



**THE DEVELOPMENT OF FRAMEWORK FOR A LIGHTWEIGHT
METALLIC DRONE FRAME USING SELECTIVE LASER
MELTING (SLM) 3D PRINTING MACHINE**

MUHAMMAD SYAFIQ SYAZWAN BIN ABU ZAKI

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

M042210038

MASTER OF SCIENCE IN MECHANICAL ENGINEERING

2024



Faculty of Mechanical Technology and Engineering

**THE DEVELOPMENT OF FRAMEWORK FOR A LIGHTWEIGHT
METALLIC DRONE FRAME USING SELECTIVE LASER MELTING
(SLM) 3D PRINTING MACHINE**

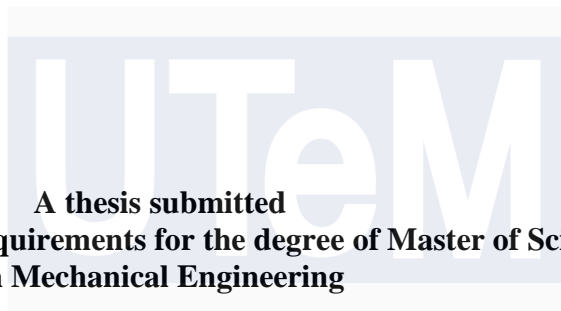
Muhammad Syafiq Syazwan Bin Abu Zaki

Master of Science in Mechanical Engineering

2024

**THE DEVELOPMENT OF FRAMEWORK FOR A LIGHTWEIGHT METALLIC
DRONE FRAME USING SELECTIVE LASER MELTING (SLM) 3D PRINTING
MACHINE**

MUHAMMAD SYAFIQ SYAZWAN BIN ABU ZAKI



اونيورسيتي تيكنيكل مليسيا ملاك
UNIVERSITI TEKNIKAL MALAYSIA MELAKA

Faculty of Mechanical Technology and Engineering

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2024

DECLARATION

I declare that this thesis entitled “Development of Sturdy Lightweight Drone Frame Printed with Selective Laser Melting Printer” is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.



Signature

اونيورسيتي تيكنيكل مليسيا ملاك

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

Name : Muhammad Syafiq Syazwan Bin Abu Zaki

Date : 1 May 2025

.....

APPROVAL

I hereby declare that I have checked this thesis and in my opinion, this thesis is sufficient in terms of scope and quality for the award of Master of Science in Mechanical Engineering.

Signature :

Supervisor Name : Dr Mohd Taufik Bin Taib

Date : 1 May 2025

اونيورسيتي تېكنيكل مليسيا ملاك

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

DEDICATION

To my beloved parents,

Abu Zaki Bin Romli and Che Liah Binti Ahmad

Thank you for all the support, encouragement, enthusiasm, patience, and willingness.

To my honoured supervisor,

Dr Mohd Taufik Bin Taib, Prof. Madya IR. Dr Mohd Hadzley Bin Abu Bakar and all
UTeM lecturers and staff.

To my dearest friends

Thank you for always giving me guidance and persistent help to complete this thesis
project.

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

ABSTRACT

The efficient execution of heavy-duty tasks by drones necessitates a robust frame capable of lifting heavy objects from a stable, elevated position. However, traditional solid materials contribute to excessive weight, accelerating battery deterioration. Moreover, complex designs pose challenges for conventional machining methods. This study aims to design a lightweight and sturdy drone frame using stainless steel via generative design. Strength and stability are evaluated through simulation and experimentation. The proposed solution leverages additive manufacturing, specifically Selective Laser Melting (SLM) 3D printing, with stainless steel powder. To design a drone frame that is suitable for that requirement, first needs to study the machine's behaviour and the mechanical properties of the material. To understand the machine's capability, the experiment that was decided is a surface roughness test by experimenting with the printing orientation of specimens. The specimens were printed using three parameters: the effect of surface area, the effect of height, and the effect of printing angle. Then, the specimens underwent a surface roughness test to determine which printing orientation was the best for manufacturing the drone frame. For the mechanical properties, the experiments that were executed were impact tests and tensile tests. The specimens were drawn first using Autodesk Fusion 360, guided by the American Society for Testing and Materials (ASTM), and fabricated using a Selective Laser Melting (SLM) 3D printing machine. The parameters for these experiments are the material state of the stainless steel powder (virgin and recycled powder), the thickness of the specimens, and the coordination of the specimens on the production bed. After finishing all the physical experiments, the process proceeds to the simulation experiment. First, sketch multiple designs of the drone frame. Those designs that were sketched will be drawn using Autodesk Fusion 360 and undergo a Generative Design process. After that process, the design file was exported to STEP format (.step) for simulation using the Static Structural study in Finite Element Analysis (FEA) within Autodesk Fusion 360. This allowed for the evaluation and selection of the best drone frame design before proceeding to the manufacturing stage. The best design that was selected from the FEA simulation test is manufactured using the Additive Manufacturing method, which is the Selective Laser Melting (SLM) 3D Printing machine using stainless steel powder as the main material. As a result, a sturdy and lightweight drone frame was successfully fabricated by combining innovative design strategies with advanced manufacturing techniques. The feasibility of generating sufficient thrust from the selected brushless motors to lift the frame was also evaluated. This research offers a practical solution to the challenges of weight, strength, and complexity in drone frame construction.

**PEMBANGUNAN RANGKA KERJA UNTUK KERANGKA PESAWAT UDARA
TANPA PEMANDU (UAV) RINGAN DIBINA DENGAN PENCETAK 3D
PELEBURAN LASER TERPILIH**

ABSTRAK

Pelaksanaan tugas berat yang cekap oleh dron memerlukan rangka teguh yang mampu mengangkat objek berat dari kedudukan yang stabil dan tinggi. Walau bagaimanapun, bahan pepejal tradisional menyumbang kepada berat berlebihan dan mempercepatkan kemerosotan bateri. Selain itu, reka bentuk yang kompleks menimbulkan cabaran untuk kaedah pemesinan konvensional. Oleh itu, kajian ini bertujuan untuk mereka bentuk rangka dron yang ringan dan kukuh menggunakan keluli tahan karat melalui reka bentuk generatif. Kekuatan dan kestabilan dinilai melalui simulasi dan eksperimen. Penyelesaian yang dicadangkan adalah pembuatan bahan tambahan, khususnya pencetakan 3D Peleburan Laser Terpilih (SLM), dengan menggunakan serbuk keluli tahan karat. Untuk merekabentuk bingkai dron yang sesuai untuk keperluan diatas, terlebih dahulu perlu mengkaji kelakuan mesin dan sifat mekanikal bahan tersebut. Untuk memahami keupayaan mesin, eksperimen yang diputuskan ialah ujian kekasaran permukaan dengan melakukan eksperimen dengan mempelbagaikan orientasi cetakan untuk setiap spesimen. Spesimen dicetak menggunakan tiga jenis parameter: kesan luas permukaan, kesan ketinggian, dan kesan sudut cetakan. Kemudian, spesimen menjalani ujian kekasaran permukaan untuk menentukan orientasi pencetakan yang terbaik untuk menghasilkan bingkai dron. Bagi sifat mekanikal bahan yang dicadangkan, eksperimen yang telah dilaksanakan ialah ujian hentaman dan ujian tegangan. Spesimen dilukis terlebih dahulu menggunakan Autodesk Fusion 360, dipandukan oleh American Society for Testing and Materials (ASTM), dan direka menggunakan mesin pencetak 3D Peleburan Laser Terpilih (SLM). Parameter untuk eksperimen ini ialah keadaan bahan serbuk keluli tahan karat (serbuk dara dan serbuk kitar semula), ketebalan spesimen, dan penyelarasan spesimen pada tapak pembinaan. Selepas selesai semua eksperimen fizikal, proses diteruskan ke eksperimen simulasi. Langkah pertama ialah dengan melakarkan lima reka bentuk bingkai dron. Reka bentuk yang dilakar akan dilukis menggunakan Autodesk Fusion 360 dan menjalani proses Reka Bentuk Generatif. Selepas proses itu, proses simulasi menggunakan kajian Tekanan Statik dalam Finite Element Analysis (FEA) dalam perisian Autodesk Fusion 360 untuk memilih hasil reka bentuk bingkai dron yang terbaik lalu meneruskan proses pembuatan. Reka bentuk terbaik yang dipilih daripada ujian simulasi FEA dihasilkan menggunakan kaedah Pembuatan Aditif iaitu mesin Pencetakan 3D Peleburan Laser Terpilih (SLM) dengan menggunakan serbuk keluli tahan karat (dara) sebagai bahan utama. Hasilnya, bingkai dron yang kukuh dan ringan berjaya direka dengan menggabungkan strategi reka bentuk yang inovatif dengan teknik pembuatan termaju. Kebolehlaksanaan menjana tujahan yang mencukupi daripada motor untuk mengangkat bingkai juga dinilai. Penyelidikan ini menawarkan penyelesaian praktikal kepada cabaran berat, kekuatan dan kerumitan dalam pembinaan rangka dron.

ACKNOWLEDGEMENTS

In the Name of Allah, the Most Gracious, the Most Merciful

First and foremost, I want to express my gratitude and thanks to Allah the Almighty, my Creator and Sustainer, for everything that I have received from the beginning of my existence. I'd like to express my gratitude to Universiti Teknikal Malaysia Melaka (UTeM) and Grant no: PJP/2022/FTKMP/S01890 for providing the research environment as well as funding to succeed this project.

Dr. Mohd Taufik Bin Taib, Faculty of Mechanical Technology and Engineering, Universiti Teknikal Malaysia Melaka (UTeM), is my main supervisor, and I am grateful for all of his help, guidance, and inspiration. His unwavering patience in mentoring and offering invaluable insights will be remembered for the rest of my life. Also, thank you to Prof. Madya IR Dr. Mohd Hadzley Bin Abu Bakar, my Co-Supervisor at Universiti Teknikal Malaysia Melaka (UTeM), for his unwavering support throughout my journey.

Last but not least, I want to express my heartfelt appreciation to both of my loving parents, Abu Zaki Bin Romli and Che Liah Binti Ahmad, for their support and encouragement throughout my life. For their tolerance and understanding, I extend my eternal love to Muhammad Aidil Zuhri Bin Abu Zaki, Muhammad Anas Munawwar Bin Abu Zaki, and Nur Sofea Idzlyani Binti Abu Zaki. I'd want to express my gratitude to my family and closest relatives for their unwavering support, love, and prayers. Finally, I'd want to express my gratitude to everyone who has helped, supported, and inspired me to pursue my studies.

TABLE OF CONTENTS

	PAGE
DECLARATION	
APPROVAL	
DEDICATION	
ABSTRACT	i
ABSTRAK	ii
ACKNOWLEDGEMENTS	iii
TABLE OF CONTENTS	iv
LIST OF TABLES	vii
LIST OF FIGURES	xiv
LIST OF APPENDICES	xxiii
LIST OF EQUATIONS	xxiv
LIST OF ABBREVIATIONS	xxv
LIST OF SYMBOLS	xxvii
LIST OF PUBLICATIONS	xxix
CHAPTER 1 INTRODUCTION	1
1.1 Background of study	1
1.1.1 Drone Frame	1
1.1.2 Motor	2
1.1.3 Propellers	3
1.1.4 Electronic Speed Controller	4
1.1.5 Flight Controller Board	4
1.1.6 Battery	5
1.2 Problem Statement	7
1.3 Objective	8
1.4 Scope of Research	9
CHAPTER 2 LITERATURE REVIEW	10
2.1 Introduction	10
2.2 Types of Drone	12
2.2.1 Monocopter Drone	13

2.2.2	Bicopter Drone	14
2.2.3	Tricopter Drone	15
2.2.4	Quadcopter Drone	16
2.2.5	Hexacopter Drone	17
2.2.6	Octocopter Drone	18
2.3	Metallic Drone Frame	19
2.3.1	Conventional Drone Frame Design	19
2.3.2	Modern Drone Frame Design	22
2.3.3	Advantages and Disadvantages of Metallic Drone Frame	26
2.4	Comparison of the Drone	28
2.5	Additive Manufacturing Method	32
2.6	Types of Additive Manufacturing Methods	37
2.6.1	Fused Deposition Modelling (FDM)	38
2.6.2	Selective Laser Sintering (SLS)	39
2.6.3	Digital Light Processing (DLP)	41
2.6.4	Binder Jetting	42
2.6.5	Drop of Demand (DOD)	43
2.6.6	Selective Laser Melting (SLM)	44
2.6.7	Electron Beam Melting (EBM)	45
2.7	Comparison of Additive Manufacturing method	47
2.8	Previous research	50
2.9	Summary	62
CHAPTER 3	METHODOLOGY	66
3.1	Introduction	66
3.2	Research Flowchart	68
3.3	Morphological Chart	70
3.4	Manufacturing Design Aid Blueprint	73
3.4.1	Design 1	73
3.4.2	Design 2	74
3.4.3	Design 3	75
3.4.4	Design 4	76
3.4.5	Design 5	77
3.4.6	Selected Drone Components	78
3.5	Drawing Process in Autodesk Fusion 360	80
3.6	Physical Experiment	86
3.6.1	Machine Capability Test	87
3.6.2	Material Properties Test	97
3.7	Simulation Experiment	111
3.7.1	Load Distribution	112
3.7.2	Generative Design and Finite Element Analysis (FEA)	124
3.8	Manufacturing Process	136
3.9	Bill of the Materials/Components	151
CHAPTER 4	RESULTS AND DISCUSSION	158
4.1	Introduction	158

4.2	The Orthographic Drawing of the Drone Frame	160
4.2.1	The Orthographic Drawing of the Original Design 1	161
4.2.2	The Orthographic Drawing of the Original Design 2	162
4.2.3	The Orthographic Drawing of the Original Design 3	163
4.2.4	The Orthographic Drawing of the Original Design 4	164
4.2.5	The Orthographic Drawing of the Original Design 5	165
4.3	Physical Experiment Results	166
4.3.1	Surface Roughness Test Result	166
4.3.2	Impact Strength Experiment Results	185
4.3.3	Tensile Strength Experiment Results	196
4.3.4	Summary of Physical Experiment	204
4.4	Simulation Experiment Result	206
4.4.1	Material Properties Parameters	206
4.4.2	Load Distribution	211
4.4.3	Generative Design Results	229
4.4.4	The Technical Drawing of the Drone Frame	254
4.4.5	The Finite Element Analysis (FEA) Simulation Results	260
4.4.6	Summary of Simulation Experiment	274
4.5	Manufacturing Process	276
4.5.1	Pre-Printing Process	276
4.5.2	Printing Process	278
4.5.3	Post-Printing Process	279
4.5.4	Assembly Process	283
4.5.5	Summary of Manufacturing Process	285
CHAPTER 5	CONCLUSION AND RECOMMENDATIONS	292
5.1	Conclusion	293
5.2	Recommendation	296
REFERENCES		298
APPENDICES		306

LIST OF TABLES

TABLE	TITLE	PAGE
Table 2.1:	The comparison between the advantages and disadvantages of using a metal drone frame based on (Arief, Wicaksono and Yarman, 2022), (Obli, 2020b), (Ehsanul, Daud and Ammoo, 2018), and (Herrero, 2016) studies.	26
Table 2.2:	The comparison of 6 types of drones' inner and outer characteristics based on (Basit <i>et al.</i> , 2021), (Caprace <i>et al.</i> , 2022), (Swapnil Yemle, Yogeshwar Durgude, Ganesh Kondhalkar, 2019), (Houghton and Hoburg, 2008), (Taherinezhad, Ramirez-Serrano and Abedini, 2022), (M Bharadwaj, 2015), (Saric, Masic and Delic, 2021), and (Oscarson, 2015).	28
Table 2.3:	The descriptions of the 7 categories of an additive manufacturing method by (Nakano, 2021).	33
Table 2.4:	Differentiation of the 7 types of additive manufacturing methods from a variety of aspects by (Wu <i>et al.</i> , 2023) and (Daminabo <i>et al.</i> , 2020).	47
Table 2.5:	The production of drone components using the AM method was studied.	51
Table 2.6:	The studies of additive manufacturing methods in all types of industry by other researchers.	54
Table 2.7:	The study of drone manufacturing and its application related to a project assignment by another researcher.	59
Table 3.1:	The morphological chart of the drone frame components.	70
Table 3.2:	The description of the selected components of the drone frame.	78

Table 3.3: The procedure of the drawing process of the drone frame components in the Autodesk Fusion 360.	81
Table 3.4: The dimensions of EOSA specimens.	88
Table 3.5: The dimensions of EOH specimens.	89
Table 3.6: The dimensions of EOAP specimens.	90
Table 3.7: The parameters of the SLM 3d printing machine when fabricating the specimens of surface roughness experiment.	91
Table 3.8: The procedure of surface roughness experiment using the 3D Non-Contact Profilometer and measuring software.	94
Table 3.9: The coordinates of the impact strength specimens on the production bed.	100
Table 3.10: The parameters of the SLM 3d printing machine when fabricating the specimens for the impact strength experiment.	101
Table 3.11: The procedure of impact strength experiments using an Impact Testing Machine and the measuring software.	102
Table 3.12: The details of the dimensions of the specimen for the tensile strength experiment.	105
Table 3.13: The parameters of the SLM 3d printing machine when fabricating the specimens for the tensile strength experiment.	108
Table 3.14: The procedure of tensile strength experiments using a Tensile Testing Machine and the measuring software.	109
Table 3.15: The load distribution parameters on the Design 1 drone frame.	114
Table 3.16: The load distribution parameters on the Design 2 drone frame.	116
Table 3.17: The load distribution parameters on the Design 3 drone frame.	118

Table 3.18: The load distribution parameters on the Design 4 drone frame.	120
Table 3.19: The load distribution parameters on the Design 5 drone frame.	122
Table 3.20: The working procedure of the Generative Design application in the Autodesk Fusion 360.	124
Table 3.21: The procedures of how to assemble the drone components after the generative design process in Autodesk Fusion 360.	128
Table 3.22: The working procedure of the Finite Element Analysis (FEA) simulation in the Autodesk Fusion 360.	132
Table 3.23: The default printing parameters are used when manufacturing the drone frame.	138
Table 3.24: The procedure for using the Materialise Magics 3D printing software.	140
Table 3.25: The procedure of the Pre-Printing process when printing the drone frame components.	142
Table 3.26: The procedure of the Printing process when printing the drone frame components.	145
Table 3.27: The procedure of the Post-Printing process when printing the drone frame components.	148
Table 3.28: The bill of materials/components that assist in completing this research project.	151
Table 4.1: The surface topography of the EOSA parameter specimens in a 3D view.	167
Table 4.2: The surface roughness data, Ra of the EOSA parameter specimens.	169
Table 4.3: The average surface roughness results, Ra of the EOSA's specimens.	171
Table 4.4: The surface topography of the EOH parameter specimens in a 3D view.	173

Table 4.5: The surface roughness data, Ra of the EOH parameter specimens.	175
Table 4.6: The average surface roughness results, Ra of the EOH's specimens.	177
Table 4.7: The surface topography of the EOAP parameter specimens in a 3D view.	179
Table 4.8: The surface roughness data, Ra of the EOAP parameter specimens.	181
Table 4.9: The average surface roughness results, Ra of the EOAP's specimens.	183
Table 4.10: The parameters that were used to execute the impact strength experiment.	185
Table 4.11: The results of the impact strength experiment on the (5 mm and 10 mm width) Virgin powder specimens.	187
Table 4.12: The results of the impact strength experiment on the (5 mm and 10 mm width) Recycled powder specimens.	189
Table 4.13: The parameters that were used to execute the tensile strength experiment.	196
Table 4.14: The results of the tensile strength experiment on the (virgin/recycled) powder specimens.	197
Table 4.15: The variables that were used to calculate the material properties of the (Virgin) stainless steel powder.	206
Table 4.16: The material properties parameters of the stainless steel powder used on the drone frame for the Generative Design application and Finite Element Analysis (FEA) simulation.	208
Table 4.17: The details of the load distribution that was applied to the drone frame components in Design 1, Design 2, and Design 5.	212
Table 4.18: The details of the load distribution that was applied to the drone frame components in Design 3 and Design 4.	213

Table 4.19: The variables that were used to calculate the load distribution on the Design 1 drone frame components.	214
Table 4.20: The variables that were used to calculate the load distribution on the Design 2 drone frame components.	217
Table 4.21: The variables that were used to calculate the load distribution on the Design 3 drone frame components.	220
Table 4.22: The variables that were used to calculate the load distribution on the Design 4 drone frame components.	223
Table 4.23: The variables that were used to calculate the load distribution on the Design 5 drone frame components.	226
Table 4.24: The comparison of Outcome 1 and Outcome 2 based on the characteristics generated by the generative design application software for Drone Base 1.	231
Table 4.25: The comparison of Outcome 1 and Outcome 2 based on the characteristics generated by the generative design application software for Drone Base 2.	234
Table 4.26: The comparison of Outcome 1 and Outcome 2 based on the characteristics generated by the generative design application software for Drone Base 3.	237
Table 4.27: The comparison of Outcome 1 and Outcome 2 based on the characteristics generated by the generative design application software for Drone Arm 1.	240

Table 4.28: The comparison of Outcome 1 and Outcome 2 based on the characteristics generated by the generative design application software for Drone Arm 2.	243
Table 4.29: The comparison of Outcome 1 and Outcome 2 based on the characteristics generated by the generative design application software for Drone Arm 3.	246
Table 4.30: The comparison of Outcome 1 and Outcome 2 based on the characteristics generated by the generative design application software for Drone Arm 4.	249
Table 4.31: The comparison of Outcome 1 and Outcome 2 based on the characteristics generated by the generative design application software for Drone Arm 5.	252
Table 4.32: The finite element analysis (FEA) results of the Design 1 drone frame.	261
Table 4.33: The finite element analysis (FEA) results of the Design 2 drone frame.	263
Table 4.34: The finite element analysis (FEA) results of the Design 3 drone frame.	265
Table 4.35: The finite element analysis (FEA) results of the Design 4 drone frame.	267
Table 4.36: The finite element analysis (FEA) results of the Design 5 drone frame.	269
Table 4.37: The comparison of the FEA analysis result of all of the Drone frame results.	273
Table 4.38: The procedure of the assembly process of the selected drone frame with details	283
Table 4.39: The weight (kg) of the Design 1 drone components before and after the Generative Design process.	286

Table 4.40: The variables that were used to assist in the calculation of the ratio of

Total Maximum thrust power and Total Net Weight of the drone

288



LIST OF FIGURES

FIGURE	TITLE	PAGE
Figure 1.1:	The Quadcopter Drone Frame.	2
Figure 1.2:	The brushless motor for the drone.	3
Figure 1.3:	The variety of drone propellers.	3
Figure 1.4:	The Electronic Speed Controller (ESC) for the drone.	4
Figure 1.5:	The regular type of flight controller board for a drone.	5
Figure 1.6:	The 1000 mAH plus 6S 22.2V 25C Lithium Battery for heavy load drone.	6
Figure 2.1:	The military drone is known as an Unmanned Combat Aerial Vehicle (UCAV).	11
Figure 2.2:	The suggested method of forest firefighting system using drones.	12
Figure 2.3:	The modern monocopter drone and the working principle of the monocopter drone.	13
Figure 2.4:	The bicopter drone and the working principle of the bicopter drone.	14
Figure 2.5:	The tricopter drone and the working principle of the tricopter drone.	15
Figure 2.6:	The quadcopter drone and the working principle of the quadcopter drone.	16
Figure 2.7:	The hexacopter drone and the working principle of the hexacopter drone.	17
Figure 2.8:	The octocopter drone and the working principle of the octocopter drone.	18
Figure 2.9:	The isometric view design of the aluminium drone frame by (Arief, Wicaksono and Yarman, 2022).	20
Figure 2.10:	The Force (F) point at the metal drone arm by (Arief, Wicaksono and Yarman, 2022).	21

Figure 2.11: The drone frame results by (Arief, Wicaksono and Yarman, 2022).	22
Figure 2.12: The generative design application on the metal drone frame by (Obli, 2020b).	23
Figure 2.13: The selected design of the metal drone frame by (Obli, 2020b).	23
Figure 2.14: The manufacturing process of the drone frame using metal filament by (Obli, 2020b).	24
Figure 2.15: Comparison result of drone frame design by using the Generative Design application by (Obli, 2020b).	25
Figure 2.16: The working process of making remote housing by (Bazli <i>et al.</i> , 2023).	35
Figure 2.17: The manufacturing of biodegradable and non-biodegradable implants that were executed using the additive manufacturing method by (Zhang, Hu and Wang, 2020).	36
Figure 2.18: The chart of the 3D printing method and its machine name.	37
Figure 2.19: The working principle of the Fused Deposition Method (FDM) from (Parupelli and Desai, 2019).	39
Figure 2.20: The working principle of the Selective Laser Sintering (SLS) machine by (Parupelli and Desai, 2019).	40
Figure 2.21: The working principle of the digital light processing (DLP) machine and their application by (Zhang, Hu and Wang, 2020).	41
Figure 2.22: The working principle of the binder jetting machine from (Parupelli and Desai, 2019).	43
Figure 2.23: The working principle of the drop of demand machine by (Parupelli and Desai, 2019).	44

Figure 2.24: The working principle of the Selective Laser Melting (SLM) machine by (Nakano, 2021).	45
Figure 2.25: The working principle of the Electron Beam Melting (EBM) machine by (Walton and Moztarzadeh, 2017).	46
Figure 2.26: The working concept of the topology optimization method by (Walton and Moztarzadeh, 2017).	64
Figure 3.1: The flowchart of this project.	69
Figure 3.2: The sketching of the assembly parts of Design 1.	73
Figure 3.3: The sketching of the assembly parts of Design 2.	74
Figure 3.4: The sketching of the assembly parts of Design 3.	75
Figure 3.5: The sketching of the assembly parts of Design 4.	76
Figure 3.6: The sketching of assembly parts of Design 5.	77
Figure 3.7: The range of the production bed of the SLM 3D printing machine inside the Materialize Magic Software.	81
Figure 3.8: The specimens for the EOSA parameter.	88
Figure 3.9: The specimens for the EOH parameter.	89
Figure 3.10: The specimens for the EOAP parameter.	90
Figure 3.11: The 3D Non-Contact Profilometer.	92
Figure 3.12: The coordinate of the scanning area of EOSA specimens	93
Figure 3.13: The coordinate of the scanning area of EOH specimens.	93
Figure 3.14: The coordinate of the scanning area of EOAP specimens.	94
Figure 3.15: The dimensions of the 5 mm specimens impact strength experiment.	98
Figure 3.16: The dimensions of the 10 mm specimens impact strength experiment.	99

Figure 3.17: The coordinates of the specimens on the production bed in Materialize Magic software.	99
Figure 3.18: The Model JBW-500 Computer Pendulum Impact Testing Machine and the Impact Testing Machine Professional Measurement and Control software ver 3.0.	101
Figure 3.19: The dimensions of the specimens according to ASTM E8/E8M.	105
Figure 3.20: The coordinates of the specimens on the production bed in Materialize Magic software.	107
Figure 3.21: The SHIMADZU Universal Testing machine and SHIMADZU Trapezium X version 1.4.2 software as the measuring software.	108
Figure 3.22: The illustration diagram of Newton's Second Law and Total Moment.	112
Figure 3.23: The distribution force on the Design 1 drone frame.	114
Figure 3.24: The distribution force on the Design 2 drone frame.	116
Figure 3.25: The distribution force on the Design 3 drone frame.	118
Figure 3.26: The distribution force on the Design 4 drone frame.	120
Figure 3.27: The distribution force on the Design 5 drone frame.	122
Figure 3.28: The Materialise Magics 3D printing software.	136
Figure 3.29: The Envision 120 SLM 3D printing machine (left) and the 10 kg container of the Spherical Ermak S-316 L-A11 stainless steel powder (right).	137
Figure 4.1: The flowchart of the working process in Chapter 4.	159
Figure 4.2: The orthographic drawing of the Design 1 drone frame original design in 1:1 scale.	161

Figure 4.3: The orthographic drawing of the Design 2 drone frame original design in 1:1 scale.	162
Figure 4.4: The orthographic drawing of the Design 3 drone frame original design in 1:1 scale.	163
Figure 4.5: The orthographic drawing of the Design 4 drone frame original design in 1:1 scale.	164
Figure 4.6: The orthographic drawing of the Design 5 drone frame original design in 1:1 scale.	165
Figure 4.7: The scanning area of the 3D Non-Contact Profilometer on the EOSA, EOH, and EOAP specimens.	166
Figure 4.8: The graphic view of the surface roughness data, Ra of the EOSA parameter specimens.	170
Figure 4.9: The graphic view of the average surface roughness data, Ra of the EOSA parameter specimens.	170
Figure 4.10: The graphic view of the surface roughness data, Ra of the EOH parameter specimens.	176
Figure 4.11: The graphic view of the average surface roughness data, Ra of the EOH parameter specimens.	176
Figure 4.12: The graphic view of the surface roughness data, Ra of the EOAP parameter specimens.	182
Figure 4.13: The graphic view of the average surface roughness data, Ra of the EOAP parameter specimens.	182