

DESIGN FOR ADDITIVE MANUFACTURING USING
TRIZ-AM PRINCIPLES IN SUPPORTING PRODUCT DESIGN AND
DEVELOPMENT

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DEDICATION

This thesis is dedicated to my father, Haji Mazlan bin Hussin, who taught me that the best kind of knowledge to have is that which is learned for its own sake. It is also dedicated to my mother, Hajah Siti Khadijah binti Mohammad, who taught me that even the largest task can be accomplished if it is done one step at a time. Not to forget, my husband, Ahmad Hariz bin Mustaffa and my sister, Siti Nur Farhana binti Mazlan for the continues support in terms of moral and also financial. I thank God every day for His blessing and helps from the beginning of my study until the ends. Thank you for the endless support and endless love you give to me. I am promised to give the best that I can and provide all of you with the never-ending happiness and love. Love all of you guys so much.

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ABSTRACT

Design for additive manufacturing (DFAM) can be categorized into design and manufacturing decisions to support designers in utilizing additive manufacturing (AM) capabilities such as design freedom and complex geometry. The idea of DFAM is similar to the goals of TRIZ (Theory of inventive problem solving), where it provides tools for innovative and creative solutions to address design problems during product design and development (PDD). Past researches in connecting TRIZ and AM indicated that it can be realistically used in assisting DFAM. However, it was found that the existing 40-innovative principles (40IPs) of TRIZ could not solely provide inclusive solutions to be applied to all AM technologies and terminologies. Moreover, the usage of TRIZ 40IPs in AM is highly dependent on the available AM examples which are subjective to researchers' problem-solving viewpoints and does not cover new innovative principles represented by AM design knowledge. Therefore, this study aimed to develop a DFAM procedure integrated with TRIZ-AM by enhancing the definition of classical TRIZ inventive principles according to AM applicability and suitable AM scenario. The 40 IPs were revised according to the classifications of design heuristics, principles, and guidelines applicable to AM. TRIZ-AM cards were developed to assist designers with infographic design knowledge. In addition, a manufacturability analysis of AM-printed parts was performed for the material extrusion process using composite materials. Experimental work was conducted using carbon fiber- polylactide acid (PLA) and Wood-PLA filaments involving seven types of basic structures, and four types of lattice structures. All of the printed parts were then inspected, measured, and compared with Virgin PLA. The outcomes were based on the data obtain from computer aided design (CAD) and printed part with regard to the development of design rules. To demonstrate its applicability, a new mobile application for composite design rules (CDRs) applications was developed. Fourteen outcomes of case studies were produced, including the design modification and improvement of consumer products. Designers from various industrial backgrounds were involved to perform the design task according to the specific DFAM requirements. Resultantly, the dimensional accuracy of basic structures produced was approximately 80% to 90% closer to CAD data when compared with Virgin PLA. The strut lattice size of more than 2.00 mm produced a higher fabrication rate compared to the smaller strut lattice (< 2.00 mm). The designer also managed to improve the design up to 89% of part reductions and 50% of material reduction compared to the existing product design when using the TRIZ-AM approach. The CDRs applications were validated with capabilities such as design feature guide, size checking, either pass and fail outcomes. The case study reveals that TRIZ-AM method is beneficial in producing concept generation in early phases of PDD. In conclusion, the proposed method simplifies the design process in terms of build time, materials, weight, and prevents repetitive design iteration. It can also be useful to promote AM capabilities to amateur and professional designers based on TRIZ-AM design practice.

ABSTRAK

Rekabentuk untuk pembuatan tambahan (DFAM) boleh dikategorikan kepada reka bentuk dan keputusan pembuatan untuk membantu pereka menggunakan keupayaan pembuatan tambahan (AM) seperti kebebasan merekabentuk produk dan penghasilan geometri yang kompleks. Idea DFAM dan TRIZ (Teori penyelesaian masalah inventif) serupa iaitu menyediakan alat penyelesaian masalah secara inovatif dan kreatif semasa reka bentuk dan pembangunan produk (PDD). Penyelidikan lepas ke atas TRIZ dan AM menunjukkan bahawa ianya boleh digunakan secara realistik dalam membantu DFAM. Walau bagaimanapun, 40 prinsip inovatif (40IPs) TRIZ yang sedia ada tidak dapat menyediakan penyelesaian secara inklusif untuk digunakan pada semua teknologi dan istilah AM. Selain itu, penggunaan TRIZ 40IPs dalam AM hanyalah berpandukan kepada contoh AM sedia ada yang hanya subjektif kepada sudut pandangan penyelidik dan tidak meliputi prinsip inovatif baharu yang mewakili pengetahuan reka bentuk AM itu sendiri. Oleh itu, kajian ini bertujuan untuk membangunkan prosedur DFAM yang disepadukan bersama TRIZ-AM dengan mengolah definisi prinsip inventif TRIZ klasik mengikut kebolehpayaan dan senario AM yang sesuai. 40IPs disesuaikan dengan klasifikasi reka bentuk heuristik, prinsip, dan panduan untuk AM. Kad TRIZ-AM telah dibangunkan melalui pengetahuan reka bentuk infografik. Kerja eksperimental dilakukan menggunakan bahan daripada serat karbon- asid polilaktik (PLA) dan Kayu-PLA, melibatkan tujuh struktur asas, serta empat jenis kekisi. Semua bahagian yang telah difabrikasi kemudiannya diperiksa dan diukur melalui perbandingan antara nilai reka bentuk terbantu komputer (CAD) dan nilai dari komponen bercetak. Bagi menunjukkan kebolehpayaannya, satu aplikasi mudah alih iaitu aturan reka bentuk komposit (CDRs) telah dibangunkan. Empat belas hasil kajian kes telah dibuat, termasuk pengubahsuaian dan penambahbaikan rekabentuk produk pengguna termasuk pereka industri dari pelbagai latar belakang terlibat dalam tugas rekabentuk menurut keperluan spesifik DFAM. Beberapa jenis struktur asas menunjukkan ketepatan di antara 80% hingga 90% lebih hampir dengan nilai CAD jika dibandingkan dengan PLA asli. Manakala, untuk kekisi yang lebih dari 2.00 mm, keputusan menunjukkan kadar fabrikasi yang lebih tinggi berbanding kekisi yang lebih kecil (< 2.00 mm). Pereka juga berjaya meningkatkan keupayaan reka bentuk produk sehingga 89% dari segi pengurangan bahagian komponen dan 50% bagi pengurangan penggunaan bahan berbanding reka bentuk produk yang sedia ada menggunakan TRIZ-AM. Aplikasi CDRs telah dibangunkan dengan keupayaan yang terdiri daripada panduan ciri reka bentuk, semakan saiz, serta informasi mengenai ciri rekabentuk samada lulus atau gagal untuk difabrikasi. Kajian kes telah membuktikan bahawa kaedah TRIZ-AM bermanfaat dalam menghasilkan konsep pada fasa awal PDD. Kesimpulannya, kaedah yang dicadangkan memudahkan proses reka bentuk dari segi masa pembangunan produk, bahan, berat, dan mengelakkan reka bentuk berulang. Ia juga membantu dalam mempromosikan keupayaan AM kepada pereka amatir serta pereka profesional berdasarkan amalan reka bentuk TRIZ-AM.

TABLE OF CONTENTS

	TITLE	PAGE
	DECLARATION	ii
	DEDICATION	iii
	ACKNOWLEDGEMENT	iv
	ABSTRACT	v
	ABSTRAK	vi
	TABLE OF CONTENTS	vii
	LIST OF TABLES	xiii
	LIST OF FIGURES	xvi
	LIST OF ABBREVIATIONS	xxiii
	LIST OF SYMBOLS	xxiv
	LIST OF APPENDICES	xxv
CHAPTER 1	INTRODUCTION	1
1.1	Design for Additive Manufacturing (DFAM)	2
1.2	TRIZ Evolution: Current Status and Issues of Concern	5
1.3	Problem Statement	6
1.4	Significance of the Study	8
1.5	Research Questions	9
1.6	Research Objectives	9
1.7	Research Scopes	10
1.8	Thesis Outline	11
CHAPTER 2	LITERATURE REVIEW	13
2.1	Overview of the Literature Review	13
2.2	Overview of Additive Manufacturing Technologies	15
2.3	Design for Additive Manufacturing (DFAM)	17
2.3.1	Design Knowledge in DFAM	19
2.3.1.1	Design Heuristics	21

2.3.1.2	Design Principles	23
2.3.1.3	Design Guidelines	25
2.3.1.4	Design Rules	26
2.3.2	Development of DFAM Approaches	29
2.3.2.1	Creativity Enhancement Approach	31
2.3.2.2	Design Ideation Approach	33
2.4	Theory of Inventive Principle (TRIZ)	37
2.4.1	Classical TRIZ	37
2.4.2	Integration of TRIZ and DFAM	40
2.5	DFAM Development: Literature Findings	47
2.6	Benchmarking Artefacts and AM Design Feature	51
2.6.1	AM Basic Design Feature	57
2.6.2	AM Lattice Design Feature	58
2.6.2.1	Strut Lattice Design	59
2.6.2.2	AM Lattice Printing	62
2.7	Materials in Additive Manufacturing	65
2.7.1	Polymer-Based Materials	65
2.7.2	Composite Materials in AM	66
2.7.2.1	Carbon Fibre Reinforced Polymer (CFRP)	68
2.7.2.2	Natural-based Composite	70
2.7.2.3	Summary of AM Material Studies	71
2.8	Evaluation of AM Printed Part Quality	74
2.8.1	Process Parameter Optimisation	75
2.9	Summary of the Literature Review	82
CHAPTER 3	RESEARCH METHODOLOGY	85
3.1	Overview of the Methodology	85
3.2	Development of DFAM Procedure	87
3.2.1	DFAM Structure Inspired by ASTM/ISO 52910	87
3.2.2	TRIZ-AM Integration Method	90
3.2.3	Development of TRIZ-AM Cards	102

3.2.4	Verification and Validation Procedure for TRIZ-AM Method	103
3.3	Manufacturability Analysis Methodology	107
3.3.1	AM 3D CAD Feature Development	108
3.3.1.1	Thin Wall	108
3.3.1.2	Slots	109
3.3.1.3	Small Hole Diameter	110
3.3.1.4	Maximum Hole Diameter	111
3.3.1.5	Overhang Length	112
3.3.1.6	Overhang Angles	113
3.3.1.7	Bridges	114
3.3.1.8	Square Strut Lattice	116
3.3.1.9	Circle Strut Lattice	117
3.3.1.10	Triangle Struts Lattice	118
3.3.1.11	Octagon Strut	119
3.3.2	Pass-Fail Criteria	120
3.3.3	Parameter Settings Using Taguchi Analysis	127
3.3.3.1	Model Development for Taguchi	127
3.3.3.2	Parameter Input and Log of Experiments	128
3.3.3.3	Signal-to-noise ratio, and ANOVA (Kruskal–Wallis Test)	130
3.4	Fabrication Setup	131
3.4.1	General Fabrication Steps	132
3.4.2	AM Facilities Specifications	133
3.4.3	Composite Material Properties	134
3.5	Part Quality Evaluation Method	135
3.5.1	Dimensional Accuracy	136
3.6	Composite Design Rules (CDRs) Development	137
3.6.1	CDRs Flash Card Development	137
3.6.2	Mobile Applications Development	138
3.6.3	Demonstration and Verification of CDRs	144

3.7	Summary of Methodology	145
CHAPTER 4	DFAM WITH TRIZ INVENTIVE PRINCIPLES	147
4.1	Overview of DFAM with TRIZ Architecture	147
4.2	DFWT Components and Descriptions	150
4.2.1	Stage 1- Design Requirements	150
4.2.2	Stage II- Conceptual Design	151
4.2.2.1	TRIZ-AM Inventive Principle Method	156
4.2.3	Stage III - Embodiment Design & Detailed Design	167
4.2.4	Stage IV- Manufacturing and Finishing	169
4.3	Summary of DFAM with TRIZ Inventive Principles	171
CHAPTER 5	IMPLEMENTATION OF TRIZ-AM METHOD IN CONCEPTUAL DESIGN	173
5.1	Overview	173
5.2	TRIZ-AM Cards	174
5.3	<i>Case Study A: Part Consolidation with TRIZ</i>	175
5.4	Hanging Shelf with Roller	175
5.4.1	Experienced Designer with Basic AM knowledge	176
5.4.2	Novice Designer with Intermediate AM Knowledge	179
5.5	PCB Casing	182
5.5.1	Experienced Designer with Expert AM Knowledge	183
5.5.2	Novice Designers with Intermediate AM Knowledge	185
5.6	Belt Roller Support	188
5.6.1	Experienced Designer with Expert AM Knowledge	188
5.6.2	Novice with Intermediate AM Knowledge	191
5.7	<i>Case Study B: Creativity Enhancement (CE) with TRIZ-AM Cards</i>	195
5.7.1	Concept 1- Jewelry Box	196

5.7.2	Concept 2- Safety Box	198
5.7.3	Concept 3- LEGO Box	199
5.7.4	Concept 4- Honeycomb Space	201
5.7.5	Concept 5- Stacking Drawer Box	202
5.8	Analysis of <i>Case Study A</i> and <i>Case Study B</i>	203
5.9	Discussions	208
CHAPTER 6	IMPLEMENTATION OF COMPOSITE DESIGN RULE IN DETAILED DESIGN	213
6.1	Overview	213
6.2	Results and Discussion on Parameter Optimization Using Taguchi	214
6.2.1	Signal to Noise Ratio (S/N Ratio)	215
6.2.2	Results of ANOVA Analysis : Kruskal-Wallis Test	221
6.3	Results and Discussion of AM-Feature Fabrications	223
6.3.1	Thin-walled Feature	223
6.3.2	Slots Feature	228
6.3.3	Small Hole Diameter Feature	231
6.3.4	Maximum Hole Diameter	235
6.3.5	Overhang Features	239
6.3.5.1	Overhang Length	240
6.3.5.2	Overhang Angles	243
6.3.5.3	Bridges Feature	245
6.3.6	Strut Lattice Feature Design	248
6.3.6.1	Square Struts	248
6.3.6.2	Circle Struts	250
6.3.6.3	Triangle Struts	252
6.3.6.4	Octagon Struts	254
6.4	Composite Design Rules (CDRs) for Material Extrusion Technique	255
6.4.1	Mobile Applications for CDRs Implementation	258
6.4.2	Case Study C: Innovative Design	259

6.5	Phone Holder Concept	260
	6.5.1 Validation of CDRs Applicability in 3D Model	265
	6.5.2 Discussion of Fabricated Phone Holder	266
6.6	Summary	268
CHAPTER 7	CONCLUSIONS AND FUTURE WORKS	269
7.1	Conclusions	269
7.2	Academic Contributions	273
7.3	Recommendation for Future Works	276
	REFERENCES	279
	APPENDICES	301
	LIST OF PUBLICATIONS	347

LIST OF TABLES

TABLE NO.	TITLE	PAGE
Table 2.1	DFAM design typologies	21
Table 2.2	Other examples of DFAM approaches in product design phases	36
Table 2.3	Summary of integration studies between TRIZ-DFAM	46
Table 2.4	Summary of benchmarking designs	54
Table 2.5	Examples of AM basic design features extracted from literature (Mani et al., 2017; Deja et al., 2018; Beniak et al., 2019; Knoop and Schoeppner, 2020)	57
Table 2.6	Summary of related studies of AM material between 2014 and 2020	73
Table 2.7	Average parameter inputs for AM process	81
Table 3.1	Examples of variation keywords and synonyms used for HPGs	92
Table 3.2	Guidelines extracted from the collated HPGs	94
Table 3.3	Guidelines extracted from HPGs collation	99
Table 3.4	Overview of TRIZ-AM case studies and DFAM tasks	104
Table 3.5	Existing product for <i>Case Study A</i>	106
Table 3.6	Summary of the AM basic structure	122
Table 3.7	Summary of the pass or fail criteria for the basic structure	123
Table 3.8	Summary of the strut lattice design	125
Table 3.9	Pass or fail criteria for strut lattice design	126
Table 3.10	Process parameters and their levels	129
Table 3.11	Constant process parameters	129
Table 3.12	Control log of the experiment for fabrications	130
Table 3.13	Important specification of Prusa MK3S 3D printer	134
Table 3.14	Composite material specifications	135
Table 3.15	Overview of DFAM task to demonstrate CDRs applications	145

Table 4.1	TRIZ-AM HPGs mapping	160
Table 4.2	AM unique knowledge	161
Table 4.3	Classifications of classical TRIZ and TRIZ-AM based on three design schemes	162
Table 5.1	Original design of hanging shelf with roller consists of 20 parts	175
Table 5.2	Original design of PCB casing consists of 18 parts count	183
Table 5.3	Original design of roller belt support consist of 10 parts	188
Table 5.4	Summary table of TRIZ-AM IPs used for <i>Case Study A</i>	205
Table 6.1	Results of percentage error for Virgin PLA, CF-PLA and Wood-PLA	215
Table 6.2	Experimental results of average percentage error with S/N ratio	216
Table 6.3	S/N ratio for percentage error of dimensional accuracy by factor level	220
Table 6.4	ANOVA value for percentage error of dimensional accuracy of PLA and composite material	221
Table 6.5	Response optimisation for dimensional accuracy for Virgin PLA	222
Table 6.6	Response optimisation for dimensional accuracy for CF-PLA	222
Table 6.7	Response optimisation for dimensional accuracy for Wood-PLA	223
Table 6.8	Inspections results of thin-walled produced by FDM	224
Table 6.9	Measurements of thin wall and its observational error	225
Table 6.10	Inspection results of fabricated slots	228
Table 6.11	Measurements of slots and its observational error	229
Table 6.12	Inspection results of the fabricated small hole diameter	231
Table 6.13	Measurements of small hole diameter and its observational error	232
Table 6.14	Visual inspections of maximum hole diameter	235
Table 6.15	Overall measurements of CAD data and actual data of maximum hole	236

Table 6.16	Inspection results of overhang lengths produced using FDM	240
Table 6.17	Inspections for overhang angles (OA) producing by FDM	244
Table 6.18	Visual inspections for fabricated bridges	245
Table 6.19	Visual inspection for square strut design of PLA composite material	248
Table 6.20	Inspection for circle strut design of PLA composite materials	250
Table 6.21	Inspections of triangle struts design of PLA composite materials	252
Table 6.22	Inspections of triangle strut design of PLA composite materials	254
Table 6.23	Original design of a phone holder	260
Table 6.24	Comparison of various concept design of phone holder in terms of build time and material use	266

LIST OF FIGURES

FIGURE NO.	TITLE	PAGE
Figure 1.1	DFAM synergistic with PDD	4
Figure 1.2	TRIZ problem-solving process (Yeoh and Song, 2009)	6
Figure 2.1	General steps in the 3D printing process	15
Figure 2.2	A roadmap of DFAM process in assisting product design and development (Gao et al., 2015)	19
Figure 2.3	Example of a heuristic card developed by Blösch-Paidosh and Shea (2019)	23
Figure 2.4	Examples of AM design principle cards (Perez and Wood, 2019)	24
Figure 2.5	Extract from the design rule in a form of (a) worksheet by Booth et al. (2017) and (b) design catalogue by Adam and Zimmer (2014)	28
Figure 2.6	An example of design rules produced in magazine articles (EOS, 2016)	29
Figure 2.7	Examples of AMK cards in (a) front view and (b) back view	32
Figure 2.8	The comparison of the route between the traditional problem-solving method and the TRIZ method illustrated by Peng et al. (2020)	38
Figure 2.9	Example of proposed TRIZ matrix involving improving and worsening features (Gross et al., 2018)	40
Figure 2.10	DFAM framework integrated with TRIZ and axiomatic design theory (Renjith et al., 2020)	43
Figure 2.11	Proposed TRIZ-based DFAM framework by Gross et al. (2018)	44
Figure 2.12	The classification of TRIZ related AM examples that fit within the TRIZ principle	45
Figure 2.13	DFAM system and overall method (Rosen, 2007)	47
Figure 2.14	DFAM implementation in the industry (Mellor et al., 2014)	48
Figure 2.15	New AM-enabled design theory by Yang and Zhao (2015)	49

Figure 2.16	A component in lattice structure consisting of strut, nodes, and beams	59
Figure 2.17	(a) Cubic lattice; (b) cross-sectional cubic lattice; and (c) square strut	59
Figure 2.18	BCC in (a) 3D unit cell; (b) cross-sectional area in slicing program and (c) circle strut	60
Figure 2.19	(a) infill pattern of the triangle in 2D and (b) triangle strut in 3D	61
Figure 2.20	Honeycomb lattice in (a) 3D model; (b) cross-section; and (c) octagon strut	61
Figure 2.21	Five lattice designs fabricated using FDM (Iyibilgin et al., 2013)	62
Figure 2.22	(a) CAD lattice design; (b) fabricated lattice with different quality; (c) compression lattice by Dong et al. (2018)	63
Figure 2.23	Biocompatible printed lattice for biomedical applications (Egan et al., 2019)	63
Figure 2.24	(a) overheating effects; (b) gaps between contours and infill; (c) layer separation; (d) skipped layer; (e) whiskers; (f) gaps in thin walls; (g) stringing; (h) blobs and zits; and (i) ringing (Galati and Minetola, 2020)	74
Figure 2.25	Example of process parameter in (a) slicing software; (b) infill patterns such as line, triangle, honeycomb, and Gyroid	76
Figure 2.26	Compilation of process parameter study towards part quality illustrated using the fishbone diagram (Dey and Yodo, 2019)	78
Figure 3.1	Overview of overall research methodology	86
Figure 3.2	Redesign strategies adopted from ASTM/ISO 52910 in assisting the DFAM development with TRIZ-AM principles	89
Figure 3.3	The interaction of TRIZ-AM inventive principles	101
Figure 3.4	Illustration of the TRIZ-AM card's design	103
Figure 3.5	Experimental design task inspired from a study by (Blösch-Paidosh and Shea, 2017).	107
Figure 3.6	Simple cube with dimension of 200 mm x 200 mm x 100 mm	107

Figure 3.7	(a) Isometric view of the benchmark model; (b) front view describing the thin wall in red arrow; (c) detailed dimension of thin wall	109
Figure 3.8	Thin wall dimensions in mm	109
Figure 3.9	a) Slots benchmark; (b) detail dimensions of slot	110
Figure 3.10	Slots dimension in mm	110
Figure 3.11	(a) CAD of small hole; (b) detail dimensions of a small hole	111
Figure 3.12	Small hole dimensions in mm	111
Figure 3.13	(a) CAD of maximised hole diameter; (b) detail dimensions of the maximum hole in dimension 1–14; (c) dimension of 15–28	112
Figure 3.14	Maximum hole dimensions in mm	112
Figure 3.15	(a) CAD data of overhang length; (b) detail dimensions	113
Figure 3.16	Overhang length dimensions in mm	113
Figure 3.17	(a) CAD data of overhang angle; (b) detail dimensions	114
Figure 3.18	Overhang length dimensions in angle°	114
Figure 3.19	(a) CAD data of bridges; (b) detail dimensions	115
Figure 3.20	(a) Bridges dimensions ranging from 5 mm to 50 mm and (b) Bridges dimensions ranging from 55 mm to 100 mm	115
Figure 3.21	(a) CAD model of square struts; (b) detail dimensions of the square strut	116
Figure 3.22	Square strut dimensions in mm	116
Figure 3.23	(a) CAD model of circle strut; (b) detail dimensions	117
Figure 3.24	Circle strut dimensions in front view, (mm)	117
Figure 3.25	(a) CAD model of triangle strut and its individual shapes; (b) detail dimensions	118
Figure 3.26	Triangle struts labelled ranging from smallest to the largest value (refer to Figure 3.24 for the detail dimensions)	119
Figure 3.27	(a) CAD model of octagon strut; (b) detail dimensions	120
Figure 3.28	Octagon strut dimensions in mm	120
Figure 3.29	Specimens for dimensional accuracy with dimensions	128
Figure 3.30	General process flow for printed part fabrication	132

Figure 3.31	3D printer MK3S with special features by Joseph Prusa	133
Figure 3.32	The process flow using (a) image analyser connected to monitor; (b) monitor to display the observed parts; and (c) point taken for measurements	136
Figure 3.33	The layout of a CDRs flash card	138
Figure 3.34	Part 1 of application algorithm	140
Figure 3.35	Application algorithm for DFG and size	141
Figure 3.36	Overall wireframe for CDRs mobile applications	142
Figure 3.37	A mock-up example taken from <i>Android Studio</i>	143
Figure 3.38	Example of XML coding for basic structure (small hole diameter)	144
Figure 4.1	DFAM procedure integrated with TRIZ-AM principles	149
Figure 4.2	AM process selection based on functional parameters	153
Figure 4.3	Process selection for aesthetic parameters	155
Figure 4.4	Process flow of TRIZ-AM method using the card	158
Figure 4.5	Post-processing technique for FDM parts	170
Figure 5.1	TRIZ - AM Card #1 <i>Segmentation</i>	174
Figure 5.2	Comparison of shape complexity demonstrated by experienced designer without AM knowledge using TRIZ-AM cards	176
Figure 5.3	3D CAD model using TRIZ-AM of hanging shelf roll	179
Figure 5.4	Design simplicity of hanging shelf roller by novice designer with AM knowledge	180
Figure 5.5	3D CAD model of modify hanging shelf roller by a novice designer	182
Figure 5.6	Examples of two concept of PCB cover demonstrated by experienced designer	184
Figure 5.7	3D CAD model of modify PCB casing using TRIZ-AM IPs	185
Figure 5.8	Idea enhancement of PCB casing by novice designer	186
Figure 5.9	3D CAD model of PCB casing by a novice designer	187
Figure 5.10	New concept generation using innovative solution translated from TRIZ-AM IPs by experienced designers of belt roller support	189

Figure 5.11	3D CAD model of innovative roller belt support	191
Figure 5.12	Comparison of belt roller support concept generation	192
Figure 5.13	Annular snap fit design to replace the snap rings applications	193
Figure 5.14	The bracket with and without mesh design	194
Figure 5.15	Assembly of evolutionary belt roller support in 3D model perform by a novice designer with AM knowledge	194
Figure 5.16	Exemplified sketches varied from experienced designer with different level of AMK	195
Figure 5.17	Concept 1- Jewellery box by experienced designer with basic AMK level	196
Figure 5.18	Concept 2- Safety box by experienced designer with intermediate AMK level	198
Figure 5.19	Concept 3- Lego box performed by experienced designer with expert AMK level	200
Figure 5.20	Concept 4- Honeycomb space performed by experienced designer with expert AMK level	201
Figure 5.21	Concept 5 – Stacking drawer box performed by experienced designer with expert level of AMK	203
Figure 5.22	IPs of #7 <i>Nested doll</i> used between (a) experienced and (b) novice designer at modified hanging shelf roller	206
Figure 5.23	Initial concept of multipurpose box produced by experienced designer with basic AMK level.	207
Figure 6.1	Main effect charts for the effect of process parameters on S/N ratio of (a) Virgin PLA; (b) CF-PLA; (c) Wood-PLA	218
Figure 6.2	Comparison of CAD data and measured data of thin-walled feature fabrication	226
Figure 6.3	Schematic diagram of die swell effects	227
Figure 6.4	Schematic diagram on how the warping effects produced	227
Figure 6.5	Comparison of CAD data and measured data of slots	230
Figure 6.6	Excessive filament illustration on Wood-PLA slots	231
Figure 6.7	Comparison of CAD data and measured data of small hole diameter	233
Figure 6.8	Schematic diagram of small hole showing (a) Air gaps produced on Wood-PLA holes and (b) schematic diagram of the air gaps in 3D printing	233

Figure 6.9	Schematic of thermal expansion of small hole diameter at (a) Printed hole under microscope image and (b) illustration of thicker wall on the outer circle	234
Figure 6.10	Comparison of CAD data and actual data of maximum holes	237
Figure 6.11	Separated layer found at the Wood-PLA printed hole	238
Figure 6.12	Illustration diagram when printing with horizontal holes	239
Figure 6.13	Sagging of filaments produced as the lengths increased	241
Figure 6.14	Overhang lengths (a) before parameter adjustment; (b) after parameter adjustment	243
Figure 6.15	Overhang angle at 70° produced using Wood-PLA	244
Figure 6.16	Schematic diagram of bridging process	246
Figure 6.17	(a) Printed bridges at 100 mm; (b) loose strands from sagging effects produce curvy line instead of straight line	247
Figure 6.18	Fabrication of multiple overhang length using 3D printer	247
Figure 6.19	Printed strut with (a) 1.5 mm length; (b) 2.00 mm length and (c) 4.00 mm length	249
Figure 6.20	Soft filament unsolidified layer	250
Figure 6.21	Differences of circle strut at (a) 0.846mm; (b) 1.129mm and (c) 1.693mm radius	251
Figure 6.22	Example of unsuccessful circle strut fabrication	252
Figure 6.23	Slicing parameter with base ; (a) 1.50 mm and (b) 2.00 mm	253
Figure 6.24	Triangle base, <i>b</i> value of (a) Triangle with 1.50 mm and (b) triangle with 2.00 mm	253
Figure 6.25	Octagon strut sliced in length of (a) 0.456 mm; (b) 0.910 mm and (c) 1.365 mm	255
Figure 6.26	CDRs flash cards for AM basic feature and its descriptions	256
Figure 6.27	CDRs card for strut features and its descriptions	257
Figure 6.28	Interface of CDRs mobile apps and the screen map used by designers to verify the design rules	259
Figure 6.29	Various phone holder concepts illustrated by designers	261
Figure 6.30	‘Easel’ concept for design K with integrated TRIZ-AM IPs	262

Figure 6.31	Simple phone holder design with added function for concept L	263
Figure 6.32	Concept design M with slanted surface and extra holders at base plate	264
Figure 6.33	Example of CDRs application uses by designer to develop 3D model	265
Figure 6.34	Summary of concept design K, L and M for fabrication of phone holder	267

LIST OF ABBREVIATIONS

AM	-	Additive Manufacturing
FDM	-	Fused Deposition Modeling
SLS	-	Selective Laser Sintering
SLA	-	Stereolithography
DLMS	-	Direct Laser Metal Sintering
HPGs	-	Heuristics, Principle and Guideline
DPs	-	Design Principle
DRs	-	Design Rules
DFAM	-	Design for Additive Manufacturing
DFMA	-	Design for Manufacturing and Assembly
PLA	-	<i>Polylactic Acid</i>
ABS	-	<i>Acrylonitrile Butadiene Styrene</i>
TO	-	Topology Optimization
PC	-	Part Consolidation
TRIZ	-	Theory of Inventive Principle
IPs	-	Inventive Principles
TRIZ-AM	-	TRIZ and Additive Manufacturing
S/N	-	Signal-to-Noise Ratio
DFWT	-	Design for Additive Manufacturing with TRIZ
CDRs	-	Composite Design Rules
AMPD	-	Additive Manufacturing Process Dependent
C-TRIZ	-	Classical TRIZ
AMK	-	Additive Manufacturing Knowledge
O-DFAM	-	Opportunistic Design for Additive Manufacturing
R-DFAM	-	Restrictive Design for Additive Manufacturing
CE	-	Creativity Enhancement

LIST OF SYMBOLS

δ	-	Error
D, d	-	Diameter
F	-	Force
A	-	Area
π	-	Value of Pi
h_b	-	Value of Height for Triangle
b	-	Base for Triangle
a^2	-	Octagon's Side Value
V_A	-	Actual Value
V_E	-	Expected Value
Σ	-	Sum or Total
Y	-	Response Factors
n	-	Number of Experiments
A	-	Actual Measurements
N	-	Nominal Measurements
$^{\circ}\text{C}$	-	Degrees Celsius
A	-	Function for Functional Quality
B	-	Function for Aesthetic Quality
c	-	Tolerances
s	-	Tensile Strength

LIST OF APPENDICES

APPENDIX	TITLE	PAGE
Appendix A	(Inventive Principle of Classical Triz)	301
Appendix B	(TRIZ Contradiction Matrix)	304
Appendix C	(.XML Coding)	305
Appendix D	(JAVA Coding)	312
Appendix E	(Expert Validation)	324
Appendix F	(TRIZ-AM Cards)	335

CHAPTER 1

INTRODUCTION

In the 1980s, additive manufacturing (AM) or three-dimensional (3D) printing was only an idea described by Hideo Kodama of the Nagoya Municipal Industrial Research Institute in Japan. He discovered a way to produce prototypes using layers of material concepts. Unfortunately, Kodama was unable to patent the technology. Since then, many efforts have been done to find a better way to create 3D-printed objects. Finally, in 1986, Charles Hull, an American engineer has successfully created a prototype for a process called Stereolithography (SLA) (Yakout et al., 2018). At the very beginning, Hull used photopolymers, better known as acrylic-based materials, to evolve the idea from liquid to solid using ultraviolet lights. Hull then patented the SLA printer and became the ‘father’ of 3D printing. Following SLA, other key technologies were also successfully patented, which are selective laser sintering (SLS) and fused deposition modelling (FDM). Both technologies use powder grains and filament types, respectively.

Additive manufacturing refers to the process of joining materials together layer by layer under a controlled program to develop 3D dimensional objects. AM has various commercial names. It can also be known as 3D printing (3DP), rapid prototyping (RP), layer manufacturing, and freeform fabrication. AM has grown over the last decade and it has been used to overcome the limitations in conventional manufacturing (Pereira et al., 2019). The AM plays a major role in the manufacturing industries to produce 3D geometrical intricate structures of different materials. A huge variety of polymers, ceramics, metal alloys, plastics, and composites has been used in the AM sector (Ngo, 2020). Every material contributes to different applications and sectors. For example, the medical industry uses AM to produce high-quality joint bone transplants and dentistry. Tissue engineering is also a main medical application that uses AM (Shick et al., 2019). The unquestionable

advantages of the additive technique are the possibility to design parts with design freedom allowing complex shapes to be produced, improving mechanical strength properties of products, and shortening production and lead times. However, there is still a limited number of available materials and there is a need for post-processing to improve the quality of printed parts such as dimensional accuracy and surface finishing. Nowadays, a proper selection of manufacturing methods and machine tools is one of the main critical decisions in the product development process (Deja and Siemiatkowski, 2018) as well as for AM technology. Designers are facing great challenges when designing AM parts resulting in an increasing number of iterations along with the product design phases. This is because they are still adopting the use of traditional design thinking and methods, which, in most cases, do not suit the capabilities of AM (Rosen, 2014). Therefore, aiming to assist designers and to simplify AM design activities and structured methodologies, a new design concept, known as design for additive manufacturing (DFAM), was introduced.

1.1 Design for Additive Manufacturing (DFAM)

In general, DFAM is the skill to design for manufacturability using 3D printing technology. Several researchers have defined DFAM scientifically. For example, Gibson et al. (2010) define DFAM as *“maximising the product performance through the synthesis of the shapes, sizes, hierarchical structures, and also material consumptions subjected to the capabilities of AM technologies”*. According to Laverne and Anwer's (2014) perspective, DFAM is a *“set of methodology and tools that assists designers to fully specify additive manufacturing into considerations during a product design stage”*. Briard et al. (2020) describe DFAM as *“a set of tools dedicated to utilising the full potential of AM technologies for design”*. According to the “ASTM standard 52910, 2018”, the goal of DFAM is to design a product that is easily and economically manufactured even for a complex structure. The primary goal is to localise four DFAM unique capabilities which are shape complexity, material complexity, hierarchical complexity, and functional complexity in the designated products (Rosen, 2007). By implementing DFAM, designers can exploit the unique capabilities of additive manufacturing (AM) and

benefit manufacturers and users to create an exceptional value for their product (Laverne and Anwer, 2014). Kumke et al. (2016) classify the DFAM approaches into two categories which are; DFAM decision inclusive of design and manufacturing. Since the focus of DFAM is to aid designers mainly in the design decision, the developed DFAM methodology may be reflected based on product design and development concept (PDD).

Figure 1.1 presents the overall idea of DFAM development inspired by a group of researchers (Maidin et al., 2012; Doubrovski et al., 2016). It starts with the requirements from customers. Then, the designer needs to apply the design heuristic and principle influenced by the idea generations. In the embodiment design, design guideline is applied, influencing the geometry and the product layout. The detailed design emphasises the design rules and specifications mainly influenced by the geometry such as part shapes and sizes. Once completed, the design is ready for fabrication and manufacturing. The DFAM route is compromised with design and manufacturing sections. The design sections consist of conceptual to detailed design phases, while the manufacturing section, the part programming, and finishing, is included as important phase to produce the parts.

The manufacturing section in Figure 1.1 is divided into part programming as well as manufacturing and finishing. Factors influencing the AM process and criteria in selecting the suitable AM process are also reviewed. Part programming can also be known as the slicing process (Sikder et al., 2014). In a slicing process, a few factors need to be considered. These include build orientation, support, and tool path optimisation, as well as parameter optimisation (included in process planning and optimisation). For manufacturing and finishing, support removal, the quality of the finishing process, and reduction of unwanted part defects, such as warping and shrinkage, must also be reviewed. The idea of DFAM also includes the factors affecting AM selection and the criteria to select proper AM technology for users. In general, the rate of successful manufacturability of the printed part depends on the AM process selections (Alkahari et al., 2017).

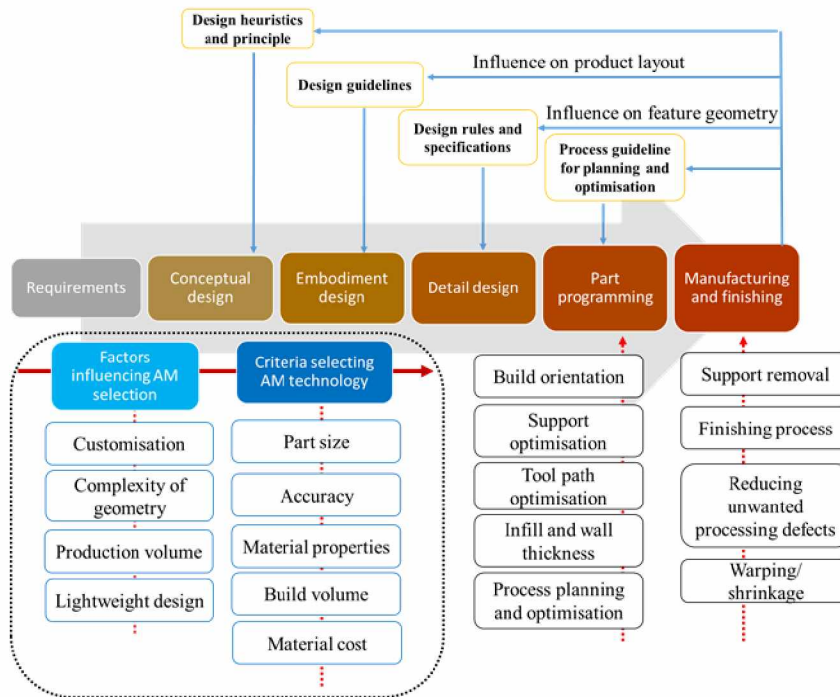


Figure 1.1 DFAM synergistic with PDD

PDD for AM using the DFAM concept is essential to drive the commercialisation and growth of AM in the manufacturing sector. To capitalise on the current and future market opportunities in AM, designers, and manufacturers should focus on PDD strategies by utilising customer requirements. In DFAM, product design may involve adopting new products or may require the refinement or upgrading of the features of existing designs to improve the parts' functionality, performance, or aesthetic quality. Despite the abilities of DFAM in producing lightweight and complex designs, a few unsettled issues in DFAM require additional support to enhance its visibility, especially in the industry. Therefore, this research is motivated to give the inter-relationship and understanding of DFAM comprising of design knowledge, design methodology, and design tools, all integrated into a newly developed DFAM procedure. This development would allow designers with no AM knowledge as well as novices to consider AM abilities in the early design phases for better AM utilisation.

1.2 TRIZ Evolution: Current Status and Issues of Concern

T, R, I, Z in TRIZ (/ˈtri: z/) is the English acronym for the Cyrillic words pronounced as “*Teoriya Resheniya Izobretatelskikh Zadatch*”, translated as Theory of the Solution of Inventive Problems. TRIZ is commercially known as Theory of Inventive Problem Solving developed by G. Altshuller in 1946. He was a Russian patent engineer who discovered that problems, solutions, and patterns of technical evolution were repeating over the industries and sciences. Based on the study, over 200,000 patents were narrowed down to 40,000 innovative patents. Therefore, the TRIZ principle was invented to support engineers and scientists to solve problems using the knowledge of former inventors. The essence to support this solution was consolidated into 40 Inventive Principles (Lin and Wu, 2016). The definition of TRIZ was accordingly defined as a philosophy, a process, and a series of tools primarily based on the concept of resolving contradictions (Yeoh and Song, 2009).

There are several reasons to use TRIZ as a problem-solving tool. The reasons are; (i) TRIZ uses the concept of the world’s knowledge, (ii) it is systematic and repeatable, (iii) it is based on proven successful patents, and (iv) it is designed not just for engineers and engineering, but for universal applications. TRIZ tools have been developed to allow the users to oversee the solutions to the given technical problems. In the TRIZ tool, 39 engineering parameters are extracted which usually cause a conflict when designing a product. They are also known as the 39-contradiction matrix. According to the survey made by Ilevbare et al. (2013), 85% of the respondents used technical problem solving (using 40 inventive principles), while 61% of the respondents used product and technology innovation. In business management and technology strategy, only 24% and 37% of respondents used TRIZ, respectively. The TRIZ process flow is shown in Figure 1.2. The first three steps of the TRIZ process flow are extracted from the typical problem-solving process to complement TRIZ requirements and recognised as the TRIZ problem-solving tool as shown in Figure 1.2. After a problem has been identified, the user can apply the TRIZ tool to generate the TRIZ general solution. After the general solution is introduced, the user can apply the TRIZ model of the solution to enhance the idea so that the specific solution can be moulded and designed.

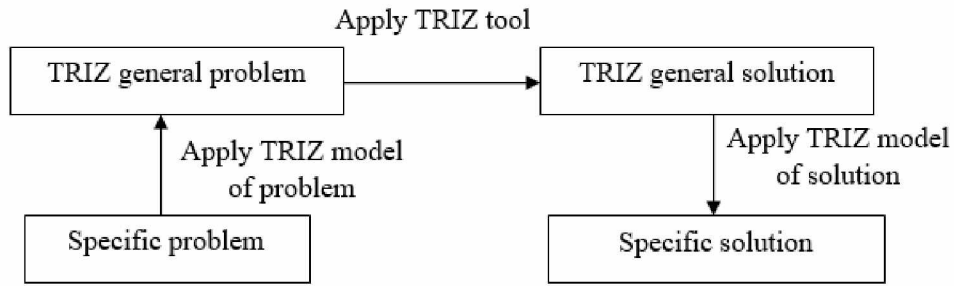


Figure 1.2 TRIZ problem-solving process (Yeoh and Song, 2009)

TRIZ can be considered as a set of all methods to solve an inventive problem from the beginning to the end. Many approaches have been developed by combining TRIZ with other methods. A total of 200 case studies have been found where TRIZ had been used throughout the industry (Spreafico and Russo, 2016). There have been successful attempts to apply TRIZ methodology in the context of DFAM (Kretzschmar and Chekurov, 2018). TRIZ was first invented in 1946, hence, there are concerns about whether the 'universal' concepts of TRIZ can be applied to AM technology, considering the 40-year technological gap between TRIZ and AM. Thus, the pathway for synergising TRIZ and AM (TRIZ-AM) may not be clearly explained concerning AM capabilities and complexities. The discussion on the applicability between TRIZ and DFAM will be further discussed in Chapter 2 and Chapter 4.

1.3 Problem Statement

DFAM is a set of rules and tools designed to make the AM constraint and capability easier to manage during the product design stages. Therefore, the practical methodology is necessary to assist the designers and engineers to generate effective product design for AM (Newell et al., 2019). Existing DFAM methodology is rarely found in a way that is accessible to novice designers. Most methodology assume that the designer has extensive prior knowledge of the process, applies to only a few AM technologies, has very specific applications, or describes the benefits of the technology that novice designers already know.

In DFAM, the design method plays a significant role to produce the AM-printed part based on a principle given. Examples of design methods in AM include topology optimisation, part consolidation, axiomatic design, and TRIZ. TRIZ has attracted the AM community to assist product development and can be used as a method for generating new ideas and solutions (Renjith et al., 2020). Past research connecting TRIZ and AM indicates that it can be realistically used in assisting DFAM. However, there are limitations which include; (i) the usage of TRIZ which is highly dependent on the available AM examples, and direct usage of the classical TRIZ 40IPs which are subjective to researchers' problem-solving viewpoints; (ii) the 40IPs of TRIZ do not cover all new innovative principles represented by AM design knowledge, and (iii) the existing innovative principle of TRIZ could not solely provide inclusive solutions to be applied to all AM technologies and terminologies. Thus, further research is required to enhance the applicability of TRIZ into AM environment (Gross et al., 2018; Lang et al., 2019; Yuan et al., 2019).

Design knowledge is also important to establish DFAM. Available design knowledge in DFAM is the design rules. According to Mani et al. (2017), gaps exist in the design process because designers are challenged with a lack of understanding of AM capabilities, process-related constraints, and their effects on the final product development. Focusing on the process-related constraint, designers are uncertain of the limitations and possibilities of the AM process (Adam and Zimmer, 2014). Therefore, according to Schmidt and Fornasini, (2015), designers tend to apply and design the parts using incompatible design rules from familiar manufacturing processes such as injection moulding or other traditional manufacturing process guidelines.

Other than design method and design knowledge in DFAM, material is also a component that drive the successful of fabrications. Composite material has been recently introduced to fulfil the niche of 3D printing applications in the industry especially on producing lightweight composite parts for automotive and aerospace. The existing research on the composite material in AM mainly addresses the mechanical properties of the printed part and rarely discussed on the geometrical limitations and manufacturability of the AM-composite featured design including the AM lattice design. In conjunction to the AM-featured lightweight design, Kessler, et

al. (2017) state that the product-oriented with lattice structure is becoming more challenging to produce as the industry's demand for lattice application are keep on growing. As a result, designers often perform trial-and-error investigations before attaining the optimal outcomes for their printed parts in order to meet the demand. This is because composite filaments are complicated to handle with, especially for inexperienced users. Therefore, this research intends to focus on the manufacturability analysis of the composite materials involving the AM-design feature to assist on the design rule developments for composite parts.

1.4 Significance of the Study

The findings of this study will contribute greatly towards designers and AM practitioners by considering the importance of AM role. In Malaysia, particularly, AM has become a key technology that drives the Industrial Revolution 4.0 and can potentially contribute to Malaysia's economy. The findings specifically align with the *'Application of the 10-10 MySTIE framework to the energy socio-economic driver'* where 3D printing has become an important element to drive the IR 4.0. In the current technology highlighted by MySTIE, 3D printed respirators, face shields, and PPEs have been used to combat the shortage of medical protection equipment supply. Other than that, the study has introduced the TRIZ-AM cards that can help designers to use virtual 3D designs and printing for rapid prototyping in engineering and creative arts as stated in MySTIE. It is also beneficial to assist the industry in an assembly line where the spare parts are automatically 3D-printed and installed by robots.

Therefore, designers who apply the recommended design methodology derived from the results of this study will be able to systematically practice the overall DFAM procedure and can help them to speed up the research and development (R&D) process. Designers will also be guided on the geometrical constraint to improve fabrications performance using the developed design rules. On the other hand, the results of this study will help researchers uncover critical areas in the DFAM, especially on the design method that is still adapting from the concept of

conventional design thinking. Thus, the design method for DFAM will be explored more comprehensively.

1.5 Research Questions

Based on the problem statement, the research questions are identified to achieve the research objectives and goals of this study. The research questions are listed as follows:

- i. How designers can adopt TRIZ-AM inventive principle with the combinations between AM complexity and unique capabilities during product design and development stages?
- ii. How to ensure the success of design rules development in design knowledge to produce AM parts?
- iii. How to ensure the effectiveness of TRIZ-AM method and design rules to produce AM parts?

1.6 Research Objectives

The research objectives are made to answer the previous research questions. Accordingly, the three objectives of this study are:

- i. To develop design for additive manufacturing procedure integrated with AM process capability and TRIZ-AM inventive principle
- ii. To evaluate the DFAM design knowledge using manufacturability analysis in assisting design rule applications
- iii. To verify and validate the effectiveness of the TRIZ-AM method and design rule using case studies

1.7 Research Scopes

To conduct this study, a few boundaries have been identified. The research scopes have been described as follows:

- i. Only 40-classical TRIZ inventive principle has been used to synergise with the AM capability and limitations.
- ii. ISO/ASTM (52910) standard has been used as the guideline for the DFAM strategy and architecture.
- iii. Seven AM feature designs inclusive of basic design structures are developed. They are thin walls, slots, small hole diameters, maximum hole diameters, overhang lengths, overhang angles and bridges.
- iv. An AM-lightweight feature design involving only four types of strut lattice designs is also developed. They are square strut, circle strut, triangle strut, and octagon strut.
- v. All designs are fabricated using PLA-based composite materials of carbon fibre reinforced PLA and Wood-PLA as well as Virgin PLA.
- vi. The process parameter optimisation is conducted using Taguchi. The analysis uses Minitab software where S/N ratio, and ANOVA are also performed.
- vii. The dimensional accuracy of AM fabricated parts is measured using an image analyser to inspect the quality or defects of the printed parts.
- viii. All designs are fabricated using the material extrusion technique to assist the design rule development.
- ix. Digital design rules are developed using *Android Studio* to ease the modification process.
- x. An evaluation of case studies focuses only on creativity enhancement involving custom geometries or combinations of special features as well as characteristics for various products.
- xi. The case study involves fifteen (14) participants consisted of an experienced designer and novices' designer with the industrial experiences between 2 to 8 years, respectively.

1.8 Thesis Outline

The work presented in this thesis consists of the development of a DFAM procedure integrated with the extended version of classical TRIZ known as the TRIZ-AM inventive principle. The DFAM procedure consists of design rules development using a composite material of AM-featured design. The particular focus in this thesis is to develop a systematic design approach and tool, especially for AM novice designers. This thesis is divided into 7 chapters. In Chapter 2, a comprehensive literature review of the design for additive manufacturing (DFAM) is presented. DFAM knowledge, which is HPGs (Heuristics, Principles, and Guidelines), is proposed. The main goal is to identify the gaps in knowledge where the TRIZ-AM definition can be performed. Aside from this, DFAM's earlier developments were discussed to identify potential areas of research development that are likely to be applicable in industry.

In Chapter 3, a detailed discussion on the research methodology is presented. The chapter begins with the general flowchart consisting of 4 phases. Phase 1 covers the development of the DFAM procedure, Phase 2 includes the manufacturability analysis and setup, Phase 3 discusses the fabrication and testing using the composite material, and Phase 4 describes the composite design rule development (CDR). Chapter 4 describes the TRIZ-AM integrated into the DFAM procedure which is first introduced in the product design phase (PDD). The procedure is known as DFAM with TRIZ (DFWT) targeted to promote AM technology among TRIZ users and vice versa. The case studies to demonstrate the feasibility and validity of the TRIZ-AM method are presented in Chapter 5. Two major tasks involving four types of products (hanging shelf with a roller, PCB casing, belt roller support, and multipurpose box) are used for creativity enhancement demonstration. The tasks include *Case Study A: Part consolidations with TRIZ* and *Case Study B: Creativity enhancement with TRIZ*.

In Chapter 6, the manufacturability analysis is described, presenting the results and discussions of the composite fabricated features together with the development of composite design rules in the form of flashcards and mobile applications. To demonstrate the applicability of CDR applications for AM content

and creativity, *Case study C: Innovative design* is performed. Lastly, in Chapter 7, the conclusions, intellectual contributions, and future works are described.

REFERENCES

- Abdulhameed, O., Al-Ahmari, A., Ameen, W. and Mian, S. H. (2019) 'Additive manufacturing: Challenges, trends, and applications', *Advances in Mechanical Engineering*, 11(2), pp. 1–27.
- Adam, G. A. O. and Zimmer, D. (2014) 'Design for Additive Manufacturing- Element transitions and aggregated structures', *CIRP Journal of Manufacturing Science and Technology*. CIRP, 7(1), pp. 20–28.
- Afrose, M. F., Masood, S. H., Iovenitti, P., Nikzad, M. and Sbarski, I. (2016) 'Effects of part build orientations on fatigue behaviour of FDM-processed PLA material', *Progress in Additive Manufacturing*. Springer International Publishing, 1(1–2), pp. 21–28.
- Ahmed, S., Wallace, K. M. and Blessing, L. T. M. (2003) 'Understanding the differences between how novice and experienced designers approach design tasks', *Research in Engineering Design*, 14(1), pp. 1–11.
- Alkahari, M. R., Mazlan, S. N. H., Sun, O. I., Ramli, F. R., Maidin, N. A. and Sudin, M. N. (2017) 'Manufacturability of overhang structure using open source 3D printer', (May), pp. 158–159.
- Amandine, R. (2018) *What is thermal expansion and how does it affect objects?*, *Sculpteo*. Available at: <https://www.sculpteo.com/blog/2018/03/13/thermal-expansion> (Accessed: 5 September 2021)
- Angrish, A. (2014) 'A critical analysis of additive manufacturing technologies for aerospace applications', *IEEE Aerospace Conference Proceedings*.
- Annoni, M., Giberti, H. and Strano, M. (2016) 'Feasibility Study of an Extrusion-based Direct Metal Additive Manufacturing Technique', *Procedia Manufacturing*. The Author(s), 5, pp. 916–927.
- Bakar, N. S. A., Alkahari, M. R. and Boejang, H. (2010) 'Analysis on fused deposition modelling performance', *Journal of Zhejiang University: Science A*, 11(12), pp. 972–977.
- Barile, G., Leoni, A., Muttillio, M., Paolucci, R., Fazzini, G. and Pantoli, L. (2020) 'Fused-deposition-material 3D-printing procedure and algorithm avoiding use of any supports', *Sensors*, 20(2).

- Bárník, F., Vaško, M., Sága, M., Handrik, M. and Sapietová, A. (2019) 'Mechanical properties of structures produced by 3D printing from composite materials', *MATEC Web of Conferences*, 254, p. 01018.
- Bazin, M. M., Othman, M. Z. M., Padzi, M. M. and Ghazali, F. A. (2019) 'Optimisation of 3D printing parameter for improving mechanical strength of ABS printed parts', *International Journal of Mechanical Engineering and Technology*, (1), pp. 255–260.
- Beniak, J., Križan, P., Šooš and Matuš, M. (2019) 'Research on Shape and Dimensional Accuracy of FDM Produced Parts', *IOP Conference Series: Materials Science and Engineering*, 501(1), pp. 1–7.
- Bi, M., Tran, P. and Xie, Y. M. (2020) 'Topology optimization of 3D continuum structures under geometric self-supporting constraint', *Additive Manufacturing*, 36, p. 101422.
- Bikas, H., Lianos, A. K. and Stavropoulos, P. (2019) 'A design framework for additive manufacturing', *International Journal of Advanced Manufacturing Technology*, 103(9–12), pp. 3769–3783.
- Blanco, I. (2020) 'The use of composite materials in 3D Printing', *Journal of Composites Science*, 4(2), p. 42.
- Blösch-Paidosh, A. and Shea, K. (2017) 'Design heuristics for additive manufacturing', *Proceedings of the International Conference on Engineering Design, ICED*, 5(DS87-5), pp. 91–100.
- Blösch-Paidosh, A. and Shea, K. (2018) 'Preliminary user study on design heuristics for additive manufacturing', *Proceedings of the ASME Design Engineering Technical Conference*, 2A-2018, pp. 1–10.
- Blösch-Paidosh, A. and Shea, K. (2019) 'Design heuristics for additive manufacturing validated through a user study', *Journal of Mechanical Design, Transactions of the ASME*, 141(4), pp. 1–40.
- Booth, J. W., Alperovich, J., Chawla, P., Ma, J., Reid, T. N. and Ramani, K. (2017) 'The design for additive manufacturing worksheet', *Journal of Mechanical Design, Transactions of the ASME*, 139(10), pp. 1–8.
- Bourell, D., Kruth, J. P., Leu, M., Levy, G., Rosen, D., Beese, A. M. and Clare, A. (2017) 'Materials for additive manufacturing', *CIRP Annals - Manufacturing Technology*. CIRP, 66(2), pp. 659–681.
- Boyard, N., Christmann, O., Richir, S., Boyard, N., Christmann, O. and Richir, S.

- (2013) 'A design methodology for parts using additive manufacturing', *International Conference on Advanced Research in Virtual and Rapid Prototyping*, p. 6.
- Briard, T., Segonds, F. and Zamariola, N. (2020) 'G-DfAM: a methodological proposal of generative design for additive manufacturing in the automotive industry', *International Journal on Interactive Design and Manufacturing*, 14(3), pp. 875–886.
- Camburn, B., Ismail, E., Blake Perez, K., Lauff, C. and Wood, K. (2019) 'Additive manufacture of fibre-reinforced structures: Design process and principles', in *Proceedings of the ASME Design Engineering Technical Conference*.
- Castillo, L. (2005) Study about the rapid manufacturing of complex parts of stainless steel and titanium, *Institute Technology*. pp.1-31.
- Chaitanya, S. and Singh, I. (2018) 'Ecofriendly treatment of aloe vera fibers for PLA based green composites', *International Journal of Precision Engineering and Manufacturing - Green Technology*, 5(1), pp. 143–150.
- Chang, T. Y., Lu, H. P., Luor, T. Y. and Wu, C. Y. (2018) 'Research and innovative design of a drawing instrument - A case study of dashed line pen', in *Proceedings of 4th IEEE International Conference on Applied System Innovation 2018*, IEEE, pp. 712–715.
- Chekurov, S., Wang, M., Salmi, M. and Partanen, J. (2020) 'Development, implementation, and assessment of a creative additive manufacturing design assignment: Interpreting improvements in student performance', *Education Sciences*, 10(6), pp. 1–17.
- Cheng, J. (2018) 'Product design process and methods', in *Product Lifecycle Management-Terminology and Applications*, pp. 36–37.
- Chohan, J. S. and Singh, R. (2017) 'Pre and post processing techniques to improve surface characteristics of FDM parts: A state of art review and future applications', *Rapid Prototyping Journal*, 23(3), pp. 495–513.
- Choy, S. Y., Sun, C. N., Leong, K. F. and Wei, J. (2017) 'Compressive properties of Ti-6Al-4V lattice structures fabricated by selective laser melting: Design, orientation and density', *Additive Manufacturing*, 16, pp. 213–224.
- Clemens Lieberwirth, Arne Harder and Hermann Seitz (2017) 'Extrusion based additive manufacturing of metal parts', *Journal of Mechanics Engineering and Automation*, 7(2).

- Crispo, L and Kim, I. (2021) 'Part consolidation for additive manufacturing: A multi-layered topology optimization approach', *International Journal for Numerical Methods in Engineering*, 122(18), pp. 4987–5027.
- Cuan-Urquizo, E., Barocio, E., Tejada-Ortigoza, V., Pipes, R. B., Rodriguez, C. A. and Roman-Flores, A. (2019) 'Characterization of the mechanical properties of FFF structures and materials: A review on the experimental, computational and theoretical approaches', *Materials*, 16(6).
- David stooft, Kim pickering, Y. Z. (2017) 'Fused deposition modelling of natural fibre/polylactic acid composites', *Journal of Composites Science*, 1(2), p. 8.
- Decker, N. and Yee, A. (2015) 'A simplified benchmarking model for the assessment of dimensional accuracy in FDM processes', *International Journal of Rapid Manufacturing*, 5(2), p. 145.
- Deja, M., Dobrzyński, M., Flaszynski, P., Haras, J. and Zieliński, D. (2018) 'Application of rapid prototyping echnology in the manufacturing of turbine blade with small diameter holes', *Polish Maritime Research*, 25(s1), pp. 119–123.
- Deja, M., Dobrzyński, M. and Rymkiewicz, M. (2019) 'Application of reverse engineering technology in part design for shipbuilding industry', *Polish Maritime Research*, 26(2), pp. 126–133.
- Deja, M. and Siemiatkowski, M. S. (2018) 'Machining process sequencing and machine assignment in generative feature-based CAPP for mill-turn parts', *Journal of Manufacturing Systems*, 48, pp. 49–62.
- Deja, M., Siemiatkowski, M. S. and Zielinski, D. (2020) 'Multi-criteria comparative analysis of the use of subtractive and additive technologies in the manufacturing of offshore machinery components', *Polish Maritime Research*, 27(3), pp. 71–81.
- Denzik, Z. D. (2017) *Investigation of lattice structures and analysis of strut geometry*. Master Engineering Thesis, University of Louisville, Kentucky.
- Dey, A. and Yodo, N. (2019) 'A systematic survey of FDM process parameter optimization and their influence on part characteristics', *Journal of Manufacturing and Materials Processing*, 3(3), pp. 1–30.
- Dickson, A. N., Barry, J. N., McDonnell, K. A. and Dowling, D. P. (2017) 'Fabrication of continuous carbon, glass and Kevlar fibre reinforced polymer composites using additive manufacturing', *Additive Manufacturing*, 16, pp.

146–152.

- Ding, S., Zou, B., Wang, P. and Ding, H. (2019) ‘Effects of nozzle temperature and building orientation on mechanical properties and microstructure of PEEK and PEI printed by 3D-FDM’, *Polymer Testing*, 78, p. 105948.
- Dong, G., Wijaya, G., Tang, Y. and Zhao, Y. F. (2018) ‘Optimizing process parameters of fused deposition modeling by Taguchi method for the fabrication of lattice structures’, *Additive Manufacturing*, 19, pp. 62–72.
- Doubrovski, Z., Verlinden, J. C. and Geraedts, J. M. P. (2016) ‘Optimal design for additive manufacturing: opportunities and challenges’, *Proceedings of the ASME Design Engineering Technical Conference*, pp. 1–12.
- Le Duigou, A., Castro, M., Bevan, R. and Martin, N. (2016) ‘3D printing of wood fibre biocomposites: From mechanical to actuation functionality’, *Materials and Design*, 96, pp. 106–114.
- Egan, P. F. (2019) ‘Design and biological simulation of 3D printed lattices for biomedical applications’, in *Proceedings of the ASME Design Engineering Technical Conference*, pp. 1–10.
- Egan, P. F., Bauer, I., Shea, K. and Ferguson, S. J. (2019) ‘Mechanics of Three-Dimensional Printed Lattices for Biomedical Devices’, *Journal of Mechanical Design, Transactions of the ASME*, 141(3), pp. 1–12.
- EOS (2016) ‘Basic Design Rules for Additive Manufacturing’, *EOS Magazine*, pp. 1–16.
- Eynde M, and Van Puyvelde, P. (2017) ‘3D printing of polylactic acid’, *Advances in Polymer Sciences*, pp. 139–158.
- Faes, M., Valkenaers, H., Vogeler, F., Vleugels, J. and Ferraris, E. (2015) ‘Extrusion-based 3D printing of ceramic components’, *Procedia CIRP*, 28, pp. 76–81.
- Fahad, M. and Hopkinson, N. (2012) ‘A new benchmarking part for evaluating the accuracy and repeatability of additive manufacturing (AM) processes’, *2nd International Conference on Mechanical, Production, and Automobile Engineering*, pp. 234–238.
- Feng, Q., Cong, W. L., Pei, Z. J. and Ren, C. Z. (2012) ‘Rotary ultrasonic machining of carbon fiber-reinforced polymer: Feasibility study’, *Machining Science and Technology*, 16(3), pp. 380–398.
- Ferreira, R. T. L., Amatte, I. C., Dutra, T. A. and Bürger, D. (2017) ‘Experimental

- characterization and micrography of 3D printed PLA and PLA reinforced with short carbon fibers’, *Composites Part B: Engineering*, 124, pp. 88–100.
- François, M., Segonds, F., Rivette, M., Turpault, S. and Peyre, P. (2019) ‘Design for additive manufacturing (DfAM) methodologies: a proposal to foster the design of microwave waveguide components’, *Virtual and Physical Prototyping*, 14(2), pp. 175–187.
- Fu, K. K., Yang, M. C. and Wood, K. L. (2016) ‘Design principles: Literature review, analysis, and future directions’, *Journal of Mechanical Design, Transactions of the ASME*, 138(10), pp. 1–13.
- Gajdoš, I., Spišák, E., Kaščák, L. and Krasinskyi, V. (2015) ‘Surface finish techniques for FDM parts’, *Materials Science Forum*, 818(1), pp. 45–48.
- Galati, M. and Minetola, P. (2020) ‘On the measure of the aesthetic quality of 3D printed plastic parts’, *International Journal on Interactive Design and Manufacturing*, 14(2), pp. 381–392.
- Galati, M., Minetola, P., Marchiandi, G., Atzeni, E., Calignano, F., Salmi, A. and Iuliano, L. (2019) ‘A methodology for evaluating the aesthetic quality of 3D printed parts’, *Procedia CIRP*, 79, pp. 95–100.
- Gao, W., Zhang, Y., Ramanujan, D., Ramani, K., Chen, Y., Williams, C. B., Wang, C. C. L., Shin, Y. C., Zhang, S. and Zavattieri, P. D. (2015) ‘The status, challenges, and future of additive manufacturing in engineering’, *CAD Computer Aided Design*, 69, pp. 65–89.
- Gardner, D. J. and Wang, L. (2019) ‘Additive Manufacturing of Wood-based Materials for Composite Applications’, *SPE Automotive Composites Conference & Exhibition*, (September).
- Gausemeier, J., Echterhoff, N. and Wall, M. (2013) ‘Thinking ahead the Future of Additive Manufacturing – Innovation Roadmapping of Required Advancements’, *University of Paderborn Direct Manufacturing Research Center*, p. 110.
- Gharbi, F., Sghaier, S., Al-Fadhlah, K. J. and Benameur, T. (2011) ‘Effect of ball burnishing process on the surface quality and microstructure properties of aisi 1010 steel plates’, *Journal of Materials Engineering and Performance*, 20(6), pp. 903–910.
- Gibson, I., Rosen, D. W. and Stucker, B. (2010) *Additive manufacturing technologies: Rapid prototyping to direct digital manufacturing*,

<https://doi.org/10.1007/978-1-4939-2113-3>

- Gibson L and Ashby, M. (1997) *Cellular Solids: Structure and properties*, Cambridge University Press.
- Gonzalez-Gutierrez, J., Cano, S., Schuschnigg, S., Kukla, C., Sapkota, J. and Holzer, C. (2018) ‘Additive manufacturing of metallic and ceramic components by the material extrusion of highly-filled polymers: A review and future perspectives’, *Materials*, 11(5).
- Gross, J., Park, K. and Okudan Kremer, G. E. (2018) ‘Design for additive manufacturing inspired by TRIZ’, *Proceedings of the ASME Design Engineering Technical Conference*, 4(August).
- Hancock, D., Homfray, D., Porton, M., Todd, I. and Wynne, B. (2018) ‘Exploring complex high heat flux geometries for fusion applications enabled by additive manufacturing’, *Fusion Engineering and Design*, 136(September 2017), pp. 454–460.
- Hao, W., Liu, Y., Zhou, H., Chen, H. and Fang, D. (2018) ‘Preparation and characterization of 3D printed continuous carbon fiber reinforced thermosetting composites’, *Polymer Testing*, 65(November 2017), pp. 29–34.
- Haruna, A. and Jiang, P. (2020) ‘A Design for additive manufacturing framework: product function integration and structure simplification’, in *IFAC-PapersOnLine*, pp. 77–82.
- Hopkinson, N., Hague, R. and Dickens, P. (2006) ‘Introduction to rapid manufacturing’, in *Rapid Manufacturing: An Industrial Revolution for the Digital Age*, pp. 1–4.
- I Ian, B., Deakin, G. and Rosen, D. (2015) ‘Additive manufacturing technologies : 3D printing, rapid prototyping, and direct digital manufacturing’, *Johnson Matthey Technology Review*, 59(3), pp. 193–198.
- Ikenyiri, P. and Ukpaka, C. (2016) ‘Overview on the effect of particle size on the performance of wood based adsorbent’, *Journal of Chemical Engineering & Process Technology*, 7(5), pp. 5–8.
- Ilevbare, I. M., Probert, D. and Phaal, R. (2013) ‘A review of TRIZ, and its benefits and challenges in practice’, *Technovation*, 33(2–3), pp. 30–37.
- International Standards Organisation (ISO)/ASTM International (2018) *ISO/ASTM 52910:2017(E). Standard Guidelines for Design for Additive Manufacturing.*,

ISO/ASTM International.Ganeva, Switzerland.

- Ishak, I. B., Moffett, M. B. and Larochele, P. (2018) ‘An algorithm for generating 3D lattice structures suitable for printing on a multi-plane FDM printing platform’, *Proceedings of the ASME Design Engineering Technical Conference*, 2B-2018, pp. 3–10.
- Ivanova, O., Williams, C., Engineering, M., Tech, V. and Campbell, T. (2013) ‘Additive manufacturing (AM) and nanotechnology: promises and challenges’, *Rapid Prototyping Journal*, 5, pp. 353–364.
- Iyibilgin, O., Yigit, C. and Leu, M. C. (2013) ‘Experimental investigation of different cellular lattice structures manufactured by fused deposition modeling’, *24th International SFF Symposium - An Additive Manufacturing Conference, SFF 2013*, pp. 895–907.
- Jankovics, D., Barari, A., Jankovics, D., Barari, A., Jankovics, D., Barari, A. and Barari, A. (2019) ‘Customization of automotive structural components using additive manufacturing and topology optimization’, in *IFAC-PapersOnLine*, pp. 212–217.
- Jardini, A. L., Larosa, M. A., Filho, R. M., Zavaglia, C. A. D. C., Bernardes, L. F., Lambert, C. S., Calderoni, D. R. and Kharmandayan, P. (2014) ‘Cranial reconstruction: 3D biomodel and custom-built implant created using additive manufacturing’, *Journal of Cranio-Maxillofacial Surgery*, 42(8), pp. 1877–1884.
- Jesthi, D. K. and Swarup, S. (2017) ‘Flexure and impact properties of glass fiber reinforced nylon 6-polypropylene composites flexure and impact properties of glass fiber reinforced nylon 6-polypropylene composites’, *Conference Series: Materials Science and Engineering*, 319, pp. 2–7.
- Jiang, J., Stringer, J., Xu, X. and Zhong, R. Y. (2018) ‘Investigation of printable threshold overhang angle in extrusion-based additive manufacturing for reducing support waste’, *International Journal of Computer Integrated Manufacturing*. 31(10), pp. 961–969.
- Jin, Y. A., Li, H., He, Y. and Fu, J. Z. (2015) ‘Quantitative analysis of surface profile in fused deposition modelling’, *Additive Manufacturing*, 8, pp. 142–148.
- Johnson, W. M., Rowell, M., Deason, B. and Eubanks, M. (2014) ‘Comparative evaluation of an open-source FDM system’, *Rapid Prototyping Journal*, 20(3), pp. 205–214.

- Kamps, T., Gralow, M., Schlick, G. and Reinhart, G. (2017) 'Systematic Biomimetic Part Design for Additive Manufacturing', *Procedia CIRP*, 65, pp. 259–266.
- Kamps, T., Münzberg, C., Stacheder, L., Seidel, C., Reinhart, G. and Lindemann, U. (2015) 'TRIZ-based biomimetic part-design for Laser Additive Manufacturing', in *Lasers in Manufacturing Conference 2015*, pp. 1–10.
- Kessler, J., Balci, N., Gebhardt, A. and Abbas, K. (2017) 'Basic design rules of unit cells for additive manufactured lattice structures', in *MATEC Web of Conferences*, pp. 1–10.
- Klahn, C., Leutenecker, B. and Meboldt, M. (2014) 'Design for additive manufacturing - Supporting the substitution of components in series products', *Procedia CIRP*, 21, pp. 138–143.
- Knoop, F. and Schoeppner, V. (2020) 'Geometrical accuracy of holes and cylinders manufactured with fused deposition modeling', in *Solid Freeform Fabrication 2017: Proceedings of the 28th Annual International Solid Freeform Fabrication Symposium - An Additive Manufacturing Conference, SFF 2017*, pp. 2757–2776.
- Ko, H., Moon, S. K. and Hwang, J. (2015) 'Design for additive manufacturing in customized products', *International Journal of Precision Engineering and Manufacturing*, 16(11), pp. 2369–2375.
- Kremer, G. O., Chiu, M. C., Lin, C. Y., Gupta, S., Claudio, D. and Thevenot, H. (2012) 'Application of axiomatic design, TRIZ, and mixed integer programming to develop innovative designs: A locomotive ballast arrangement case study', *International Journal of Advanced Manufacturing Technology*, 61(5–8), pp. 827–842.
- Kretschmar, N. and Chekurov, S. (2018) 'The applicability of the 40 TRIZ principles in design for additive manufacturing', *Annals of DAAAM and Proceedings of the International DAAAM Symposium*, 29(1), pp. 888–893.
- Krugelis, L. (2018) '3D printing technology as a method for discovering new creative opportunities for architecture and design.', *Landscape Architecture and Art*, 13(13), pp. 87–94.
- Kubota, F. I. and Da Rosa, L. C. (2013) 'Identification and conception of cleaner production opportunities with the theory of inventive problem solving', *Journal of Cleaner Production*. Elsevier Ltd, 47, pp. 199–210.
- Kulak, O., Cebi, S. and Kahraman, C. (2010) 'Applications of axiomatic design

- principles: A literature review', *Expert Systems with Applications*. Elsevier Ltd, 37(9), pp. 6705–6717.
- Kumbhar, N. N. and Mulay, A. V. (2018) 'Post processing methods used to improve surface finish of products which are manufactured by additive manufacturing technologies: A Review', *Journal of The Institution of Engineers (India)*, 99(4), pp. 481–487.
- Kumke, M., Watschke, H. and Vietor, T. (2016) 'A new methodological framework for design for additive manufacturing', *Virtual and Physical Prototyping*, 11(1), pp. 3–19.
- Lamm, M. E., Wang, L., Kishore, V., Tekinalp, H., Kunc, V., Wang, J., Gardner, D. J. and Ozcan, S. (2020) 'Material extrusion additive manufacturing of wood and lignocellulosic filled composites', *Polymers*, 12(9).
- Lang, A., Gazo, C., Segonds, F., Mantelet, F., Jean, C., Guegan, J. and Buisine, S. (2019) 'A proposal for a methodology of technical creativity mixing TRIZ and additive manufacturing', *IFIP Advances in Information and Communication Technology*, 572, pp. 106–116.
- Lanzotti, A., Del Giudice, D. M., Lepore, A., Staiano, G. and Martorelli, M. (2015) 'On the geometric accuracy of RepRap open-source three-dimensional printer', *Journal of Mechanical Design, Transactions of the ASME*, 137(10), pp. 1–8.
- Laverne, F. and Anwer, N. (2014) 'DFAM in the design process: A proposal of classification to foster early design stages', in *Confere 2014 Croatie*, pp. 1–12.
- Laverne, F., Segonds, F., Anwer, N. and Le Coq, M. (2015) 'Assembly based methods to support product innovation in design for additive manufacturing: An exploratory case study', *Journal of Mechanical Design, Transactions of the ASME*, 137(12), pp. 1–8.
- Leary, M., Merli, L., Torti, F., Mazur, M. and Brandt, M. (2014) 'Optimal topology for additive manufacture: A method for enabling additive manufacture of support-free optimal structures', *Materials and Design*. Elsevier Ltd, 63, pp. 678–690.
- Leicht, A., Rashidi, M., Klement, U. and Hryha, E. (2020) 'Effect of process parameters on the microstructure, tensile strength and productivity of 316L parts produced by laser powder bed fusion', *Materials Characterization*.

- Elsevier, 159(November 2019), p. 110016.
- Leutenecker-Twelsiek, B., Klahn, C. and Meboldt, M. (2016) 'Considering part orientation in design for additive manufacturing', *Procedia CIRP*, 50, pp. 408–413.
- Lewis, J. A., Smay, J. E., Stuecker, J. and Cesarano, J. (2006) 'Direct ink writing of three-dimensional ceramic structures', *Journal of the American Ceramic Society*, 89(12), pp. 3599–3609.
- Li, J. L. Z., Alkahari, M. R., Rosli, N. A. B., Hasan, R., Sudin, M. N. and Ramli, F. R. (2019) 'Review of wire arc additive manufacturing for 3d metal printing', *International Journal of Automation Technology*, 13(3), pp. 346–353.
- Liang, J. Z. (2008) 'Effects of extrusion conditions on die-swell behavior of polypropylene/diatomite composite melts', *Polymer Testing*, 27(8), pp. 936–940.
- Lin, S. Y. and Wu, C. T. (2016) 'Application of TRIZ inventive principles to innovate recycling machine', *Advances in Mechanical Engineering*, 8(5), pp. 1–8.
- Lindwall, A. and Törlind, P. (2018) 'Evaluating design heuristics for additive manufacturing as an explorative workshop method', *Proceedings of International Design Conference*, 3(1), pp. 1221–1232.
- Lippert, K. and Cloutier, R. (2019) 'Triz for digital systems engineering: New characteristics and principles redefined', *Systems*, 7(3), pp. 1–23.
- Liu, Z., Lei, Q. and Xing, S. (2019) 'Mechanical characteristics of wood, ceramic, metal and carbon fiber-based PLA composites fabricated by FDM', *Journal of Materials Research and Technology*, 8(5), pp. 3743–3753.
- Love, L. J., Kunc, V., Rios, O., Duty, C. E., Elliott, A. M., Post, B. K., Smith, R. J. and Blue, C. A. (2014) 'The importance of carbon fiber to polymer additive manufacturing', *Journal of Materials Research*, 29(17), pp. 1893–1898.
- Ma, Q., Rejab, M. R. M., Kumar, A. P., Fu, H., Kumar, N. M. and Tang, J. (2020) 'Effect of infill pattern, density and material type of 3D printed cubic structure under quasi-static loading', in *Proceedings of the Institution of Mechanical Engineers, Part C: Journal of Mechanical Engineering Science*, pp. 1–19.
- Maconachie, T., Tino, R., Lozanovski, B., Watson, M., Jones, A., Pandelidi, C., Alghamdi, A., Almalki, A., Downing, D., Brandt, M., Leary, M. and Leary,

- M. (2020) 'The compressive behaviour of ABS gyroid lattice structures manufactured by fused deposition modelling', *International Journal of Advanced Manufacturing Technology*. The International Journal of Advanced Manufacturing Technology, 107, pp. 4449–4467.
- Maharjan, G. K., Khan, S. Z., Riza, S. H. and Masood, S. H. (2018) 'Compressive behaviour of 3D printed polymeric gyroid cellular lattice structure', *IOP Conference Series: Materials Science and Engineering*, 455(1), p. 012047.
- Mahesh, M., Wong, Y. S., Fuh, J. Y. H. and Loh, H. T. (2004) 'Benchmarking for comparative evaluation of RP systems and processes', *Rapid Prototyping Journal*, 10(2), pp. 123–135.
- Maidin, S. Bin, Campbell, I. and Pei, E. (2012) 'Development of a design feature database to support design for additive manufacturing', *Assembly Automation*, 32(3), pp. 235–244.
- Mani, M., Jee, H. and Witherell, P. (2017) 'Design rules for additive manufacturing: A categorization', *Proceedings of the ASME Design Engineering Technical Conference*, 1, pp. 1–10.
- Marwah, O. M. F., Yahaya, N. F., Darsani, A., Mohamad, E. J., Haq, R. H. A., Johar, M. A. and Othman, M. H. (2019) 'Investigation for shrinkage deformation in the desktop 3d printer process by using DOE approach of the ABS materials', *Journal of Physics: Conference Series*, 1150(1).
- Maurya, N. K., Rastogi, V. and Singh, P. (2019) 'Comparative study and measurement of form errors for the component printed by FDM and polyjet process', *Instrumentation Measure Metrologie*, 18(4), pp. 353–359.
- Mawale, M. B., Kuthe, A., Mawale, A. M. and Dahake, S. W. (2018) 'Development of an ear cap in chronic suppurative otitis media using additive manufacturing and TRIZ', *Proceedings of the Institution of Mechanical Engineers, Part H: Journal of Engineering in Medicine*, 232(7), pp. 733–738.
- Mazlan, S. N. ., Abdul Kadir, A. ., Md Sirat, R. and Mohd Saad, R and Muhamad, Z. (2021) 'Manufacturability analysis of strut lattice design using PLA- based composite material', *Jurnal Mekanikal*, 44, pp. 46–61.
- Mazlan, S. N. H., Abdul Kadir, A. Z., Ngadiman, N. H. A. and Alkahari, M. R. (2020) 'Evaluation of geometrical benchmark artifacts containing multiple overhang lengths fabricated using material extrusion technique', *Journal of Mechanical Engineering and Sciences*, 14(3), pp. 7296–7308.

- Mazlan, S. N. H., Alkahari, M. R., Ramli, F. R. and Maidin, N. A. (2017) 'Effect of laser post-processing on surface roughness of fused deposition modeling (FDM) part', *Proceedings of Innovative Research and Industrial Dialogue* 16, pp. 101–102.
- Mazlan, S. N. H., Alkahari, M. R., Ramli, F. R., Sudin, M. N., Maidin, N. A. and Sun, O. K. (2018) 'Manufacturability of mechanical structure fabricated using entry level 3D printer', *Journal of Mechanical Engineering*, 5(3), pp. 98–122.
- Mazlan, S. N. H., Zuhra, A., Kadir, A., Hasrul, N. and Ngadiman, A. (2019) 'Optimization of truss collinear lattice fabricated using fused deposition modeling technique', *International Journal of Innovative Technology and Exploring Engineering*, 9(2), pp. 3133–3139.
- Mazlan, S. N. H., Zuhra, A., Kadir, A. and Yusof, Y. (2020) 'Overhang analysis fabricated using fused deposition modeling technique', *Journal of Advanced Industrial Technology and Application*, 1(1), pp. 38–47.
- McGregor, D. J., Tawfick, S. and King, W. P. (2019) 'Mechanical properties of hexagonal lattice structures fabricated using continuous liquid interface production additive manufacturing', *Additive Manufacturing*, 25, pp. 10–18.
- Meisel, N. and Williams, C. (2015) 'An Investigation of key design for additive manufacturing constraints in multimaterial three-dimensional printing', *Journal of Mechanical Design, Transactions of the ASME*, 137(11), pp. 1–9.
- Melgoza, E. L., Serenó, L., Rosell, A. and Ciurana, J. (2012) 'An integrated parameterized tool for designing a customized tracheal stent', *CAD Computer Aided Design*, 44(12), pp. 1173–1181.
- Mellor, S., Hao, L. and Zhang, D. (2014) 'Additive manufacturing: A framework for implementation', *International Journal of Production Economics*, 149, pp. 194–201.
- Mercado-Colmenero, J. M., Rubio-Paramio, M. A., Dolores La Rubia, M., Lozano-Arjona, D. and Martin-Doñate, C. (2019) 'A numerical and experimental study of the compression uniaxial properties of PLA manufactured with FDM technology based on product specifications', *International Journal of Advanced Manufacturing Technology*. 103(5–8), pp. 1893–1909.
- Mitchell, A., Lafont, U., Hołyńska, M. and Semprimoschnig, C. (2018) 'Additive manufacturing — A review of 4D printing and future applications', *Additive*

- Manufacturing*, 24, pp. 606–626.
- Mori, K. I., Maeno, T. and Nakagawa, Y. (2014) ‘Dieless forming of carbon fibre reinforced plastic parts using 3D printer’, *Procedia Engineering*, 81, pp. 1595–1600.
- Motyl, B. and Filippi, S. (2020) ‘Investigating the relationships between additive manufacturing and TRIZ: Trends and perspectives’, *Lecture Notes in Mechanical Engineering*, 1, pp. 903–911.
- Moylan, S. (2013) *Proposed Standardized Test Artifact for Additive Manufacturing NIST Projects in Additive Manufacturing Process Part*.
- Moylan, S., Slotwinski, J., Cooke, A., Jurens, K. and Donmez, M. A. (2014) ‘An additive manufacturing test artifact’, *Journal of Research of the National Institute of Standards and Technology*, 119, pp. 429–459.
- Murr, L. E., Gaytan, S. M., Medina, F., Lopez, H., Martinez, E., MacHado, B. I., Hernandez, D. H., Martinez, L., Lopez, M. I., Wicker, R. B. and Bracke, J. (2010) ‘Next-generation biomedical implants using additive manufacturing of complex cellular and functional mesh arrays’, *Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences*, 368(1917), pp. 1999–2032.
- Nancharaiah, T. (2011) ‘Optimization of Process Parameters in FDM Process Using Design of Experiments’, *International Journal on Emerging Technologies* 2(1); 2(1), pp. 100–102.
- Newell, A., George, A., Papakostas, N., Lhachemi, H., Malik, A. and Shorten, R. (2019) ‘On design for additive manufacturing: Review of challenges and opportunities utilising visualisation technologies’, in *Proceedings - 2019 IEEE International Conference on Engineering, Technology and Innovation, ICE/ITMC 2019*, pp. 1–7.
- Ngo, T.-D. (2020) ‘Introduction to composite materials’, *Fiber Composites*, 1, pp. 1–28.
- Ngo, T. D., Kashani, A., Imbalzano, G., Nguyen, K. T. Q. and Hui, D. (2018) ‘Additive manufacturing (3D printing): A review of materials, methods, applications and challenges’, *Composites Part B: Engineering*, 143(February), pp. 172–196.
- Nie, Z., Jung, S., Kara, L. B. and Whitefoot, K. S. (2019) ‘Optimization of parts consolidation for minimum production costs and time using additive

- manufacturing', in *Proceedings of the ASME Design Engineering Technical Conference*, pp. 1–28.
- Ning, F., Cong, W., Hu, Y. and Wang, H. (2017) 'Additive manufacturing of carbon fiber-reinforced plastic composites using fused deposition modeling: Effects of process parameters on tensile properties', *Journal of Composite Materials*, 51(4), pp. 451–462.
- Ning, F., Cong, W., Qiu, J., Wei, J. and Wang, S. (2015) 'Additive manufacturing of carbon fiber reinforced thermoplastic composites using fused deposition modeling', *Composites Part B: Engineering*, 80, pp. 369–378.
- Peng, Z., Shen, H. and Tao, Y. (2020) 'Research on innovative design method based on TRIZ - Taking the elderly-oriented transformation of outdoor seats as an example', in *E3S Web of Conferences*, pp. 1–12.
- Pereira, T., Kennedy, J. V. and Potgieter, J. (2019) 'A comparison of traditional manufacturing vs additive manufacturing, the best method for the job', *Procedia Manufacturing*, 30, pp. 11–18.
- Perez, K.B and Wood, K. (2019) *Additive Manufacturing (AM) Design Principle Cards*.
- Perez, B., Hilburn, S., Jensen, D. and Wood, K. L. (2019) 'Design principle-based stimuli for improving creativity during ideation', *Proceedings of the Institution of Mechanical Engineers, Part C: Journal of Mechanical Engineering Science*, 233(2), pp. 493–503.
- Perez, K. B., Anderson, D. S. and Wood, K. L. (2015) 'Crowdsourced design principles for leveraging the capabilities of additive manufacturing', in *International Conference of Engineering Design*, pp. 1–10.
- Ponche, R., Kerbrat, O., Mognol, P. and Hascoet, J. Y. (2014) 'A novel methodology of design for Additive Manufacturing applied to additive laser manufacturing process', *Robotics and Computer-Integrated Manufacturing*, 30(4), pp. 389–398.
- Porpíglío, I., Scalice, R. K. and Silveira, Z. C. (2019) 'Axiomatic design and solution variants applied to a modular 3D printing head based in material extrusion', *Procedia CIRP*, 84, pp. 143–148.
- Prabhu, R. Simpson, T.W, Miller, S.R and Meisel, A. (2021) 'Fresh in my minds! Investigating the effects of the order of presenting opportunistic and restrictive design for additive manufacturing content on student's creativity',

- Journal of Engineering Design*, 32(4), pp. 187–212.
- Prabhu, R., Bracken, J., Armstrong, C. B., Jablolkow, K., Simpson, T. W. and Meisel, N. A. (2020) ‘Additive creativity: investigating the use of design for additive manufacturing to encourage creativity in the engineering design industry’, *International Journal of Design Creativity and Innovation*, 8(4), pp. 198–222.
- Pradel, P., Zhu, Z., Bibb, R. and Moultrie, J. (2018) ‘A framework for mapping design for additive manufacturing knowledge for industrial and product design’, *Journal of Engineering Design*, 29(6), pp. 291–326.
- Prakash, W. N., Sridhar, V. G. and Annamalai, K. (2014) ‘New product development by DFMA and rapid prototyping’, *ARPN Journal of Engineering and Applied Sciences*, 9(3), pp. 274–279.
- Pupo, Y., Monroy, K. P. and Ciurana, J. (2015) ‘Influence of process parameters on surface quality of CoCrMo produced by selective laser melting’, *International Journal of Advanced Manufacturing Technology*, 80, pp. 985–995.
- Rajpurohit, S. R. and Dave, H. K. (2018) ‘Effect of process parameters on tensile strength of FDM printed PLA part’, *Rapid Prototyping Journal*, 24(8), pp. 1317–1324.
- Ranjan, R., Samant, R. and Anand, S. (2017) ‘Integration of design for manufacturing methods with topology optimization in additive manufacturing’, *Journal of Manufacturing Science and Engineering, Transactions of the ASME*, 139(6), pp. 1–14.
- Regassa, Y., Lemu, H. G. and Sirabizuh, B. (2019) ‘Trends of using polymer composite materials in additive manufacturing’, *IOP Conference Series: Materials Science and Engineering*, 659(1).
- Reichwein, J., Vogel, S., Schork, S. and Kirchner, E. (2020) ‘On the applicability of agile development methods to design for additive manufacturing’, in *Procedia CIRP*, pp. 653–658.
- Renjith, S. C. and Kremer, G. E. O. (2018) ‘A design framework for additive manufacturing through the synergistic use of axiomatic design theory and TRIZ’, in *Proceedings of the 2018 IISE Annual Conference*, pp. 1–6.
- Renjith, S. C., Okudan Kremer, G. E. and Park, K. (2018) ‘A design framework for additive manufacturing through the synergistic use of axiomatic design theory and TRIZ’, in *IISE Annual Conference and Expo 2018*, pp. 551–556.
- Renjith, S. C., Park, K. and Okudan Kremer, G. E. (2020) ‘A design framework for

- additive manufacturing: Integration of additive manufacturing capabilities in the early design process', *International Journal of Precision Engineering and Manufacturing*, 21(2), pp. 329–345.
- Rias, A. L., Bouchard, C., Segonds, F., Vayre, B. and Abed, S. (2017) 'Design for additive manufacturing: Supporting intrinsic-motivated creativity', in *Emotional Engineering*, 5, pp. 99–115.
- Rifaie, M. Al and Mian, A. (2018) 'Compression behavior of three-dimensional printed polymer lattice structures', *Journal of Materials Design and Applications*, 0(0), pp. 1–11.
- Rivin., V. R. F. and E. I. (2007) 'Innovation on demand: New product development using TRIZ', *Journal of Product Innovation Management*, 24(6), pp. 635–636.
- Rosen, D. W. (2007) 'Design for additive manufacturing: A method to explore unexplored regions of the design space', in *18th Solid Freeform Fabrication Symposium, SFF 2007*, pp. 402–415.
- Rosen, D. W. (2014) 'Research supporting principles for design for additive manufacturing: This paper provides a comprehensive review on current design principles and strategies for AM', *Virtual and Physical Prototyping*, 9(4), pp. 225–232.
- Rupal, B. S., Ahmad, R. and Qureshi, A. J. (2018) 'Feature-based methodology for design of Geometric benchmark test artifacts for additive manufacturing processes', *Procedia CIRP*, 70, pp. 84–89.
- Sabiston, G. and Kim, I. Y. (2020) '3D topology optimization for cost and time minimization in additive manufacturing', *Structural and Multidisciplinary Optimization*. *Structural and Multidisciplinary Optimization*, 61(2), pp. 731–748.
- Salonitis, K. (2016) 'Design for additive manufacturing based on the axiomatic design method', *International Journal of Advanced Manufacturing Technology*, 87(1–4), pp. 989–996.
- Santos, A. and Alves, T. (2019) 'Dimensional accuracy for additive manufacturing', in *Conference: 25 Th ABCM International Congress Mechanical Engineering*, pp. 1–11.
- Sapuan, S. M. (2017) *Conceptual Design Methods for Composites, Conceptual Design in Concurrent Engineering for Composites*. Elsevier Inc.

- Scaravetti, D., Dubois, P. and Duchamp, R. (2008) 'Qualification of rapid prototyping tools: Proposition of a procedure and a test part', *International Journal of Advanced Manufacturing Technology*, 38(7–8), pp. 683–690.
- Schmelzle, J., Kline, E. V, Dickman, C. J., Reutzel, E. W., Jones, G. and Simpson, T. W. (2019) '(Re) Designing for part consolidation : Understanding the challenges of etal additive manufacturing', *Journal of Mechanical Design*, 137, pp. 1–12.
- Schmidt, C. L. and Fornasini, G. (2015) 'A call for fdm design rules to include road deposition', in *Proceedings of the 20th International Conference on Engineering Design (ICED 15)*, 1, pp. 1–12.
- Seaman, S., Kerezoudis, P., Bydon, M., Torner, J. C. and Hitchon, P. W. (2017) 'Titanium vs. polyetheretherketone (PEEK) interbody fusion: Meta-analysis and review of the literature', *Journal of Clinical Neuroscience*, 44, pp. 23–29.
- Shi, J. (1996) 'Composite materials in aerospace design', *Materials & Design*, 17(1), pp. 56.
- Shick, T. M., Abdul Kadir, A. Z., Ngadiman, N. H. A. and Ma'aram, A. (2019) 'A review of biomaterials scaffold fabrication in additive manufacturing for tissue engineering', *Journal of Bioactive and Compatible Polymers*, 34(6), pp. 415–435.
- Shirwaiker, R. A. and Okudan, G. E. (2008) 'Triz and axiomatic design: A review of case-studies and a proposed synergistic use', *Journal of Intelligent Manufacturing*, 19(1), pp. 33–47.
- S Sikder, S., Barari, A. and Kishawy, H. A. (2014) 'Effect of adaptive slicing on surface integrity in additive manufacturing', *Proceedings of the ASME Design Engineering Technical Conference*, 1A, pp. 1–10.
- Slapnik, J., Bobovnik, R., Mešl, M. and Bolka, S. (2016) 'Modified polylactide filaments for 3D printing with improved mechanical properties', *Contemporary Materials*, 2, pp. 142–150.
- Spreafico, C. and Russo, D. (2016) 'TRIZ Industrial Case Studies: A Critical Survey', *Procedia CIRP*, 39, pp. 51–56.
- Stoof, D. and Pickering, K. (2018) 'Sustainable composite fused deposition modelling filament using recycled pre-consumer polypropylene', *Composites Part B: Engineering*, 135, pp. 110–118.
- Suh, N. P. (1998) 'Engineering design axiomatic design theory for systems',

- Research in Engineering Design*, 10(4), pp. 189–209.
- Tang, Y. and Zhao, Y. F. (2016) ‘A survey of the design methods for additive manufacturing to improve functional performance’, *Rapid Prototyping Journal*, 22(3), pp. 569–590.
- Tanikella, N. G., Wittbrodt, B. and Pearce, J. M. (2017) ‘Tensile strength of commercial polymer materials for fused filament fabrication 3D printing’, *Additive Manufacturing*, 15(2010), pp. 40–47.
- Tao, Y., Wang, H., Li, Z., Li, P. and Shi, S. Q. (2017) ‘Development and application of wood flour-filled polylactic acid composite filament for 3d printing’, *Materials*, 10(4), pp. 1–6.
- Thompson, M. K. and Mischkot, M. (2015) ‘Design of test parts to characterize micro additive manufacturing processes’, *Procedia CIRP*, 34, pp. 223–228.
- Thompson, M. K., Moroni, G., Vaneker, T., Fadel, G., Campbell, R. I., Gibson, I., Bernard, A., Schulz, J., Graf, P., Ahuja, B. and Martina, F. (2016) ‘Design for Additive Manufacturing: Trends, opportunities, considerations, and constraints’, *CIRP Annals - Manufacturing Technology*, 65(2), pp. 737–760.
- Tian, C., Li, X., Chen, Z., Guo, G., Wang, L. and Rong, Y. (2020) ‘Study on formability, mechanical property and finite element modeling of 3D-printed composite for metal-bonded diamond grinding wheel application’, *Journal of Manufacturing Processes*, 54, pp. 38–47.
- Torosian, M. (2022) *What is Design for Additive Manufacturing*, JABIL. Available at: <https://www.jabil.com/blog/design-for-additive-manufacturing.html> (Accessed: 1 January 2022).
- Triyono, J., Sukanto, H., Saputra, R. M. and Smaradhana, D. F. (2020) ‘The effect of nozzle hole diameter of 3D printing on porosity and tensile strength parts using polylactic acid material’, *Open Engineering*, 10, pp. 762–768.
- Urbanic, R. J. and Hedrick, R. (2016) ‘Fused deposition modeling design rules for building large, complex components’, *Computer-Aided Design and Applications*, 13(3), pp. 348–368.
- Valjak, F. and Bojčetić, N. (2019) ‘Conception of design principles for additive manufacturing’, in *Proceedings of the International Conference on Engineering Design, ICED*, pp. 689–698.
- Vaneker, T., Bernard, A., Moroni, G., Gibson, I. and Zhang, Y. (2020) ‘Design for additive manufacturing: Framework and methodology’, *CIRP Annals*, 69(2),

pp. 578–599.

- Vayre, B., Vignat, F. and Villeneuve, F. (2012) ‘Designing for additive manufacturing’, *Procedia CIRP*, 3(1), pp. 632–637.
- Vicente, M. F., Canyada, M. and Conejero, A. (2015) ‘Identifying limitations for design for manufacturing with desktop FFF 3D printers’, *International Journal of Rapid Manufacturing*, 5(1), p. 116.
- Wang, X., Li, S., Fu, Y. and Gao, H. (2016) ‘Finishing of additively manufactured metal parts by abrasive flow machining’, *Solid Freeform Fabrication 2016: Proceedings of the 27th Annual International Solid Freeform Fabrication Symposium - An Additive Manufacturing Conference, SFF 2016*, pp. 2470–2472.
- Wang, Y., Zhou, Y., Lin, L., Corker, J. and Fan, M. (2020) ‘Overview of 3D additive manufacturing (AM) and corresponding AM composites’, *Composites Part A*, 139, p. 106114.
- Wiberg, A., Persson, J. and Ölvander, J. (2021) ‘An optimisation framework for designs for additive manufacturing combining design, manufacturing and post-processing’, *Rapid Prototyping Journal*, 27(11), pp. 90–105.
- Yakout, M., Elbestawi, M. A. and Veldhuis, S. C. (2018) ‘A review of metal additive manufacturing technologies’, *Solid State Phenomena*, 278, pp. 1–14.
- Yaman, U. (2018) ‘Shrinkage compensation of holes via shrinkage of interior structure in FDM process’, *International Journal of Advanced Manufacturing Technology*, 94(5–8), pp. 2187–2197.
- Yang, S., Page, T. and Zhao, Y. F. (2019) ‘Understanding the role of additive manufacturing knowledge in stimulating design innovation for novice designers’, *Journal of Mechanical Design, Transactions of the ASME*, 141(2), pp. 1–12.
- Yang, S., Tang, Y. and Zhao, Y. F. (2016) ‘Assembly-level design for additive manufacturing: Issues and benchmark’, *Proceedings of the ASME Design Engineering Technical Conference*, 2A-2016(August).
- Yang, S. and Zhao, Y. F. (2015) ‘Additive manufacturing-enabled design theory and methodology: a critical review’, *International Journal of Advanced Manufacturing Technology*, 80(1–4), pp. 327–342.
- Yang, T.-C. and Yeh, C.-H. (2020) ‘Morphology and mechanical properties of 3D printed wood fiber / polylactic acid composite parts using’, *Polymers*,

12(1334), pp. 2–13.

- Yasa, E. and Ersoy, K. (2020) ‘A review on the additive manufacturing of fiber reinforced polymer matrix composites’, in *Solid Freeform Fabrication 2018: Proceedings of the 29th Annual International Solid Freeform Fabrication Symposium - An Additive Manufacturing Conference, SFF 2018*, pp. 1024–1033.
- Yeoh, T.S. Yeoh, T.J. Song, C. (2009) *TRIZ systematic innovation in manufacturing*.
- Yilmaz, S. and Seifert, C. M. (2010) ‘Cognitive heuristics in design ideation’, *11th International Design Conference, DESIGN 2010*, (May 2010), pp. 1007–1016.
- Yuan, H., Xing, K. and Hsu, H. Y. (2019) ‘Generate basic conceptual solutions for 3DPVS via utilizing TRIZ’, *Bio-Design and Manufacturing*. Springer Singapore, 2(2), pp. 76–95.
- Zaman, U. K. uz, Boesch, E., Siadat, A., Rivette, M. and Baqai, A. A. (2019) ‘Impact of fused deposition modeling (FDM) process parameters on strength of built parts using Taguchi’s design of experiments’, *International Journal of Advanced Manufacturing Technology*. 101(5–8), pp. 1215–1226.
- Zhang, K. and Cheng, G. (2020) ‘Three-dimensional high resolution topology optimization considering additive manufacturing constraints’, *Additive Manufacturing*. Elsevier, 35(August 2019), p. 101224.

LIST OF PUBLICATIONS

Journal with Impact Factor

1. Deja, M., Zielinski, D., Abdul Kadir, A.Z., & **Mazlan, S.N.H.** (2021). Applications of additively manufactured tools in abrasive machining-a literature review. *Materials*, 14 (1318), pp. 2-24. **(Q2, IF: 3.623)**
2. **Mazlan, S.N.H.**, Abdul Kadir, A.Z., Deja, M., Zielinski, D., & Alkahari, M.R. (2021) Development of technical creativity featuring modified TRIZ-AM inventive principle to support additive manufacturing. *Journal of Mechanical Design*, 144(5), pp. 052001-0520015. **(Q2, IF:3.251)**.
3. **Mazlan, S.N.H.**, Abdul Kadir, A.Z., Ngadiman, N.H.A., & Alkahari, M.R. (2020). Evaluation of geometrical benchmark artifacts containing multiple overhang lengths fabricated using material extrusion technique, *Journal of Mechanical Engineering and Sciences*, 14(3), pp. 7296-7308. **(Indexed by WOS)**
4. Maidin, N.A., Abdul Rahman, M.H., Ahmad, M.N., **Mazlan, S.N.H.**, Wahid, M.K., Othman, M.H., & Jumaidin, R. (2020). Design for manufacturability (DFM) of 3D printed parts fabricated using open source 3D printer, *International Journal of Integrated Engineering*, 12(5), pp.203-209. **(Indexed by WOS)**
5. Maidin, N.A., Abdul Rahman, M.H., Ahmad, M.N., Osman, M.H., & **Mazlan, S.N.H.** (2019). Airco wind turbine prototype design and development, *International Journal of Recent Technology and Engineering*, 8(5):79-85. **(Indexed by SCOPUS)**.
6. **Mazlan, S.N.H.**, Alkahari, M.R., Ramli, F., & Sudin, M.N. (2018). Manufacturability of mechanical structure fabricated using entry level 3D printer, *Journal of Mechanical Engineering*, 5(3): 98-122. **(Indexed by SCOPUS)**
7. **Mazlan, S.N.H.**, Alkahari, M.R., Ramli, F., & Maidin, N.A. (2018). Surface finish and mechanical properties of parts after blow cold vapor treatment, *Journal of Advance Science Letter*, 48(2): 148-155. **(Indexed by SCOPUS)**

8. **Mazlan, S.N.H.**, Abdul Kadir, A.Z., Yusof, Y., & Wahab, M.S., (2020). Overhang analysis fabricated using fused deposition modelling technique, *Journal of Advanced Industrial Technology and Application*, 1(1), pp. 38-47.
9. **Mazlan, S.N.H.**, Abdul Kadir, A.Z., Ngadiman, N.H.A., Yusof, Y., & Wahab, M.S., (2019). Optimisation of truss collinear lattice structure fabricated using fused deposition modeling technique, *International Journal of Innovative Technology and Exploring Engineering*, 9(2), pp.1-7.
10. **Mazlan, S.N.H.**, Abdul Kadir, A.Z., Md Sirat., R., Mohd Saad, R., & Muhamad Z., (2021). Manufacturability Analysis of Strut Lattice Design Using PLA-based Composite Material. *Jurnal Mekanikal*, 44(02), 46–61.

Proceedings and Conferences

1. Miao, L., Abdul Kadir, A.Z., **Mazlan, S.N.H.**, Sudin, I., Md Sirat., R., & Ngadiman, N.H.A., (2022). Development and application of TRIZ-DFAM contradiction matrix: A case study of juice squeezer. Sustainable and Integrated Engineering International Conference (SIE 2022). Accepted.
2. **Mazlan, S.N.H.**, Alkahari, M.R., Ramli, F., & Maidin, N.A., (2018). Influence of inert gas assisted 3D printing machine on the surface roughness and strength of printed component. Proceedings of Mechanical Engineering Research Day 2018, 154-155.
3. Alkahari, M.R., **Mazlan, S.N.H.**, Ramli, F., & Maidin, N.A., (2017). Manufacturability of overhang structure using open source 3D printer, Proceedings of Mechanical Engineering Research Day 2017, 158-159.
4. **Mazlan, S.N.H.**, Alkahari, M.R., Ramli, F., & Maidin, N.A., (2016). Effects of laser post-processing on surface roughness of fused deposition modelling (FDM) part. Innovative Research and Industrial Dialogue 2016.

Book Chapter

1. Additive Manufacturing for Process Optimization Using Architecture Lattice Structures (2020) – Indexed in WOS
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