-dimensional objects. Based on a 3D computer-aided design (CAD) model, it is a powder bed fusion process that uses a high-powered laser to selectively fuse or sinter pulverised material together, layer by layer. Preparing the CAD model of the object to be produced is the initial step. Using specialized software, narrow cross-sectional layers are created from the model. In 1989, the Selective Laser Sintering (SLS) technique was patented, and DTM Corporation was the first company to market and sell it. 3D Systems completed the acquisition of DTM in the year 2001(Custompart.net, 2023). Moreover, the quality of SLS parts is dependent on a lot of process and material parameters, such as the type of polymer, grain size, layer thickness, laser power, diameter of laser beam, scanning speed, spacing between laser scans, powder spreading speed, preheat temperature.(Mokrane et al., 2018)

This is mostly due to its suitability for processing virtually any material, including polymers, metals, ceramics (including foundry sand), and numerous composites. The material should be supplied as a powder that may contain a polymer binder that must be removed (debound) after use (Kruth et al., 2003). Thus, Laser Sintering is a process in which a powerful laser application the surface of the powdered material, selectively sintering or fusing the particles together based on the cross-sectional layer of the CAD model. The intensity and scanning pattern of the laser are precisely regulated to guarantee precise fusion.

A high-energy laser is then used to selectively fuse the powdered material together, according to a 3D model's cross-section, solidifying the desired shape for that layer. The build platform is then lowered, and a new layer of powder is spread on top. The process is repeated, layer by layer, until the entire object is formed within the powder bed. After the printing is complete, the object is typically left to cool down in the powder bed before it is removed. Excess powder can be brushed or blown away, and the printed object may require some post-processing, such as sanding or polishing, to achieve the desired finish.

Selective Laser Sintering (SLS) is widely used in various industries, including automotive, aerospace, healthcare, and consumer products. It has advantages such as the ability to create complex parts, functional prototypes, and small production runs with relatively high accuracy and good mechanical properties.

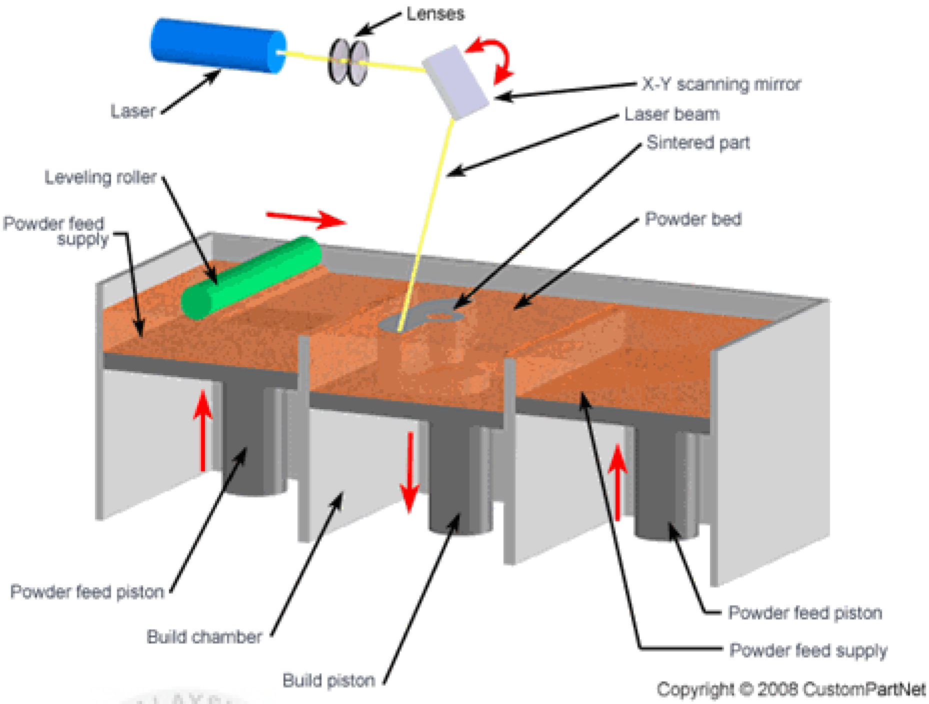


Figure 2.16: Selective Laser Sintering (SLS) process

2.3.4 Advantages and Limitations of Additive Manufacturing

2.3.5 Advantages of Additive Manufacturing

Now, additive manufacturing can enable and facilitate the production of products in moderate to mass quantities, each of which can be uniquely customized. The development of technologies that enable additive manufacturing is resulting in the opening of new doors in terms of the production paradigm and the possibilities for manufacturing. The amount of time it takes to manufacture a product will be cut down significantly, the introduction of new designs will take less time, and demand from customers will be fulfilled more rapidly. Furthermore, AM is able to greatly expedite more conventional procedures and a powerful instrument to reduce complexity in the supply chain in a variety of ways, according to various academic studies that have been conducted on the topic.(Attaran, 2017)

2.3.5.1 Lower start-up costs

Manufacturing start-up costs can be high. The need to create custom tooling for any new item you wish to manufacture, can limit the scope of what is economically viable to produce. Industrial AM machinery costs as little as a few thousand pounds, with home or enthusiast solutions as little as a few hundred. Even better, when the time comes to change the design, simply tell the 3D printer the new design there is no need to throw away the investment you have made in AM equipment. This reduction in material waste can contribute to financial savings in addition to benefits for the environment.

2.3.5.2 Decreased amount of wasted raw materials

A vast number of the conventional methods of production begin with a larger block of metal or piece of wood, which is then reduced in size. The remnants of the material after it have been milled away typically have no value from an economic standpoint. These wasteful production processes result in a significant loss of the raw material. Additive manufacturing begins with nothing and then adds what is required, resulting in up to a ninetieth reduction in the amount of raw material that is wasted.

2.3.5.3 Fast speed to produce prototype

The term "additive manufacturing" has also been referred to as "rapid prototyping," and there is a strong justification for this usage. Because of the low cost and quick speed at which a single item can be produced, it is simple to develop a first prototype and examine how well it functions in the setting for which it was designed. After that, CAD can be used to make any necessary modifications or alterations, and the procedure can be repeated. starting prototypes frequently make use of materials with a lower starting cost, such as Polylactic Acid (PLA).

Subsequent prototypes, however, frequently introduce the materials that are likely to be used for the final design.

2.3.5.4 Digital design integration

The advent of computer-aided design (CAD) marked the beginning of the transition away from the traditional 2D drawing board and into the world of 3D virtual design. Additive manufacturing takes this a step further by enabling those virtual 3D designs to be generated in the physical world at the touch of a button. Additive manufacturing is a form of manufacturing that was developed in the 1990s. There are now a variety of design software available that support the capability of 3D printing, which helps to automate needed design procedures such as the incorporation of inner honeycombed reinforcing or exterior scaffolding. Because of additive manufacturing, turning a 3D model into a real-world object is now simpler, more efficient, and less expensive than it has ever been before.

2.3.6 Limitations of Additive Manufacturing

2.3.6.1 Limit Material

One disadvantage of additive manufacturing is that it can only simultaneously print with a limited number of materials. Even though the number of materials is increasing, it is still minuscule compared to traditional methods. This limitation could affect the functionality, durability, and longevity of the ultimate product depending on your part specifications, this can restrict the variety of products that can be manufactured using additive manufacturing (Zachery Padasak, 2022).

2.3.6.2 Surface Grade

The surface quality of the manufactured parts is a conspicuous limitation of additive manufacturing. Especially when complex structures are created, it is difficult to obtain a smooth surface finish.

2.3.6.3 Productivity Rate

Compared to conventional manufacturing methods, additive manufacturing can be relatively slow, particularly when producing large or complex objects. The process's layer-by-layer nature can result in longer production times, making it less optimal for mass production. The slow build rates result from the serial nature of most available AM techniques, which typically require hours to construct a structure.(Shusteff et al., 2017)

2.3.6.4 Limited Scale

Another disadvantage of additive manufacturing is its inability to produce large quantities. Additive manufacturing is ideal for small-batch production, but it is not yet suitable for mass production. This is since additive manufacturing is a sluggish process that can take a long time to produce a large number of parts.

2.4 Summary

In summary, the background of the Additive manufacturing (AM) and Reverse Engineering (RE) the historical artifacts and CAD data have been studied in this chapter. According to the research, Additive Manufacturing (AM) technologies have been used to restore and preserve the historical artifacts due to the strength of the AM technologies. Additive manufacturing (AM) offers greater design freedom and customization options, allowing for more complex geometries and designs. Moreover, it is a more resource-efficient process, minimizing waste and consolidating multiple parts into a single component, reducing assembly and inventory costs.

However, Reverse Engineering (RE) is the process of analyzing a product to understand its design, functionality, and operation. Thus, in the 17th century weapon of Pemuras one of historical artifact from The Stadthuys museum have been selected to fulfil the objectives of this project. One of the most significant benefits of additive manufacturing is its capacity to produce highly complex geometries and intricate designs that may be difficult or impossible to produce using conventional manufacturing techniques. Additionally, it provides greater design flexibility and customization options, as objects can be readily modified or customized without incurring additional costs or delays. The information that has studied in this chapter will be applied to chapter 3 which is methodology

CHAPTER 3

METHODOLOGY

3.1 Introduction

In this chapter, the process flow of the project methodology and the experimental work of the study work are explained in detail. Step by step, the steps of how this project works are shown. Firstly, this chapter describes the method used in the data collection of the research. The primary and secondary data were used to obtained data. In addition, after the data collection have been made, the next process explain the reverse engineering (RE) and Addictive Manufacturing (AM) method that were used in the research. Based on the research and the data obtain it explain how to fabricate and replicated the historical artifact to preserve its original condition and appearance. Other than that, after getting the data by STL file captured the scanned object from previous experiment, will go thru pre-processing, post-processing, and conversion steps before it been fabricate using additive manufacturing system by using method process Selective Laser Sintering (SLS)

3.2 Flow Chart of the Methodology

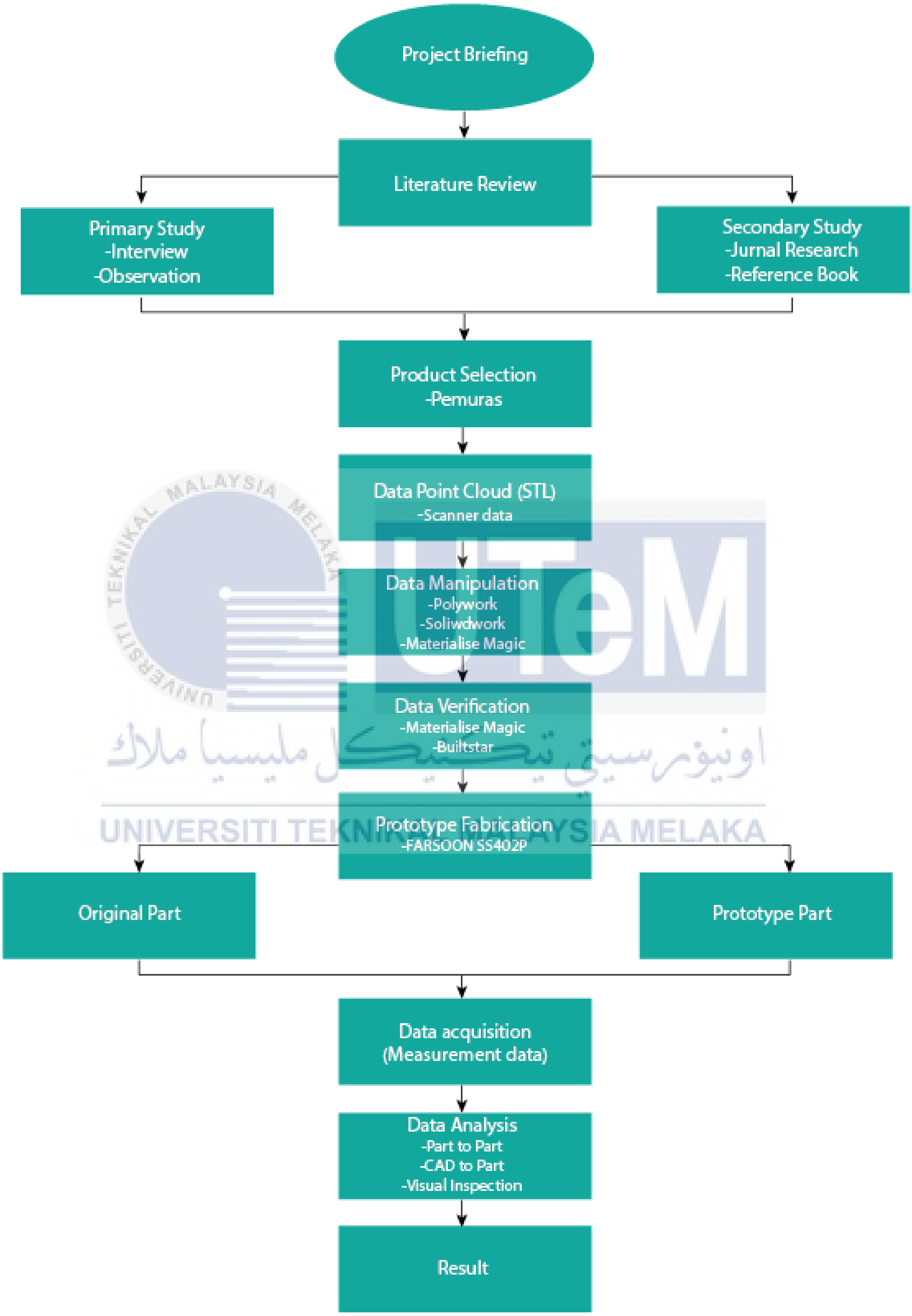


Figure 3.1: Flow chart process to replicate the historical artifact

3.3 Experimental Study

The appropriate discussion and planning have been carried out for this project under the direction of the supervisor to gather and collect all of the information that is relevant to it. Throughout the process of the discussion, the informational resources that are most suitable for this project were determined. In addition to that, it is categorized into the two categories of research known as primary research and secondary research.

3.3.1 Primary study

Primary data is information that is collected for the first time for a specific purpose by the researcher. It is collected directly from the source, for instance through surveys, interviews, experiments, or observations. In this study, through an arranged appointment with a member of the Stadthuys Museum staff in order find out regarding the historical of Stadthuys Museum and its historical artefacts. Moreover, the dimension of original part of Pemuras was measured by using vernier caliper.

Figure 3.2: Make an observation the condition of Pemuras Artifact

3.3.2 Secondary study

Secondary study is data that has already been collected by someone else and is available for researchers to use. It can be found in a variety of sources, such as government publications, academic journals, and commercial databases. Secondary data can be used to support research, to identify trends, and to develop new theories. There are two main types of secondary data published data and unpublished data. Published data has been collected and published by a government agency, a research institution, or a commercial organization. It is typically available in the form of reports, surveys, or databases. Next, unpublished data has not been published and is only available to researchers who have access to it. It can be found in archives, libraries, and government agencies. However, data can be a valuable resource for researchers, but it is important to be aware of its limitations and may not be specific to the researcher's needs. Other than that, secondary data may be outdated or inaccurate and the data may have been collected for a different purpose than the researcher's research. Despite these limitations, secondary data can be a valuable tool for researchers. It can save time and money, and it can provide a starting point for research.

3.4 Product Selection

A product selection history artifact is a document or object that shows how a product or set of goods were chosen. This item can be used to learn about the things that were taken into account when choosing a product and why the final choice was made. Artifacts from the past can be used to teach people about the past and help us understand how our world has changed over time. By studying and figuring out what the historical objects mean, we can learn more about the past and the societies that have shaped our world.

Before starting study, face-to-face interviews are done with curators at the Perbadanan Muzium Malaysia (PERZIM) to get knowledge and insights about historical artifacts. During the conversation, the curators said that the Museum of Malacca only uses traditional methods and basic techniques to keep historical items in good shape. It can cause more damage to the surface of a historical relic.

In the end, PERZIM suggests the Pemuras gun as a good historical artifact for this study project because it is rare, has a high value, and is made in a unique way. Aside from that, the Pemuras gun's design is very complicated and one-of-a-kind, so it is important to look at how accurate the measurements are and how rough the surface is. Also, PERZIM gave our project team permission to use 3D scanning on objects in the Stadthuys museum.

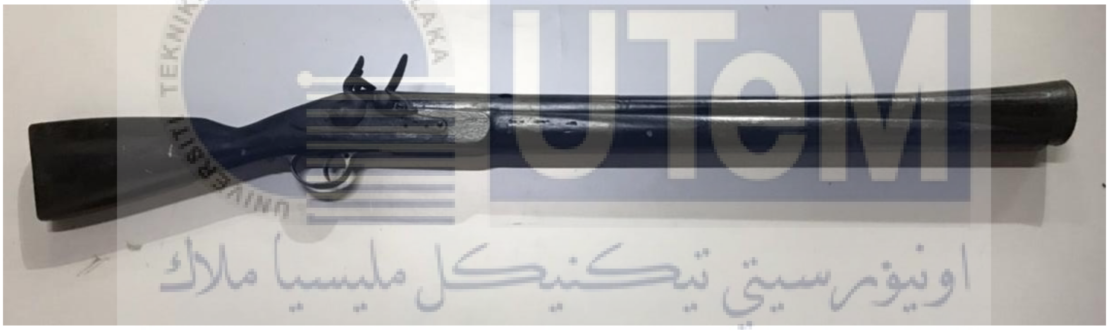


Figure 3.3: History Artifact of Pemuras

3.5 Data Manipulation (STL File)

At this point, the data that was gathered during the scanning process needs to be moved to an STL file. In the field of reverse engineering, this STL data editing stage is a complex part. After the pre-processing steps, the scanned data's point cloud will be saved into an STL file so that Soliwork, Polywork and Materialise magics software can be used to modify and edit the missing part in an STL file so that the prototype can be constructed. This includes filling in holes, removing useless parts, and smoothing the surface of the scanned data. Direct STL file creation from scanned data is helpful because it can cut reduce time and mistakes in the modelling process.

Figure 3.4: PolyWorks 2018 sofware used for data manipulation

Figure 3.5: Solidwork sofware used for data manipulation

Figure 3.6: Materialise magics sofware used for data manipulation

3.5.1 Pre-Processing

Pre-processing is also known as setup procedures, which are performed before to the scanning process. Preparation is typically required prior to employing the scanning procedure. First, identify the final use of the data, select the features that will be used, define the coverage and accuracy requirements, identify the appropriate RE system, prepare the surface to be identified by cleaning the object and defining the part fixture or location where the object should be placed.

3.5.2 Post-Processing

Post-processing tasks include editing, alignment, Re-sampling, and geometry creation. Also known as the data manipulation procedure. After the scanning procedure, the CAD data may be obtained. Using Polyworks software for the ZEISS T-SCAN, the data manipulation process can be accomplished. Polyworks is designed exclusively for the conversion of 3D scan data into high-quality, feature-based CAD models. Thus, the Solidwork and Materialise magics software was also used to modify such as created the new 3D part to replace the missing part. Since it is a programmed used to prepare data before sending it to Selective Laster Sintering machines. This programmed might additionally inspect the quality of an STL file. It could also use Triangle Reduction to get rid of extra triangles and smooth out the mesh without losing important details.

3.6 Data verification

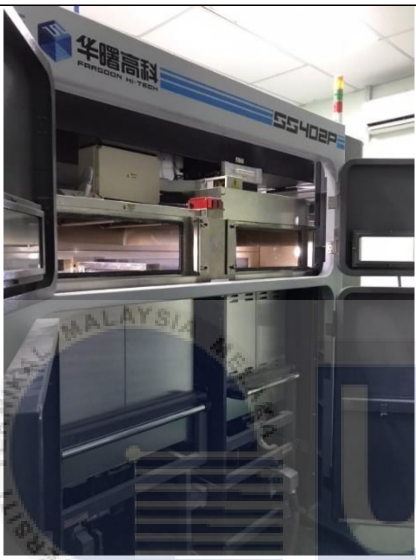
Data verification is the process of ensuring that different types of data that have been changed or entered into a system or database are correct, consistent, and fully utilized. The purpose of data checking is to make sure that the data matches the source data and helps the new system operate. Data from CAD programs that have been edited will be saved in STL format once the program has finished processing the data (Precisely Editor, 2022)

However, direct conversion and indirect conversion are the two methods available for converting 3D scan data into the STL file format. Direct indicates that the data can be transformed into the STL format without requirements for any additional processes. Meanwhile, the term "indirect" is used when referring to the IGES file format, which cannot be modified using Catia or Solidworks but can be updated using other CAD programs. Therefore, the data obtained from the 3D scanning may be converted into an STL file format with the guidance of these CAD tools.

3.7 Prototyping Fabrication

3.7.1 Selected Laser Sintering (SLS) machine process

Table 3.1: Equipment of Selective Laser Sintering (SLS) process

No.	Equipment	Name
1		FARSOON Technology Selective Laser Sintering Machine
2		Powder purify station

3		Blasting machine
4		Blend mixer powder powder bed fusion.

3.8 Data Acquisition

The measured value was taken and recorded. Each feature was measured for five times to get average reading at the same position, the dimension had been taken five times to get the average values and the reading was recorded. After collecting the printed prototypes, the next stage to be proceeded is data collection. Firstly, observation and analysis on detail dimensional of printed prototype was carried out. There are five special features of prototypes were identified and carried out the comparison. Next, the original artifact of Pemuras gun and prototypes were measured by using Vernier caliper and measuring tape. In the measuring process, each printed prototype was measured in the directions of X-axis, Y-axis, and Z-axis. Moreover, two features were marked as the measuring points for each direction and the diameter of barrel of gun.

Table 3.2: Dimensional result of the original part and prototype

Part	**Point**	**Measure (mm)**					**Average**
Original Part	**A**	1100	1100	1099	1099	1100	1099.6
	B	46.40	46.60	46.70	47.30	46.70	46.74
	C	46.50	46.50	47.90	46.60	47.00	46.9
	D	65.87	65.00	65.80	66.00	65.80	65.694
	E	68.00	67.80	68.00	67.40	68.00	67.84

3.9 Data Analysis

3.9.1 Part to Part analysis

Part-to-part analysis focuses on evaluating the geometric compatibility of individual parts. It involves comparing the dimensions, shapes, and features of the parts to ensure they align correctly and fit together as intended. Engineers can verify the compatibility, fit, and functionality of individual parts within an assembly or system. It involves evaluating the dimensional variations and tolerances of individual parts to ensure they meet the design requirements.

3.9.2 Part to CAD analysis

Part to CAD analysis enables the translation of actual components into digital CAD models, which in turn enables the design to be modified, documentation to be created, or manufacturing to be replicated. When the first CAD model is finished being developed, it is validated by being checked against the actual component. To accomplish this, the CAD model must be aligned with the data that was obtained, and then a visual and dimensional comparison must be carried out. It goes through some processing to get a point cloud. The surface of the part is represented by a point cloud, which is a collection of three-dimensional coordinates. In this stage, we will generate a new dataset by arranging and combining the data that we have received.

3.9.3 Visual Inspection

Visual inspection is a common method of quality control, data acquisition, and data analysis. Visual inspection is a quality control method that involves observing an object or system with the human eye in order to evaluate its condition or performance. This inspection procedure is commonly used to detect flaws, irregularities or deviations from set standards. However, the visual inspection is used in a variety of industries, such as manufacturing, construction, healthcare, and electronics. Once a process has been created, organizations can conduct visual inspections using a variety of method, including random sampling. Randomly selected products or physical assets are subjected to quality tests. Products are frequently scrutinized for obvious visual flaws on the manufacturing line. Next, manual sampling. All items are manually inspected by a person who has been trained to detect flaws. This can be a physically demanding work with repetitive movements thus, safety standards, ergonomic equipment, and proper tools should be in place.

3.10 Summary

In this chapter, a process flow chart for a project approach is organized. Following the steps until the results are achieved. Based on the methodology flow chart, this study is to identify the percentage the dimensional accuracy that produced and replicated by selective laser sintering (SLS). Next, the STL data will then be generated by a 3D scanner, edited in the PolyWorks, Solidwork software, and validated with the Materialise Magic software. In addition, powdered-based additive manufacturing machines, such as Project 460Plus 3D printers and Farsoon Technology SS402P is Selected Laser Sintering machines are used in the 3D printing process. Other than that, a vernier caliper and measuring tape was used to measure the dimensions of the original product and prototypes product. In addition, the results of all experimental tasks are obtained and analyzed in the following chapter.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

This chapter includes a detailed overview of the experimental process as well as the findings that were acquired from the experiment that was performed for this project. Data STL file, prototype fabrication, and dimensional accuracy will be carried out as part of the experimental procedure. This analysis performs a Part-to-Part analysis and Part-to-CAD analysis to identify the percentage error of each part. It is according to the capability of the scanner in terms of scanning and capturing the object. However, a previous interview was held to discover the specifics details of Pemuras artifact with accurate measurement. The final expected outcome of this project is that the identify the percentage dimensional accuracy of the prototype product and the original product by using method Part to Part analysis and Part to CAD analysis

4.1.1 Data obtained

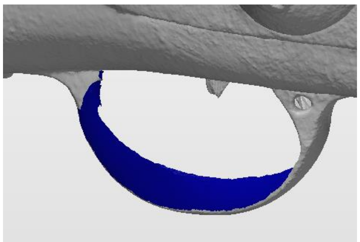
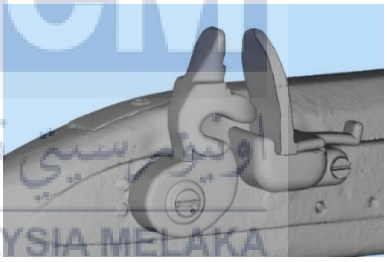
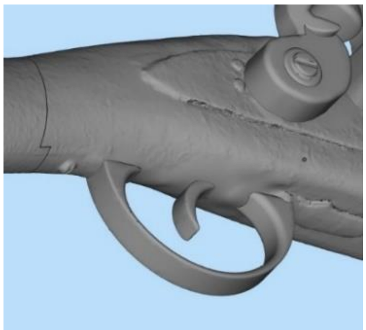
In this study, 3D cad data was obtained from previous experiment. The quality of the data can vary depending on the study. It is important to evaluate the quality of the data before using it. The STL file data of the original part has a surface, complex part problem and need to reconstruct it. It very useful for studying to making a modifications data and procedure to fabricated the prototype to identify the dimensional accuracy of Pemuras artifact.

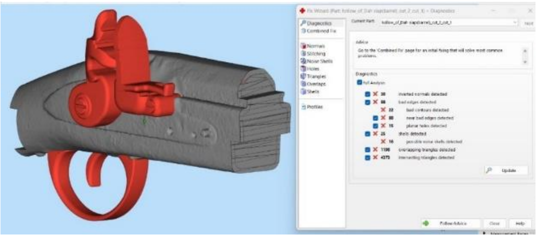
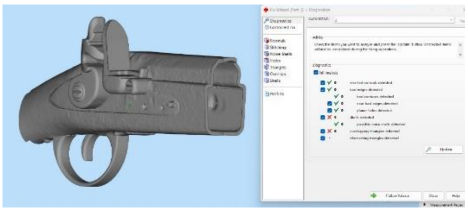
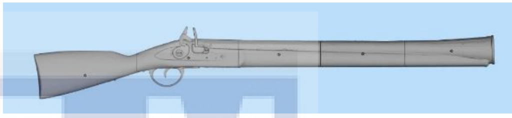
4.1.2 Data manipulation

The ZEISS T-SCAN have direct data processing. Direct means that the data can be changed into STL format without any extra steps. Polywork, Solidwork and Materialise Magic sofware is the softwares was used to determine the direct data. Furthermore, the issue and solution the part problem have been explained. The details of the procedure of data manipulation and verification of STL file also have been explained by the following procedure

4.1.2.1 Issue And solution the part problem

Figure 4.1: Issue and solution

Issue	Solution
  Polywork is unable to cover the large holes on the surface.	  Create the new 3D part of flintlock using Solidwork sofwares

<table>
<tr>
<td>
The data were unable to fabricate the prototye</td>
<td>
The data was verified using Materialise Magis sofwares to remove the all overlapping triangle, intersecting triangle and bed edges</td>
</tr>
<tr>
<td>
SLS machine has a limit measurement with their printing space to fabricate the prototype.</td>
<td>

The 3D model was separated to 5 parts using Materialise Magis sofwares to enable the printing process</td>
</tr>
</table>

4.1.2.2 Procedure by using Polywork

1. Click on the software icon at the pc desktop to operate the software
2. Click on the 'Start polywork|modeller' icon to launched the software

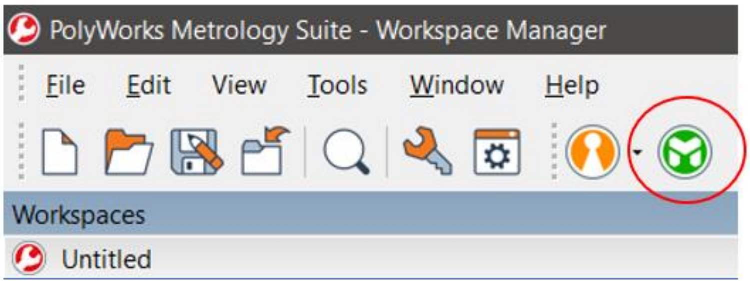


Figure 4.2: 'Start polywork|modeller' icon

3. Import the STL file gained from previous experiment. Used polygonal model to import the object canned.
4. Open the folder of Pemuras to import the Polywork sofware.

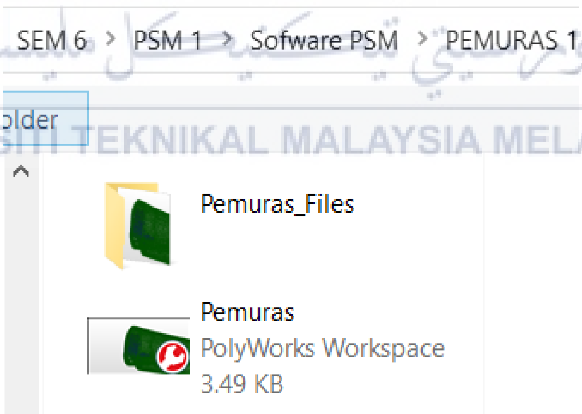


Figure 4.3: folder of Pemuras to import the Polywork sofwares

5. Once the workspace file appear select the file part to be import

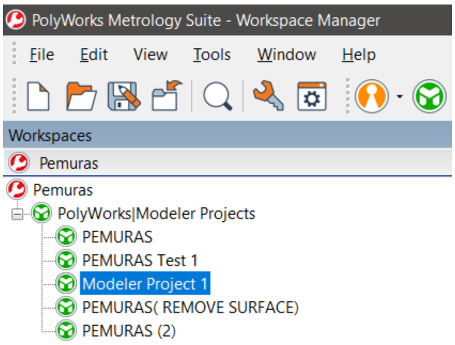


Figure 4.4: workspace file

6. Determine the critical suface that need to filling holes.

Figure 4.5: critical surface that need to filling holes

7. Click on 'Polygon' icon to use the Interactive holes filling so that the software will begin to patch the hole and repair the surface.

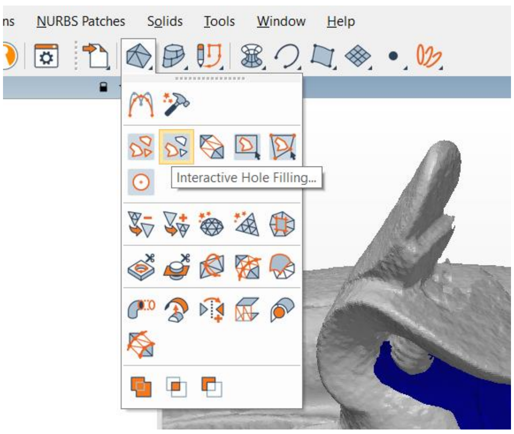


Figure 4.6: Interactive holes filling

8. Select the Fill under operation and use the single boundary hole method to filling the holes surface

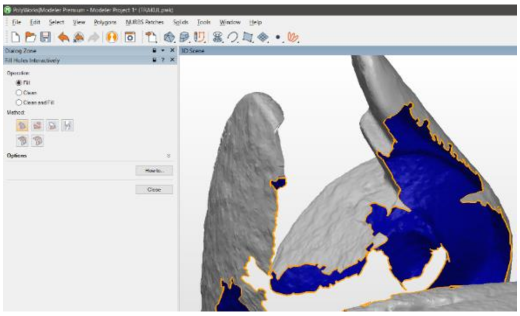


Figure 4.7: Used Fill and the single boundary hole method

9. The surface of the part dimensional not accuracy compare with original part

Figure 4.8: The part dimensional not accuracy compare with original part

10. The process are repeated at the barrel surface

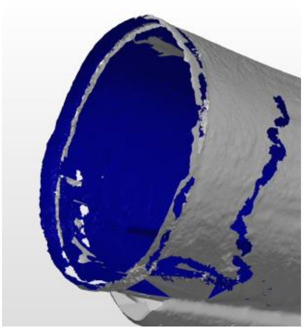


Figure 4.9: The barrel surface

11. The surface of the barrel part is critical to construct because the surface is curve and the part not fulfill compare with orginal part

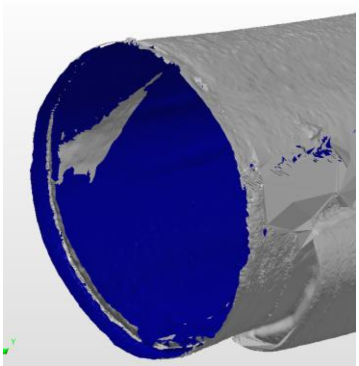


Figure 4.10: The barrel part in polyword sofware

12. The measurements of Pemuras was inaccurate, and the surface was not smooth. To get the best result, it may need to think about the other solution by using Solidwork sofware.

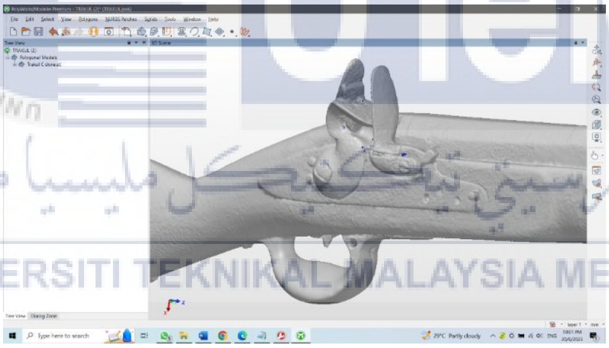


Figure 4.11: The surface is rough and not smooth

4.1.2.3 Procedure by using Solidwork software

1. Open the STL file data from polywork software and identify the problem part in Solidwork software
2. The plane was selected to sketch the new part for the 3D model referenced by original part dimensional

3. Trace the surface original part data on the plane to avoid the actual measurement errors
4. The sketch was extruded to 3D part model to fulfil the hole at flintlock and trigger area as shown in Figure4.13
5. The flintlock and the trigger were combined to the surface of 3D model to making a new 3D model

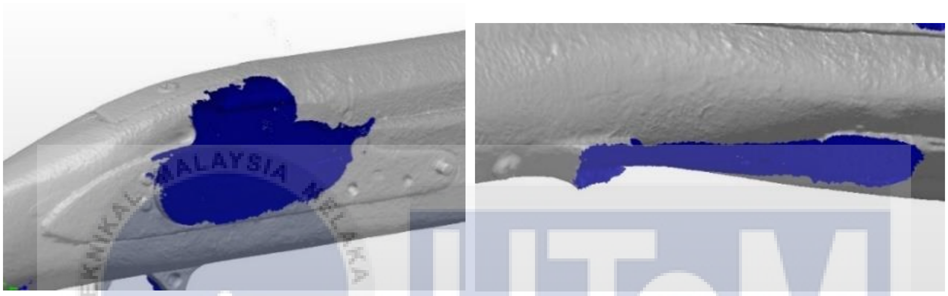


Figure 4.12: The flintlock and the trigger area were removed

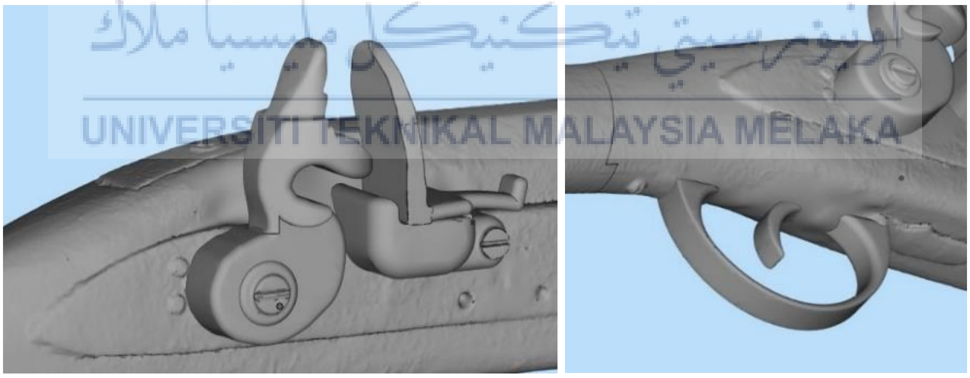


Figure 4.13: The new 3D part of flintlock and the trigger was created

4.1.2.4 Procedure by using Materialise Magic sofware

1. STL file of the Pemuras was imported into the Materialise Magic to verify the CAD model

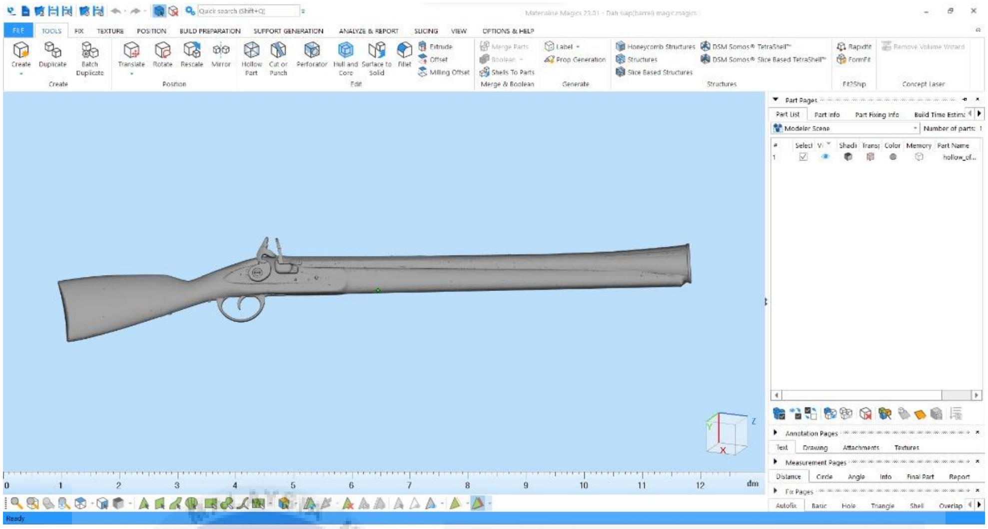


Figure 4.14: STL file was open in Materialise Magic

2. The each of the 3D model part need to analyze the overlapping triangle by using Fix wizard tool to define the problem

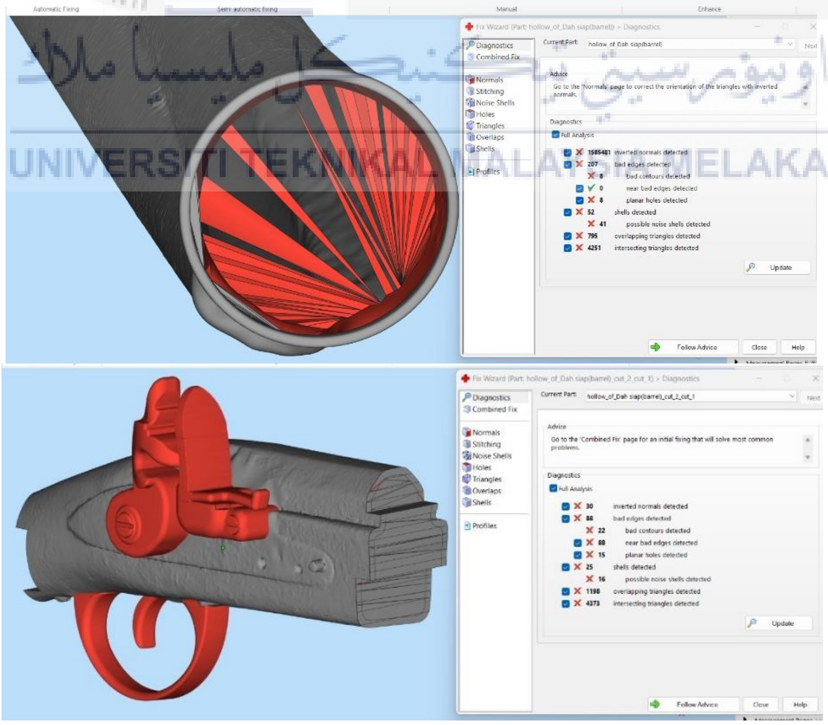


Figure 4.15: The part has a critical issue at the complex part

3. Remove the all overlapping triangle, intersecting triangle and bed edges of each part until the 3D part fully define to analyze

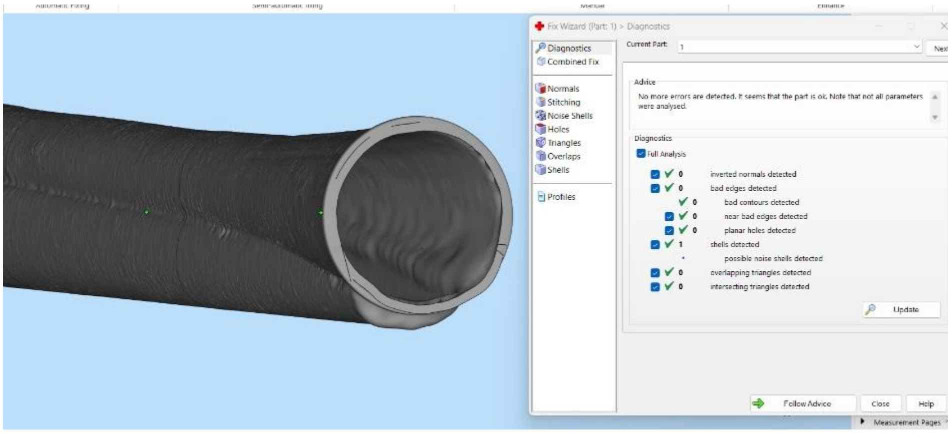


Figure 4.16: The Flintlock part was fully verified by Fix wizard

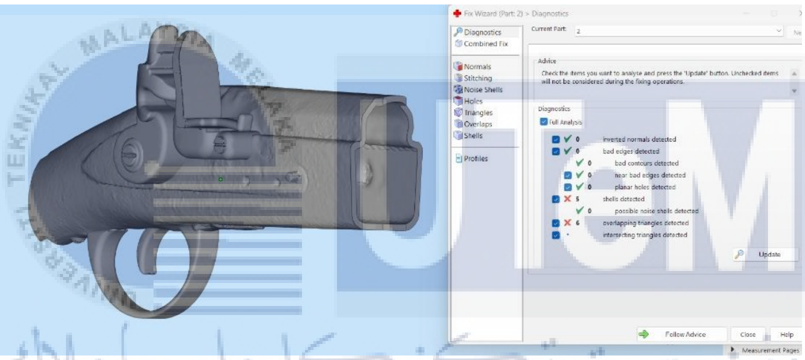


Figure 4.17: The Flintlock part was fully verified by Fix wizard

4. The square teeth type was defined under teeth line parameter. This teeth was chosen to easy the assembly process after the product produce.

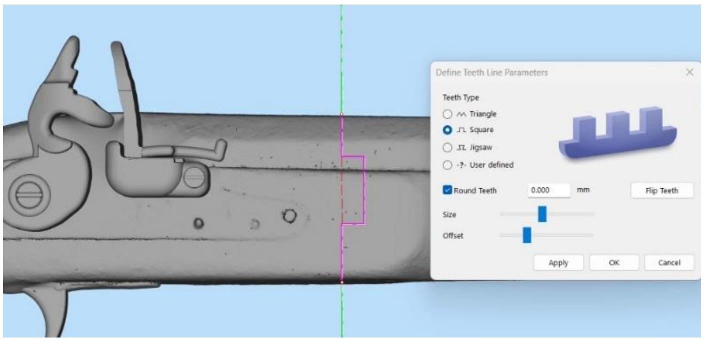


Figure 4.18: The square teeth were set to separate the part to 5 part

5. The 3D model was separated to 5 parts because the SLS machine has a limit measurement with their printing space to fabricate the prototype.

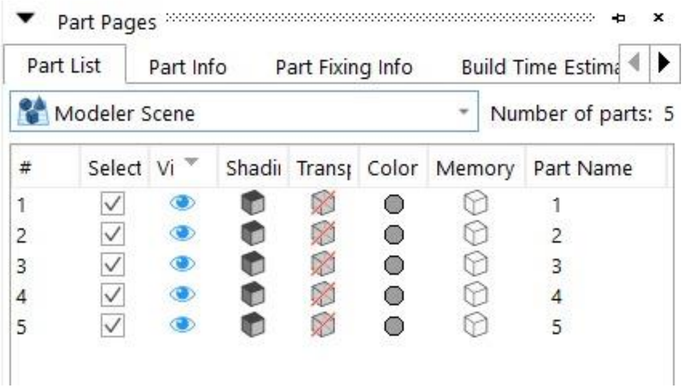


Figure 4.19: The data of the parts were separated in 5 parts

6. The 3D model from Materialise Magic was already to verify with Builstar software to fabricate the product in SLS machine.

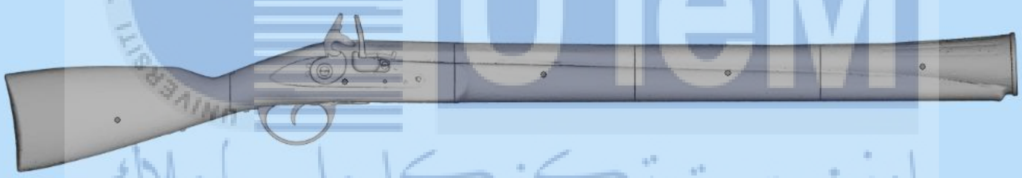


Figure 4.20: The 3D model already to fabricate process

4.2 Standard Operation Procedure (SOP) for Laser Sintering (SLS) Machine

The details of the procedure of prototype fabrication have been explained by the following procedure. The equipment that has been used to fabricate prototype is Farsoon Laser Sintering Machine

Figure 4.21: Farsoon Laser Sintering Machine

1. STL file of the Pemuras was imported into the Buildstar to set up the layout of build parts. The part orientation of the build part is set Y-direction which is in recline position

Figure 4.22: BuildStar icon

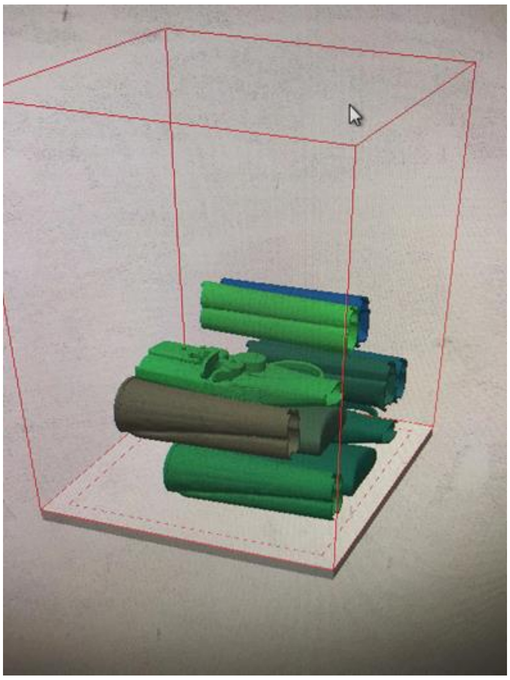


Figure 4.23: Layout of parts

2. The layer thickness for the prototype fabrication have been set with the value of 0.102mm. The layer thickness with the value 0.102 mm is the default parameter setting of the laser sintering machine.
3. The imported build parts are verified by using the option of 'Verify File' as shown to detect the occurrence of collision between the build parts. Build time and powder requirement for the printing process are estimated.

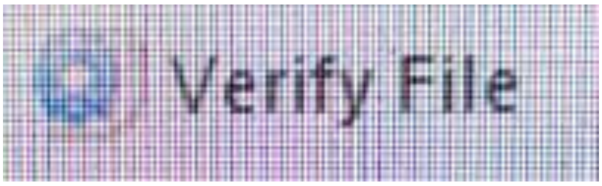


Figure 4.24: 'Verify File" function in BuildStart software

4. Platform position was adjusted based on the build height of the build parts. An exceed height of 20mm was prepared to prevent warping of the build parts. The platform of LS machine have shown as Figure 4.25.

Figure 4.25: Platform of the LS machine

5. Powder have been prepared based on the estimation on powder requirement. Left side build chamber of the SLS machine was pulled out and poured the powder into the build chamber. The powder was flattened by using the blade and pushed the build chamber back into the machine.

Figure 4.26: Flatten the powder with blade

6. Printing simulation was checked through 'Slicer' to ensure printing process can be proceed. The printing process have been started after the simulation was checked.
7. Powder is flattened again by performing the 'Motion' operation of the machine to make sure the powder covers both platforms.

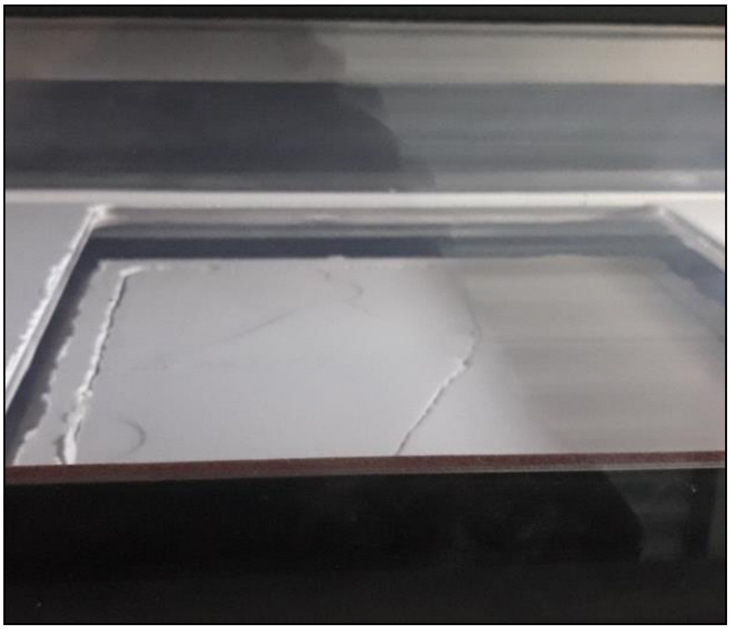


Figure 4.27: Flatten with ‘Motion’ operation

8. Printing simulation is checked through ‘Slicer’ and started the printing process.

Figure 4.28: SLS machine was set up by En.Idain

9. The powder have been placed to the Powder Purify Station as shown as Figure 4.29 and removed the powder that surrounded the prototypes

Figure 4.30: Powder Purify Station

10. Next, start the cleaning process for the prototypes by separates the part from powder block. The powder is placed block is placed to the powder purify station to remove the excessive powder to be recycled back.

Figure 4.31: Process remove powder from the built part and separate the 5 parts

11. Finally, the prototype was cleaned with compressed air by using the blasting machine

Figure 4.31: The prototype was clean by using compressed air

4.3 Result and Discussion of the dimensional accuracy of product

4.3.1 Part to part analysis

The dimensional accuracy measurement has been conducted to check the dimensional of the original product and prototypes. The prototypes were produced by STL file which generated from the RexScan 3D scanner and T-Track 3D scanner. This experiment analyses on the 5 areas of the original product and prototypes.

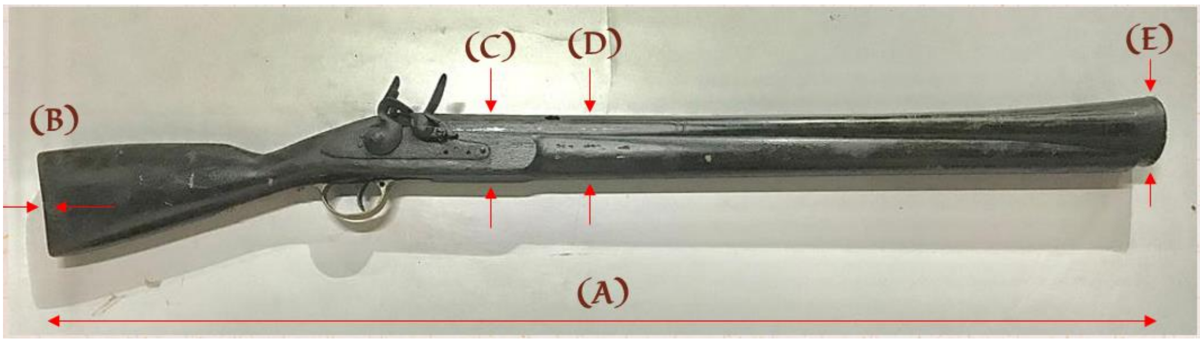


Figure 4.32: Analyses on the 5 areas of the original product

Figure 4.33 : Prototype product

4.3.1.1 Comparison of original and prototype part

There are 5 point has been selected on the original part and prototype part. The dimensional accuracy of each point were measured in five times to obtain the average experimental reading. The dimensional of the original part and prototype part is shown as the Table 5.

Table 3: Original and Prototype part data result of each point

Part	Point	Measure (mm)					Average
Original Part	A	1100	1100	1099	1099	1100	1099.6
	B	46.40	46.60	46.70	47.30	46.70	46.74
	C	46.50	46.50	47.90	46.60	47.00	46.90
	D	65.87	65.00	65.80	66.00	65.80	65.69
	E	68.00	67.80	68.00	67.40	68.00	67.84
Prototype Part	A	1090	1089	1090	1090	1090	1089.80
	B	45.60	45.80	46.40	46.30	46.20	46.06
	C	45.50	46.70	46.60	46.50	46.70	46.40
	D	64.20	64.30	64.40	64.30	64.10	64.26
	E	68.00	67.80	67.90	67.80	67.80	67.86

Base on the Table 5 is value the average of the dimensional accuracy of each product has been listed. The value average of the percentage comparison between the prototype and the original product was completely computed by averaging each point.

4.3.1.2 Chart data result

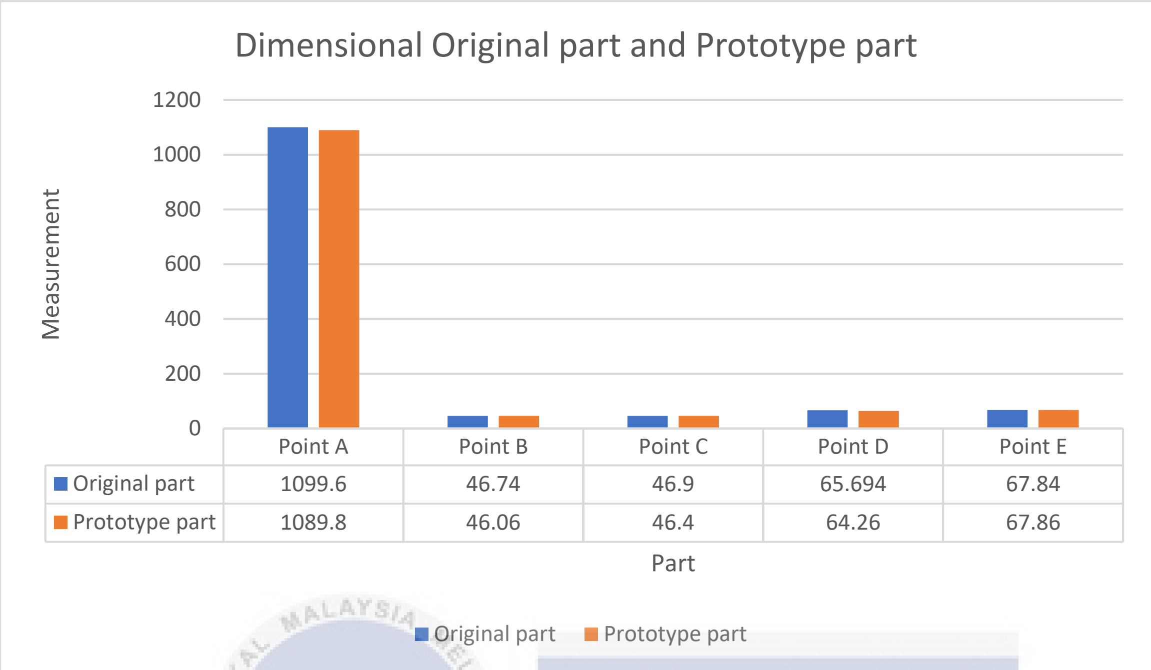


Figure 4.34 : Dimensional of Original part and Prototype part result data

Table 4 : Percentage error result between original product and prototype product

Original part (mm)		Prototype part (mm)		Difference percentage %	Overall different percentage %
A	1099.6	**A**	1089.8	0.89	1.12
B	46.74	**B**	46.06	1.45	
C	46.90	**C**	46.40	1.07	
D	65.694	**D**	64.26	0.03	
E	67.84	**E**	67.86	0	

Base on the Table 6 is value the overall different percentage of both product is 1.12% . The print material that was used one of the factor of percentage error. The powder is recycle and not hight quality it can produce the low quality surface that can effect the product dimensional. However, the assembly process is one of the reason percentage error. The 5 seperated parts that was assembled by using super glue can affect the length of the product because the glue can reduce the material and dry to fast that it dificult to assemble the jointing between part by part correctly. The value of percentage error is slighty different but still in acceptable range.

4.3.2 Part to CAD analysis

Figure 4.35: Prototype product

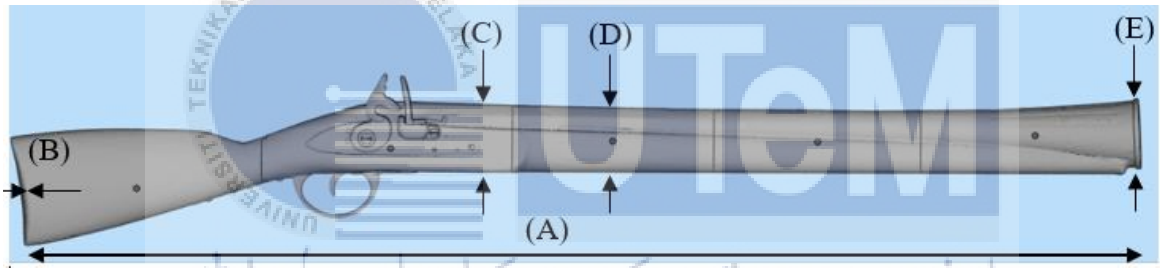


Figure 4.36: CAD Model

4.3.2.1 Comparison of Prototype part and CAD part

There are 5 point has been selected on the Prototype part and CAD part. The dimensional accuracy of each point were measured in five times to obtain the average experimental reading. The dimensional of the Prototype part and CAD part have shown as the Table 5.

Table 5: Prototype part and CAD part data result of each point

Part	Point	Measure (mm)					Average
Prototype Part	**A**	1090	1089	1090	1090	1090	1089.80
	B	45.60	45.80	46.40	46.30	46.20	46.06
	C	45.50	46.70	46.60	46.50	46.70	46.40
	D	64.20	64.30	64.40	64.30	64.10	64.26
	E	68.00	67.80	67.90	67.80	67.80	67.86
CAD Part	**A**	1095	1090	1090	1098	1100	1094.6
	B	46.40	46.50	47.30	46.70	46.70	46.72
	C	47.50	46.60	47.80	46.80	46.00	46.94
	D	65.70	64.50	64.30	65.80	64.20	64.9
	E	67.90	68.20	67.80	67.50	68.00	67.88

Base on the table 7 is value the average of the dimensional accuracy of each product have been listed . The value average of the percentage comparison between the prototype and the original product was completely computed by averaging each point.

4.3.2.2 Chart data result

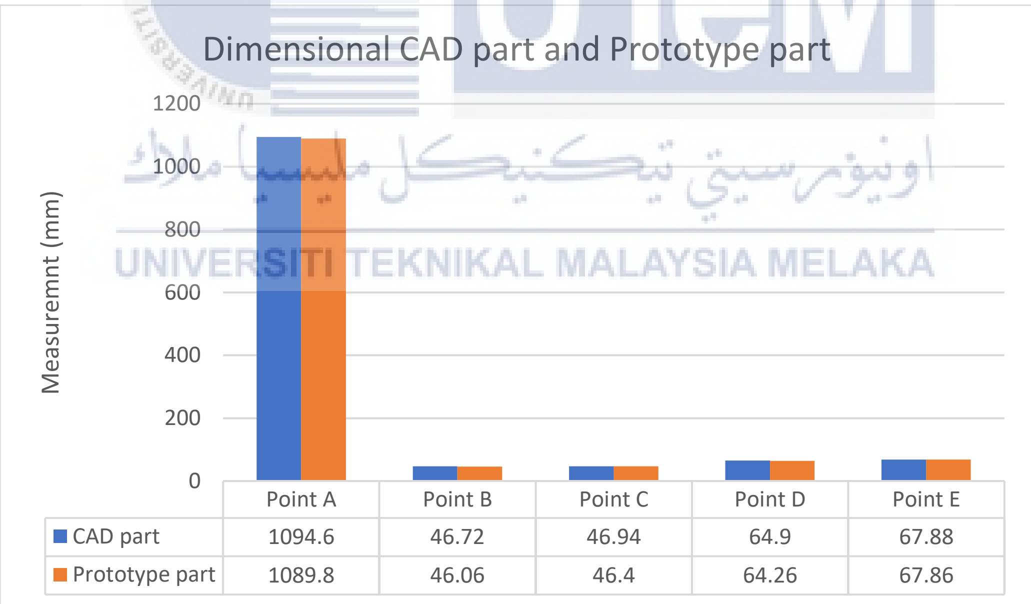


Figure 4.37 : Dimensional of CAD part and Prototype part result data

Table 6: Percentage result between original part and prototype part

CAD part (mm)		Prototype part (mm)		Difference percentage %	Overall different percentage %
A	1094.6	**A**	1089.8	0.73	0.80
B	46.72	**B**	46.06	1.41	
C	46.94	**C**	46.40	1.49	
D	64.90	**D**	64.26	2.46	
E	67.88	**E**	67.86	0	

Based on the table 8 is value the overall different percentage of both product is 0.8% .The factor of percentage error of original part and prototype part from SLS machine is the parameter setting for each prototype on the layer thickness is 0.102mm in the printing process and the part orientation is in Y-direction. The parameter setting are important to making a good structure. The poorly designed structures can provide inadequate support for overhanging features or thin sections, leading to bending and deformation. Since both STL file were generated to fabricate a prototype, the adding material at the surface layer by layer one of factor. Furthermore, the specification of both product are slightly different and the quality of the file also will be slightly different. The print multiple pieces of prototypes at the same time also the factor to affect the dimensional accuracy because too many parts needed to be printed and the surface was cold during printed to another surface. It is challenging to print when the temperature of the layer surface is unsuitable for that purpose. The machining technique using selective laser sintering (SLS) is capable of achieving high dimensional precision. As a consequence, this project successfully achieves a low percentage error between the product and the total data dimensional correctness, which is nearly identical.

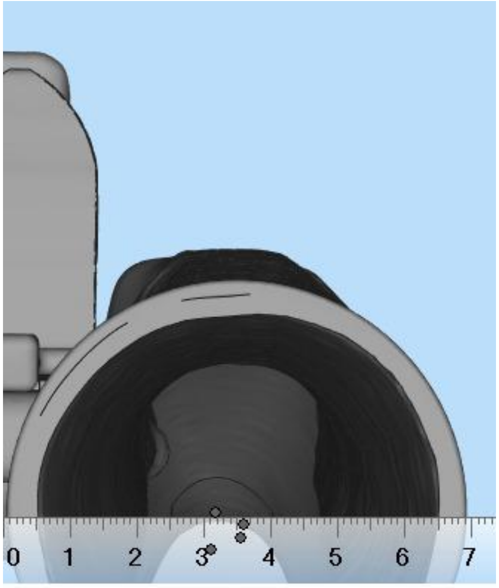


Figure 4.38:The dimensional of the part barrel was measured

at the point “E”

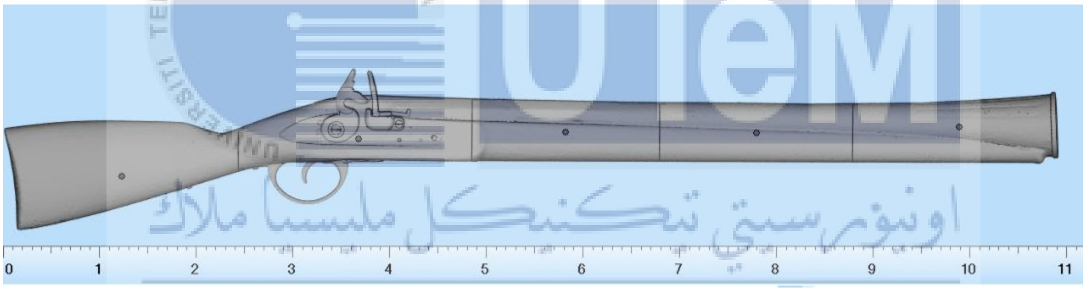
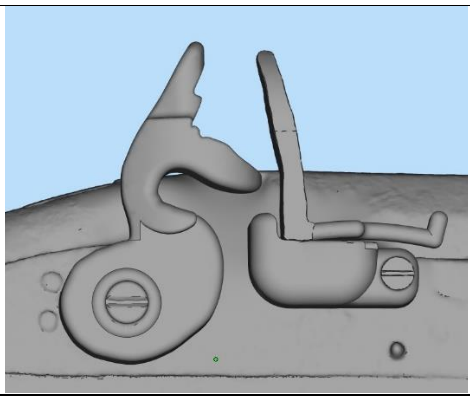
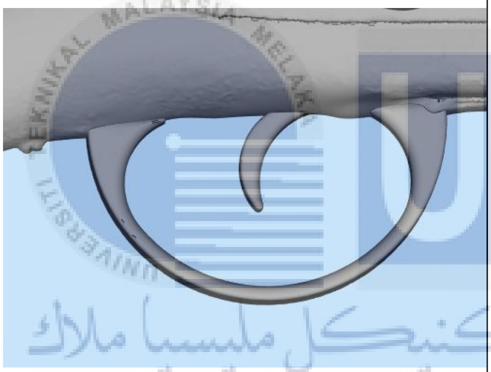


Figure 4.39: The dimensional of 3D model was recorded

in 5 times at the point “A “

4.3.1 Visual Inspection

Table 7: Comparison CAD part and Original part

Name part	**CAD part**	**Original Part**
Flintlock		
Trigger		

Based on the table 9 is comparison CAD part and Original Part. The design and fabrication of products have been completely transformed by computer-aided design (CAD), enabling to used advanced equipment to precisely and accurately produce digital representations of original part. When CAD-designed components are compared to original parts, minor shape deviations within an acceptable range are highlighted. Nevertheless, the transition from CAD models to actual parts may bring differences due to fabricate procedures. A manual sample technique was used to evaluate the shape differences between the original part and the CAD part. The measuring tape and vernier calipers was used to measure of the two pieces of product dimensions and features. To ensure accuracy, measurements were made 5 times at each point. This hands-on method made it possible to analyse the physical characteristics of both product and gave significant insight into any possible variability.

4.4 Challenges Encounter and Counter Measures Taken

Throughout carrying this thesis few challenges have been encounter which is firstly during data manipulation process. The data need to used 3 software to complete 3D model with accuracy dimensional. The complete scanned data dimension has exceeded the SLS platform size. But the scanned data is not fulfilling the requirement to fabricate the prototype by using SLS machine. The surface of 3D model by scanned data not complete and need to reconstruct by using Soliwork, Polywork and Materialise magics software following the original product dimensional.

After the STL data was complete, the data need to be divided into 5 separated parts by using Materialise magics sofware before fabricate it using SLS machine. They are a total of 8 copies of prototypes been fabricated. There are few rejected prototype due to the defects that occur during fabricating the prototype. The defect formation is a common problem in selective laser sintering (SLS). The defects can clearly be seen in Figure 4.39 where the defects have poor bonding formation due to complication during positioning and placing the data before print it. The axis selection is very important before placing the 'Pemuras' as the effects of choosing wrong plane can lead to poor bonding formation. Besides, to fabricate the prototype with using SLS machine that have more challenges. The schedule is tight for booking the slot with lab technician to print the prototype because many students use SLS machine to complete their final year project. It could affect the schedule for prototype fabrication.

However, after complete the data manipulation, the STL file data of the Pemuras was imported into the Buildstarthe sofware. The STL file data of Pemuras need to verify by using Buildstar software before run the machine to fabricate the prototype. But the critical challenge is the STL data of Pemuras has a problem when verify. The data need to regenerate by using solidwork and geomagic software to identify the problem. The problem is a several parts has an overlapping triangle, intersecting triangle and bed edges. It is not possible for the machine to produce a product with incorrect data. After identify the problem the STL file data, the data need return back to Buildstar software to verify the final STL data to fabricate the prototype in SLS machine.

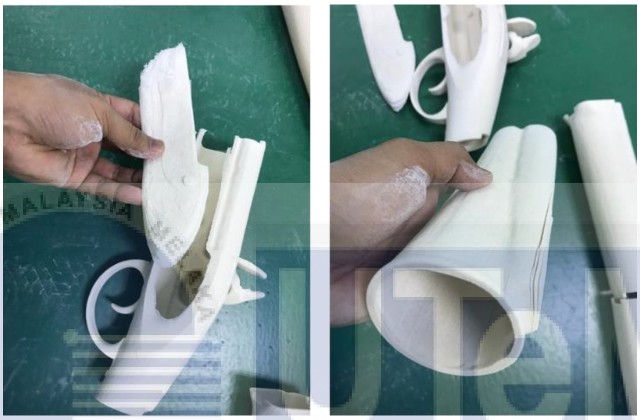


Figure 4.40: A flintlock and barrel part was defect during printing process

Figure 4.41: All of the part was assembly part by part by using super glue

4.5 Summary

In this chapter, there will be a review of how to develop this thesis using the reverse engineering system. It all begins with the accumulation of data from primary and secondary sources. This chapter also discusses how to implement the RE method into experimental research activity. However, PolyWorks ,Solidwork and Materialise magics software will be used in this investigation as CAD software. It can be used to modify and edit the missing part in an STL file so that the prototype can be manufactured by using selective laser sintering (SLS). Lastly, this programmed can also examine the quality of an STL file, and the 3D scanning data can be converted into an STL file with the assistance of these CAD tools. It is essential to achieve dimensional precision between the original part and the prototype part fabricate by SLS machine.

CHAPTER 5

5.1 Conclusion

From this project, the standard operation procedures (S.O.P) for non-contact reverse engineering (RE) and Laser Sintering Machine. Polywork, Solidwork and Materialise Magic softwares (data manipulation) was created to develop the CAD data from point cloud. The geometric data of the historical artifact object are duplicated by using non-contact reverse engineering (RE) and the Laser Sintering was used to fabricate pemuras prototype is an Additive Manufacturing (AM). The vernier caliper and measuring tape was used to measure the dimensional accuracy of the original and prototypes that produced by SLS machine. The comparison analysis Part to CAD , Part to Part and Visual inspection was used to compare the percentage error between the original part and prototypes part based on dimension data. Based on the result the dimensional accuracy between of original product and prototype product is achieved.

5.2 Recommendation

For future development regarding this project, below are several recommendations;

1. Use the new powder to produce prototype because it can increase the quality of surface roughness compare to recycled powder.
2. Select the appropriate part orientation to enable process printing and surface finishing of the prototype.
3. Do not print multiple pieces of prototypes at the same time to reduce the risk of the printing error.
4. Properly setup the layer thickness parameter during product fabrication.

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APPENDICES

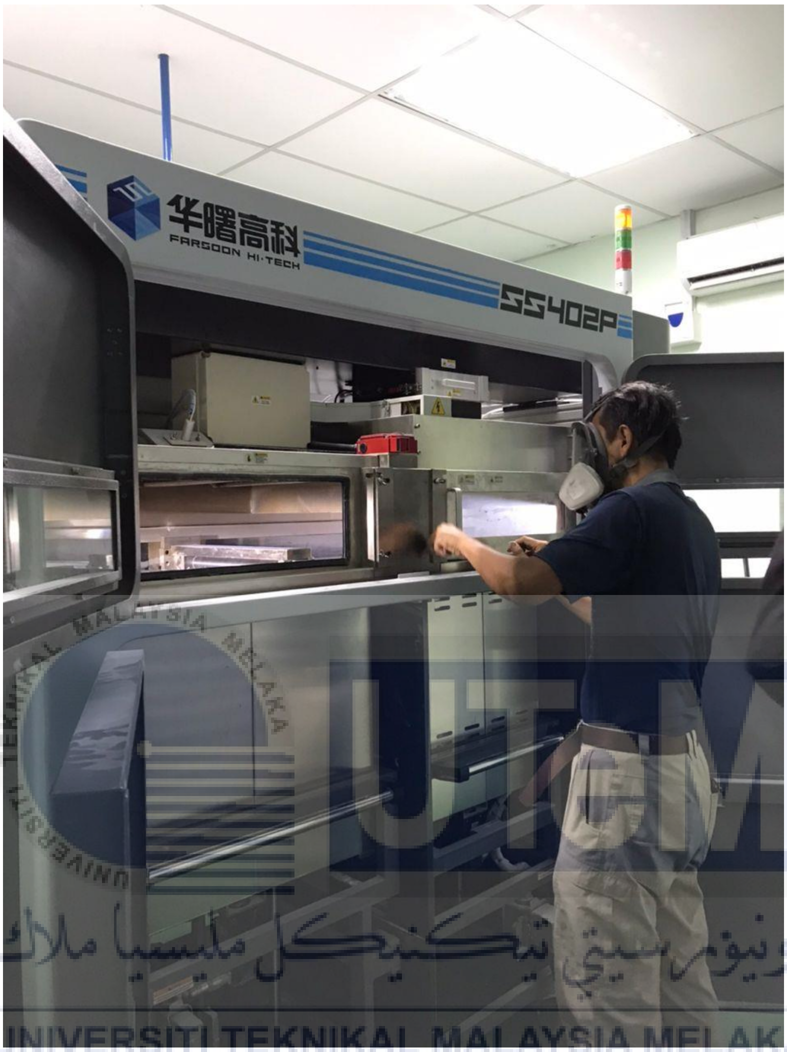
Appendix A: Details of Pemuras artifact

Diagram	Description
	The original of Pemuras artifact at Stadthuys Musuem of Malacca
	Pemuras artifact and Istinggar artifact

	The details part of trigger and flintlock
	The barrel part was measured by using vernier caliper
	The butt stock part was measured by using vernier caliper

Appendix B: Interview session with Mr. Sabri Staff of Stadthuys Musuem

Appendix C: FARSOON SS402P Technology: Selective Laser Sintering machine



FS402P

By Farsoon ✓

Technology	Selective Laser Sintering (SLS)
Materials	Thermoplastics
Feedstock format	Powder
Build envelope	350 × 350 × 430 mm
Country	China

Price

upon request

Technical specifications

General

Model	FS402P
Manufacturer	Farsoon
Price	upon request
Release date	-
Country	China
Status	Available
Topics	Hybrid manufacturing, Large format, SLS

Technology

Technology	Powder Bed Fusion (PBF) > Laser beam > Selective Laser Sintering (SLS)

Materials

Materials	Polymers Thermoplastics Polyamides
Feedstock format	Powder

Performance

Build envelope	350 × 350 × 430 mm
Build volume	52.68 L
Max. temperatures	
Max. extruder temp.	-
Max. chamber temp.	-
Max. plate temp.	-
Min. layer thickness	0.02 mm
XY accuracy	0.02 mm
Max. print speed	-

Appendix D: Gantt Chart PSM1

PSM 1 PLANNING (GANTT CHART)																
Replication and Part Validation of Melaka Historical Artifact (Pemuras) made using Selective Laser Sintering (SLS)																
TASK	Plan VS Actual	WEEK														
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Tittle selection	Plan															
	Actual															
Project briefing	Plan															
	Actual															
Product selection	Plan															
	Actual															
Collect the primary data	Plan															
	Actual															
Install the polywork sofware	Plan															
	Actual															
Data point cloud	Plan															
	Actual															
Literature review	Plan															
	Actual															
Product background study	Plan															
	Actual															
Identify Reverse engineering, Additive manufacturing	Plan															
	Actual															
Repair the survace problem	Plan															
	Actual															
Research evaluation (summarize journal)	Plan															
	Actual															
Report progress	Plan															
	Actual															
Repair the survace problem with other method	Plan															
	Actual															
Weekly meeting and Update progress	Plan															
	Actual															
Final draf & Discussion with supervisor	Plan															
	Actual															
PSM 1 Final Report	Plan															
	Actual															
PSM 1 Presentation	Plan															
	Actual															

Appendix E: Gantt Chart PSM2

PSM2 PLANNING (GANTT CHART)																	
Replication and Part validation of Melaka historical artifact (Pemuras) made using Selective Laser Sintering (SLS)																	
TASK	Plan VS Actual	WEEK															
		Semester Break	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Project briefing	Plan																
	Actual																
Identify the Selective Laser Sintering machine	Plan																
	Actual																
Determine the material for Selective Laser Sintering	Plan																
	Actual																
Collect the secondary data (scanner data)	Plan																
	Actual																
Repair the surface using Polywork	Plan																
	Actual																
Work progress (5%)	Plan																
	Actual																
Identify advantages of Polywork	Plan																
	Actual																
Identidy the Solution to smooth the surface	Plan																
	Actual																
Create new 3D part by using Solidwork	Plan																
	Actual																
Meeting and discuss of overall progress	Plan																
	Actual																
Print the prototype	Plan																
	Actual																
Collect data measument original and protoype	Plan																
	Actual																
Analyze result	Plan																
	Actual																
Progress report	Plan																
	Actual																
Poster presentation	Plan																
	Actual																
PSM 2 Report writing	Plan																
	Actual																
PSM 2 Presentation	Plan																
	Actual																