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

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Date : 10/1/2024

DEDICATION

This work is wholeheartedly dedicated for all of my family especially my beloved parent, Nordin Bin Mohamed Yusof and Suhaidayati Binti Sulong. To all my siblings Siti Nur Syuhada Asyiqin and Nur Anisah Solehah.

To my extraordinary supervisor Ts. Dr. Syahibudil Ikhwan Bin Abdul Kudus and co supervisor En. Mohd Rafi Omar for the endless knowledge and support during the whole process until the fabrication of the prototype for this thesis.

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ABSTRACT

The purpose of this projects is to recreate and preserve the historical artifacts, producing 3D replicas to sustain its cultural value by reverse engineering and using machines that available in Faculty of Mechanical and Manufacturing Engineering Technology (FTKIP), which is used to determine the best device that produce STL data from scanned object. Apart from that, this research work is carried out based on a case study of an artifact namely " ISTINGGAR" that was obtained from Stadthuys Museum and the artifact will be used in Reverse engineering (RE) process as well as will be fabricated using additive manufacturing technologies (AM). This research will be focusing on powder based process as it will be used in fabrication of scanned objects. 3D scanner can helps fix defects on certain objects as well as it captured data was very accurate to the actual object scan. The main issues highlighted in this project is the dimensional accuracy study of 3D printed component. Hence, in this research project, reproduction of the Istinggar using non contact reverse engineering (RE) systems and powder-based additive manufacturing (AM) of selective laser sintering (SLS) techniques. The collected data were analyzed using statistical analysis. Thus, 3D scanned data, RE system specifications, and angle of scanning are the significant factors that influence the quality of the printed prototype in terms of asthetics, and dimensional accuracy.

ABSTRAK

Tujuan projek ini adalah untuk mencipta semula dan memelihara artifak sejarah, menghasilkan replika 3D untuk mengekalkan nilai budayanya dengan kejuruteraan terbalik dan menggunakan mesin yang terdapat di Fakulti Teknologi Kejuruteraan Mekanikal dan Pembuatan (FTKIP), yang digunakan untuk menentukan peranti terbaik. yang menghasilkan data STL daripada objek yang diimbas. Selain itu, kerja penyelidikan ini dijalankan berdasarkan kajian kes artifak iaitu "ISTINGGAR" yang diperolehi dari Muzium Stadthuys dan artifak tersebut akan digunakan dalam proses Reverse engineering (RE) serta akan difabrikasi menggunakan pembuatan bahan tambahan. teknologi (AM). Penyelidikan ini akan memfokuskan kepada proses berasaskan serbuk kerana ia akan digunakan dalam fabrikasi objek yang diimbas. Tambahan pula, kajian ini menunjukkan cara pemulihan dan pengeluaran semula artifak sejarah yang berkesan. Pengimbas 3D boleh membantu membetulkan kecacatan pada objek tertentu serta data yang ditangkap adalah sangat tepat dengan imbasan objek sebenar. Isu utama yang diketengahkan dalam projek ini ialah kajian ketepatan dimensi komponen cetakan 3D. Oleh itu, dalam projek penyelidikan ini, pembiakan Istinggar menggunakan sistem kejuruteraan balik tanpa sentuhan (RE) dan pembuatan bahan tambahan berasaskan serbuk (AM) teknik pensinteran laser terpilih (SLS). Data yang dikumpul dianalisis menggunakan analisis statistik. Oleh itu, data imbasan 3D, spesifikasi sistem RE dan sudut imbasan adalah faktor penting yang mempengaruhi kualiti prototaip cetakan dari segi astetik dan ketepatan dimensi.

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CHAPTER 1

INTRODUCTION

1.1 Background

The goal of this research project is to examine the dimensional correctness of an actual historical artifact from Istinggar as well as the construction quality of a prototype made using a selective laser sintering (SLS) additive manufacturing (AM) equipment. The method of 3D printing, also known as additive manufacturing (AM), involves laying down successive layers of material while being guided by a computer to create a 3D object of any shape from a 3D model or other electronic data sources. Processes that give increased accuracy have the potential to produce parts with finer features.

Reverse engineering (RE) and additive manufacturing (AM) are crucial to the design and development of new products because of their significant contribution to speeding up product development. Reverse engineering (RE) and 3D scanning have made tremendous advancements in recent years, making it a practical choice for capturing the geometry of complex design models. Despite the benefits of the technique, the biggest problem is currently surface roughness. There have been numerous attempts to regulate, observe, and forecast the surface roughness of the printed portion.

The term "historical artifact" refers to items that were made or utilized by humans in the past. They may be anything, such as pottery or tools and weapons. We can learn a great deal about the people who made artifacts, including their culture, technology, and way of life.

Numerous locations, such as archaeological sites, museums, and private collections, include artifacts. Artifacts aid in the reconstruction of the past by archaeologists. Archaeologists can learn about the technology and culture of the people who made artifacts by examining the materials used to build them, their construction, and their adornment.

As a result, the objective of this study is to examine the surface quality of items produced by an Additive Manufacturing (AM) printing system that is currently in use at UTeM's Fakulti Teknologi Kejuruteraan Mekanikal & Pembuatan (FTKMP). This investigation is being done to see if the generated part's surface finish resembles that of the original product. In the future, this technique might also be utilized to preserve and restore Malaysia's historical artifacts.

Additionally, based on the local historical artifact object, the experiment will be carried out using non-contact reverse engineering and a Laser Sintering Machine. The geometry of the object will be duplicated using non-contact RE, a 3D scanner, and the part will be constructed using laser sintering equipment. In closing, the project's expected outcome is that the generated part's surface finish will be comparable to that of the original part.

1.2 Problem Statement

Historical artifacts are priceless cultural gems that provide deep insights into our past and help us comprehend the accomplishments, tribulations, and traditions of earlier civilizations. These artifacts give us a physical link to our shared history and help us to reconnect with our roots. The longevity and integrity of historical artifacts are threatened by a number of variables, which makes preservation extremely difficult. This problem statement intends to examine the subject of historical artifact preservation and emphasize how urgent it is to resolve these problems in order to safeguard our cultural heritage.

Mitigating the negative impacts of environmental conditions and natural degradation is one of the main issues in maintaining historical artifacts. Organically made artifacts like wood, leather, textiles, and paper are especially susceptible to deterioration over time. Pests, varying humidity, light, and temperatures can all lead to permanent harm. If proper conservation procedures aren't taken, these artifacts could deteriorate, losing important historical data and losing their value as instructional materials.

Keeping appropriate storage conditions is also essential for the long-term preservation of historical artifacts. To prevent deterioration, museums, archives, and other cultural organizations must maintain controlled settings with consistent temperature, relative humidity, and illumination levels. Unfortunately, many institutions lack the infrastructure and resources needed to satisfy these demands. The risk of damage, theft, and deterioration is increased by inadequate storage facilities, a lack of finance, and antiquated infrastructure, which places historical artifacts at serious risk.

The critical and difficult task of preserving historical artifacts calls for focused and coordinated efforts. It will take resources to invest in appropriate storage conditions, infrastructure improvements, conservation expertise, and raised public awareness to address the problem statement around artifact preservation. We can make sure that future generations have access to our rich cultural legacy and may continue to learn from the mistakes of the past by appreciating the value of historical artifacts and taking proactive steps to conserve them.

Therefore, there is a chance to do research in partnership with The Stadthuys Museum of Melaka, with the goal of creating 3D reproductions of the artifacts to preserve their cultural significance before they lose their original state. The application of artifact restoration has benefited from the use of additive manufacturing (AM), as the surface finish of produced parts is typically only having little differences from original historical artifacts.

1.3 Research Objective

The objective of this research can be concluded as follows:

a) To generate CAD data obtained from point cloud data.

b) To replicate the geometric data of the historical artifact by using non-contact reverse engineering (RE) and Laser Sintering machine.

c) To do comparison of analysis for dimensional accuracy between the original historical artifact and the 3D printed prototype based on the dimensional accuracy result produced by Laser Sintering machine.

1.4 Scope of Research

The scope of this research are as follows:

1. To do literature search and review.
2. To identify the potential of scanned artifact using reverse engineering.
3. To familiarize with reverse engineering, computer aided design and selective laser sintering.

4. To manipulate the cad data obtained from cloud data.
5. To verify the usage of STL data and fabrication of prototype by using selective laser sintering.
6. To perform analysis of comparison for dimensional accuracy between original historical artifact and printed prototype.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

The literature and explanations of information use presented in this chapter serve as the criteria for conducting the research on the history of cultural heritage, additive manufacturing, and reverse engineering. To ensure a thorough grasp of the subjects presented, this chapter provides descriptions of the concept, purpose, advantages, classification, limitations, methodology, and application of each technology. Books, journals, and interviews were cited as the primary sources of knowledge. Search engines for literature like Google Scholar, ResearchGate, and Mendeley were used to remove this material. The following research areas or topics were used to filter the literature: Dimensional precision.

2.1.1 Historical artifacts

The study and preservation of historical artifacts provides us with a tangible connection to the past, allowing us to delve into the rich tapestry of human history. These artifacts, ranging from ancient tools and artworks to documents and archaeological finds, offer valuable insights into the lives, beliefs, and achievements of our ancestors. They are the physical remnants of bygone eras, serving as windows into the past and invaluable resources for historical research, education, and cultural preservation.

Anything or item that has historical value and shows signs of earlier human activity qualifies as a historical artifact, according to a broad definition. These artifacts, which include a wide variety of items from many eras and cultures, can differ substantially in size, form, and material composition. They could consist of common items like pottery, utensils, and clothing as well as major buildings, architectural ruins, manuscripts, works of art, and religious artifacts (Sharer & Ashmore, 2003).

Figure 2.1: Mycenaean stirrup jar from Ras Shamra (Spagnoli, 2016)

Additionally, historical artifacts can be divided into many sorts according to their place of origin, purpose, or context. For instance, archaeological artifacts found at excavation sites offer important details on historic civilizations' technologies and cultural practices. Historical artifacts, like mediaeval manuscripts or Renaissance paintings, provide a window into the artistic and intellectual prowess of earlier civilizations.

The use of historical artifacts in research and teaching is invaluable. They serve as the foundation for several disciplines, including anthropology, art history, archaeology, and history. To learn more about earlier cultures, traditions, and social systems, researchers analyze artifacts. These items contain information that sheds light on issues such as how people interacted with their environment, what they valued, and how they lived.

Likewise, artifacts are essential in educational contexts since they are effective teaching tools. They make history more approachable and interesting for kids by bringing it to life. Students can gain a greater comprehension of historical ideas, critical thinking abilities, and empathy for many cultures and eras through interacting with artifacts.

Given their rarity and fragility, historical artifacts require extensive preservation. These items may deteriorate as a result of a number of things, such as exposure to light, humidity, temperature changes, pests, and human handling. Without the right conservation measures, important historical data could be lost forever.

In order to preserve historical artifacts and make them accessible to future generations, conservation specialists use specialized procedures and methodologies. These precautions include appropriate handling, climate management, storage, and, if required, restoration procedures. Additionally, improvements in digital imaging and documenting have opened up new opportunities for keeping information about artifacts alive and spreading it without endangering their physical integrity.

2.1.2 Restoration Method of Historical Artifact

Historical artifacts are priceless windows into the past that give us insightful knowledge about the customs, achievements, and lifestyles of our ancestors. These artifacts may sustain damage or deterioration over time as a result of environmental variables, human activity, or natural processes. For these artifacts to be preserved over time and remain accessible to future generations, restoration, the process of mending and maintaining them, is essential.

In order to preserve our cultural heritage and let future generations understand and benefit from the accomplishments of the past, historical artifact restoration is essential. The development of contemporary technology like 3D printing has opened up new possibilities for the preservation and restoration of these priceless artifacts. In this essay, the use of 3D printing in the restoration process is examined, along with its advantages, disadvantages, and effects on the field of cultural heritage conservation.

Figure 2.2: Example of 3D Printing Restoration

A cutting-edge technology called 3D printing, commonly referred to as additive manufacturing, enables the manufacture of three-dimensional items by layering materials based on computer designs. 3D printing provides a non-invasive way for replacing missing or damaged components of historical artifacts, allowing conservators to restore their original form without the need for invasive interventions.

2.1.3 History of Malacca, Malaysia

Malacca, also known as Melaka, is a historic city located on the southwestern coast of the Malay Peninsula. Renowned for its rich history and cultural heritage, Malacca has played a significant role in shaping the region's history and serves as a testament to the diverse influences that have left their mark on the city.

The beginning of Malacca's history may be found in the 14th century when it first became a thriving port city. Malacca became an important trading central because of its advantageous location at the strait's narrowest point, drawing traders from China, India, Arabia, and Europe. Due to the city's strategic location, trade in products, concepts, and cultures flourished, resulting in the blending of various influences that gave Malacca its own personality.

Malacca rose to popularity as a strong and rich sultanate around the beginning of the fifteenth century. Sultan Parameswara's reign saw the city thrive as a hub for trade, diplomacy, and Islamic learning. The Malacca Sultanate established diplomatic links with surrounding kingdoms and drew traders from all over the world, which aided in the development and prosperity of the city. Islam's influence grew quickly, elevating Malacca to the status of a major Islamic hub in Southeast Asia.

Figure 2.3: Drawing of Parameswara (Sejarahtokoh, 2012)

European nations were interested in Malacca because of its richness and strategic importance. Malacca was taken by the Portuguese under the command of Afonso de Albuquerque in 1511, which was the start of European colonization in the area. Over the course of the more than a century-long Portuguese occupation, Malacca's importance as a trading port waned. The architecture, language, and habits that still reflect Portuguese influence demonstrate how deeply the Portuguese impacted the city.

Malacca was taken over by the Dutch East India Company in 1641 after the Portuguese were driven out. Stability and a period of economic growth were brought about by the Dutch era. The city once again achieved popularity as a significant commerce hub, drawing traders from all over the world. The Dutch brought new agricultural techniques to the area, such as the production of sugarcane and rubber, which had a long-lasting effect on the economy. The renowned Stadthuys and the Christ Church, as well as other Dutch-era architectural remains, are still revered Malacca icons.

In the early 19th century, the British Empire seized control of Malacca from the Dutch. The city continued to grow during the British era, with the construction of modern infrastructure like roads, hospitals, and schools. The legal and administrative frameworks, which served as the cornerstone for the region's modern governance, were also influenced by the British. Malacca remained under British rule until 1957, when Malaysia became independent.

Malacca is still a lively reminder of its colorful past. UNESCO has designated the city's distinctive fusion of cultural influences, architectural wonders, and historical treasures as a World Heritage Site since 2008. Explore the famous Jonker Street in Malacca, a thriving centre of antique stores, art galleries, and regional specialties. Additionally, they can go to the magnificent A Famosa stronghold, Cheng Hoon Teng Temple, and the ruins of St. Paul's Church, each of which is a testament to a different period in Malacca's history.

2.1.4 Museum in Malacca

Melaka is one of the states in Malaysia and is also a state with many historical buildings and artifacts. In addition to indigenous historical treasures, Melaka is home to numerous foreign antiquities that were left behind from the colonial periods of the Portuguese, Dutch, and British. These buildings and artifacts have been adequately preserved in Malacca. Malacca is home to a large number of museums that are broken down into historical, cultural, and artistic categories. The Stadthuys (Museum of History and Ethnography) in Malacca was the museum that was visited for the purpose of measuring the dimensions for the selected artifact, known as Istinggar.

Figure 2.4: Stadthuys Museum

One of the most well-known sites in Malacca, Malaysia, is The Stadthuys, also known as the Museum of History and Ethnography. This unique red structure with Dutch-inspired architecture is located in the city's centre and serves as a reminder of the area's colonial past. It is a notable historical and cultural landmark and one of the oldest still-standing Dutch structures in Southeast Asia.

During 1641, on the Dutch colonial era, after the Dutch had taken Malacca from the Portuguese, construction of the Stadthuys began. It functioned as the governors' and administrators' formal house. The Stadthuys was first constructed as an administrative hub, as well as a location for the offices of the Dutch East India Company and different government agencies.

An outstanding illustration of Dutch colonial architecture is The Stadthuys. The architecture incorporates Malay, Portuguese, and Dutch elements. The structure is made of sturdy red bricks, Dutch-style wooden doors, and louvred windows from the 17th century. The ornamental gables on the steeply pitched roof give it a unique aspect. The building's outside walls are painted red, which has come to be associated with it and is a well-known symbol of Malacca.

The Stadthuys, which is currently home to the Museum of History and Ethnography, is a striking reminder of Malacca's colonial history. It offers a peek into the city's rich history and cultural heritage with its attractive architecture and educational exhibitions. An opportunity to learn about the effects of Dutch colonization in Southeast Asia and to take in the colorful tapestry of cultures that have influenced Malacca over the years is provided by a trip to the Stadthuys.

2.1.5 Background of Istinggar

The numerous ethnic groups of Maritime Southeast Asia constructed istinggars, a form of matchlock weapon. The Portuguese influenced indigenous armament after capturing Malacca in 1511, which led to the development of the rifle. The Nusantara region already had early long-barreled weapons called bedil, or Arquebus Jawa as the Chinese named it, before the advent of the istinggar. The majority of items on the Malay Peninsula were really made in Indonesia, particularly the Sumatra region of Minangkabau (Foundation, 2023).

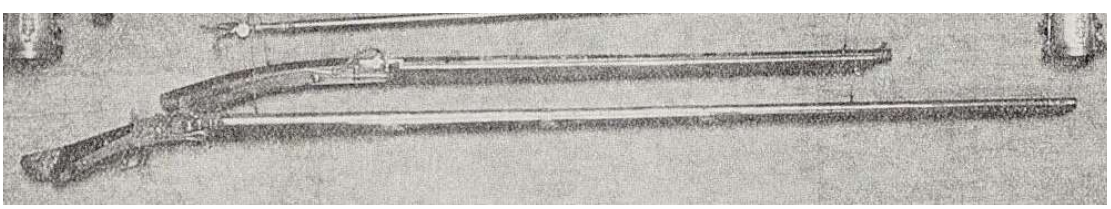


Figure 2.5: Istinggar (Foundation, 2023)

The Portuguese term espingarda, which implies arquebus or firearm, was taken as the source of the name istinggar. Later, the phrase was shortened to estingarda and then setinggar or istinggar. Istinggar normally had a long barrel that was between one and two meters long and were manufactured of brass or iron. They included a lead ball and a charge of gunpowder and were discharged by lighting the match cord that ignited the gunpowder. Istinggars had a range of up to 100 meters and could fire one shot at a time.

The many ethnic groups of the Nusantara region used istinggars for both hunting and combat. They were frequently used to disperse opposing formations and were especially effective against opponents with minimal armor. Istinggars were feared for their lethal accuracy and were often utilized by pirates and bandits.

Early in the 16th century, the Portuguese first brought the istinggar to Maritime Southeast Asia. The matchlock firearm was invented by the Portuguese in the 15th century, and they rapidly saw its benefits. Compared to conventional bows and arrows, the matchlock handgun was more potent and accurate and could shoot farther.

The istinggar was brought by the Portuguese to the Malay states, where it immediately gained popularity. The weapon became a significant component of the Malay military arsenal when the Malay states started producing their own istinggar. The Acehnese-Portuguese War (1565-1629) and the Javanese War of Succession (1677–704) were two conflicts in the Maritime Southeast Asia that involved the istinggar.

As more contemporary weapons like the rifle and the revolver took their place, the employment of istinggars began to wane in the late 19th century. However, some traditional groups in the Nusantara region still employ istinggars, which they view as a representation of their cultural legacy.

2.2 Reverse Engineering (RE)

Reverse engineering is an intriguing process that entails breaking down, examining, and comprehending the inner workings of a system, technology, or product in order to learn more about its design, functionality, and manufacturing methods. It is a strong instrument that is employed in many different industries, including engineering, manufacturing, software development, and even forensics.

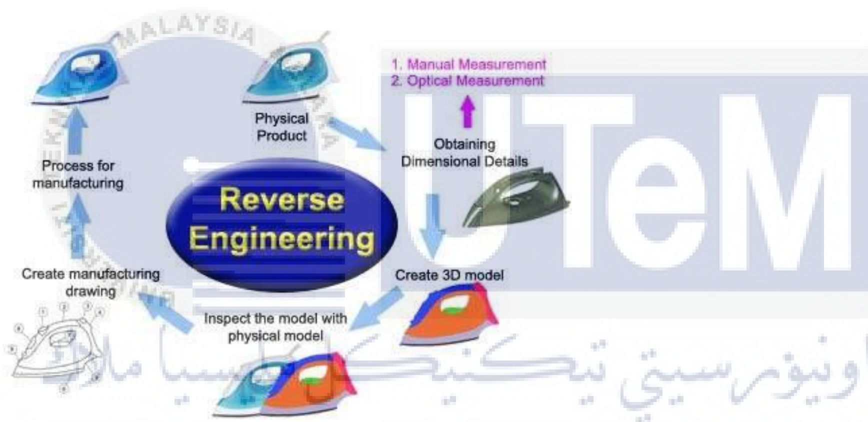


Figure 2.6: Reverse Engineering (Jayaganesh Subburaj - Karpagam Institute of Technology, n.d.)

The process of disassembling and examining an existing product or system to comprehend its parts, operation, and design principles is known as reverse engineering. It entails obtaining information from a system or object through measurement, disassembly, and occasionally by using specialized equipment and methods. The objective is to learn about the original design in order to potentially duplicate or enhance it.

2.2.1 Contact Method

In order to learn more about an object's design, structure, or functionality, the contact method of reverse engineering is making direct physical touch with it. This technique often entails interacting directly with the thing being studied while using measurement instruments and gadgets to gather data.

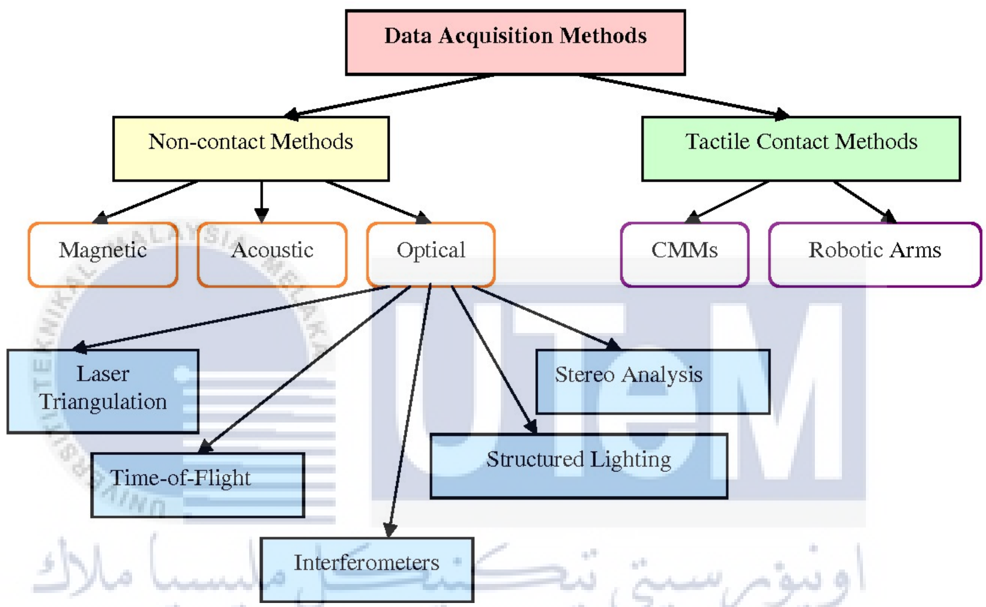


Figure 2.7: Reverse Engineering Method (N. Sherry, 1970)

The contact approach uses a variety of tools and devices, including calipers and micrometers, to obtain information about the object or system being studied. These measuring devices are employed to establish the object's exact dimensional measurements. They make it possible for reverse engineers to get precise data on the dimensions, geometries, and spatial interactions of various components.

The contact technique of reverse engineering provides a thorough and in-depth strategy for comprehending and duplicating things or systems. Reverse engineers gather exact data using measuring and scanning technologies, which is then analyzed and digitally recreated. This approach has applicability across a number of industries and enables producers to better their manufacturing processes, enhance goods, and guarantee quality control.

2.2.2 Non-Contact Method

Non-contact approaches are reverse engineering strategies that include learning information about a product or system without actually touching it. In contrast to the contact method, which relies on in-person engagement and measurement instruments, the non-contact strategy uses technology to permit data gathering remotely. This technique allows for the analysis and recreation of objects without the need for direct physical interaction.

The non-contact method uses a variety of technologies and tools to gather information about the system or object being studied. These include 3D scanning technology. The non-contact method frequently employs 3D scanning tools like laser scanners or structured light scanners. In order to build a digital representation of the object, frequently in the form of a point cloud or a 3D model, these scanners project light or laser beams onto the object's surface and collect the reflected data. The scanners are able to record the object's shape, surface characteristics, and even its color.

Figure 2.8: ZSCANNER 700 CX

To recreate the object's design or functionality, the data must be processed and analyzed after it is obtained via a non-contact technique. Typically, this entails analyzing point clouds, reconstructing surfaces, and extracting, analyzing, and comparing features. The unprocessed data from 3D scanners or remote sensing methods is frequently in the form of a point cloud, which is a sizable collection of discrete points that represents the surface of the item. To clean, align, and filter the data and provide a more accurate representation, point cloud processing techniques are used.

Surface reconstruction techniques are used to transform the point cloud or raw data into a continuous and smooth surface representation, much like the contact method. In order to produce a digital model with a pleasing appearance and useable surface, algorithms and software tools are used. Reverse engineers analyze scanned data or a digital model to find and extract certain elements of interest. This could include openings, curves, edges, or other significant design components that are essential to comprehending the functionality of the object.

The original object or other reference data are then compared to the rebuilt model to assess accuracy and spot any inaccuracies or potential improvement areas. This study makes it possible to carefully examine the design or performance qualities of the thing.

Reverse engineering using the non-contact method offers a flexible and non-intrusive way to collect information and reconstruct items or systems. Reverse engineers can gather comprehensive data without making physical touch by using tools like 3D scanning, photogrammetry, and remote sensing. Numerous industries, including manufacturing, preservation, design, and virtual reality, use this technique. Non-contact reverse engineering makes it possible to comprehend, duplicate, and enhance systems and things by fusing precise data collecting with cutting-edge analysis methods.

2.2.3 Advantage and Disadvantage of RE

There are benefits and drawbacks to the reverse engineering (RE) technique. It entails examining and comprehending a technology, system, or product's design, functionality, or construction. We can better comprehend the implications and potential restrictions of reverse engineering by examining its benefits and drawbacks.

Figure 2.9: The 6 advantages of reverse engineering (Anju, 2020)

Knowledge acquisition is one benefit of reverse engineering. Reverse engineering offers important insights into the structure and operation of already-in-use goods or systems. It gives engineers and designers the chance to examine a technology's nuances and learn information that may be used for research, development, and innovation. This new information can result in better designs, expanded functionalities, and more productive manufacturing procedures.

In addition, reverse engineering enables businesses to research and assess the market-place offerings of rivals. Companies can find areas for improvement by analyzing and comprehending the design, components, and production procedures of existing products. This information can be utilized to create more competitive alternatives or improve their own products, giving them an advantage in the market.

In order to guarantee compatibility and interoperability between various systems or technologies, reverse engineering is also especially helpful. Reverse engineering proprietary protocols, file formats, or interfaces allow engineers to build adaptable solutions that work flawlessly with already installed hardware. This encourages integration and makes it easier for people to work together across many platforms or technologies.

Finally, a big part of managing obsolescence is reverse engineering. Businesses can increase the lifespan of outdated equipment by researching and comprehending legacy systems. Critical components, their roles, and prospective replacements can be found using reverse engineering. In order to maintain the functionality of crucial systems, this enables businesses to reproduce existing systems or discover suitable substitutes.

Legal and ethical issues are one of reverse engineering's drawbacks. Particularly when it comes to intellectual property rights, reverse engineering might provide legal and ethical difficulties. Companies must take care not to violate trade secrets, copyrights, or patents. Legal requirements must be followed, and when necessary, the appropriate authority or license must be obtained. Failure to do so may result in legal issues and harm to one's reputation.

Reverse engineering heavily relies on the information that is already known and the data that has been gathered. The original design or specs might not always be readily available or accurate. As a result, the efficiency of the method may be limited by the incomplete or imperfect results of the reverse engineering.

Reverse engineering can sometimes be an expensive and time-consuming operation. Thorough analysis and reconstruction necessitate qualified personnel, specialized tools, and resources. The length of time and expense involved can be greatly impacted by the complexity of the product or system being reverse engineered and the availability of documentation or help.

In the end, while reverse engineering enables comprehension of a system or product's external design and functionality, it could not fully reveal the underlying technologies or algorithms. Reverse engineering might not be able to fully recreate the functionality or attain the same degree of performance due to the complexity of the original design.

A few benefits of reverse engineering include knowledge gathering, product enhancement, compatibility, and obsolescence management. It facilitates innovation and boosts competitiveness by offering insightful information on already-available products. However, it also has drawbacks, such as limitations on duplicating comprehensive functionality, legal and ethical issues, and the possibility of incomplete or erroneous information. Despite these difficulties, reverse engineering can be a useful technique for problem-solving and technical advancement when conducted morally and within the law.

2.2.4 Computer Aided Design (CAD)

The fields of design and engineering are experiencing a revolution thanks to computer-aided design (CAD), which has changed how goods are imagined, created, and produced. The earliest CAD systems, which were primarily used for drafting and technical drawing, first appeared in the 1960s. These systems used rudimentary input devices and mainframe computers. With the development of computing technology, CAD progressed over time, moving from two-dimensional (2D) to three-dimensional (3D) models. CAD entered the mainstream thanks to the advancement of graphical user interfaces (GUIs), better hardware capabilities, and the rise of personal computers.

Designers and engineers may develop and edit digital representations of objects with the help of CAD software, which is made up of several essential components. These elements include visualization tools that enable users to view and evaluate designs from various angles, geometric modelling, which entails specifying and representing the shape and structure of objects, numerical control (NC) programming, which enables the translation of CAD models into machine-readable instructions, and the visualization of designs through numerical control (NC) programming.

The introduction of CAD has benefited several sectors in numerous ways. First of all, CAD enhances design precision and accuracy, lowering errors and raising total product quality. Rapid prototyping and shorter time to market are made possible by the speed and ease with which design iterations may be made. Additionally, since designs can be shared digitally and changed in real time, CAD facilitates improved teamwork and communication. This increases productivity and efficiency, especially for geographically distant teams.

Many different industries use CAD, including manufacturing, consumer goods, automotive, aerospace, and architecture. Using CAD software, architects may design intricate 3D models of structures to help with visualization and planning. CAD makes it easier to design complicated systems and components in the automotive and aerospace industries, improving performance and lowering weight. Additionally, CAD is widely utilized in the manufacturing and consumer products sectors for product design, mold development, and process optimization.

Integration with simulation tools is one important development in CAD. Before creating physical prototypes, engineers can test designs online and replicate real-world circumstances using CAD software. This lowers costs, expedites the design process, and improves the functionality and security of the final product. Structural analysis, fluid dynamics, thermal analysis, and electromagnetics, among other things, can all be simulated. Together, CAD and simulation allow engineers to optimize designs and precisely forecast their behavior.

The potential for CAD in the future is really positive. Through the use of 3D modelling, every contemporary product we use or see was produced (Carmel, 2022). Designers may see and interact with their designs in realistic virtual settings because of the increasing integration of augmented reality (AR) and virtual reality (VR) with CAD. Cloud-based CAD platforms are becoming more popular because they improve accessibility, scalability, and collaboration. Additionally, CAD systems may now automatically build and optimize designs depending on particular needs thanks to the development of generative design, which is powered by artificial intelligence.

There are obstacles, nevertheless, that must be overcome. User-friendly interfaces and thorough training programs are required as CAD software grows more feature-rich and complicated. With the growing reliance on cloud-based solutions, data security and intellectual property protection are also major problems. As flawless data sharing between multiple software programs is necessary for effective cooperation, interoperability between diverse CAD systems and data formats also continues to be a concern.

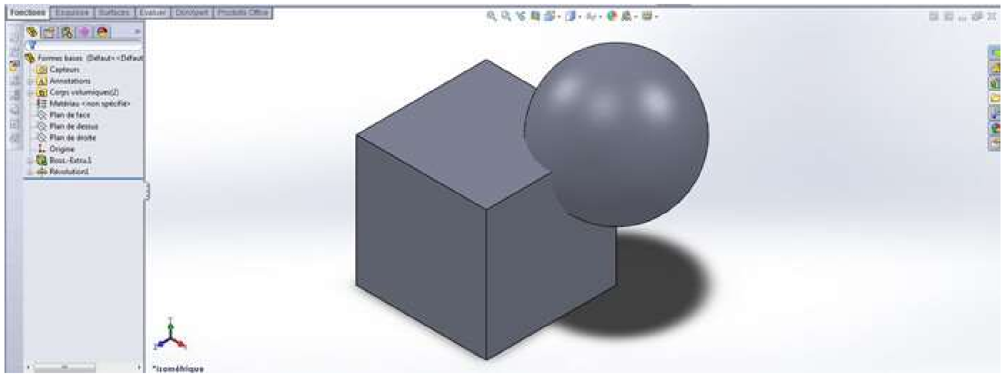


Figure 2.10: Example of CAD (Carmel, 2022)

The use of computer-aided design has revolutionized the fields of engineering and design, enabling experts to produce unique, accurate, and effective products. A combination of improvements in simulation, teamwork, and visualization, along with the development of CAD from 2D drafting to 3D modelling.

2.2.5 Standard Tessellation Language (STL)

In the context of 3D printing and computer-aided design (CAD), the Standard Triangulation Language (STL) file format is frequently utilized. Because it uses triangular facets to express 3D object geometry, it is crucial to the process of turning digital models into actual objects. Each 3D object in the STL file format is specified by a group of connected triangles or facets, which is known as a mesh representation.

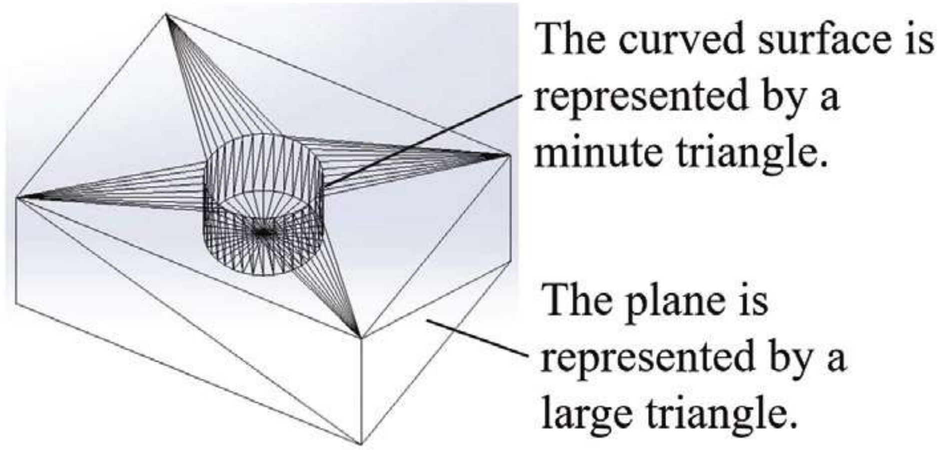


Figure 2.11: Standard triangulated language (Isamu Nishida, 2019)

A STL file's structure typically consists of a number of vertices and the triangular facets that correspond to them. The triangles are made up of three vertices and a surface normal that controls how they are oriented in three dimensions. Together, these facets create a mesh that closely resembles the object's surface shape.

Due to its many benefits, including its broad compatibility, STL has emerged as the accepted norm for 3D printing. All hardware and software for 3D printing supports STL files. The ability to export models in STL format is a feature of nearly all 3D modelling software programs, ensuring seamless compatibility with various platforms and printers. The community of 3D printers can easily share, collaborate on, and distribute 3D models thanks to this interoperability.

The STL format is straightforward, making it simple to build and comprehend. It offers an easy and effective way to define complex shapes by representing objects as a collection of triangles. The accessibility and popularity of STL files are facilitated by their simplicity.

A strong ecosystem of online repositories and communities that offer substantial libraries of downloadable STL files has developed as a result of the widespread acceptance of STL throughout the 3D printing industry. The availability of pre-designed models makes it easier for designers, enthusiasts, and hobbyists to quickly prototype, customize, and become inspired.

Although STL is widely used, it does have several drawbacks and difficulties that may affect 3D printing. Lack of information on texture and color, for instance. As opposed to naturally capturing color or texture information, STL files primarily reflect an object's shape. This constraint limits the ability to faithfully recreate complex surface patterns and visual details in 3D printed models.

Due to the triangle mesh format used by STL files, curved surfaces may not be accurately represented. Triangular facets may produce apparent facets or a loss of fine details in the printed object if the smoothness of curves is not adequately captured. Additionally, the topological connectedness of the model is not explicitly encoded in STL files. To ensure successful printing, extra processes, including mesh repair or modification, may be needed to assure tightness and maintain surface integrity.

Rapid prototyping is one of the many sectors and disciplines where STL files are widely used. Designers and engineers can easily convert computer designs into actual prototypes thanks to STL files. This method expedites product development, speeds up iterative design cycles, and allows for quicker product validation.

Through the use of STL files, customized and unique goods can be produced. Customized jewelry, individualized medical equipment, and specialized consumer items are just a few examples of the unique objects that can be made thanks to STL files. Large online repositories of STL files are a great resource for research centres and educational organizations. Students, teachers, and researchers have access to a variety of 3D models for use in experiments and further interdisciplinary study.

The use of 3D printing as a medium for artistic expression is embraced by the creative fields of art, design, and architecture. By converting their digital drawings into elaborate sculptures, architectural models, and actual works of art using STL files, these experts are able to push the limits of their creativity and imagination.

By offering a common language for representing and exchanging digital models, the Standard Triangulation Language (STL) has revolutionized the fields of 3D printing and design. Although STL has drawbacks, its adaptability, ease of use, and universal adoption have fueled the development of the 3D printing industry and created new opportunities for rapid prototyping, customization, education, and artistic expression. In the future of 3D printing and design, STL is probably going to continue to play a crucial role as technology develops.

2.3 Addictive Manufacturing (AM)

The development of additive manufacturing, also referred to as 3D printing, has made it possible for us to create, produce, and distribute items in entirely new ways. Using digital 3D models as a guide, additive manufacturing creates products layer by layer. Contrary to conventional subtractive manufacturing techniques, which entail cutting or shaping materials, additive manufacturing adds materials in a precise and accurate manner to produce complex structures. This technology has changed the manufacturing industry by making it possible to produce specialized, detailed, and light-weight items.

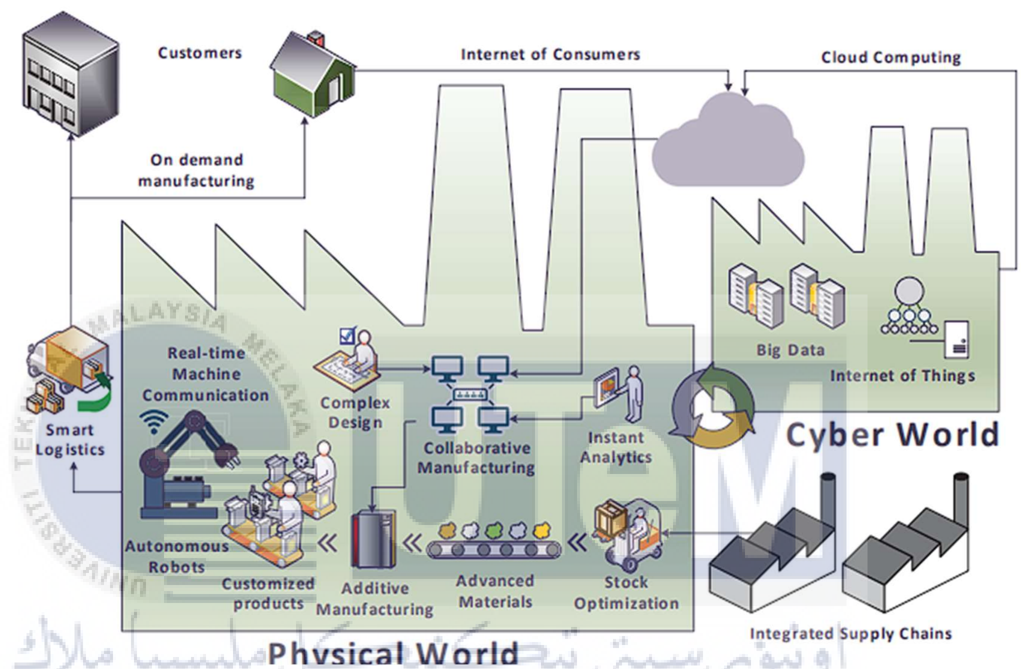


Figure 2.12: Smart factories schematic in Industry (Dilberoglu et al., 2017)

In additive manufacturing, a variety of processes are employed, each with special benefits and uses. Several frequently used techniques, such fused deposition modelling (FDM). Thermoplastic materials are used in FDM, which uses them to build up layers by being heated and extruded through a nozzle. It is frequently utilised in product development, prototyping, and low-cost manufacturing.

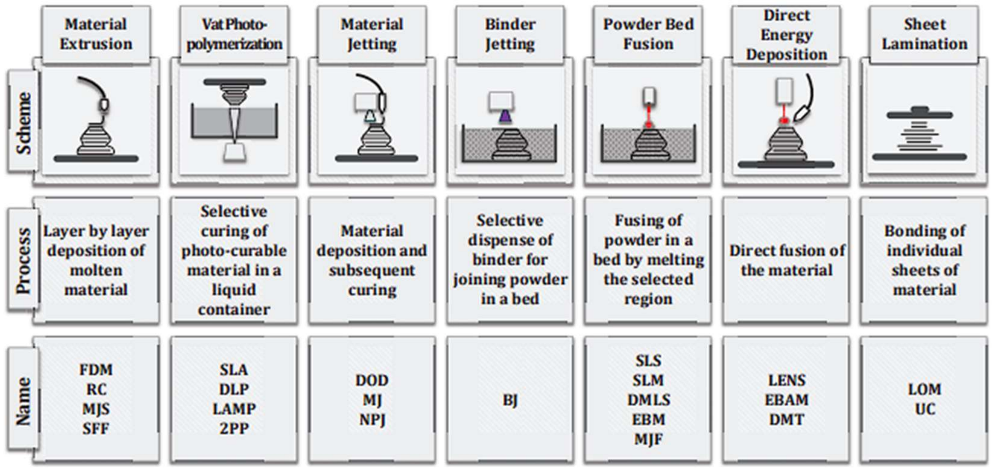


Figure 2.13:AM process categorization (Dilberoglu et al., 2017)

In addition, stereolithography (SLA) uses a liquid resin that becomes solidified when exposed to a laser or ultraviolet light. In fields like jewellery, dentistry, and automobiles, it is frequently utilised to create very accurate and detailed models. SLS stands for selective laser sintering, a process that involves layer-by-layer fusing of powdered materials, usually metals or polymers. Complex geometries, end-use components, and working prototypes can all be made using it.

EBM, or electron beam melting, is the last. Metal powder is selectively melted and fused using an electron beam in the EBM process to produce robust and high-quality components. The aerospace, medical, and automotive industries are where it is most commonly used.

2.3.1 Classification of Addictive Manufacturing

The field of additive manufacturing, generally known as 3D printing, includes a wide range of methods and tools that have revolutionized the manufacturing industry. This essay investigates the categorization of manufacturing that is addictive, emphasizing many processes and technology used to produce three-dimensional items. Understanding the many categories will help us obtain knowledge about each classification's abilities, benefits, and uses.

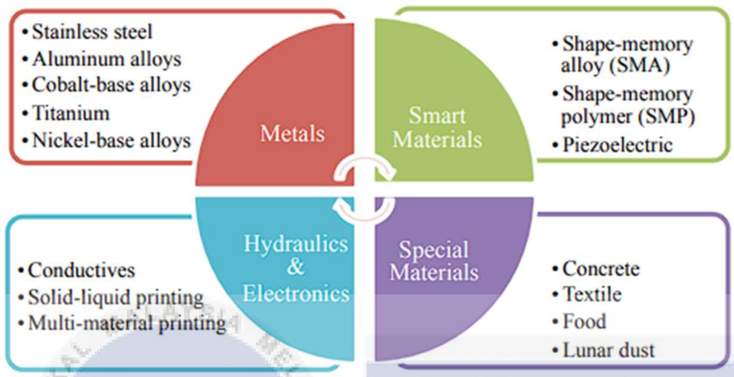


Figure 2.14: Research materials for AM (Dilberoglu et al., 2017)

According upon the type of material, polymer-based addicting manufacturing techniques are frequently utilized because of their adaptability and affordability. Thermoplastic or photopolymer materials are deposited one layer at a time using these techniques. This group includes methods like Fused Deposition Modelling (FDM), Stereolithography (SLA), and Selective Laser Sintering (SLS). Consumer products, healthcare, and the automobile industry all frequently use polymer additive manufacturing.

The term "metal additive manufacturing" refers to processes that construct objects layer by layer using metal wires or powders. Such techniques as Direct Metal Laser Sintering (DMLS), Electron Beam Melting (EBM), and Selective Laser Melting (SLM) fall under this category. Extremely precise metal additive manufacturing makes it possible to create intricate metal components with excellent strength and endurance. It has uses in the medical, automotive, and aerospace industries.

Using specialized methods, ceramic additive manufacturing includes the layer-by-layer deposition of ceramic powders. These techniques, such Binder Jetting and Ceramic Stereolithography (CSL), make it possible to fabricate complicated ceramic components with superior thermal and chemical properties. Aerospace, electronics, and biomedical industries all use ceramic additive manufacturing.

Extrusion-based additive manufacturing techniques use a nozzle or syringe to deposit material in a precise way. As an example of extrusion-based additive manufacturing, fused deposition modelling (FDM) uses heated thermoplastic filament that is extruded via a nozzle to build objects in layers.

In photopolymerization-based additive manufacturing, polymers that harden when exposed to a range of wavelengths of light are used. Popular methods in this area include digital light processing (DLP) and stereolithography (SLA). The resin is selectively cured by a light source, such as a laser or projector, to produce each layer of the object.

Using a laser or electron beam, a thin layer of powdered material—either metals or polymers—is fused selectively in powder bed fusion processes. This category includes processes like Selective Laser Sintering (SLS), Selective Laser Melting (SLM), and Electron Beam Melting (EBM). Particles are fused together by the energy source's heat to form solid layers that eventually take the form of the object.

Binder jetting is the process of layer-by-layer selectively depositing a binding agent into a powder bed to produce an item. Metals, ceramics, or even sand are all examples of powdered material. Binder jetting, which is used in prototyping, architecture, and tooling, enables the fabrication of complicated shapes and structures.

In conclusion, categorizing additive manufacturing according to material type, process, and application offers insightful information on the wide range of 3D printing technologies. Each category has its own advantages and capabilities, allowing for the creation of complicated designs, rapid prototyping, the production of useful parts, and customization. New classifications are likely to emerge as additive manufacturing develops, enhancing the potential and range of uses for this game-changing technology.

2.3.2 Application of Additive Manufacturing

The disruptive technique of additive manufacturing, usually referred to as 3D printing, has quickly garnered recognition and has numerous applications in a variety of sectors. This essay demonstrates how additive manufacturing is revolutionizing conventional production processes and opening up new opportunities for creativity, customization, and efficiency by examining the wide variety of uses for this technology.

With the help of additive manufacturing, designers and engineers can now swiftly and affordably produce physical prototypes for use in testing and assessment. This shortens the time to market, speeds up product development, and allows for iterative design changes. Applications for prototyping are found in a variety of sectors, including the automotive, aerospace, consumer products, and medical device industries.

The capability of additive manufacturing to enable customization and personalization is one of its most important benefits. Through the use of digital design and manufacturing techniques, additive manufacturing enables the creation of unique, custom items that are suited to each customer's needs. Additive manufacturing is revolutionizing the idea of mass customization, from personalized consumer goods to custom-fit medical implants and dental prosthesis.

Complex geometries that are difficult or impossible to construct using traditional techniques can be produced with great success utilizing additive manufacturing. It is possible to create complex internal structures, organic shapes, and lightweight designs using the layer-by-layer construction method. The potential of additive manufacturing to make components with optimized geometry, lowering weight, and enhancing performance, benefits industries like aerospace and automotive.

By enabling on-demand production and lowering inventory costs, additive manufacturing offers important advantages in supply chain management. With traditional manufacturing, it can be expensive and time-consuming to keep big stocks or rely on distant sourcing. Due to the ability to produce items and parts on demand, additive manufacturing reduces the need for substantial warehousing and streamlines transportation.

The uses for additive manufacturing are numerous and keep growing as technology advances. Additive manufacturing is altering sectors and creating new opportunities for innovation in a variety of areas, including prototype and customization, supply chain optimization, and developments in the healthcare industry. We may anticipate more advancements and the appearance of new applications as technology becomes more widely available and perfected, influencing the future of manufacturing.

2.3.3 Advantage and disadvantage of Manufacturing

The development of additive manufacturing, sometimes referred to as 3D printing, as a cutting-edge technology with several benefits across numerous industries. It does, however, have some restrictions and drawbacks, just like any other technology. This essay discusses the benefits and drawbacks of additive manufacturing, offering a fair assessment of both its potential and limitations.

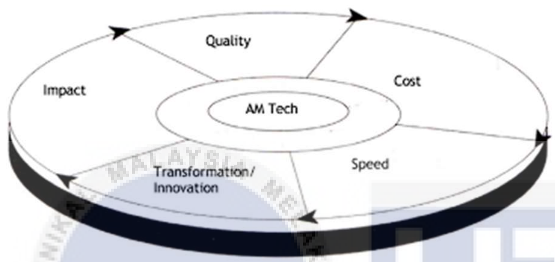


Figure 2.15: Key benefits of additive manufacturing (Attaran, 2017)

The design flexibility that additive manufacturing provides is one of its main benefits. The use of 3D printing makes it simple to produce sophisticated internal systems, complex geometries, and unique designs. This feature makes it possible to innovate and create products with enhanced performance and functionality, which would be challenging or impossible to do with conventional manufacturing techniques (Attaran, 2017).

The time and expense involved with conventional prototyping techniques are greatly reduced by the use of additive manufacturing, which enables the quick fabrication of prototypes. Implementing design changes and iterations fast helps minimize the time it takes to market and speed up product development. This advantage is especially helpful in sectors like aerospace, automotive, and consumer electronics where innovation and agility are essential.

Customization on a scale previously unattainable is now possible thanks to additive manufacturing. Individualized products and experiences are possible because to the ability to customize each item to suit specific needs. Since custom-fit medical implants and prostheses can dramatically enhance patient comfort and outcomes, this advantage has the potential to change industries like healthcare.

Due to the fact that it only uses the precise amount of material needed to construct an object, additive manufacturing is naturally resource efficient. Significant material waste is frequently produced by conventional subtractive manufacturing techniques. The use of additive manufacturing allows for the recycling and reuse of leftover materials, resulting in a more environmentally friendly production method and less waste overall.

Although there are many different types of materials available with additive manufacturing, the selection is still somewhat small when compared to conventional manufacturing techniques. The materials that can be used in 3D printing processes may not all be compatible, which limits the kinds of objects that can be created. Additionally, some materials used in additive manufacturing could not function or have mechanical qualities that are comparable to those utilized in traditional production.

For large or intricate objects, additive manufacturing procedures might take a long time. When opposed to conventional manufacturing techniques, which can mass-produce several things at once, printing each layer separately might lead to slower production times.

Scaling up additive manufacturing production can also be difficult because it necessitates considerable infrastructure and equipment investments.

In order to obtain the correct surface quality and mechanical qualities during additive manufacturing, post-processing and finishing are frequently necessary. This may entail extra steps that lengthen the production process and increase costs, such as sanding, polishing, or coating. It could take more manual labor or specialized tools to get a smooth and aesthetically acceptable finish.

Intellectual property (IP) protection is an issue due to additive manufacturing's digital nature. There is a higher risk of unauthorized copying and product counterfeiting as 3D design files are simple to distribute and reproduce. Significant obstacles in the additive manufacturing environment include protecting intellectual property and making sure that copyright and patent rules are followed.

Numerous benefits of additive manufacturing include personalization, speedy prototyping, design freedom, and material effectiveness. It also has drawbacks, such as constrained material options, slow production rates, and post-processing demands. Despite these difficulties, additive manufacturing is still developing, overcoming them, and broadening its applicability across other industries. The benefits of additive manufacturing are anticipated to exceed the drawbacks as technology develops, making it a more vital component of the manufacturing environment.

2.3.4 Selective Laser Sintering (SLS)

Selective Laser Sintering (SLS) is an additive manufacturing technology that utilizes lasers to fuse powdered materials together, layer by layer, to create three-dimensional objects. This essay explores the principles, advancements, and diverse applications of SLS, showcasing its impact on various industries and its potential for future innovation.

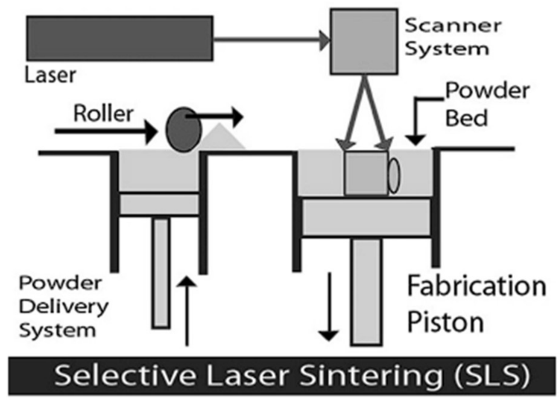


Figure 2.16: SLS diagram build process (Attaran, 2017)

SLS involves a precise and controlled process that allows for the creation of complex and functional parts. The key principles of SLS are powder bed preparation, laser melting and fusing, and layer-by-layer building. Powder bed preparation involves a thin layer of powdered material, typically polymers or metals, is uniformly spread across a build platform. The powder particles act as a medium for the laser fusion process.

Then, a high-powered laser selectively scans the powdered material, heating and melting it to the point of fusion. The laser beam fuses the particles together, creating a solidified layer based on the digital design data. Finally, after each layer is fused, the build platform lowers, and a new layer of powder is applied. The process is repeated until the desired object is fully constructed, with the unfused powder acting as support for subsequent layers.

2.4 Summary

The context of historical artifacts, reverse engineering (RE), CAD data, and additive manufacturing was covered in this chapter. Due to its intrinsic strength, the research demonstrated the significance of additive manufacturing (AM) technologies in the repair and preservation of historical artifacts. In order to achieve the project's goals, the Istinggar from The Stadthuys museum was selected as the focal point. In the following chapter, which focuses on the approach, the knowledge learned from this chapter will now be put to use. This will make it possible to use the research data in a systematic manner for the project's effective completion. The knowledge we have gained from studying this chapter will be used in chapter 3, which is about methodology.

CHAPTER 3

METHODOLOGY

3.1 Introduction

Historical artifacts are priceless relics that offer a direct link to the past. It is crucial to preserve and restore these artifacts in order to protect our cultural heritage for upcoming generations. However, a methodical approach is needed to preserve and restore historical artifacts in an effective manner. To ensure that this project is implemented successfully, the approach is thoroughly outlined in this chapter. A non-contact reverse engineering (RE) device, computer-aided design (CAD) software, and a laser sintering (LS) machine were all used in the experiment for this project. The Istinggar, a piece of local history, was the project's primary emphasis. The project also had the additional goal of looking at the surface roughness of components made with an additive manufacturing (AM) technique.

Planning, carrying out, and analyzing were the three primary steps of the project's process. To get the desired outcomes, each step required close attention to numerous phases. The project started with an experimental study in which the actual Istinggar object was scanned using a non-contact reverse engineering tool. The resulting scanned data, which took the form of a point cloud, was then edited and translated using CAD software into the STL file format. The STL data was examined using Magic RP software to confirm its accuracy.

The Istinggar prototype was then created using a laser sintering machine. In this stage, layers of material were selectively fused together using the additive manufacturing method based on the STL file. The surface roughness of the constructed prototype was subsequently examined. A comparison of the printed part and the original output was done to assess the job. This made it possible to evaluate the precision and quality of the printed prototype.

The methodologies employed in this project are depicted in the flowchart presented in Figure 3.1, which shows the sequential stages taken from the experimental study to the investigation of surface roughness.

Figure 3.1: Flow chart development of project

3.2 Experimental Study

Planning this project is essential before beginning the experiment in order to determine the data and requirements, such as hardware and software. Data collection and software and hardware needs are the two key components of the planning phase. The gathering of data is the first step in any information investigation. Additionally, it is divided into two categories: primary study and secondary study.

3.2.1 Primary Study

The primary sources of information for this research were interviews and observations. In this study, both quantitative and qualitative secondary data were utilized. Newspapers, interviews, and transcripts were used to gather qualitative data. The quantitative data, however, was gathered through statistics, surveys, and observation. The majority of the secondary material was gathered to learn more about the historical artifacts that are present in the state of Melaka. The museum curator and its officer participated in the interview session with the PERZIM Melaka organization. The majority of the background information about the artifacts came directly from the museum.

3.2.2 Secondary Study

Reviews of the literature serve as the secondary data for this study. Additionally, it is used to compile data for background research on historical artifacts, additive manufacturing (AM), and reverse engineering (RE). The information for the literature review was gathered from a variety of sources, including books, articles, journals, and online resources. In order to support the facts of digital replication of Malay relic components produced by non-contact laser-based reverse engineering. All of these resources contributed to the studies' strengthening and can help prevent research misunderstandings.

3.3 Selection of Historical Artifact

The dimensional complexity of the historical artifacts was taken into consideration when choosing them for this study pursuit. The Istinggar stood out among the different historical artifacts studied because of its alluring and sophisticated design. The Istinggar is a fascinating challenge for exploration and study because of the great level of complexity displayed in its shape, curvature, and total size.

It was decided following discussion with the supervisor that the Istinggar would be the best artifact to select for this study. Before deciding on the Istinggar, a number of issues were carefully considered. These considerations included the time needed to construct the prototype, the accessibility of 3D-printable materials, and the availability of the essential tools for efficiently completing the scanning and prototyping processes.

The Istinggar was chosen as the scanned object for this study because it satisfied the criteria laid out throughout the selection procedure. The following stage included visiting the site in order to get the essential data. The precise details and proportions of the Istinggar would be captured during this site inspection procedure at the Stadthuys Museum, creating a physical copy of the artifact for additional investigation and prototyping.

Figure 3.2: Picture of Istinggar From Stadthuys Museum

This study project chose the Istinggar and went forward with the 3D scanning data capture in order to delve into the complexity and nuances of this historical artifact. The gathered data would act as a starting point for later analysis and interpretation steps, as well as perhaps the fabrication of a prototype using 3D printing technology.

3.3.1 Experimental Setup

Following all operating instructions for the 3D scanner machines and gadgets used in the construction of the "Istinggar" is crucial to the success of the experimental activity. Additionally, general methods cover how to work with scanned data and the technique utilized to transform it. It has been established that the experimental review is the most important component of this study because it has the potential to influence the study's final findings. To achieve outstanding outcomes at this point, every process needs to be carefully planned and carried out. As a result, the four primary processes in this research are pre-processing, post-processing, data manipulation, and data conversion.

3.3.1.1 Pre-processing

Before starting the scanning process, pre-processing, sometimes referred to as setup procedures, is an important step to take care of. It entails getting everything ready and making sure everything is set up for a successful scanning procedure. Prior to scanning an object, there are six crucial processes that need to be meticulously followed.

The initial step is to determine how the information gathered during the scanning process will be used. It is easier to choose the precise characteristics and features that must be recorded throughout the scan when you are aware of the goal and intended results.

After that, it's crucial to decide which features will be used during the scanning process. Finding the object's salient features that are pertinent to the planned use of the data entails doing this. The scanning procedure can be optimized to precisely capture the relevant details by choosing the right features.

The third and most important step in pre-processing is defining the coverage and accuracy requirements. This entails figuring out the size of the object that needs to be scanned and the degree of accuracy required to achieve the desired results. This stage guarantees that the scanning procedure matches the project's unique requirements.

The following stage in pre-processing is to choose the best reverse engineering (RE) system. Different RE systems are available, each with unique features and restrictions. To get the best results, it's crucial to pick the system that's best for the job based on criteria including accuracy, resolution, and compatibility with the target object.

Another crucial pre-processing step is to prepare the surface to be scanned. This entails properly cleaning the object to remove any dirt, debris, or surface flaws that can obstruct the scanning procedure. The precision of the scan and the quality of the output data are both enhanced by a clean surface.

Finally, it's crucial to specify the component fixture or choose the right location for the object. In this stage, the right positioning or fixture must be chosen in order to hold the object firmly during scanning. Consistent posture helps reduce mistakes and improves overall scanning accuracy.

3.3.1.2 Post-processing

Editing, alignment, re-sampling, and the creation of geometry are a few of the frequent procedures included in post-processing, often known as the data manipulation process. These actions are crucial for polishing the data collected from the scanning process and getting it ready for usage later.

The creation of CAD data is one of the main results of the post-processing phase. Following design and manufacturing procedures, the CAD data offers a digital representation of the scanned object. It is usual practice to use specialized software, such as Polyworks, to make data manipulation easier.

The Polyworks software was created primarily to transform 3D scan data into excellent, feature-based CAD models. It provides strong tools and features that allow for the precise manipulation and improvement of the scanned data. To assure the precision and integrity of the finished CAD model, tweaks, alignments, and resampling can be carried out using Polyworks.

MagicsRP is another program used in the post-processing stage. Prior to being sent to rapid prototyping devices, this program is essential for data preprocessing. The STL file quality check, triangle reduction, and mesh smoothing are just a few of the features that MagicsRP makes possible without sacrificing crucial information that must be maintained.

The post-processing stage makes sure the data is optimized and ready for future use in rapid prototyping and other production processes by making use of MagicsRP's capabilities. This software helps to improve the data's overall quality and correct any flaws or inconsistencies that may have shown throughout the data manipulation process.

3.3.1.3 Data Conversion

The STL file format is often used to store CAD data that has been obtained through data modification. Direct and indirect conversion are the two processes used to turn 3D scan data into STL files. It is possible to directly convert the scan data into the STL format using the direct conversion method. This means that there is no need for additional procedures or software because the data obtained during the scanning process is already compatible with the STL file format.

The indirect conversion technique, on the other hand, entails converting the scan data into the STL format using another CAD programme, such as Solidworks. In this instance, the scan data is frequently in another file format, such IGES. The data is first loaded into the CAD programme, and then the program's tools and features are utilised to transform the data into the STL format.

The 3D scan data may be successfully converted into the STL file format by using these CAD software packages. This file type is frequently used in many different contexts, such as additive manufacturing and rapid prototyping. The surface geometry of the object is described in STL files, which show it as a collection of triangular facets.

Once the data has been properly converted to the STL format, a variety of programmes and systems can use it to process it further or use it for different reasons. This encompasses techniques like 3D printing, simulation, and more.

3.4 Fabrication of Prototyping

After transferring the final file formats to the additive manufacturing (AM) device, fabrication can start. In this instance, the model is created using the default parameters and settings on the Laser Sintering (LS) equipment. It's crucial to keep in mind that each AM process and machine may have unique setup parameters based on its capabilities and requirements.

It is essential to set up the AM machine correctly before starting the construction process. Setting up building parameters such as material limitations, energy source, layer thickness, timing, and others includes doing this. These conditions guarantee that the fabrication procedure complies with the specified requirements and yields the expected results.

The size of the part will determine how long it takes to manufacture; larger parts could take many hours or even several days. The part is painstakingly built-up layer by layer by the AM machine, gradually creating the finished result. Monitoring and logging prototype data while keeping track of numerous interesting properties is crucial during this process.

The Laser Sintering (LS) equipment, Computer-Aided-Design (CAD) software, and a non-contact reverse engineering (RE) device are used to carry out this work. These instruments allow for the analysis of the build time for components created using the AM system, the evaluation of file quality, and the investigation of surface roughness.

3.4.1.1 Selective Laser Sintering

Once the 3D scanned data has been successfully transformed into high-quality STL files, the RE system's job is finished. For the creation of the object, these STL files can then be uploaded to a rapid prototyping device. However, it's crucial to take into account the processes needed for the prototypes' post-processing. This entails taking down any supporting structures and adding finishing touches to make the pieces seem better. To attain the intended look, this can involve including fine art features and adding colours..

A selective laser sintering (SLS) device made by FARSOON, specifically the Chinese SS402P model, is used for the prototyping fabrication process. The materials used to run this SLS machine are powder-based. Both FS 3300PA, a nylon laser sintering material, and FS 3400 GF/H, a glass-filled nylon laser sintering material, are available at FTKMP as powder-based SLS materials.

In order to give the manufactured goods, the appropriate qualities and characteristics, material choice is essential. Because it is made of nylon, FS 3300PA is strong, flexible, and has a beautiful surface finish. On the other hand, FS 3400 GF/H offers improved strength, stiffness, and dimensional stability because to the incorporation of glass fibers.

These powder-based materials can be used in the SLS process to produce objects with complicated geometries, high levels of detail, and useful characteristics. The SLS technology offers adaptability and flexibility for the manufacturing of a wide variety of items across many industries when combined with the unique material alternatives available.

3.5 Dimensional Analysis of result

The quality of the STL file, machine setup, and the time needed for product production are just a few of the variables that can be used to compare data. These elements are very important when assessing the research's findings. Additionally, a comparison of numerous parameters can be done to analyze and evaluate the performance of various 3D scanners. These variables include the speed at which data is collected, the accuracy with which it is processed, and the caliber of the final model. The part to CAD approach can be used to assess the final model's quality.

It's crucial to understand that 3D scanners do not automatically generate CAD models. Instead, they produce scan data that is recorded as ply, obj, or stl files and is represented as point clouds or polygon meshes. The surface measurements of the object are represented by this scan data, but a fully functional CAD model is not provided. In order to precisely extract and model each characteristic of the part, a scan to CAD technique must be used.

The scan data file is imported into reverse engineering software to carry out the scan to CAD method, where it is used as a reference or construction manual for the CAD model. To build a fresh CAD file that may be used for CAD-to-CAD analysis or other reasons, this reconstruction process is required.

This methodology is used in the study to guarantee that the rebuilt CAD file precisely depicts the scanned object, enabling accurate and trustworthy CAD to CAD comparison. Various evaluations may be included in this analysis, including those of dimensional accuracy, part compatibility, and functional requirements, among others.

3.5.1 CAD to CAD

The exchange of digital design data across several CAD software programs is referred to as CAD to CAD. Early on in the development of CAD, proprietary formats restricted interoperability, preventing communication and information sharing between various design teams. However, CAD to CAD interoperability substantially increased with the introduction of standardized file formats such as IGES (Initial Graphics Exchange Specification) and STEP (Standard for the Exchange of Product Data).

CAD data may be readily transferred between several software systems, allowing designers to work together effectively regardless of the tools they use. Engineers can work on many parts of a bigger assembly at once thanks to CAD-to-CAD interchange, which makes it easier to share design files. This improves productivity, streamlines the design process, and lowers errors.

3.5.2 CAD to PART

The phrase "CAD to Part" denotes the change from the digital world of computer-aided design to the actual world of concrete products. A computer design can be turned into a physical part once it is finished using a variety of manufacturing techniques. The virtual and physical worlds are connected by computer numerical control (CNC) machining, 3D printing, and other additive and subtractive manufacturing processes.

The CAD to Part procedure entails converting the digital design into guidelines that manufacturing equipment can use to create the desired component. The criteria that these instructions provide include toolpaths, material requirements, and manufacturing tolerances. The combination of CAD and manufacturing technology has expanded design freedom, sped up prototyping, and decreased lead times.

3.5.3 PART to PART

Part to Part is a development in manufacturing that uses digital models of actual parts to produce precise reproductions or supplementary parts. This method uses existing parts that have been scanned or digitally captured to create 3D models that may then be edited or replicated.

In reverse engineering, where existing objects are analyzed and recreated for diverse purposes, part-to-part procedures are useful. Engineers can develop digital models that can be altered, improved, or duplicated using CAD tools by digitizing a part's geometry using scanning techniques like laser scanning or photogrammetry. Engineers may refine current designs or develop completely new ones based on real-world objects thanks to part-to-part workflows that make repairs, replication, and modification easier.

3.6 Summary

In conclusion, this chapter offers a thorough summary of the project's process. To have a better knowledge of the project requirements and define a clear course of action, it starts by carrying out an experimental study. In order to ensure that all pertinent elements are taken into account, the chapter also describes the selection procedure and experimental setup for the study. The methodology also offers a thorough explanation of the selective laser sintering prototyping fabrication process. This emphasizes the precise processes and steps needed in creating the prototypes, highlighting the utilization of this cutting-edge technology. In addition, the chapter discusses the dimensional analysis of the experimental results. This study acts as a key project assessment metric and attempts to evaluate the precision and quality of the manufactured prototypes. The experimental techniques for data manipulation, creating prototypes, and measuring surface roughness will be covered in Chapter 4 in more detail. To develop the research and provide important insights into the project's goals, these approaches will be fully described and put into practice.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

This study uses a variety of analysis techniques, including CAD-CAD analysis, part-to-part analysis and CAD-to-part analysis. These techniques seek to discover the best STL file products and the best reverse engineering tools offered by FTKMP. An initial interview was done to gain comprehensive information about a number of artifacts in the Melaka Museum in order to gather reliable data. Interviews and observations were the main methods for gathering data. The Stadthuys museum staff shared insightful information and pointed out some limits with relation to the historical artifacts.

4.1.1 Experimental Study

4.1.1.1 Primary Study

Figure 4.1: Interview Session With PERZIM Curator

Face-to-face interviews were conducted with the curators at the Perbadanan Muzium Malaysia (PERZIM) during the research process to gather pertinent data and perspectives on historical artefacts in the study of museums. These interviews have the aim of gathering important information. In order to protect historical artefacts, it was discovered from the interview sessions that Museum Malacca primarily uses conventional preservation methods and fundamental approaches. The origins, categories, and aesthetics of these artifacts from our observations at the Stadthuys Melaka Museum was gained. As a result, PERZIM suggested the Istinggar as an appropriate historical artifact for our study project due to its scarcity, high worth, and superb decorative design. Additionally, the delicate and elaborate ornamentation design on the Istinggar makes it a perfect subject for research on dimensional accuracy.

4.1.1.2 Secondary Study

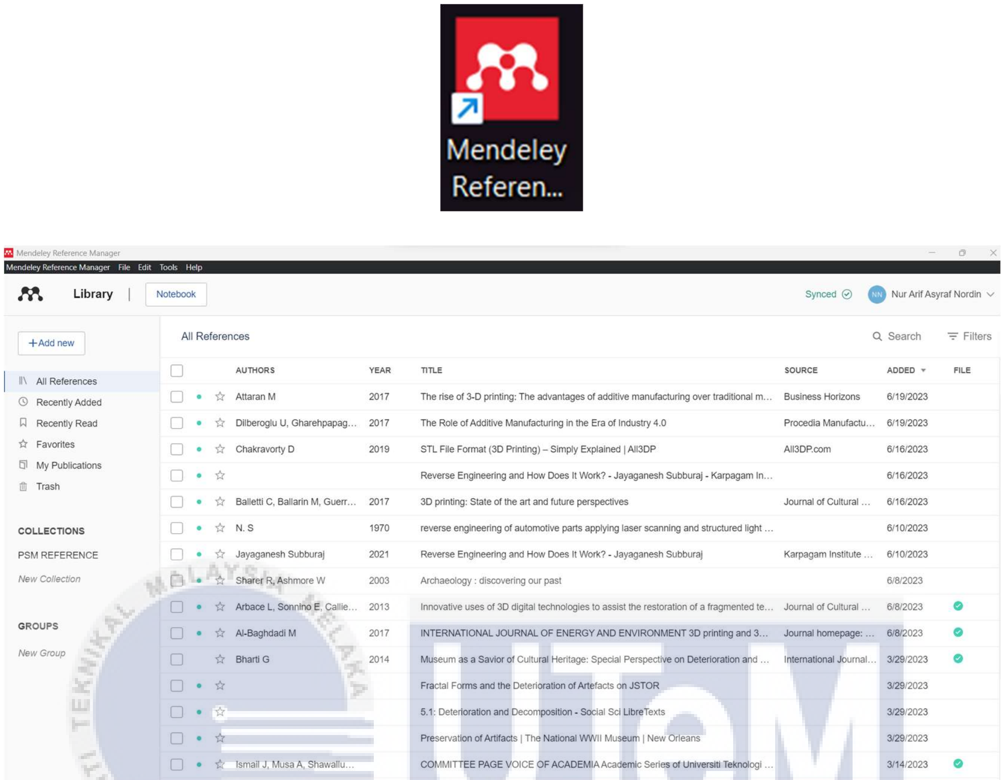


Figure 4.2: Mendelay usage for Citation and Reference

For secondary study, journal and references was taken as a material for research regarding historical artifacts history. The pdf file of journal was saved and added into the mendeley library in to order to get easier access toward making reference and citation.

4.2 Pre-processing and post-processing

Below is the standard procedure (SOP) used in overall Pre-Processing and Post-Processing during executed the experimental work:

4.2.1 Data Manipulation and STL file Verification

The details of the procedure of data manipulation and verification of STL file have been explained by the following procedure.

1. To manipulate the scanned data obtained from the point cloud, the PolyWorks by InnovMetric programme, as illustrated in Figure, was utilized.

Figure 4.3: Software Polyworks by InnoMetric

2. Data gained was imported into PolyWorks software by using workspace and PolyWorks Moduller was started.

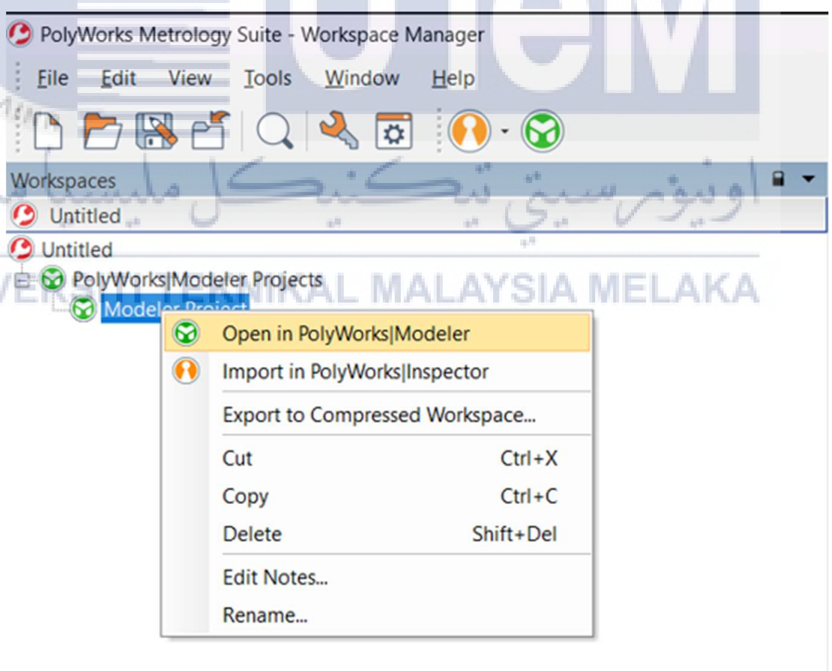


Figure 4.4: Starting PolyWorks Modeler

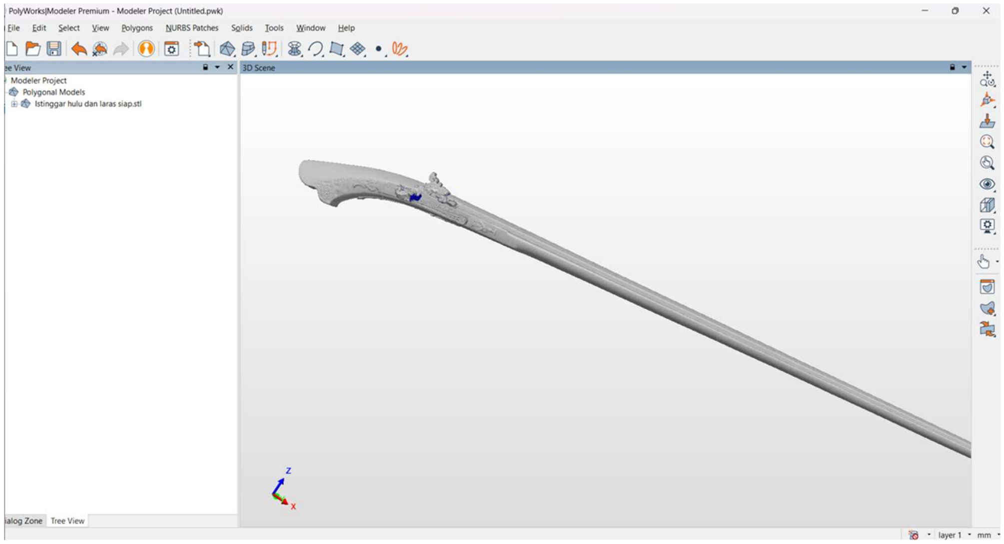


Figure 4.5: PolyWorks Modeler

3. To activate the fill holes interactive feature and choose the method of partial hole filling in the fill operation, pick the "Polygon" icon. Choose a small portion of the missing component, then click on the inside component to fill the gap.

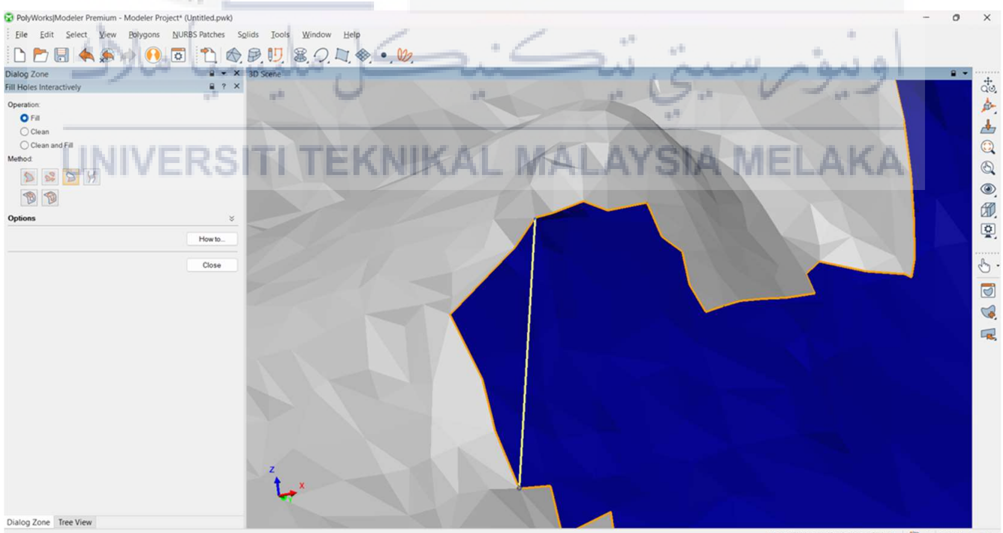


Figure 4.6: Partial hole filling in fill operation

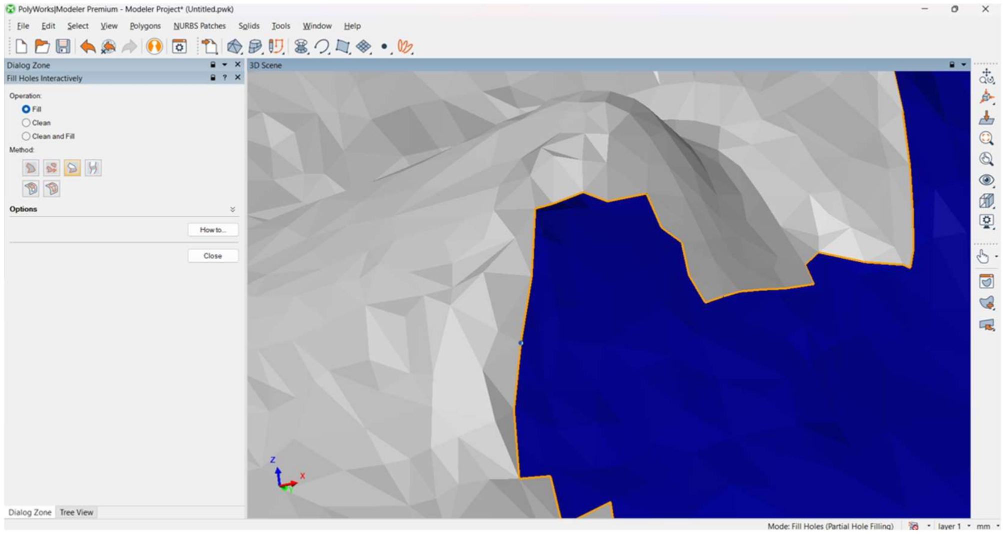


Figure 4.7: Partial hole filling filled

4. The process then was repeated multiple time for the front barrel of Istinggar until desired result achived.

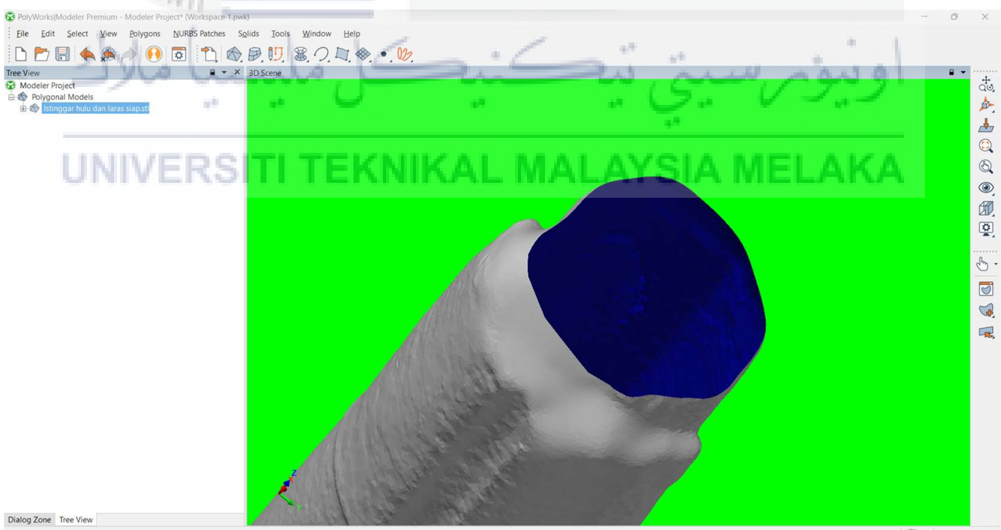


Figure 4.8: Fully filled front barrel of Istinggar

5. For multiple small hole, select elements front was used to highlight all of the small hole and automatic hole filling was selected. Click apply and observe all of the small hole. If the hole was filled correctly, click done otherwise click delete to cancel the hole filling.

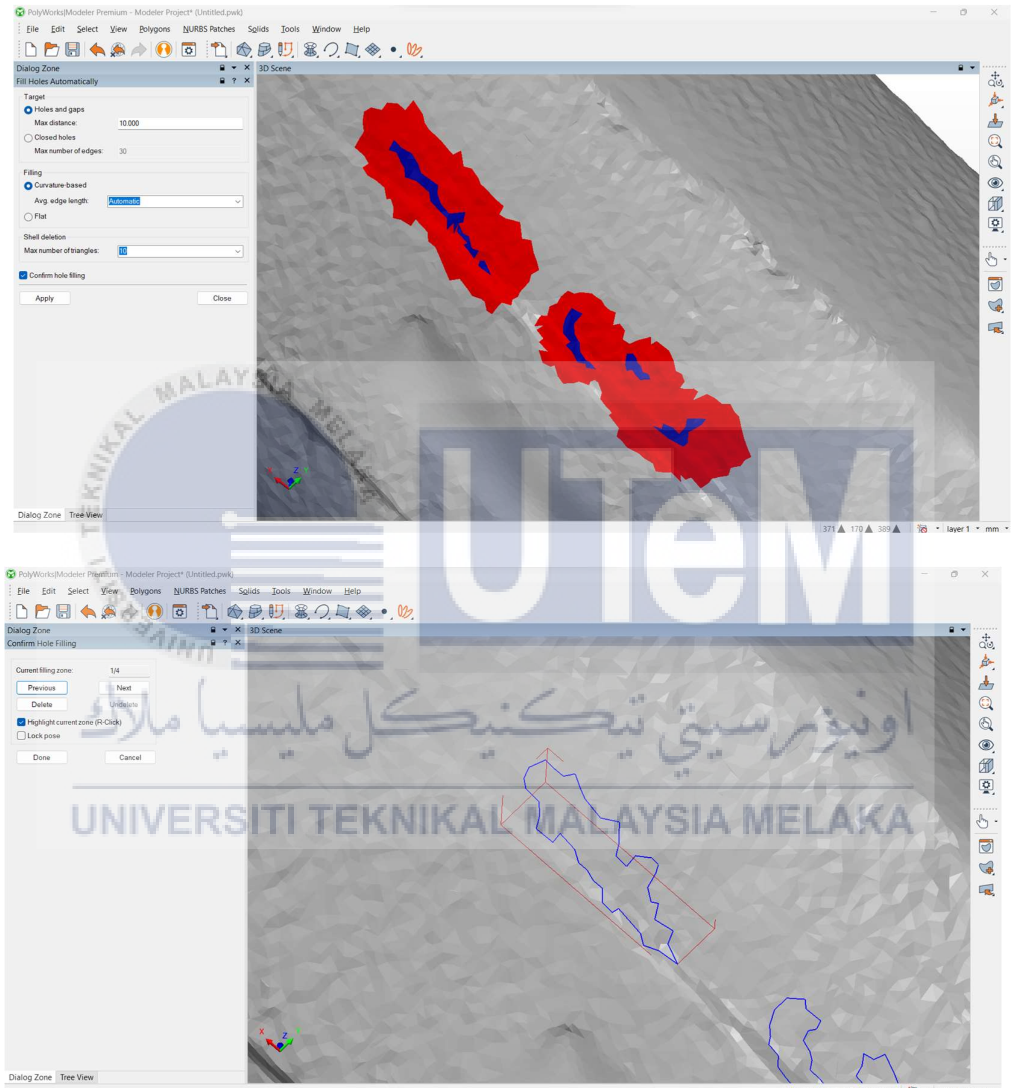


Figure 4.9: Automatically fill holes process

6. To remove extra part use select elements based on the type of surface to highlight the part and press delete to remove the part selected.

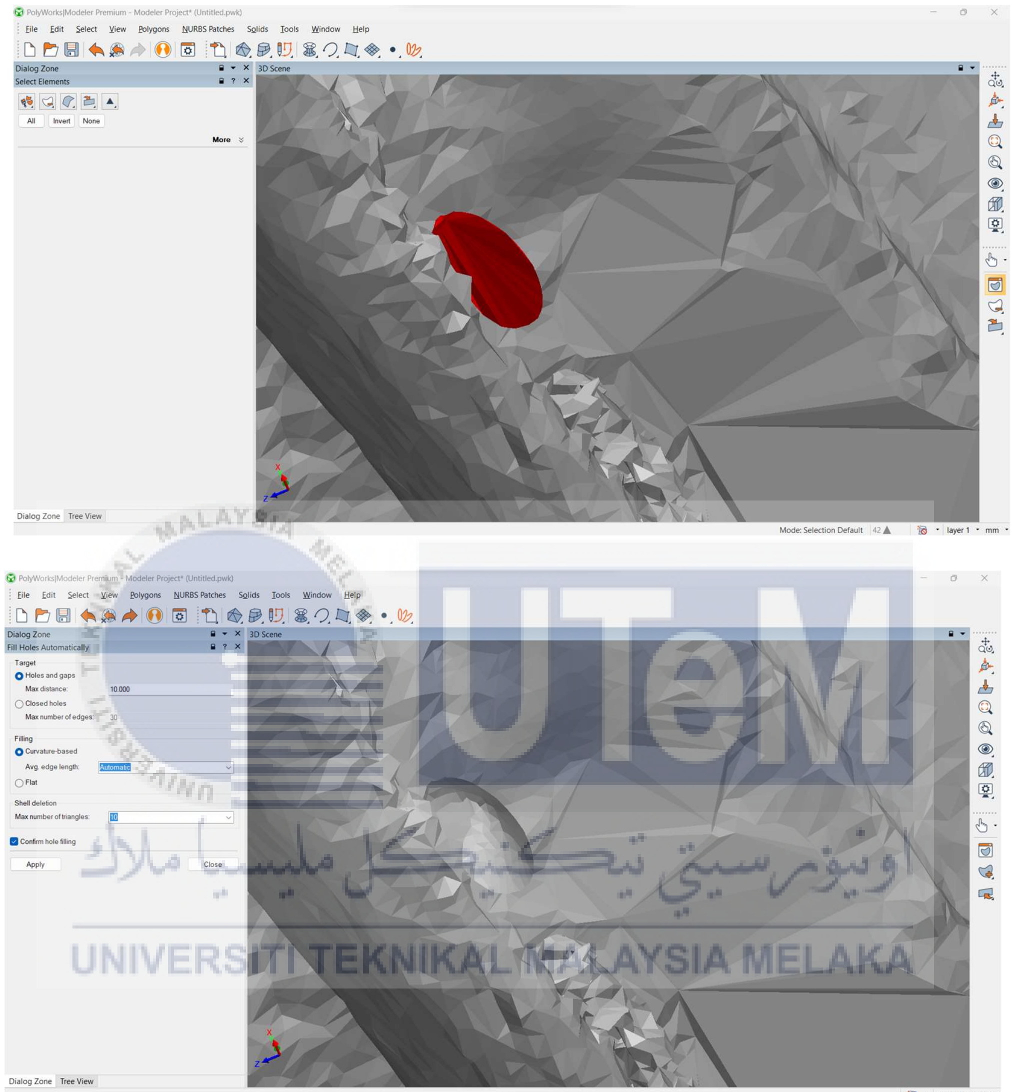


Figure 4.10: Deletion process of extra part

7. In order to fix bad mesh surface, reconstruct mesh function from polygon was used. The surface was highlighted before clicking reconstruct mesh.

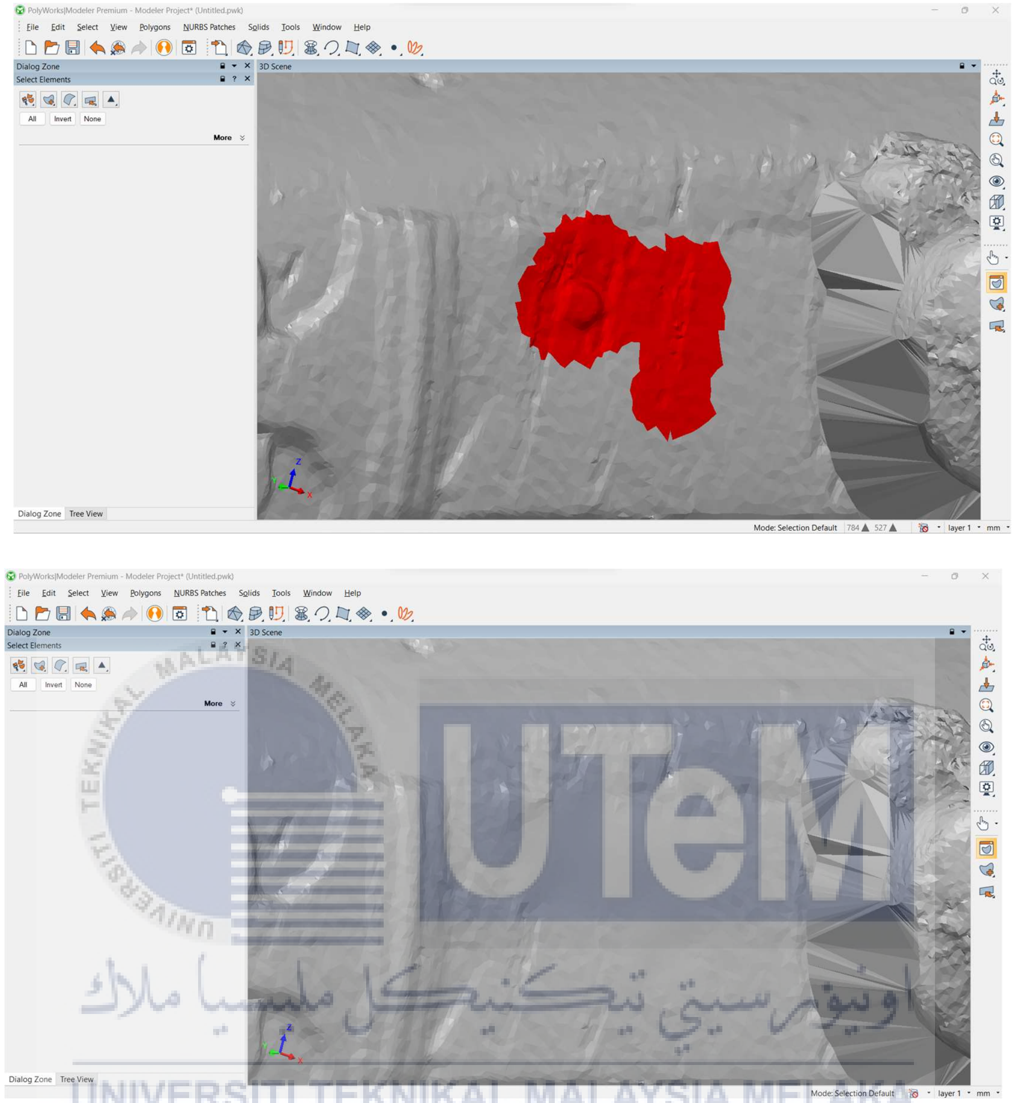


Figure 4.11: Reconstruct Mesh Process

8. After that, the side part of Istinggar which is the flintllock mechanism was slowly filled due to its complicated design.

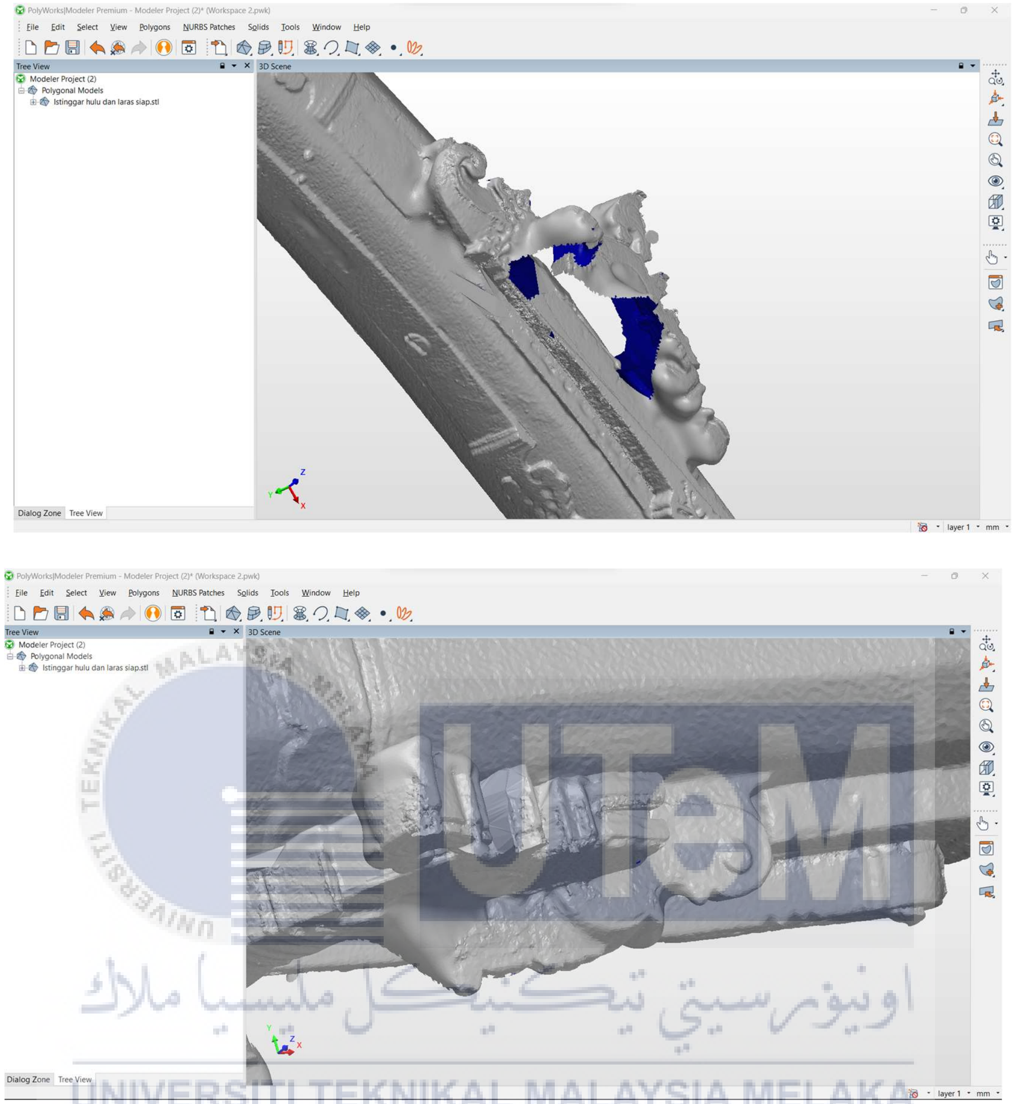


Figure 4.12: Sidepart Flintlock Filled

9. Since the flintlock was in a critical condition and Polyworks was unable to solve the issues, File was export as stl to continue in Solidworks. The flintlock was remade as a part and assembled together with the data from polyworks.

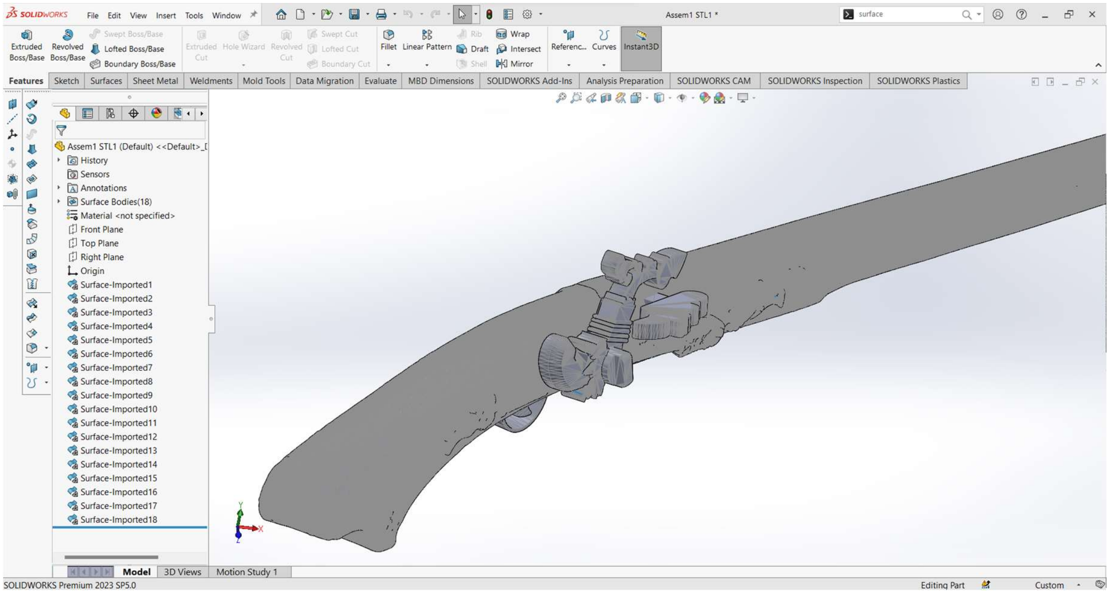


Figure 4.13: Assembly process from Solidworks

10. After the flintlock was remade by using solidworks, the file was exported as stl again to be inserted into materialise magics.

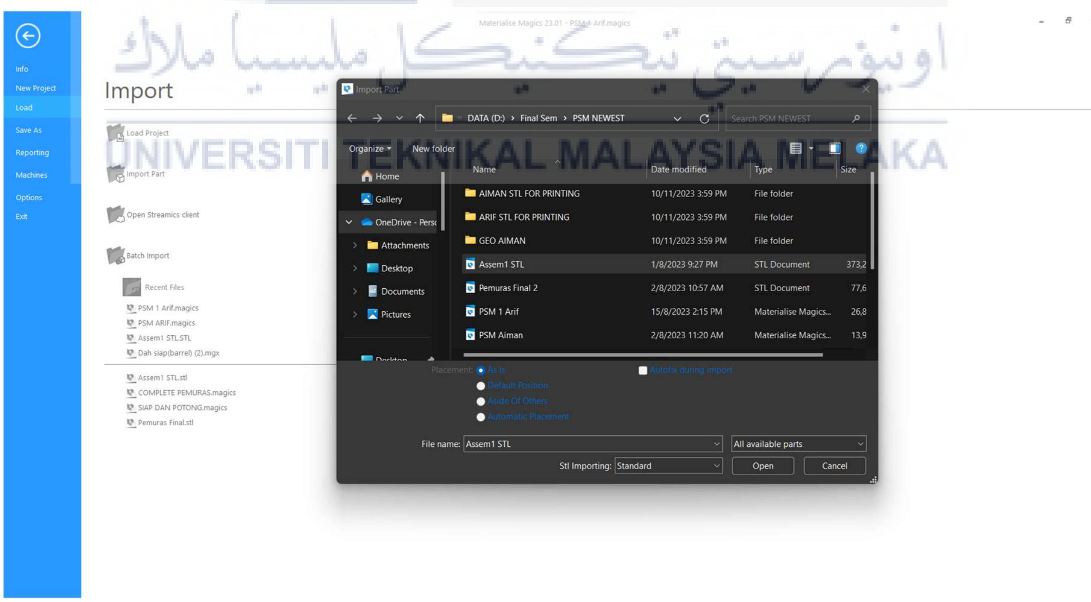


Figure 4.14: Import Part Process

11. Stl file from Solidworks was imported into Materialise magics. Using surface to solid function, the thickness of the prototype was set into 3 mm.

Figure 4.15: Thickness settings

12. Materialise magic was used to cut and make 8 part of the istinggar data by using cut or punch features. Teeth line was added in order to make assembly process after prototyping easier.

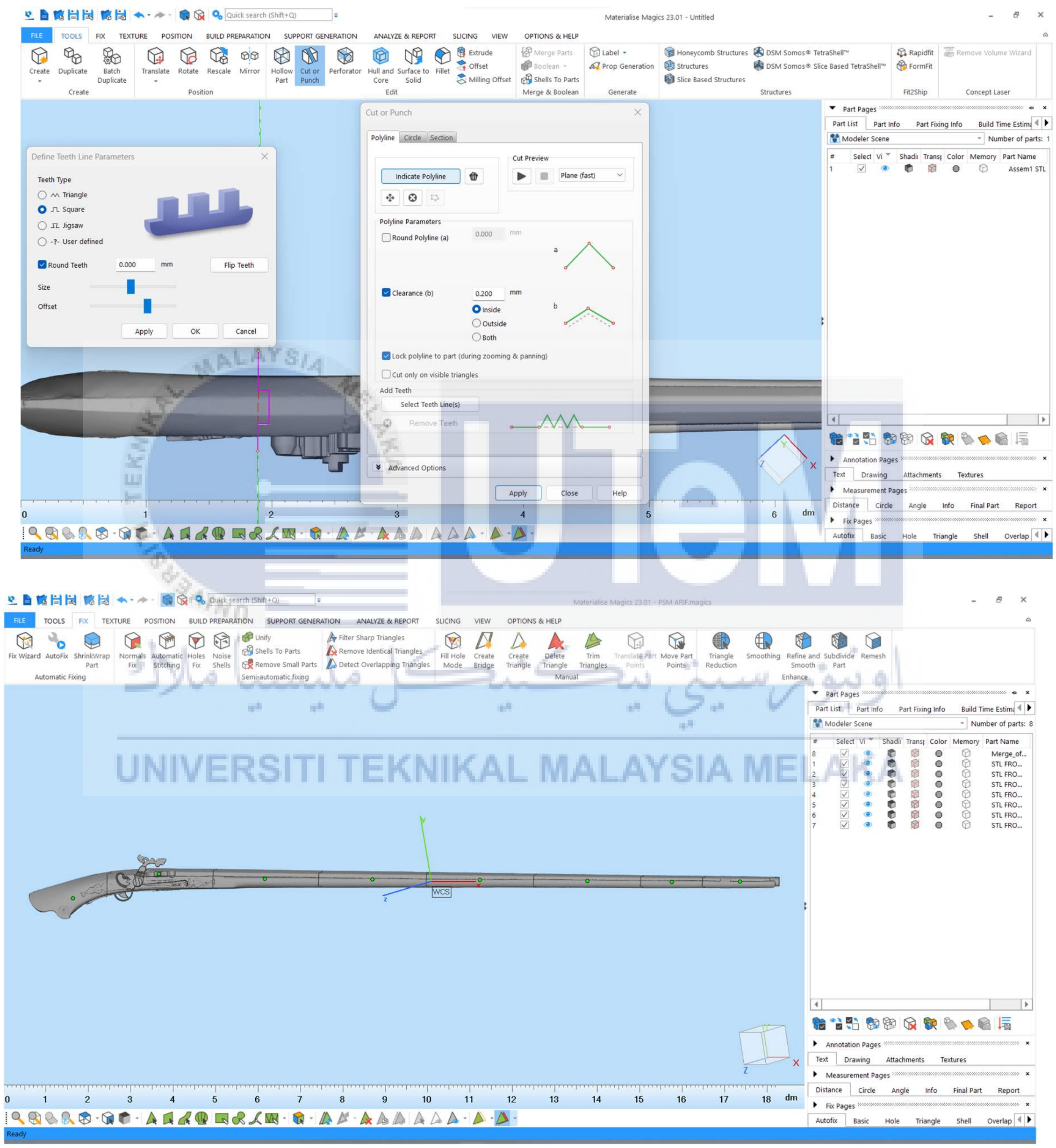


Figure 4.16: Cutting process in Materialise Magics

13. Then, autofix was used to automatically fix each part that has been cut and fix wizard was used to run diagnostic.

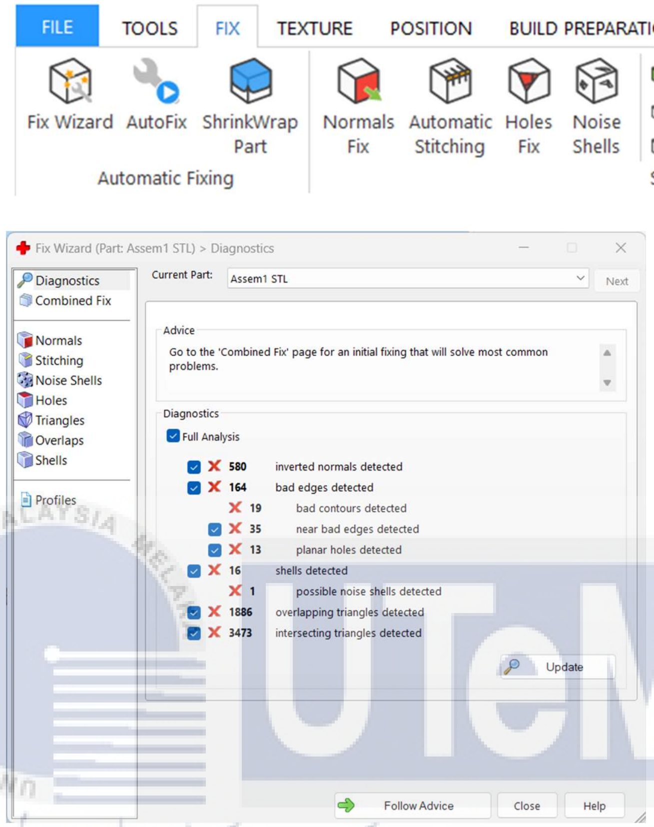


Figure 4.17: Autofix and Fix Wizard Function

14. The fix wizard help to diagnost the problem on each part, by clicking follow advice the problem can be fix 1 by 1 automatically or manually. The process was repeated until full analysis has 0 problem.

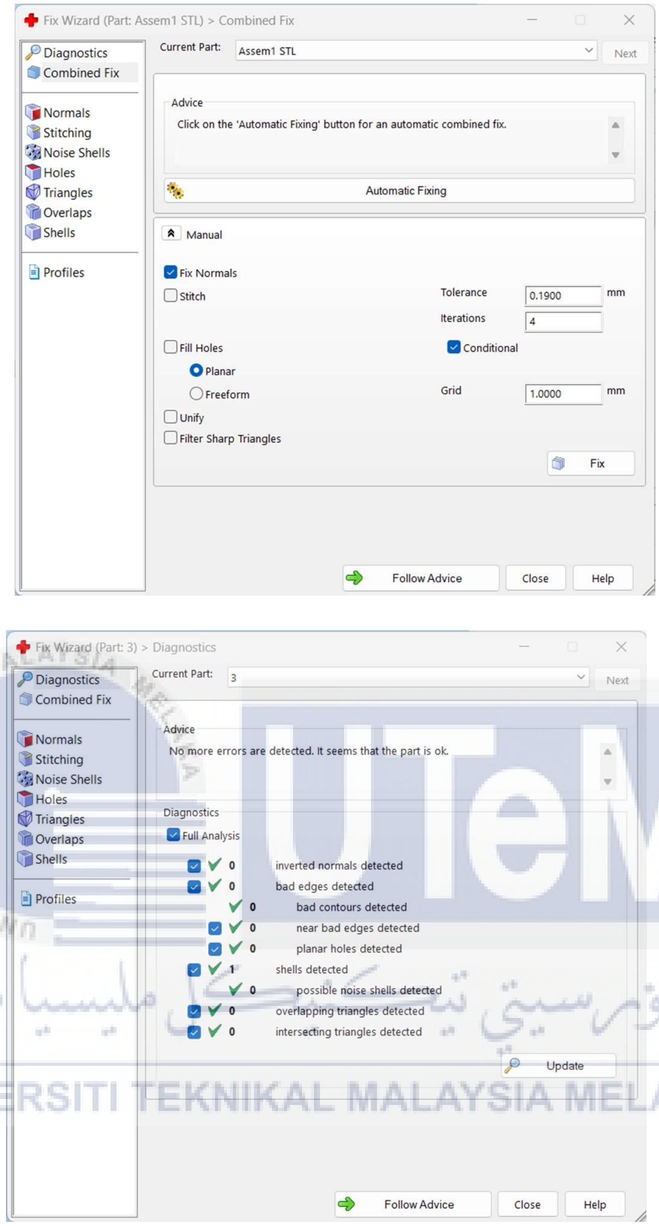


Figure 4.18: Fix Wizard Full Diagnostic

15. Then, export the file by click on the save as ‘selected part as’ to save in STL format to proceed to prototype fabrication.

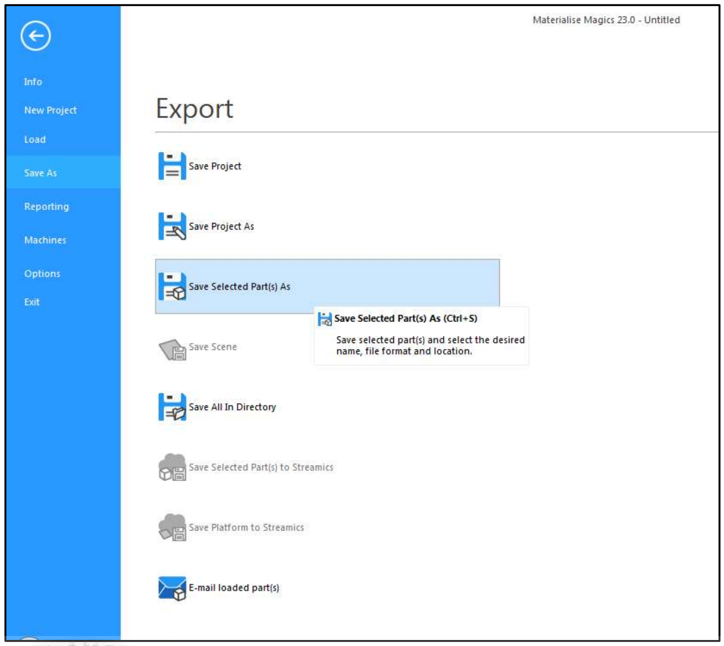
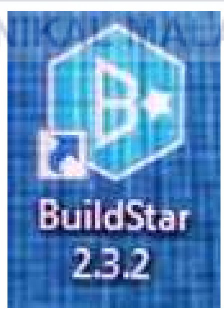


Figure 4.19: Export Selected Part

16. Each part then was exported as stl to be inserted into buildstar for prototyping in selective laser sinter machine. Inside the buildstar, the product was arranged and then verify as a preparation for prototyping inside the machine.



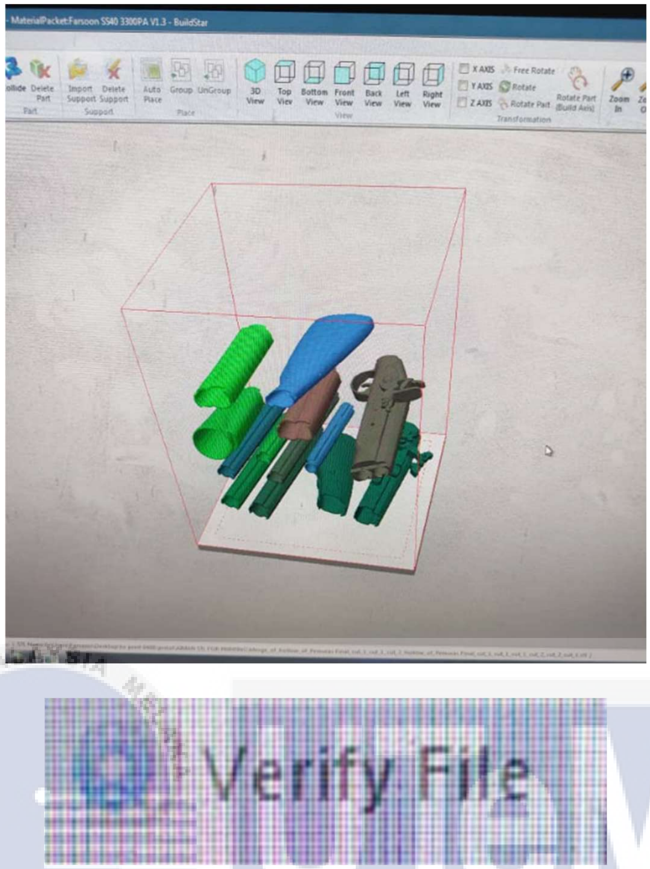


Figure 4.20: SLS Data insertion and verification

As a summary, various manipulation data technique was used. For each problem, solution was made in order to gain geometric data as close as posible with original historical artifact Istinggar.

Problem	Solution
Missing surface on scanned data.	Used polyworks to patch missing surface.
Critical missing part.	Replicated using solidworks
Error on analysis data.	Fixed using materialise magic fix wizard function.

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

The process for creating the prototype has been elucidated through the following steps. The Farsoon Laser Sintering Machine was employed in fabricating the prototype.

Figure 4.21: Farsoon Laser Sintering Machine

1. Powder was prepared according to the estimated requirement. The left side build chamber of the SLS machine was extracted, and the powder was poured into it. Using a blade, the powder was leveled and then the build chamber was reinserted into the machine.

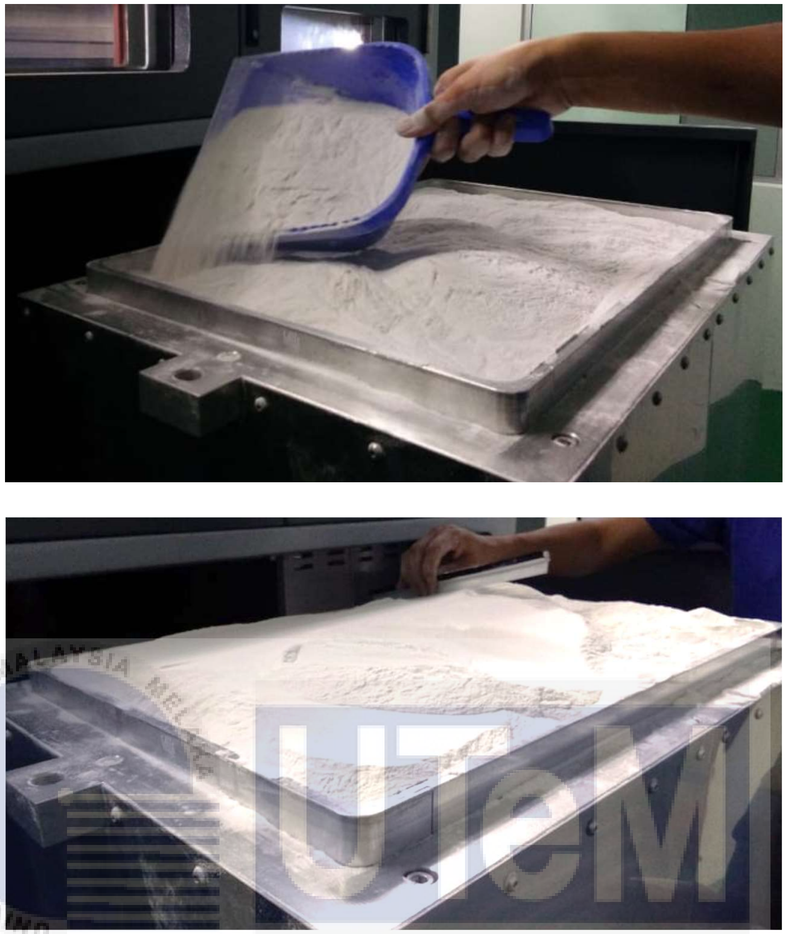


Figure 4.22: Recycled Powder insertion and leveling

2. Printing simulation then was checked through ‘Slicer’ to ensure printing process can be proceed. The printing process have been started after the simulation was checked.
3. After the prototypes were constructed, the powder surrounding them was removed by lifting them out from the build chamber and placing them into the Powder Purify Station. Then, the excess powder was remove by using a brush.

Figure 4.23: Prototype Cleaning Process

4. After that, sand blasting machine was used to remove small residual powder that stuck inside the prototype.

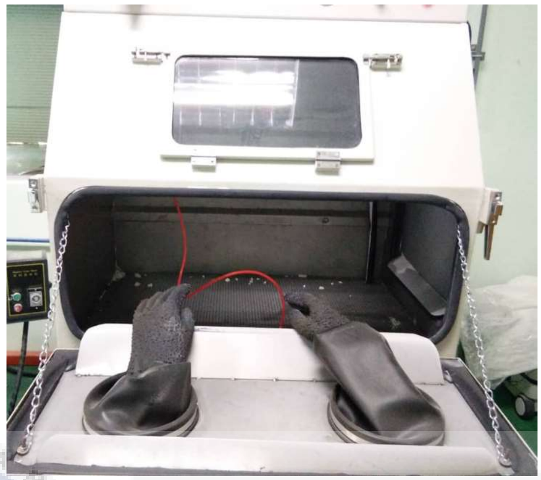


Figure 4.24: Sand Blasting Machine

4.3 CAD-to-CAD dimensional analysis

The process of CAD-to-CAD analysis involves referencing Computer-Aided Design (CAD) data and juxtaposing it with the scanned part available in STL format. A fundamental prerequisite for conducting such an analysis is possessing the original and authentic CAD data, which serves as the baseline for comparison against the gathered measurement data.

In practice, the scanned data file is imported into specialized reverse engineering software, where it operates as a foundational guide to reconstruct the CAD model. Subsequently, software tools like Materialise Magics are employed to perform the CAD-to-CAD analysis. This analysis meticulously scrutinizes the dimensional accuracy by precisely comparing the data gained from the original CAD data with that reconstructed from the scanned part.

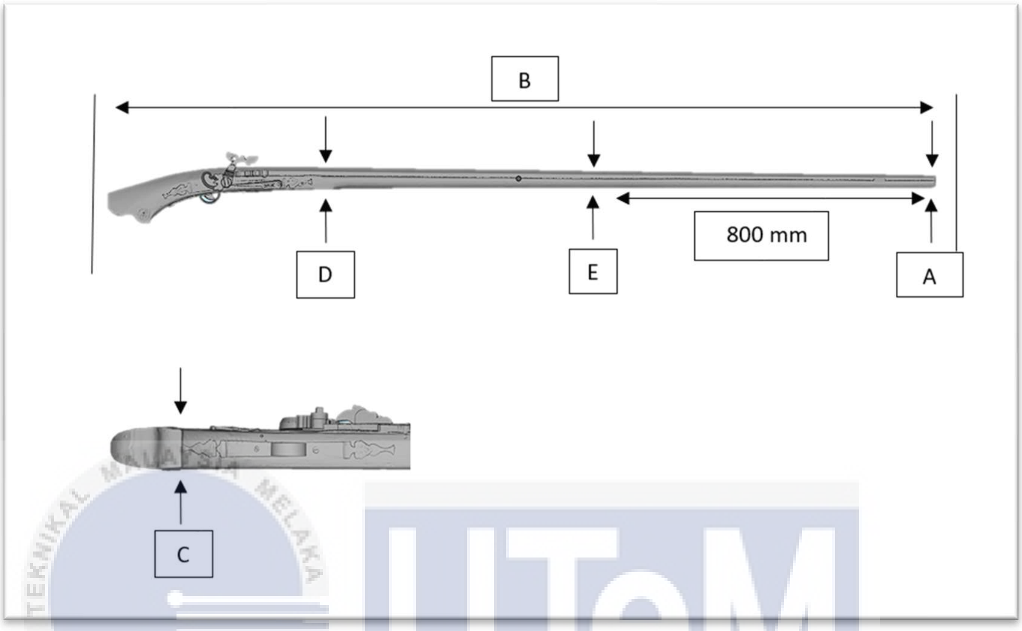


Figure 4.25: Dimensional Analysis Part Position

Polyworks Dimension						
Dimension (mm)	1	2	3	4	5	Average
A	20.80	21.10	20.80	21.10	20.85	20.93
B	1760.82	1760.51	1760.66	1760.80	1760.77	1760.71
C	47.12	47.10	47.48	46.90	47.02	47.12
D	46.68	46.66	46.68	46.64	46.67	46.67
E	32.56	32.55	32.49	32.52	32.54	32.53

Table 1: Dimensional Analysis From Polyworks

Materialise Magics Dimension						
Dimension (mm)	1	2	3	4	5	Average
A	21.10	21.30	20.90	20.80	21.05	21.03
B	1762.50	1762.90	1762.60	1762.60	1762.80	1762.68
C	47.26	47.48	47.05	47.85	47.70	47.47
D	46.65	46.60	46.45	46.75	46.60	46.61
E	32.45	32.70	32.65	32.65	32.63	32.62

Table 2: Dimensional Analysis From Materialise Magics

CAD TO CAD (Polyworks to Materialise Magics	Percentage Differences (%)
A	0.48
B	0.11
C	0.73
D	-0.12
E	0.26

Table 3: Percentage Differences CAD TO CAD Data

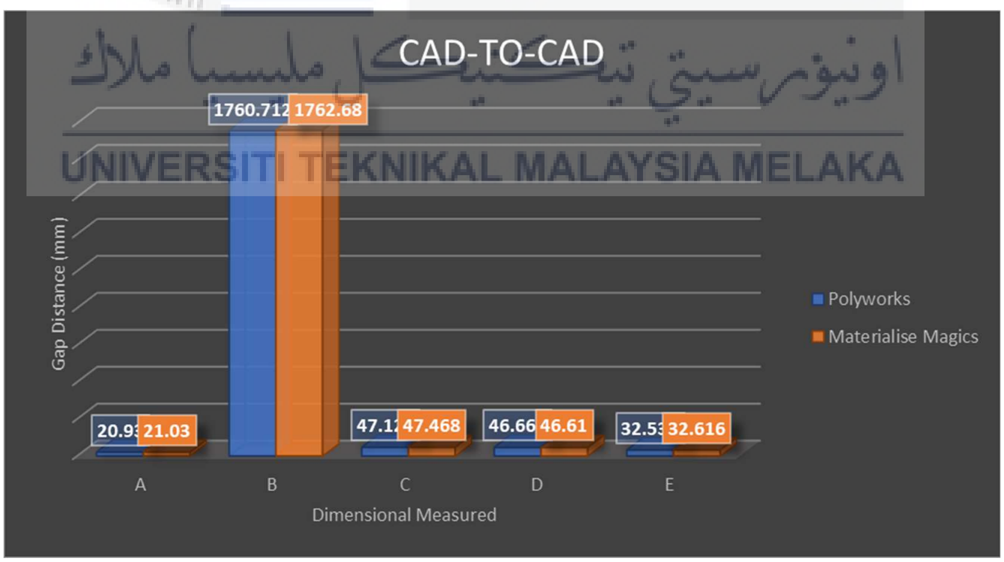


Figure 4.26: CAD TO CAD Histogram

According to the data presented in Figure 4.25, the visual representation illustrates variations in gap distances derived from two software tools: Polyworks and Materialise Magics. The analysis reveals notable differences across various positions, with the most significant disparity observed at position C, indicating a 0.73% increase in difference percentages between the two datasets. Conversely, at position B, the disparity exhibited the smallest percentage difference in increase, recording a marginal 0.112%. Furthermore, position D notably displayed a decrease in percentage difference amounting to -1.2%, suggesting a reduction in size for that specific component. These findings elucidate the comparative discrepancies in gap measurements between Polyworks and Materialise Magics, emphasizing distinct variations at different positions within the data.

4.4 CAD-to-PART dimensional analysis

The CAD-to-PART analysis procedure comprises cross-referencing CAD data retrieved from Materialise Magics with the physically created prototype. A fundamental requirement for conducting this analysis is possessing the CAD data obtained from Materialise Magics, which serves as the primary benchmark for comparison against the manually measured data obtained from the prototype.

Practically speaking, the CAD data sourced from Materialise Magics holds immense significance as it establishes the foundational reference point for evaluating the physical prototype. This comparison enables a comprehensive assessment of dimensional accuracy, unveiling any possible differences between the intended CAD model and the real-world physical prototype.

The execution of the CAD-to-PART analysis typically involves the utilization of software tools such as Microsoft Excel. This software facilitates an extensive examination of datasets, enabling a meticulous review of dimensional accuracy. Through this analysis, variations between the CAD data from Materialise Magics and the measurements of the physical prototype are carefully examined, recorded, and analyzed. The resulting insights provide a detailed evaluation that specifically highlights the precision in dimensions and potential disparities between the designed CAD model and the produced prototype. The comparison table was refer back to table 2.

Prototype						
Dimension (mm)	1	2	3	4	5	Average
A	21.40	21.50	21.50	21.70	21.60	21.54
B	1768.10	1767.90	1768.00	1768.10	1769.00	1768.22
C	47.21	47.22	47.21	47.28	47.25	47.23
D	46.50	46.10	46.50	46.40	46.60	46.42
E	32.30	32.30	32.20	32.40	32.30	32.30

Table 4: Dimensional Analysis From Prototype

CAD TO PART (Materialise Magics to Prototype)	Percentage Differences (%)
A	2.43
B	0.31
C	-0.49
D	-0.41
E	-0.97

Table 5: Percentage Differences CAD TO PART Data

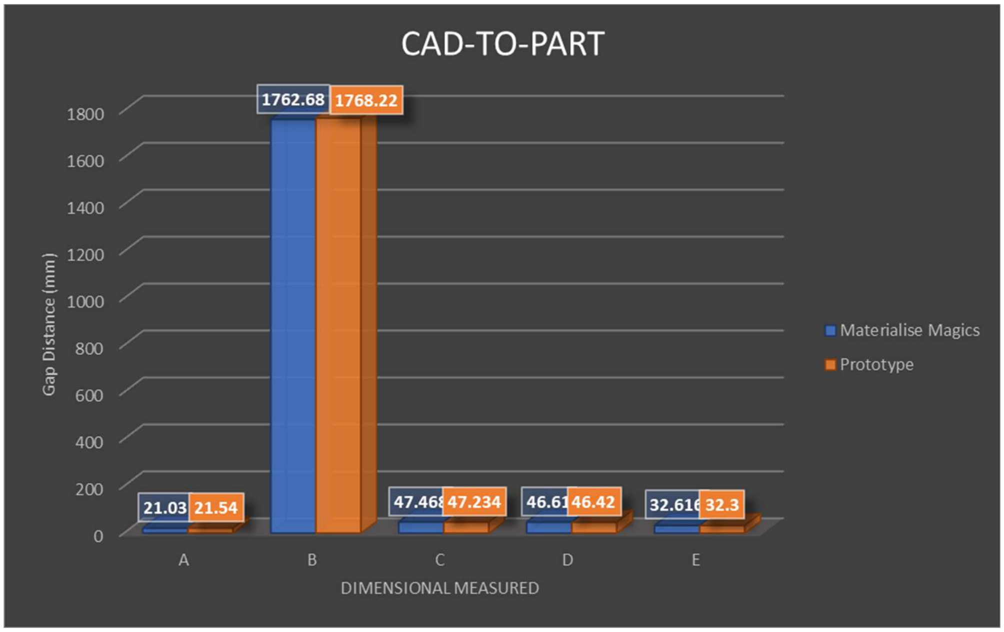


Figure 4.27: CAD-TO-PART Histogram

As per the insights gleaned from Figure 4.26, the graphical representation visually captures the disparities in gap distances obtained from two sources: the manufactured prototype and Materialise Magics. This analysis unravels noteworthy discrepancies evident across various positions, spotlighting distinct variations between the datasets. Notably, the most substantial difference emerges at position A, showcasing a 0.31% increase in disparity percentages between the two datasets. Conversely, the smallest disparity in percentage increase appears at position B, registering a marginal 0.112%.

Furthermore, position E stands out by displaying the most significant decrease in percentage difference, marked at -0.97%, indicating a reduction in size for that specific component. In contrast, the smallest decrease is discerned at position D, measuring -0.41%. These detailed observations shed light on the comparative variations in gap measurements between the produced prototype and Materialise Magics, underlining distinct differences across different positions within the dataset.

4.5 PART to PART dimensional analysis

The methodical procedure for conducting the PART-to-PART analysis involves meticulously cross-referencing the original dimensional data with the physical prototype that has been developed. An essential aspect of performing this analysis lies in utilizing precise measuring instruments such as measuring tape and vernier calipers, ensuring accurate and detailed measurements are obtained for the evaluation process.

The fundamental requirement for executing this analysis involves the meticulous utilization of measuring tape and vernier calipers. These precision tools are crucial as they enable the collection of accurate measurements from the physical prototype, ensuring that every dimension and feature is thoroughly assessed against the original dimensional data. Prototype dimensional data can be referred from table 4.

Actual Dimension (mm)	1	2	3	4	5	Average
A	21.50	22.45	21.80	22.80	22.20	22.15
B	1761.10	1761.40	1761.20	1761.40	1761.30	1761.28
C	47.10	47.15	47.10	47.21	47.20	47.15
D	46.60	46.50	46.49	46.50	46.70	46.56
E	32.20	32.50	32.60	32.55	32.65	32.50

Table 6: Dimensional Analysis from actual part

PART TO PART (Prototype to Actual Product)	Percentage Differences (%)
A	-2.75
B	-0.39
C	-0.17
D	0.30
E	0.62

Table 7: Percentage Differences PART-To-PART Data

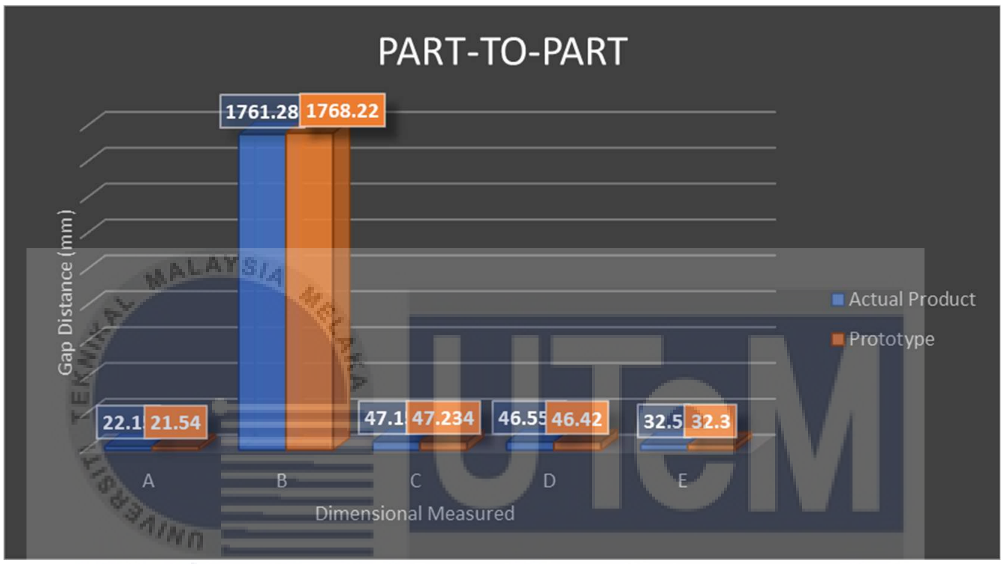


Figure 4.28: PART-TO-PART Histogram

According to the findings in Figure 4.27, the graphical representation visually illustrates the differences in gap distances obtained from two sources: the manufactured prototype and the actual product. This analysis reveals notable differences across various positions, emphasizing distinct variations between the datasets. Notably, the most significant difference is observed at position E, indicating a 0.62% increase in disparity percentages between the two datasets. Conversely, the smallest disparity in percentage increase is seen at position B, with a marginal 0.29% increase.

Moreover, position E stands out with the most significant decrease in percentage difference, marked at -2.75%, suggesting a reduction in size for that specific component. In contrast, the smallest decrease is observed at position D, measuring -0.17%. These detailed observations highlight the comparative variations in gap measurements between the produced prototype and Materialise Magics, emphasizing distinctive differences across different positions within the dataset.

4.6 Finalize Data Dimensional Analysis

Through meticulous examination using the Part-to-Part dimensional analysis, a comprehensive assessment of the total percentage difference can be obtained. This analytical process involves an intricate comparison of dimensions between different parts or iterations, aiming to determine the overall variance or discrepancy observed across the entire dataset.

Overall Percentage Difference		
Dimension (mm)	Actual	Prototype
A	22.15	21.54
B	1761.28	1768.22
C	47.15	47.23
D	46.56	46.42
E	32.50	32.30
Total	1909.64	1915.71

Percentage Difference	0.32

Table 8: Overall Percentage Difference

4.7 Challenges Encounter and Counter Measures Taken

During the course of this thesis, several challenges surfaced, one of which revolved around the occurrence of shrinkage in the prototype of Istinggar during the prototyping process. This shrinkage specifically affected the assembly part of the prototype, leading to a slight difference in size. Consequently, this shrinkage had a notable impact on both the overall length and the alignment of the prototype components.

The issue of shrinkage during the prototyping phase presented a hurdle that impacted the accurate construction and alignment of the prototype assembly. The slight reduction in size altered the dimensions and affected the intended configuration of the prototype's components, thereby posing challenges in achieving the desired alignment and overall integrity of the assembled prototype.

Figure 4.29: Shrinkage and alignment problem

The primary cause attributed to the occurrence of shrinkage lay in the utilization of recycled powder throughout the prototype printing process using the selective laser sintering machine. The decision to employ recycled powder was a contributing factor that led to the shrinkage phenomenon witnessed in the final prototype. This recycling practice, while cost-effective and eco-friendly, inadvertently compromised the integrity and overall quality of the prototype.

The reutilization of powder in the selective laser sintering machine introduced certain inconsistencies and compromised characteristics into the printing process. The structuralt, the structural integrity and quality of the prototype were diminished. The incorporation of recycled powder brought about alterations in the material properties, affecting the sintering process during printing. This alteration likely led to variations in the printed prototype, contributing to the observed shrinkage.

Addressing this issue involves considering various potential solutions. For instance, one approach could be the utilization of new powder to mitigate the effects of shrinkage. However, implementing this solution encountered a setback due to maintenance requirements of the selective laser sintering (SLS) machine. Following the initial printing process, the machine became unavailable, rendering the use of new powder unfeasible. Consequently, alternative solutions needed to be explored to rectify the shrinkage issue.

Another proposed solution involved a different approach which was utilizing a hot small cutter to melt the assembled parts. The initial step in this method involved identifying the sections affected by bending or shrinkage. For components deemed critical, the assembly part was entirely cut along the designated assembly line. In less critical areas, only a portion of the assembly part was cut. To stabilize the critical sections, a supportive structure was fashioned using PVC cardboard.

Figure 4.30: Structure made by using PVC Cardboard

Figure 4.31: Melted Part for Aligning Process

Figure 4.32: Aligning Process on Critical Part

Following this, the prototype underwent the process of realignment, with careful attention to restoring its original form. The separated parts were meticulously aligned and then reattached using an adhesive to reconstruct the prototype assembly. This method aimed to rectify the shrinkage issue and restore the integrity of the prototype by strategically modifying and reinforcing the affected areas.

Upon reaching the concluding phase of the project, the prototype underwent a meticulous sanding process aimed at refining its appearance and texture. This essential step in the finishing process aimed not only to smoothen the surface but also to eliminate any remnants of blackened or charred areas present on the prototype.

The sanding process involved the careful removal of surface imperfections, ensuring a uniform and polished finish.

Figure 4.33: Sanding Process

Figure 4.34: Finished alignment process

4.8 Summary

This chapter serves as the culmination of the project's findings, encapsulating a comprehensive summary of the conclusions drawn from the experimental pursuits conducted. A meticulous and thorough examination of the experiment's methodology provides a comprehensive understanding of the approach adopted. The complexities encountered in modifying the intricate design of the original object have been distinctly elucidated through the detailed outcomes of data manipulation, meticulously presented and rigorously analyzed.

Moreover, the process encompassed comprehensive primary and secondary research endeavors, strategically conducted to procure pivotal information essential for the project report. Delving into the nuances, the journey of data manipulation unfolded systematically, progressing from the initial stages of scanned data to the meticulous formation of comprehensive data suitable for the fabrication process.

The crux of the analysis lies in the detailed exploration and examination of the percent difference between the original Istinggar product, and the prototype produced through a rigorous data analysis process. Every step of challenge identification and the subsequent strategies deployed to address these obstacles is meticulously documented, forming the backbone of data validation within this thesis. This thorough delineation of challenges and their corresponding solutions serves as a testament to the robustness and credibility of the project's findings, providing a comprehensive understanding of the experimental journey undertaken.

CHAPTER 5

5.1 Conclusion

The culmination of this project has been a comprehensive journey encompassing multiple essential stages. The initial phase involved an extensive literature search and review, establishing a strong foundation by assimilating existing knowledge and insights. Subsequently, the focus shifted towards identifying the latent potential of scanned artifacts through the lens of reverse engineering, setting the stage for exploring innovative applications.

Throughout this endeavor, a robust understanding of reverse engineering, computer-aided design (CAD), and selective laser sintering was cultivated. This familiarization laid the groundwork for the subsequent phases, equipping the project with the necessary expertise and technical knowledge essential for effective execution.

An integral part of this project was the manipulation of CAD data extracted from cloud data. This intricate process demanded meticulous attention to detail and technical proficiency, allowing for the refinement and transformation of raw data into a format suitable for further exploration and utilization.

The verification of the utility of STL data and the subsequent fabrication of a prototype using selective laser sintering served as a pivotal step. This practical application validated the efficacy and feasibility of utilizing STL data in the fabrication process, highlighting the capabilities and potential of selective laser sintering technology in materializing prototypes from digital designs.

This project has been an exploration and application of various technological facets, from literature review to practical verification. It underscored the importance of understanding and leveraging cutting-edge technologies like reverse engineering and selective laser sintering, showcasing their potential in transforming scanned artifacts into tangible prototypes. The acquired knowledge and insights from this endeavor not only contribute to the advancement of these technologies but also open doors to further innovation and exploration in the realms of digital fabrication and artifact replication.

In conclusion, the process initiated with the conversion of point cloud data into precise Computer-Aided Design (CAD) data. Utilizing non-contact reverse engineering (RE) methods alongside a Laser Sintering machine, the primary objective was to faithfully replicate the geometric intricacies of a historical artifact Istinggar. Through meticulous comparison and analysis, the 3D printed prototype was evaluated against the original historical artifact Istinggar, specifically focusing on both appearance and dimensional accuracy.

The journey commenced with the transformation of raw point cloud data into refined CAD data, forming the foundation for recreating the historical artifact Istinggar. Employing non-contact reverse engineering techniques enabled the acquisition of intricate geometric details, crucial for the faithful reproduction of the artifact. The Laser Sintering machine played a pivotal role in materializing the 3D printed prototype, leveraging the dimensional accuracy achieved through this process as a benchmark for comparison.

A comprehensive comparison analysis was conducted, juxtaposing the appearance and dimensional accuracy of the original historical artifact with the 3D printed prototype. This comparison facilitated an in-depth evaluation, highlighting both the resemblances and disparities between the two. By researching and analyzing CAD-to-CAD, CAD-to-Part, and Part-to-Part analysis, validation of the data gained was achieved.

Insights gained from this comparative analysis not only emphasized the fidelity achieved in replicating the appearance but also underscored the precision of dimensional accuracy achieved through the Laser Sintering process.

Ultimately, this endeavor showcased the efficacy of non-contact reverse engineering coupled with advanced additive manufacturing technologies in faithfully replicating historical artifacts. The meticulous comparison analysis illuminated the successes and provided invaluable insights into the nuances of materializing accurate and visually faithful replicas, thereby contributing significantly to the realms of preservation and replication of historical artifacts using modern technological advancements.

5.2 Recommendation

For future development regarding for this project, the following are some recommendations:

- Get detailed historical background of the product. Detailed information on product will help us a lot in doing liturature review.

- Pay a lot of details during data manipulation process. Make sure that there are no small noises on data and error before fabrication process.

- Use proper thickness toward product part before fabrication process. Ensuring proper thickness before fabrication process play a major role in determining the quality of the fabricated product.

- Study the dimensional analysis result and factors that can affect the result. By performing necessary analysis, proper conclusion and discussion can be conclude to futher understanding the challenges taken during performing this project.

REFERENCES

Anju, S. (2020, March 20). *The 6 advantages of reverse engineering*. Retrieved from sphinxworldbiz: https://www.sphinxworldbiz.com/blog/the-6-advantages-of-reverse-engineering/

Attaran, M. (2017). The rise of 3-D printing: The advantages of additive manufacturing over traditional manufacturing. *The rise of 3-D printing: The advantages of additive manufacturing over traditional manufacturing*.

Carmel. (2022, March 21). *What is 3D CAD or Computer Aided Design - The Ultimate Guide*. Retrieved from .sculpteo: https://www.sculpteo.com/en/glossary/cad-definition-en/

Foundation, W. (2023, May 2). *Istinggar*. Retrieved from Wikipedia: https://ms.wikipedia.org/wiki/Istinggar

Isamu Nishida, K. S. (2019, September). *Machine Tool Assignment Realized by Automated NC Program Generation and Machining Time Prediction*. Retrieved from ResearchGate: https://www.researchgate.net/publication/335638081_Machine_Tool_Assignment_Realized_by_Automated_NC_Program_Generation_and_Machining_Time_Prediction

N. Sherry, A. (1970, January 1). *Reverse Engineering of Automotive Parts Applying Laser Scanning and Structured Light Techniques | Semantic Scholar*. Retrieved from semanticscholar: https://www.semanticscholar.org/paper/Reverse-Engineering-of-

Automotive-Parts-Applying-Sherry-Ali/f5c2ac918991956ec771e2848606fddd2dea9db8/figure/4

Sejarahtokoh. (2012, May 14). *Tokoh Sejarah*. Retrieved from wordpress: https://sejarahtokoh.wordpress.com/2012/05/11/parameswara/

simplify3d. (2021, December 22). *Restoring Museum Relics with 3D Printing*. Retrieved from Simplify3D Software: https://www.simplify3d.com/restoring-museum-relics-with-3d-printing/

Spagnoli, F. (2016, january). *Two mycenaean stirrup jars from the levant*. Retrieved from researchgate: https://www.researchgate.net/publication/301561477_Two_mycenaean_stirrup_jars_from_the_levant

Two mycenaean stirrup jars from the levant. (n.d.). Retrieved from ResearchGate: https://www.researchgate.net/publication/301561477_Two_mycenaean_stirrup_jars_from_the_levant

Arbace, L., Sonnino, E., Callieri, M., Dellepiane, M., Fabbri, M., Iaccarino Idelson, A., and Scopigno, R., 2013. Innovative uses of 3D digital technologies to assist the restoration of a fragmented terracotta statue. Journal of Cultural Heritage, 14(4), 332–345.

Author, S., Reviewed, Y. T., Review, G., Geographical, A., and Stable, S., 2012. American Geographical Society, 76(1), 10–19.

Campbell, R. I., Martorelli, M., and Lee, H. S., 2002. Surface roughness visualisation for rapid prototyping models. CAD Computer Aided Design, 34(10), 717–725.

Ford, S., Mortara, L., and Minshall, T., 2016. Technological Forecasting & Social Change The Emergence of Additive Manufacturing : Introduction to the Special Issue. Technological Forecasting & Social Change, 102, 156–159.

Gao, W., Zhang, Y., Ramanujan, D., Ramani, K., Chen, Y., Williams, C. B., … Zavattieri, P. D., 2015. The status, challenges, and future of additive manufacturing in engineering. CAD Computer Aided Design, 69, 65–89.

Gibson, I., Rosen, D. W., and Stucker, B., 2010. Additive manufacturing technologies: Rapid prototyping to direct digital manufacturing. Additive Manufacturing Technologies: Rapid Prototyping to Direct Digital Manufacturing.

Guo, N., and Leu, M. C., 2013. Additive manufacturing: Technology, applications and research needs. Frontiers of Mechanical Engineering, 8(3), 215–243.

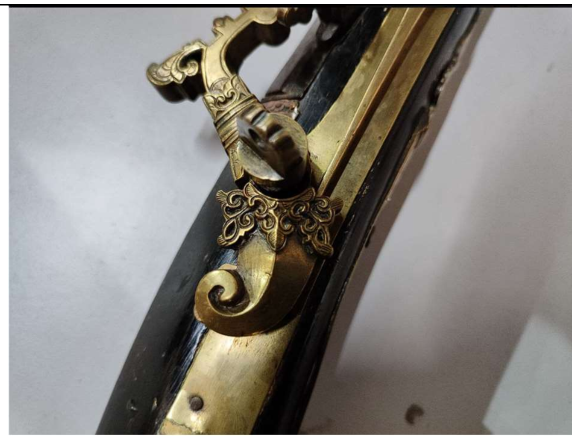
Kaji, F., and Barari, A., 2015. Evaluation of the surface roughness of additive manufacturing parts based on the modelling of cusp geometry. IFAC-PapersOnLine, 28(3), 658–663.

Koo, J. H., Ortiz, R., Ong, B., and Wu, H., 2016. Polymer nanocomposites for laser additive manufacturing. Laser Additive Manufacturing: Materials, Design, Technologies, and Applications.

APPENDICES

Appendix A: Historical Artifact Istinggar in Malaccacal Artifact Istinggar in Malacca

Historical Artifact Istinggar



Appendix B: MUSEUM VISITATION

Appendix C: GANTT CHART PSM

PSM 1 PLANNING (GANTT CHART)																
REPLICATION AND PART VALIDATION OF MELAKA HISTORICAL ARTIFACT MADE USING SELECTIVE LASER SINTERING (SLS): ISTINGGAR																
TASK	Plan vs Actual	Periods (Weeks)														
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Tittle Selection Project Briefing	Plan								MIDTERM BREAK							
	Actual															
Site Visitation	Plan															
	Actual															
Journal Research	Plan															
	Actual															
PSM Workshop	Plan															
	Actual															
Literature Review	Plan															
	Actual															
Product Background Research	Plan															
	Actual															
Reverse Engineering and Additive Manufacturing Identifying	Plan															
	Actual															
Research Evaluation	Plan															
	Actual															
First Draft Submission	Plan															
	Actual															
Weekly Meeting	Plan															
	Actual															
Proposal Report	Plan															
	Actual															
PSM 1 Report Writing	Plan															
	Actual															
PSM 1 Presentation	Plan															
	Actual															

PSM 2 PLANNING (GANTT CHART)															
TASK	Plan vs Actual	Periods (Weeks)													
		1	2	3	4	5	6	7	8	9	10	11	12	13	14
Product Development	Plan								MID SEM BREAK						
	Actual														
Product Finishing	Plan														
	Actual														
Data Collection	Plan														
	Actual														
Report Analysis	Plan														
	Actual														
Weekly Meeting	Plan														
	Actual														
PSM Report Writing	Plan														
	Actual														
Executive Summary	Plan														
	Actual														
PSM 2 Report Submission	Plan														
	Actual														
Poster Presentation	Plan														
	Actual														
PSM 2 Presentation	Plan														
	Actual														