IMPLICATIONS OF ADDITIVE MANUFACTURING APPLICATIONS FOR INDUSTRIAL DESIGN PROFESSION FROM THE PERSPECTIVE OF DESIGNERS

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ABSTRACT

IMPLICATIONS OF ADDITIVE MANUFACTURING APPLICATIONS FOR INDUSTRIAL DESIGN PROFESSION FROM THE PERSPECTIVE OF INDUSTRIAL DESIGNERS

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The purpose of this study was to investigate the implications of additive manufacturing on industrial design profession and designers through an explorative study. Through a literature survey, implications of additive manufacturing technologies on industrial designers and industrial design profession were explored. Expanding literature survey with on-line searches, several experimental and commercial application examples of rapid manufacturing of products were identified. These identified examples were then used for a qualitative evaluation on the implications of additive manufacturing for the industrial design profession and designers through semi-structured interviews conducted with seven professional industrial designers having experience with rapid manufacturing in Istanbul Turkey. The research concluded with significant implications of additive manufacturing having the potential to cause paradigm shifts in industrial designer's role, definition of the profession and design process. The conclusions derived include suggestions to exploit the potential brought by these technologies and their applications.

Keywords: industrial design, additive manufacturing, rapid manufacturing, rapid prototyping

ÖZ

TASARIMCILAR AÇISINDAN KATKILI İMALAT UYGULAMALARININ ENDÜSTRİYEL TASARIM MESLEĞİ ÜZERİNE ETKİLERİ

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Bu çalışmanın amacı, keşfedici bir çalışma ile katkılı imalatın endüstriyel tasarım mesleği ve tasarımcılar üzerindeki etkisini araştırmaktır. Literatür taraması yoluyla, endüstriyel tasarımcılar ve endüstriyel tasarım mesleği üzerinde katkılı imalat teknolojilerinin etkileri incelenmiştir. Literatür taraması on-line araştırmalar ile genişletilerek ürünlerin hızlı imalatın çeşitli deneysel ve ticari uygulama örnekleri belirlenmiştir. Tespit edilen bu örnekler, İstanbul'da bulunan ve hızlı imalat deneyimi olan yedi profesyonel endüstri ürünleri tasarımcısıyla yapılan yarı-yapılandırılmış görüşmeler yoluyla hızlı imalatın endüstriyel tasarım mesleği ve tasarımcılar üzerindeki olası sonuçları hakkında niteliksel değerlendirme için kullanılmıştır. Araştırma, katkılı imalatın endüstriyel tasarımcının rolü, meslek ve tasarım sürecinin tanımlanması gibi konularda paradigma değişimlerine yol açma potansiyeline sahip olduğu yönünde sonuçlanmıştır. Elde edilen sonuçlar bu teknolojiler ve uygulamalarının getirdiği potansiyelden faydalanmak konusunda önerileri içermektedir.

Anahtar Kelimeler: endüstriyel tasarım, katkılı imalat, hızlı imalat, hızlı prototipleme

To My Father

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TABLE OF CONTENTS

ABSTRACT iv

ÖZ vi

DEDICATION viii

ACKNOWLEDGEMENTS ix

TABLE OF CONTENTS x

LIST OF TABLES xv

LIST OF FIGURES xvi

CHAPTERS

1 INTRODUCTION 1

1.1 Background 1

1.2 Aim and Scope 4

1.2.1 Aim 4

1.2.2 Research Questions 4

1.3 Methodology 5

1.4 Structure of Thesis 5

1.5 Terminology 6

2 ADDITIVE MANUFACTURING TECHNOLOGIES & APPLICATIONS 8

2.1 Brief History of RP 8

2.2 Additive Manufacturing Processes 11

2.2.1 Liquid Based Processes 13

2.2.2 Powder Based Processes 14
2.2.3 Solid Based Processes 14
2.3 Industrial Applications 15
2.3.1 Visualization and Verification 15
2.3.2 Casting 16
2.3.3 Aerospace Industry 18
2.3.4 Automotive Industry 21
2.3.5 Dental aligners 24
2.3.6 Hearing Aids 25
2.3.7 Medical & Bioengineering 27
2.4 Implications of Additive Manufacturing for Industrial Design 30
2.4.1 Design and Manufacturing 30
2.4.2 Functionally Graded Materials 37
2.4.3 Personal Fabrication - Post Industrial Design 39
2.4.4 Designer as individual 43
2.4.5 Mass Customization 45
2.4.6 Discussions 46
3 EMERGING RAPID MANUFACTURING APPLICATIONS IN PRODUCT DESIGN .. 49
3.1 Introduction 49
3.2 Brief History of Rapid Manufacturing in Product Design 50
3.3 Endless Series 51
3.4 Freedom of Creation (FOC) 54
3.5 The Fall of the Damned Lamp 56
3.6 My Brain Lamp 57
3.7 Structural Ornament 58

3.8 Nervous System 61
3.9 N12 Bikini 65
3.10 Fashion - Iris Van Herpen 69
3.11 Online 3D printing services – Shapeways 70
3.12 Participatory and open source design space – Thingiverse 71
3.13 Summary of Emerging Applications in Rapid Manufacturing 74
4 STUDY ON BARBAR DESIGNERS 75
4.1 Introduction 75
4.2 Methodology 75
4.2.1 Aim 75
4.2.2 Selection of Participants 76
4.2.3 About Barbar Design Initiative 77
4.2.4 Flow of the Interview 80
4.2.5 Analysis of the Interview 81
4.3 Barbar Designers Analysis 82
4.3.1 General Perspective of Designers 83
4.3.2 Benefits 87
4.3.3 Concerns 91
4.3.4 Paradigm Shifts 95
4.3.5 Personal Fabrication 99
4.3.6 Environmental Effects 100
4.3.7 Potential 100
4.3.8 Empowering Designer as an Individual 102
4.3.9 Design Process 104
4.3.10 Innovation Need 106
4.3.11 Costs 107

4.3.12 Applications 108
4.3.12.1 My Brain Lamp and MGX Damned Lamp 109
4.3.12.2 Structural Ornament 110
4.3.12.3 Freedom of Creation Chair 113
4.3.12.4 Nervous System 113
4.3.12.5 Endless Series 115

5 CONCLUSIONS 117

5.1 Overview 117
5.1.1 Acceptance Rapid Manufacturing in Consumer Products 118
5.1.2 Improvements in Additive Manufacturing Processes for Industrial Design 119
5.1.3 Industrial Designer Realizing the Potential of Additive Manufacturing 119
5.1.4 Expansion of Industrial Designer's Application Space 121
5.1.5 Design Education 122
5.1.6 Parametric Design and Design Systems 123
5.1.7 Concerns on the Usage of Digital Tools 124
5.1.8 Personal Fabrication 125
5.1.9 Problems 126
5.1.10 Limitations of Rapid Manufacturing 127

5.2 Research Questions Revisited 128

5.3 Limitations of Study 131

5.4 Further Study 132

REFERENCES 135

APPENDICES

A………………. 141

B……………….….. 156

VITA………….. 161

LIST OF TABLES

TABLES

Table 2.1 Historical Development of RP and related technologies (Chua, Leong, and Lim 2010, 7) 9

Table 4.1 Demographics of interviewed Barbar Designers................................. 77

Table 5.1 Rapid manufacturing applications that are presented to the designers (in the order of appearance) 157

LIST OF FIGURES

FIGURES

Figure 2.1 The first additive manufacturing technology, patented by Hull............9
Figure 2.2 Application areas of RP models..11
2.2.1 Figure 2.3 Major rapid manufacturing processes based on Hopkinson and Dickens' classification 13
Figure 2.4 Investment casting and lost wax method..17
Figure 2.5 3D printed (left) and manufactured (right)differential housing by investment casting...17
Figure 2.6 Pattern making by ThermoJet process for jewelry manufacturing 18
Figure 2.7 Pattern (left) and the manufactured (right) ring via SLA 18
Figure 2.8 Decision tree for qualifying RM system in aeronautical industry 19
Figure 2.9 Cooling ducts with rapid manufacture 20
Figure 2.10 Capacitor box for the International Space Station...........................20
Figure 2.11 Brake duct component of a Formula 1 car from composite Windform material 21
Figure 2.12 Cooling duct of a Formula 1 car 22
Figure 2.13 Wing end-plate flick of a F1 car...23
Figure 2.14 Formula Student Car 2004 The Loughborough University 23
Figure 2.15 Dental aligners manufactured by combining RM with post processes 24
Figure 2.17 Hearing aid within scanned point cloud of ear 26
Figure 2.16 Rapid manufactured hearing aid...26
Figure 2.18 Reconstruction of the defected part by AM and investment casting 27
Figure 2.19 Tumor illustrated in a different material inside the skull.................28

Figure 2.20 CAD design, fabrication and usage of surgical cutting guides (left), fitting test and placement of the implant 29
Figure 2.21 Custom made prosthesis covers 29
Figure 2.22 Scaffold construction (left) and various scaffold structures (right) ... 30
Figure 2.23 Conventional (upper) and optimized (bottom) models 33
Figure 2.24 Aircraft duct designed for conventional (left) and AM (right) processes 34
Figure 2.25 Concrete column section 3D printed with variable density 38
Figure 2.26 Concrete block 3D printed with variable density 38
Figure 2.27. Hybrid variable materials by Bread 38
Figure 2.28 Reprap 3D printer 40
Figure 2.29 Customized body fitting car seat 45
Figure 3.1 Endless series furniture manufactured with FDM 51
Figure 3.2 5-axis robot and its extruder head used in the manufacturing process of Endless series furniture 53
Figure 3.3 Shower scrub manufactured via SLS 55
Figure 3.4 Commissioned chair manufactured via SLS and coated with glossy lacquer 55
Figure 3.5 Damned lamp by Luc Merx 56
Figure 3.6 My Brain Lamp manufactured via SLS 57
Figure 3.7 Structural Ornament chairs generated by software 58
Figure 3.8 Calculation process of the internal structures according to the given initial model 60
Figure 3.9 Uniquely generated Hypae lamps 61
Figure 3.10 Various designs of Nervous System 63
Figure 3.11 Customization interface of a bracelet design. 64
Figure 3.12 Customization of the mesh by modifying the 2D shape and material 64

Figure 3.13 Mesh modified extremely by the researcher in the design interface 65
Figure 3.14 Bikini manufactured with SLS polyamide. 65
Figure 3.15 Flexibility of the 3D printed fabric. 66
Figure 3.16 Two surfaces composed of circles which are connected with cylinder extrusions 67
Figure 3.17 Mesh-like structure that connects the circular 68
Figure 3.18 The resulting bikini and its coverage 68
Figure 3.19 Various pieces made of polyamide manufactured with SLS 69
Figure 3.20 Shapeways' tools for customizing products (left) and gallery of products available for sale (right). 71
Figure 3.21 Thingiverse: An online sharing space for open-source 3D printable models and designs 73
Figure 4.1 Various products realized by Barbar Designers 79
Figure 4.2 Designer A's reasoning for choosing RM for the manufacturing method of a product 88
Figure 4.3 Interaction between industrial designers and the development of additive manufacturing technologies according to designer E. 97
Figure 4.4 The nature of a rapid prototyping model according to designer E. ... 106
Figure 4.5 Evaluation of artistic and utilitarian side of design 112
Figure A.1 Stereolithography process 142
Figure A.2 PolyJet process 143
Figure A.3 Direct Light Processing process 144
Figure A.4 Selective Laser Sintering process 145
Figure A.5 3D printing process 147
Figure A.6 Fused Metal Deposition process 148
Figure A.7 Electron Beam Melting process 149
Figure A.8 Selective Masking Sintering process 150

Figure A.9 Selective Inhibition Sintering process 151
Figure A.10 Electrophotographic Layered Manufacturing process.................... 152
Figure A.11 High Speed Sintering process 152
Figure A.12 Fused Deposition Modeling process 153
Figure A.13 Contour crafting extruder head.. 154
Figure A.14 Sheet stacking process 155

CHAPTER 1

INTRODUCTION

1.1 Background

> "What other technology can get an artist, a medical clinician, an engineer and an environmental champion excited in the same way?" (Hopkinson, Hague, and Dickens 2006, 2)

Rapid manufacturing (also referred as direct digital manufacturing), or additive manufacturing as a broader term, brings many changes to every industry that it enters (Morris 2007). The concept of additive manufacturing processes, combined with the developments in material properties and involved processes have a potential of revolutionizing the way we perceive manufacturing of products. Morris (2007) states that this revolution might be coming sooner than expected and many other industry experts share a similar vision that rapid manufacturing (RM) will some day become a complete reality. In fact, for some specific applications rapid manufacturing has been realized (which are explored in Chapter two of this thesis).

Industrial designers have been using this technology for making prototypes of designs they make to evaluate problems related with form, fit and function together with their usability and present their ideas to their clients or communicate their design intend with other departments such as engineering, marketing (McDonald, Ryall, and Wimpenny 2001, 35). Although the initial usage intent of the rapid prototyping (RP) machines was model making for evaluation and visualization purposes (Gibson, Rosen, and Stucker 2009, 3), it did not take much time to experiment with these machines for the manufacturing of functional end use parts.

In the late 90's and beginning of 2000's the usage of additive manufacturing technologies has started to be seen in the production of final products, apart from the prototypes. Freedom of Creation, a multidisciplinary collective group of mainly industrial designers, has been experimenting with this technology for a decade. Their products mainly consist of lighting apparel, textiles, furniture and decorative objects as well as iPhone cases and personal accessories (Kytannen 2006, 276).

Additive manufacturing brings many benefits starting with the removal of the design for manufacturing constraints and extends these benefits for industrial design to many such as form freedom, no tooling requirements, on demand manufacturing, no minimum order quantities, extreme complexity, combining multiple parts into one, functionally graded materials. Such benefits bring many possibilities both related with design and manufacturing that directly affect the design process of an industrial designer (as it will be illustrated in chapters two and three).

Despite the remarkable advantages brought by additive manufacturing and its successful applications as rapid manufacturing in aerospace, automotive, medical and some other specialized industries (Hopkinson, Hague, and Dickens 2006; Gibson, Rosen, and Stucker 2009; Chua, Leong, and Lim 2010), it is observed from the literature reviewed that the applications in industrial design are mainly confined in prototyping and evaluation purposes rather than for end use products. Thus, the potential of rapid manufacturing is mainly unexplored by the industrial design profession. Nevertheless, there has been a continuous effort towards the experimental usages of this technology starting with the works of Janne Kytannen (Freedom of Creation) as mentioned above. The reachability to these tools of manufacture for experimental reasons however, has been limited due to the high initial costs of rapid prototyping machines and related materials. Thus, it can be accepted as normal to face with such few explorations of the possibilities brought by additive manufacturing by industrial designers.

Starting from 2004 (RepRap 2012), in which an open source low-cost 3D printer project called RepRap initiated by Dr. Adrian Bowyer in Bath University, there opened a new door for designers to reach additive manufacturing technologies. RepRap, being fully an open-source project, works on the same principles with rapid prototyping machines working with the principle of fused deposition modeling (explained in Chapter 2). In less than a decade, it has grown into various design iterations and lead to other 3D printer projects like Bits from Bytes, MakerBot, Ultimaker, Fab@Home and many more. Although not being state of the art, these machines enable their users to try whatever comes to their minds since the materials are very cheap when compared to the professional machines. Apart from the personal 3D printers, emerging online 3D printing services like Shapeways, Sculpteo, i.Materialise and Kraftwurx let users to upload their designs as 3D models and sell them as products that are manufactured from materials like polyamide, ceramics, and alumide upon order. Such developments in the additive manufacturing field not only facilitates the reach of technology by the industrial designer, but also empowers the ordinary user with tools of the professional.

These developments lead to questions such as: Where does an industrial designer stand among these areas?, Is industrial design profession going to go through a change?

Literature on the additive manufacturing is mainly focused on the technical, engineering and commercial aspects of the additive and rapid manufacturing (Pfeiffer 2009, 2). Although studies on the integration of rapid prototyping in design process, design education (Evans 2002; Jones and Richey 2000; Hallgrimsson 2012) and critical reviews towards the spread of additive manufacturing together with personal fabrication exist (Atkinson 2010), a thorough study concerning the implications for industrial designers and industrial design profession is missing.

1.2 Aim and Scope

1.2.1 Aim

Concerning the backround of the usage of rapid manufacturing in product design, this study aims to define and evaluate the implications of these technologies on industrial designers and industrial design profession. This research focuses on gaining an insight into the implications of newly emerging rapid manufacturing of products for industrial design and designers.

A group of designers who use these technologies to manufacture end use products are selected. They are interviewed to obtain a point of view of the industrial design profession with a focus on the additive manufacturing field.

1.2.2 Research Questions

Main question:

- What are the implications of additive manufacturing technologies for industrial designers?

Sub-questions:

- How does additive manufacturing technologies empower the industrial designer?
- What paradigm shifts do additive manufacturing technologies cause in industrial design profession?
- How industrial design professionals perceive personal fabrication brought by additive manufacturing?

1.3 Methodology

In order to be able to evaluate the implications of additive manufacturing technologies on the industrial design profession an exploratory research is conducted. Current industrial usages of additive manufacturing (AM) are explored through literature with a brief history of the technology.

The main focus of the research consists of two parts: exploration of emerging applications of rapid manufacturing (RM) and an empirical study conducted on a design initiative called Barbar Designers in Turkey based on the emerging applications of rapid manufacturing. A semi-structured interview was conducted with seven designers focusing on the implications of such applications and the use of AM technology for industrial design profession and designers. The examples chosen for the interview (Chapter 3) consist of experimental and commercial applications of this technology that are mainly realized by individual designers or group of designers. Then, these applications were used to acquire perspectives from Barbar Designers for the answers to the research questions.

1.4 Structure of Thesis

The theme of the thesis is an explorative study aimed at mapping current and possible future implications of rapid manufacturing technologies for industrial design and designers.

Chapter 2 embodies the literature review concerning a brief historical and technical introduction to additive manufacturing technologies together with common industrial applications. Related literature with the implications of AM for industrial design profession is also explored.

Chapter 3 explores emerging applications of rapid manufacturing in product design. The examples included cover experimental product development processes and commercialized products together with newly emerging online spaces through which designers can sell their designs manufactured via rapid manufacturing (RM) on demand.

In the fourth Chapter, the standpoints of the interviewed Barbar Designers are presented including all the implications stated by them. The perspectives of these designers are collected under general titles to establish a unified perspective of industrial design professionals to the field.

In the last chapter, the findings of the Barbar study are evaluated together with the implications found in the literature and research questions are revisited. Implications for further study are also presented in this chapter.

1.5 Terminology

Additive Manufacturing (AM): In the literature reviewed, use of term “additive manufacturing” varies from the manufacturing of end use products to rapid prototyping aims. This variation shows an unstandardized character on the definition. In this thesis, additive manufacturing is used to mention the manufacturing of an object by adding materials on successive layers with the principles of rapid prototyping machines. This usage of the term in this thesis refers to define a wider usage field of technology.

Rapid Manufacturing (RM): The term “rapid manufacturing” is defined by

Hopkinson, Hague and Dickens (2006, 1) as “the use of computer aided design (CAD)-based automated additive manufacturing process to construct parts that are used directly as finished products or components”. In this thesis, rapid manufacturing is used to refer to the manufacturing of usable products or components that are manufactured using additive manufacturing processes.

Rapid Prototyping (RP): RP term’s usage in this thesis refers to the applications in product development, visual and functional verification processes and the precursor of rapid manufacturing.

3D printing (3DP): Although 3DP is one of the RP technologies in which an inkjet similar printhead jets binder material on a powder based material, in some of the applications discussed in the thesis this is used to refer to manufacturing of end use products via RP machines.

CHAPTER 2

ADDITIVE MANUFACTURING TECHNOLOGIES & APPLICATIONS

2.1 Brief History of RP

Rapid prototyping (RP) has its roots in the developments of the computer industry as well as other technological inventions. The decreasing costs of computers resulted in an increase of its applications even as personal computers. Spread of computers have caused new computer related fields such as computer-aided design (CAD), computer-aided manufacturing (CAM) and computer numerical control machines to emerge and take their places in related industries. Other developments in fields such as manufacturing systems and materials that lead to the rapid prototyping have been essential (Chua, Leong, and Lim 2010, 7). These developments are summarized by Chua, Leong and Lim (2010) in Figure 2.1.

Table 2.1 Historical Development of RP and related technologies (Chua, Leong, and Lim 2010, 7)

Year of inception	Technology
1770	Mechanization
1946	First Computer
1952	First numerical control (NC) machine tool
1960	First commercial laser
1961	First commercial robot
1963	First interactive graphics system (early version of computer-aided design)
1988	First commercial rapid prototyping system

In early 1980s Charles Hull patented the first rapid prototyping system, Stereolithography apparatus (Figure 2.1), and this patent gave rise to the one of the leaders of the industry today, 3D Systems. Although there were more than one patent on the concept of fabricating a 3D object by adding material layer by layer during that period, Hull's patent was generally recognized due to the commercialization of the technology (Gibson, Rosen, and Stucker 2009, 34)

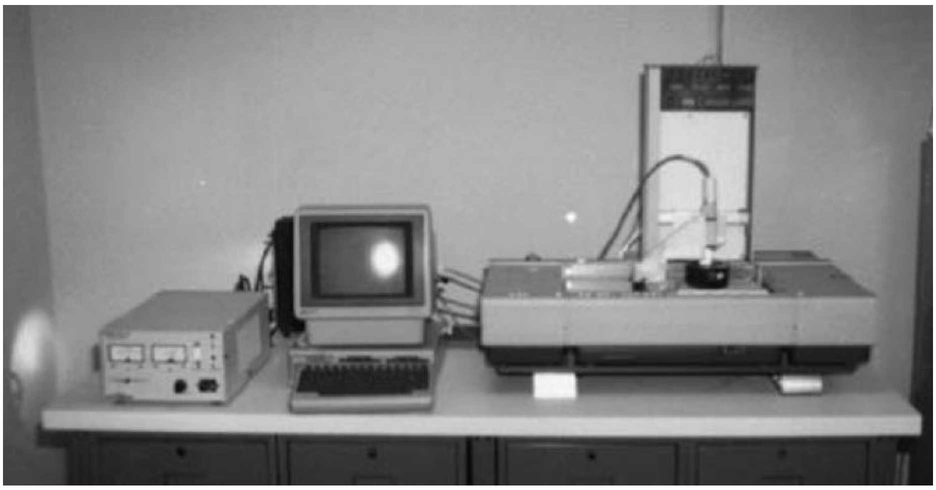


Figure 2.1 The first additive manufacturing technology, patented by Hull (Gibson, Rosen, and Stucker 2009, 34)

Gibson (2009) continues the development of the technology by stating the further patent fillings in 1986 and followed by others that gave rise to several companies and their technologies. One of them is Selective Laser Sintering process, which has become a widely spread technology, developed by DTM, merged with 3D Systems in 2001. Another world spread technology used in rapid prototyping devices, Fused Deposition Modeling (FDM) process, was patented by Scott Crump in 1989 and commercialized by the formation of Stratasys Company. In addition to these patents, a group from MIT patented the 3D Printing (3DP) process. However, instead of forming a company, the group licensed their technology to various companies that applied their technology in different ways. Most successful licensees of the technology are Zcorp followed by Objet in 2001. Zcorp used it to deposit a binder onto a powdered material mainly focusing on low-cost technology whereas Objet used another developed version in which the material (photocurable resins) are directly deposited on a substrate as droplets which harden upon UV light exposure.

Although these commercialized technologies started in USA, many developers of rapid prototyping and manufacturing technologies exist throughout the world. Europe, Japan, Korea, China and Israel are among them. Some passed through settlement disputes with previous companies, some developed derived technologies.

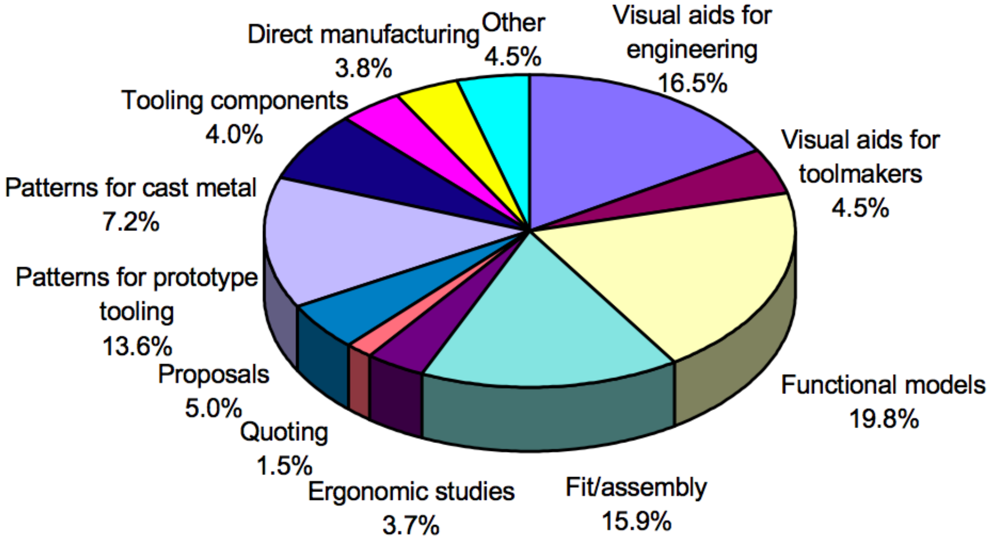


Figure 2.2 Application areas of RP models (Freitag, Wohlers, Philippi 2003, 11)

All of the mentioned technologies are used profoundly in the world of rapid prototyping and now transforming into rapid manufacturing with enhanced materials and increased accuracies of corresponding technologies' machines. Although only commercialized technologies are mentioned in this thesis, there are many experimental studies throughout the world (such as Micro-scale multi-material fabrication, direct write technologies covering fabrication of multi-material components with integrated circuitry, etc.) Since the focus of thesis is not to cover RP technologies in detail. some brief introductions are done on the subject and technological background. An interested reader is encouraged to review Hopkinson et. al. (2006), Gibson et. al. (2009) and Chua et. al. (2010) for further information.

2.2 Additive Manufacturing Processes

Additive manufacturing (AM), in its simplest terms is the construction of a three dimensional object by stacking very thin cross sections of the object in the direction of Z-axis. In this section, common additive manufacturing (AM) processes that are suitable for rapid manufacturing are explored in brief explanations together with their major differences from each other. The aim of this section is to gather a brief understanding of the involved technologies providing a bird’s eye view of the AM industry and the possibilities coming with them rather than to provide in depth information (yet, explanations of the processes in more detail are given in APPENDIX A).

Since rapid manufacturing still is an immature process (Hopkinson and Dickens 2006, 55) most of the processes used today for rapid manufacturing (RM) use the rapid prototyping machines. There exists processes that are developed with rapid manufacturing (RM) in mind, yet they are still in developmental stages. Also, there still are problematic issues related with the wider usage of these processes for rapid manufacturing such as surface quality, material strengths and distortion of material characteristics over time (Hopkinson, Hague, and Dickens 2006; Gibson, Rosen, and Stucker 2009). Throughout the research period in this thesis, it is observed that both the machine manufacturer's and service providers' corporate websites are updated to include rapid manufacturing as a seperate section of their websites.

The difference between RP and RM processes is rising from the developing material properties (polymers, photo-curable resins, elastic materials, metals, ceramics etc.), increase in the accuracy and speed of the machines and post-processing methods. Among several classification methodologies of additive manufacturing technologies (Gibson, Rosen, and Stucker 2009, 27) Hopkinson and Dickens’ classification scheme is used that collect the processes under three general titles: 1) Liquid based systems, 2) Powder based systems, 3) Solid based systems. Although there exists more processes in AM technologies, the ones that are suitable only for visualization purposes are excluded since they cannot yield functional end products. Thus, among the processes included, the capability of producing functional objects is preferred.

In

Figure 2.3, the major processes for rapid manufacturing (RM) are illustrated.

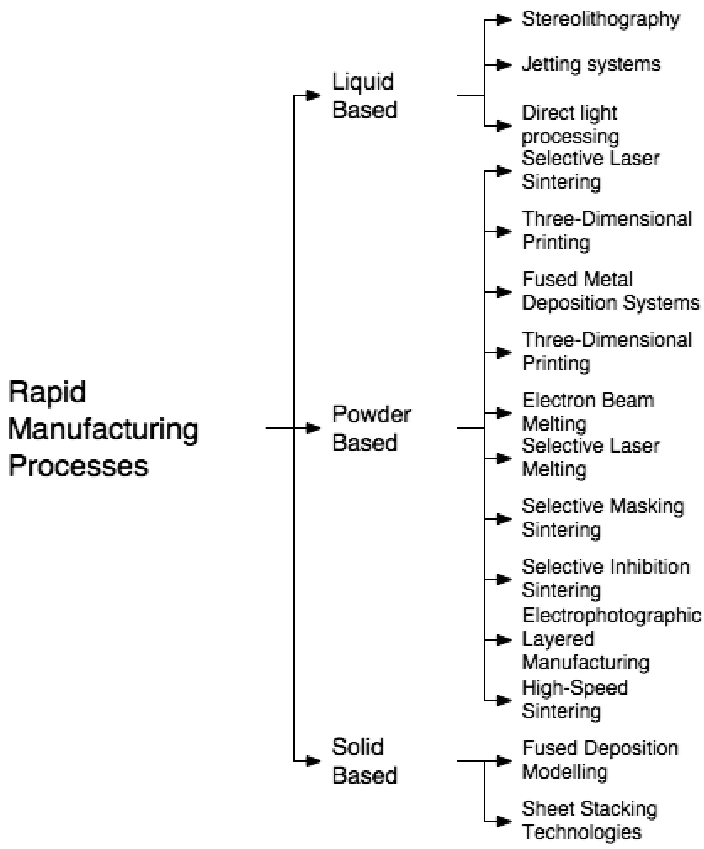


Figure 2.3 Major rapid manufacturing processes based on Hopkinson and Dickens' classification (Hopkinson and Dickens 2006, 55-80)

With the following three subsections, a brief overview of rapid manufacturing processes are given according to Hopkinson and Dickens' (2006) classification. Further explanations and figures of the processes are included in APPENDIX A.

2.2.1 Liquid Based Processes

In liquid based processes, photosensitive polymers are selectively cured to form a solid model. Although the surface quality and accuracy of these models are relatively high that can be comparable to the injection molded counterparts, their physical properties tend to change over time and physical conditions. This change in the physical properties of the models is generally caused by the continuous curing of these photosensitive materials especially when exposed to sunlight. However, as the resins that are being developed for these processes get better in characteristics, these problems tend to decrease.

Since the liquid can not act as a support for the overhangs, additional support structures are needed which are then removed upon completion of the model that require post-processing (Hopkinson and Dickens 2006, 58-63).

2.2.2 Powder Based Processes

The main principle in the powder based systems is either sintering of materials in powder form by lasers, electron beams, infrared radiation or selectively applying a binder material onto this powdered material producing in a "green state" model which is then post-processed.

Powder based processes cover broadest range of materials throughout the additive manufacturing processes. The materials range from tool steels to polymers, ceramics and alloys. Although some of these materials and processes require post-processing to make end use parts, some processes allow the direct manufacturing of end use products without further processes.

In powder based processes, the powdered material acts as a support for the overhanging parts thus generation of support structures are not required (Hopkinson and Dickens 2006, 64-75).

2.2.3 Solid Based Processes

Solid-based processes involve building of parts with a solid material that is either in the form of sheets that are cut and stuck layer by layer, or in the form of a filament that is extruded through a nozzle. These processes are mainly slower and have lower part resolution than powder based and liquid based processes

(Hopkinson and Dickens 2006, 75-79).

2.3 Industrial Applications

In this section, various application fields of additive manufacturing (AM) technologies are explored. It is aimed to obtain a bird's eye view of the industrial uses of the technology rather than investigating them in detail. Another aim is to provide an understanding of to what extend these methodologies can be used as rapid manufacturing. Thus, this understanding will lead to a formation of an insight on applicability of these technologies in industrial design.

It should be noted though some of the applications mentioned in this chapter are completely commercialized whereas some are experimental or in-house developments specialized for corporations' workflow. Since the aim of the chapter is to focus on the rapid manufacturing of products and parts rather than indirect or evaluative processes, some application fields are excluded.

2.3.1 Visualization and Verification

Rapid prototyping technologies are widely used in form fit and function testing of products and machine parts by engineers and industrial designers. 3D printing method also allows full color models to be printed. The usability of the models for functional testing varies with the materials used in the process. With the advancing material properties, RP models have started to be used for the manufacturing of functional prototypes (Evans and Campbell 2003).

Among diverse technologies used in rapid prototyping, Objet's Polyjet technology (Objet Geometries 2012) allows multiple materials to be printed at the same build. This brings in the potential of printing parts with variable mechanical and visual properties. For example, Rubber like materials can be combined with strong and less flexible materials which resemble over-molded parts.

2.3.2 Casting

Because of the limited materials at the time of the invention of rapid prototyping machines, rapid prototyped parts or models have weak mechanical strengths. Secondary processes are used in order to convert these parts to functional components. Investment casting (also called lost wax method) is one of these processes. This process, having an ages old history, is very widely used in industrial applications such as in the casting of metal parts of tools, engines, jewelry. Additive manufacturing technologies provide the master pattern to be used for the casting process. Parts are initially manufactured by fused deposition modeling, selective laser sintering, 3D printing or similar processes that are to be molded from other materials such as metal alloys, titanium and tooling steels (Dimitrov, Schreve, and Beer 2006; Gibson, Rosen, and Stucker 2009; Hopkinson and Dickens 2006).

Molding of the original part is generally produced by dipping the built part which is made of either wax or plastics into a ceramic slurry, creating an expandable mold. Then the ceramic mold shell is placed in an oven burning or melting the original pattern inside the shell. This process is also called lost wax method since the original pattern inside the shell is literally lost. The ceramic shell is preheated according to temperatures needed for the type of metal that is going to be cast. The molten metal is poured into the shell which is then allowed to cool and solidify. Finally the shell is broken and the cast part is removed. Due to the necessity of gateways for the entrance of the liquid metal into the mold, some excessive parts are cut and removed which is then followed by finishing operations like grinding or sandblasting (Chua, Leong, and Lim 2010, 372-373).

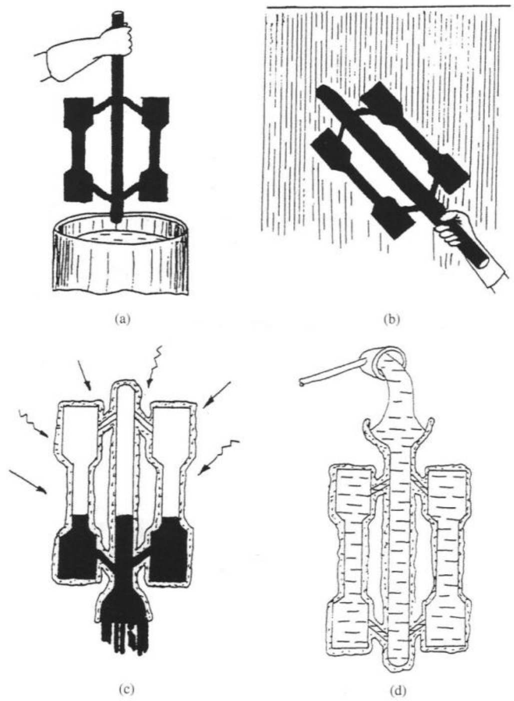


Figure 2.4 Investment casting and lost wax method (Chua, Leong, and Lim 2010, 374)

Figure 2.4 shows casting process in which the part is dipped into ceramic slurry (a) and then coated with refractory grain. This process (a and b) is repeated until the desired shell thickness is established. Then, the shell is heated to meld or burn out the original part. Finally, the desired molten metal is poured into the mold.

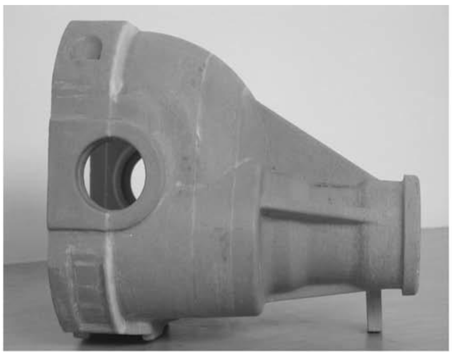


Figure 2.5 3D printed (left) and manufactured (right)differential housing by investment casting (Dimitrov, Schreve, and Beer 2006, 140)

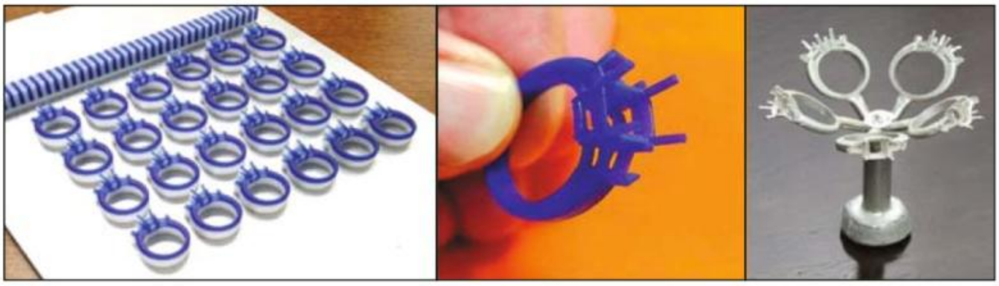


Figure 2.6 Pattern making by ThermoJet process for jewelry manufacturing (Gibson, Rosen, and Stucker 2009, 414)

Figure 2.7 Pattern (left) and the manufactured (right) ring via SLA (Negis 2009)

Jewelry field has become a significant application field for the additive manufacturing. Intricacy of the objects and being a laborious process when manufactured by hand, creates a field that RM can be exploited.

2.3.3 Aerospace Industry

Aerospace industry is another important application field for AM technologies since the amount of the manufactured products are generally in limited amounts. Thus, limited number of production runs and very high costs per item makes this field a feasible sector for the application of AM processes (Fox 2006, 225).

AM in aerospace industry has huge potential in reducing costs. More importantly it may enable designers to create systems, applications and vehicles that are even unimaginable with the conventional processes (Fox 2006, 221) Throughout the industry, AM processes used ranges from master patterns for investment casting processes, drill blankets, models for wind tunnel testing, to rapid manufacturing of parts that are used in real conditions (Fox 2006, 227).

In order for RMed parts to be used in aerospace, qualifications of the parts has to be established since they should survive the real life conditions just as good as their counterparts manufactured with conventional methods. For this, companies such as Boeing and Northrop Grumman developed their own qualification processes for the initial implementation of the technology. According to the results they obtained from the qualification processes, the systems used for RM are modified to achieve the required properties and after these modifications they qualified SLS, SL and FDM processes to be used in their manufacturing pipeline. As stated by Fox (2006) the qualification process is the most important factor in the industry wide implementation of RM. The decision process on whether to qualify the RM system or not is illustrated in Figure 2.8:

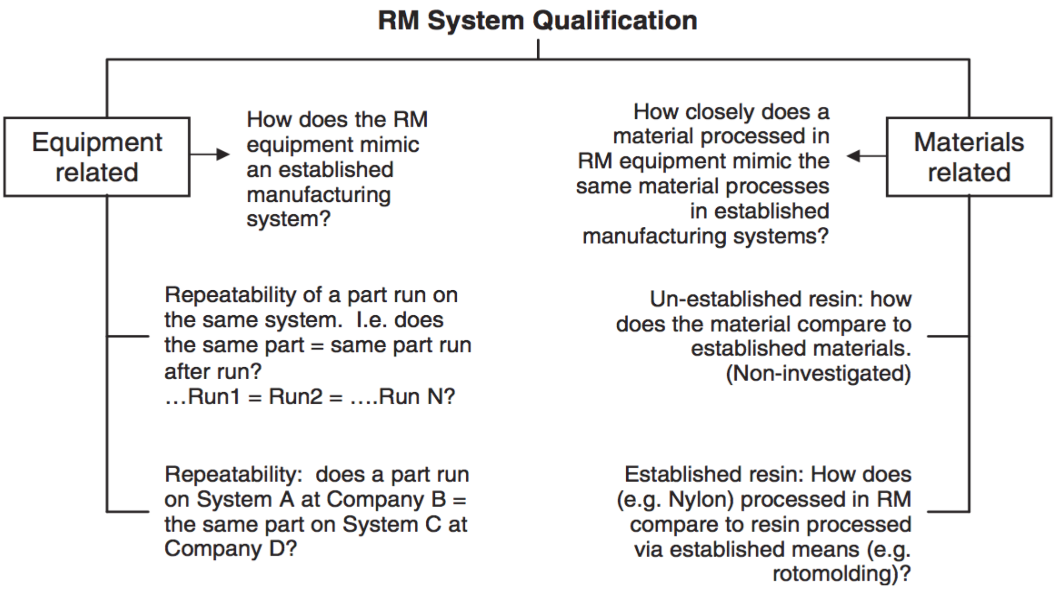


Figure 2.8 Decision tree for qualifying RM system in aeronautical industry (Fox 2006, 227)

Figure 2.9 Cooling ducts with rapid manufacture (Levy,Schindel, and Kruth 2003)

Boeing uses RM to manufacture cooling ducts for space shuttle fleet, F18 fighter jets and even the international space station (Freitag, Wohlers and Philippi 2003, 12). The parts that are harder and costly to manufacture on conventional systems are manufactured on demand via RM in fewer segments and decreased costs while meeting the safety requirements such as fire retardancy (Levy, Schindel, and Kruth 2003).

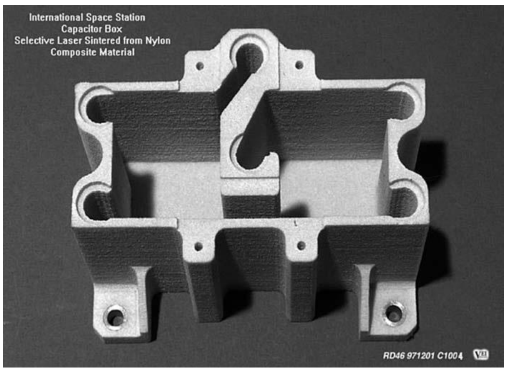


Figure 2.10 Capacitor box for the International Space Station (Spielman 2006)

The capacitor box in Figure 2.10 is a housing for the integral system of International Space Station manufactured using SLS by Rocketdyne. After a feasibility study (for the first implementation of this technology) and establishing required qualifications, it is been approved and the necessary standardization procedures are developed. The developed process not only saves 2 months of time compared to the injection molding but also provides the advantage of manufacturing all of these components in-house under the supervision of the manufacturing team of Rocketdyne.

2.3.4 Automotive Industry

Automotive industry plays an important role in the deployment of AM technologies since a strict competition exists throughout the industry where innovation plays an important role. Among automotive industry and potential areas of RM, motor sports field provides a solid ground for the employment of AM technologies because of low volume production rates and high added value (Tromans 2006). It is believed that the developments attained in the integration of AM into motor sports manufacturing processes will “filter through to other areas of automotive industry” (Tromans 2006). The benefits gained by the integration of AM into automotive industry are mentioned by Tromans (2006) as removal of design constraints caused by tooling design and individual customization of cars to suit users’ needs.

Figure 2.11 Brake duct component of a Formula 1 car from composite Windform material (Gibson, Rosen, and Stucker 2009, 433)

Windform company uses special composites developed according to performance needs that contain polyamides mixed with different powders establishing greater stiffness, strength and also the ability to deflect heat (Gibson, Rosen, and Stucker 2009, 432). Figure 2.11 shows a brake duct component of a Formula 1 car which can withstand the real racing conditions. Although the part requires some manual post-processing, this part represents a good example of rapid manufacturing that results In a short turnaround cycle.

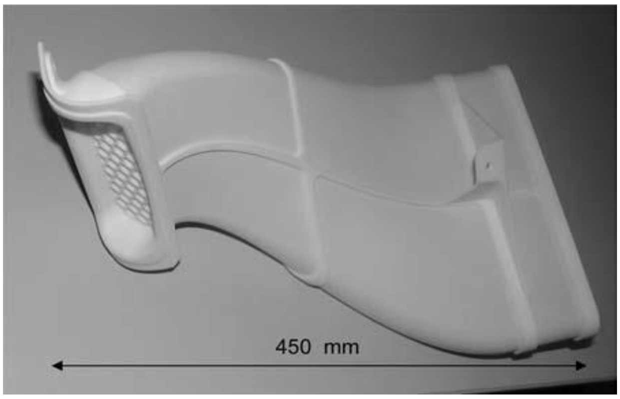


Figure 2.12 Cooling duct of a Formula 1 car (Tromans 2006, 213)

Although many F1 teams use AM parts in races (since early 2000's), due to extensive competition in the field most of the teams do not disclose their processes (Tromans 2006, 214).

Renault F1 team, one of the pioneers of the usage of AM in F1 industry uses rapid manufactured parts in real races together with Jordan and Toyota (Tromans 2006, 212). Figure 2.12 shows the cooling duct part of a Formula 1 car used in real race conditions. The potential of AM is exploited by reducing or eliminating the need for assembly as well as eliminating design constraints.

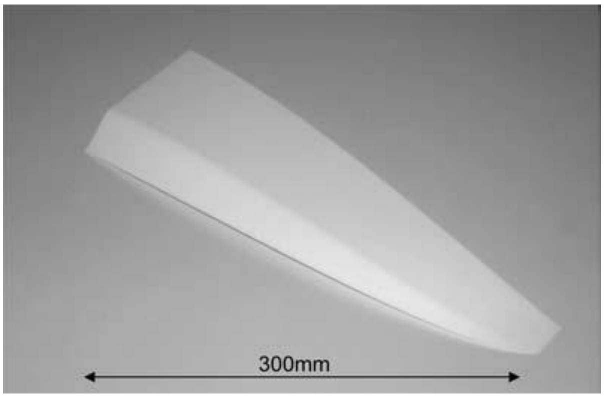


Figure 2.13 Wing end-plate flick of a F1 car (Tromans 2006, 213)

The wing end-plate flick of a F1 car in Figure 2.27 was designed, manufactured and transported to the racing area in just 2 days by Renault F1 team upon an aerodynamic development found in wind tunnel testing (Tromans 2006). Although these application examples can be interpreted as RP, since they are manufactured to be used in real life conditions it becomes a proof of the applicability and reliability of these systems as Tromans states (2006).

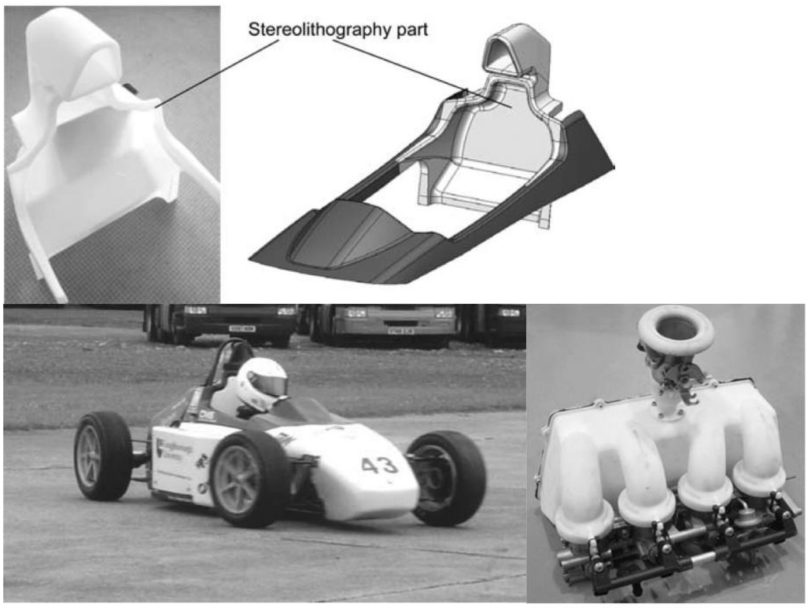


Figure 2.14 Formula Student Car 2004 The Loughborough University (Tromans 2006, 219)

Formula Student is an annual automotive racing competition between teams from universities worldwide. Because of the strict timing of the competition schedule, the students have very limited time to complete their entry cars which directs the students to the extensive usage of RM facilities (Tromans 2006, 215). Figure 2.14 shows the completed car at Loughborough University in 2004. The car includes many parts manufactured by stereolithography. AM manufacturing oriented approach allows the team to manufacture parts within the weight, tight packaging, and time constraints of the competition.

2.3.5 Dental aligners

Align Technologies provides orthodontic treatment devices, more specifically dental aligners. Align Tech manufactures clear braces called "aligners" that the patients wear on their teeth. The treatment works on the principle of incrementally moving the distorted teeth to their desired positions by changing the aligner in 1-2 weeks periods. Each aligner moves the teeth one increment towards the desired position.

Figure 2.15 Dental aligners manufactured by combining RM with post processes (Gibson, Rosen, and Stucker 2009, 364)

Since every patient's need is unique, and there is a need for many parts, their process involves a mass customization approach to aligner production as stated by Gibson (2009, 364) Every patient's teeth positions are first captured via a dental clay which is then sent to Align Technologies for digitizing using laser digitizers. After digitization and several modeling processes, the molds of the aligners are manufactured via SLA-7000 machines which are later used to form a sheet of clear plastic that become the dental aligners.

Align Technology's process constitutes a highly engineered process which involves the process from the measuring to final distribution of the aligners. Also, they are using customized software that automatically prepares the parts including support generation and slicing. Most of the post-processes needed in AM are modified or self-developed to be automated in Align's system only being support removal process manual (Gibson, Rosen, and Stucker 2009, 364). This mostly automated and specifically modified process allows 44000 unique aligners to be manufactured per day by Align Technologies which far reaches prototyping and becomes mass production.

2.3.6 Hearing Aids

In-ear hearing aids manufactured with conventional methods involve a process that the impression of a patient's ear is taken and used as a pattern that is used to make a mold for the shell of the hearing aid. An acrylic material is injected into the mold. The process is completed by the placement of electronics, controls and a cove plate (Gibson, Rosen, and Stucker 2009, 366). However, for the hearing aid to be successful, it should fit snugly but not too tightly also ensuring that during patient's talk or chewing it stays in place. Since in conventional method all the process is manual, the return rates for the hearing aid products were very high (1 of 4 aids were returned).

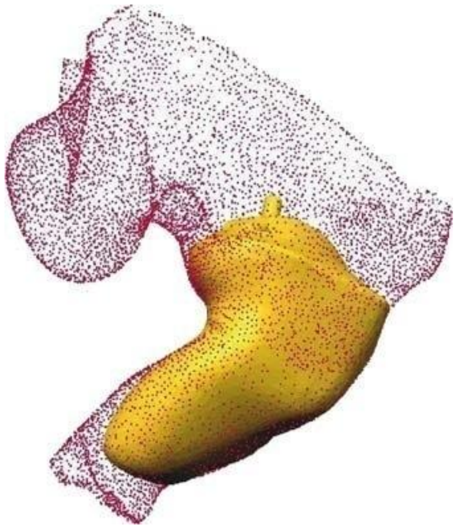


Figure 2.16 Hearing aid within scanned point cloud of ear (Gibson, Rosen, and Stucker 2009, 367)

A new process is developed by Siemens Hearing Instruments and Phonak Hearing Systems that uses selective laser sintering (also stereolithography) systems in the manufacturing of these hearing aids via AM. The patients' ears are now scanned by a laser scanner which are then converted into solid models. These solid models are then fine-tuned to establish a good fit in the ear. The resulting hearing aid is shown in Figure 2.17.

Figure 2.17 Rapid manufactured hearing aid (Gibson, Rosen, and Stucker 2009, 366)

After the implementation of AM, the return rates of the hearing aids are decreased dramatically (Gibson, Rosen, and Stucker 2009, 366).

2.3.7 Medical & Bioengineering

Developments in the 3D MRI imaging and related processes enabled an accurate visualization and re-construction of inner parts of human body. Increasing usage of these technologies brought the necessity of sharing the digital information in common standards (Gibson, Rosen, and Stucker 2009). These advancements in digitization of human body brings a huge potential in surgical and diagnostic aids, prosthetic development, manufacturing of medically related products and tissue engineering (Gibson, Rosen, and Stucker 2009, 387).

In Figure 2.18, patient's CT scans are used to design a reconstructive part of the patient's skull. Then ThermoJet process is used to manufacture the necessary part which is then used for investment casting to manufacture the final part in Titanium.

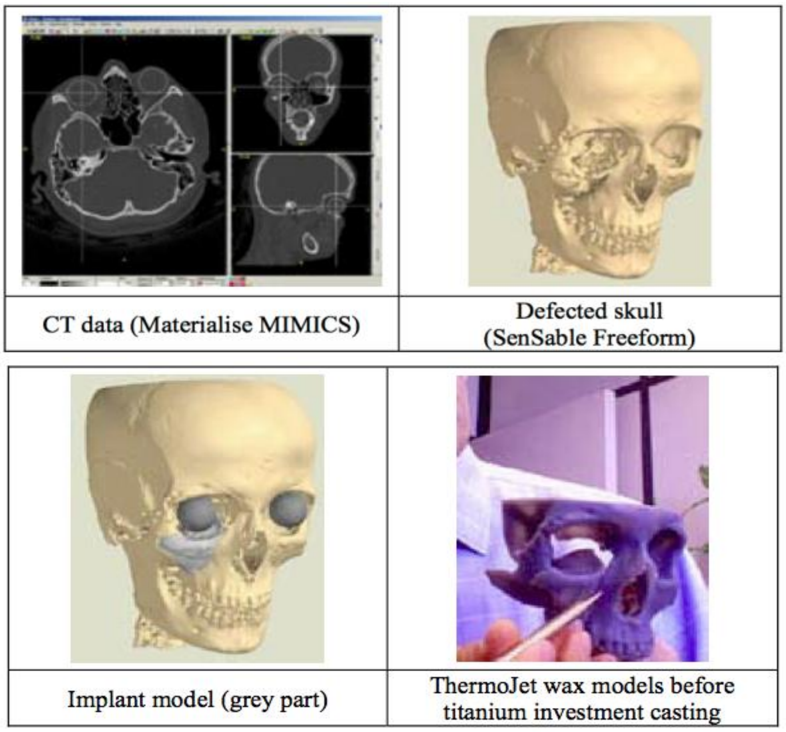


Figure 2.18 Reconstruction of the defected part by AM and investment casting (Negis 2009)

AM is also used for the planning of operations with high risks. 3D MR data is used to construct one to one model of the patient's inner body and the regions that need to be taken out. Multi-materials allow the visualization of different parts of the body. For example the regions having a tumor can be manufactured with an opaque material whereas surroundings in transparent material. Figure 2.19 shows a model of a patient's skull having a tumor inside.

Figure 2.19 Tumor illustrated in a different material inside the skull (Gibson, Rosen, and Stucker 2009, 388)

Figure 2.20 shows surgical guides used in a surgical experimentation conducted on a pig mandible. These guides are used to act as guides while cutting the defected mandible part in a pre-designed path. Then the resected condyle is replaced with a rapid prototyped plastic scaffold.

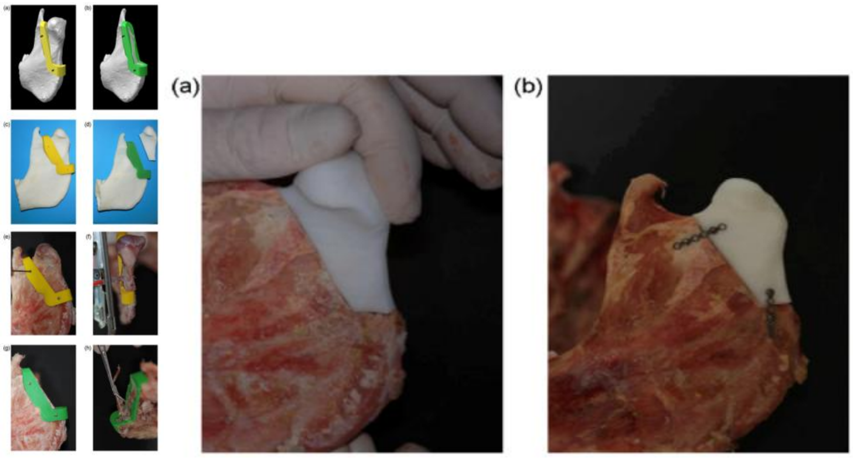


Figure 2.20 CAD design, fabrication and usage of surgical cutting guides (left), fitting test and placement of the implant (Ciocca et al. 2009)

Figure 2.21 Custom made prosthesis covers (www.bespokeinnovations.com)

Bespoke Innovations design and manufacture custom made prosthetic covers manufactured by AM (Figure 2.21). These covers called Fairings ™ are plugged onto the existing prosthetics that the patient uses letting them to complete the missing form and contour of their body.

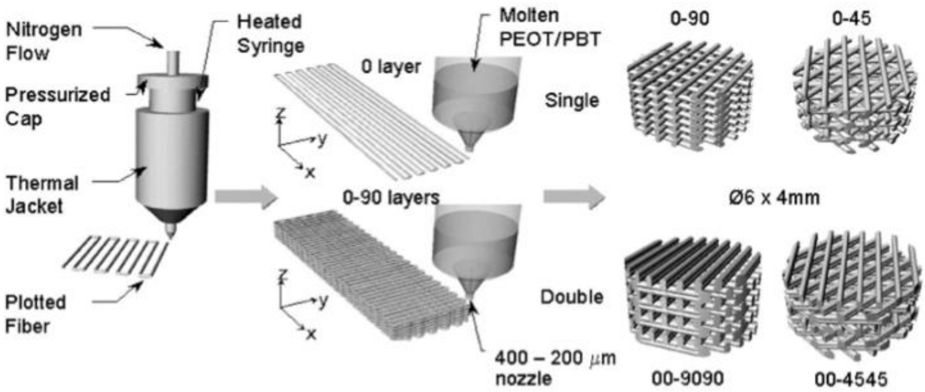


Figure 2.22 Scaffold construction (left) and various scaffold structures (right) (Moroni, de Wijn, and van Blitterswijk 2006)

There is an increased interest in AM processes for their applications in scaffold fabrication in tissue engineering field (Moroni, de Wijn, and van Blitterswijk 2006, 974). Variants of FDM process has been developed in which bio-compatible and biodegradable polymers are used to create scaffolds. These scaffolds are used to grow tissue cells providing a structure to hold onto. Also, living cells, proteins and other materials are used to facilitate tissue generation. Different materials and structure formations are issues of research being conducted. Although there are intensive research in this field, more research is needed to reach practical applications like organ printing, replacement body parts (Gibson, Rosen, and Stucker 2009, 391).

2.4 Implications of Additive Manufacturing for Industrial Design

Among the diverse implications of AM technologies (especially RM) on many industries, this section explores the literature on implications of AM on industrial design and design process.

2.4.1 Design and Manufacturing

> "For years, designers have been restricted in what they can produce as they have generally had to design for manufacture, i.e. adjust their design

> intent to enable the component (or assembly) to be manufactured using a particular process or processes."
> (Hague, Campbell, and Dickens 2005, 25)

Most of today's products manufactured with conventional methods are far from optimal as stated in ATKINS feasibility study on RM conducted by Loughborough University (ATKINS, 1). Design for Manufacture (DFM) that is dictated by conventional manufacturing methods prevent the optimization of the products' inner structures that cause unnecessary weight and material usage. Also, the limitations brought by DFM such as material wall thicknesses, undercuts, draft angles etc. prevent the products to be in optimal form and function. Rather they are designed in a way that will enable a viable manufacturing process. Thus, either form or function of the part becomes far from optimal. (ATKINS, 1).

These limitations intrinsic to the conventional manufacturing methods create an invisible cage that designers are allowed to think within its borders only. Gibson refers to this problem:

> The embrace of DFM has resulted in a design culture where the design space is limited from the earliest conceptual design stage to those designs that are manufacturable using conventional techniques. With AM, these design constraints are no longer valid, and the designer can have much greater design freedom.
> (Gibson, Rosen, and Stucker 2009, 289)

The possibility to use rapid manufacturing (RM) for the manufacturing method frees the designer off the inherent constraints of conventional methods. Gibson Rosen and Stucker (2009, 289) state that the AM technologies require designers to learn far less manufacturing constraints. Instead of learning the constraints of RM, they assert, design for additive manufacturing (DFAM) has a challenge to find innovative ways of exploiting the freedoms brought by it such as “new product structures and thinking about products in unconventional ways”. They see these challenges as opportunities and state that the engineering community must be open to new ideas and “exercise their collective creativity”.

Although AM frees the designer from many constraints of DFM in conventional methods, it would be unrealistic to say there are no rules in AM (Sinclair 2008; Gibson, Rosen, and Stucker 2009). There are limitations arising from the type of AM process and build orientations of the parts in the machines since x-y-z resolutions are not the same. Also, in AM processes that require support structures, enclosed volumes have to be avoided since these supports are removed manually (Sinclair 2008). Nevertheless, as these processes are perfected and the build resolutions increase, such limitations will be less of an issue.

Regarding the design for manufacture constraints Figure 2.23 and Figure 2.24 illustrates the possibilities brought by AM:

Figure 2.23 Conventional (upper) and optimized (bottom) models (Hopkinson, Hague, and Dickens 2006, 11)

An initial study at Loughborough University was conducted to see how a diesel front plate would be like if it is designed specifically for rapid manufacturing. It is redesigned by optimizing air flow channels and weight. The result (Figure 2.23 bottom right) not only shows a progress towards minimal weight but also the smoothing transitions of the air channels provide better air flow.

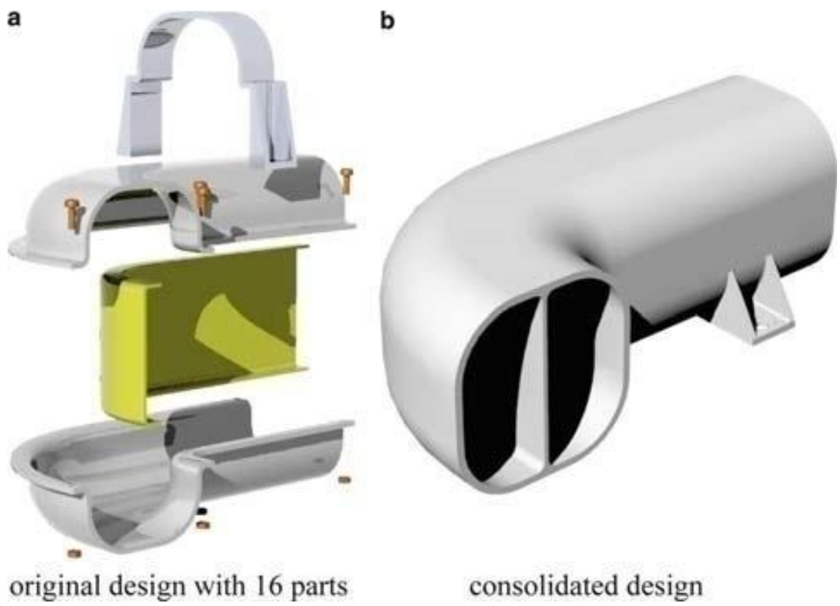


Figure 2.24 Aircraft duct designed for conventional (left) and AM (right) processes (Gibson, Rosen, and Stucker 2009, 287)

Figure 2.24 shows the redesign of a ducting used in fighter aircraft. AM allows the consolidation of several parts into one reducing assembly time and enable the manufacturing of more complex structures. Gibson Rosen and Stucker (2009, 11) state that a similar approach is being utilized by US aircraft industry.

Grimm (2007, 2) states the industry is unaware of most of the opportunities offered by rapid manufacturing (RM) that has the potential of extraordinary cost savings and facilitations on the manufacturing processes. Also, new solutions to the manufacturing constraints will be easier to develop. Besides reduction In manufacturing costs and facilitation of new methods, he asserts that RM will change the way of manufacturing is done leading to a real industrial revolution.

Gibson Rosen and Stucker (2009, 287) state that in design for additive manufacturing (DFAM) the objective should be the maximization of "product performance through the synthesis of shapes, sizes, hierarchical structures, and material compositions, subject to the capabilities of AM technologies". Thus, in order to realize this objective they assert a guideline for designers to consider while designing products:

- AM enables the usage of complex geometry in achieving design goals without incurring time or cost penalties compared with simple geometry
- AM enables the usage of customized geometry and parts by direct production from 3D data
- With AM, it is often possible to consolidate parts, integrating features into more complex parts and avoiding assembly issues
- AM allows designers to ignore all of the constraints imposed by conventional manufacturing processes (although AM-specific constraints might be imposed)

AM processes have a significant application field under industrial design profession regarding the product design and evaluation process. There are emerging rapid manufacturing applications in product design, and will be discussed in the following chapter. Following paragraphs deal with benefits of the usage of AM as a prototyping tool in the design process.

In a case study on the design and prototyping of a garden trimmer (Evans and Campbell 2003), the use of RP removes the need for the production of appearance model and let the designer to directly advance to a fully working appearance prototype.

Another benefit of AM to the designer cited by Evans in his doctoral research (Evans 2002, 102) is the usage of these technologies lets the designers to experiment with relatively more design iterations even if the forms are very complex, thus harder or even impossible to model by conventional methods. Since the complexity of the design does not affect the part manufacturing time , the side benefit of this freedom provided to the designer is to innovate more on design decisions and able to test them (the complexity mentioned here should not be understood as intricacy of objects since even slightly varying wall thickness or an assembly hole in a hard to reach position can make the object very complex to manufacture). These physical models can also be used further for a better communication between designers, engineers and non-engineering departments thus increases the ability to detect errors during the design phase (Dimitrov, Schreve, and Beer 2006).

The design process that is conducted through 3D CAD interfaces force designers to be more realistic while designing, cited as an advantage of RP by Mather (Mather 2003, 17). There is a conflicting view cited by Aldoy (Aldoy and Evans 2011, 345) but it will be mentioned under Discussions section in the following paragraphs.

Apart from the professional field, in a delphi survey conducted on the effects of RP technologies on engineering design education one respondent stated that "the industry must get the technology in the hands of the students" (Mather 2003, 119). Thus, such an update in the design education may facilitate the realization of the mentioned potentials of AM.

Updating the education might also be required when Campbell et al.'s (2003) assertion on a new type of designer is considered:

> In conventional product design, an industrial designer would pass the initial design ideas to an engineering designer who would incorporate the 'internals' and consider the manufacturing route. As the industrial designer would be able to 'print' a part directly, much more consideration of engineering design is needed by the industrial designer, or a 'hybrid' designer in the future. Currently, few designers possess all the necessary skills.

Thus, the distribution of tools that are used by certain disciplines to other disciplines might require a broader education system in disciplines related with design, engineering and manufacturing that provides a common language for better communication and facilitate innovation.

2.4.2 Functionally Graded Materials

Functionally graded materials (FGM) is a term used to define a heterogeneous object that has varying materials or densities. Although FGM has more than two decades of history which was first proposed for aerospace applications (Knoppers et al. 2004), conventional methods need specialized processes developed for the manufacturing of such materials. The initial applications involved the gradient in material properties only in one direction. AM brings the advantage of manufacturing a part that has varying properties in any direction. However it should be noted that not all of AM processes are suitable for the manufacturing of FGM (see Knoppers et al. 2004; Erasenthiran and Beal 2006, 119). Also different processes have their unique issues that are to be overcome (Erasenthiran and Beal 2006, 119). Since the technical aspects of these issues are beyond the scope of this thesis, they will not be mentioned here.

The 3D Printed concrete by Steven Keating at MIT Media Lab's Mediated Matter Group illustrates the concept of mono-material variable density concrete fabrication (Figure 2.25). The outer shell is denser providing strength while the inner core is sparser providing lightness.

Figure 2.25 Concrete column section 3D printed with variable density (Chandler 2012)

Figure 2.26 shows another part printed in variable density put on a small wooden block to illustrate the weight distribution among the block. Such applications, according to NeriOxman at MIT, opens new horizons both in terms of form and function.

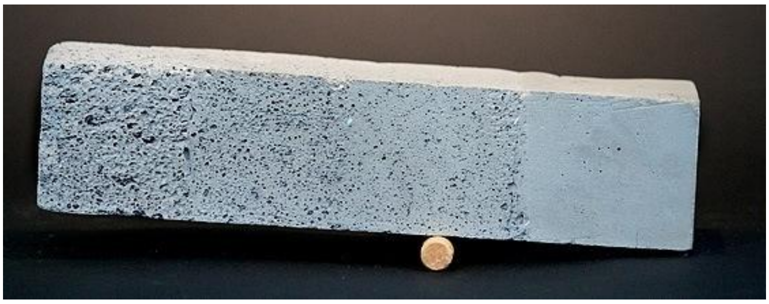


Figure 2.26 Concrete block 3D printed with variable density (Chandler 2012)

Figure 2.27. Hybrid variable materials by Bread (2012)

Figure 2.27 shows a milk jug with a hidden pouch structure embedded that comes out upon squeezing. It is manufactured with an experimental method used by Bread (Bread 2012) to manufacture functionally graded objects which they call “hybrid variable materials”.

The emerging ability with the use of AM is being able to control the inner material distribution of an object. This possibility gives designers chance to design products without constraints caused by conventional methods but rather in a different way (Knoppers et al. 2004, 38). As the above figures illustrate, with functionally graded materials, mechanical, visual, chemical or many other properties of an object or product can be changed throughout its surface or inner space.

2.4.3 Personal Fabrication - Post Industrial Design

Starting with an open-source experimental project by Dr. Adrian Bowyer (Bath University Mechanical Engineering Department) called RepRap in 2004, a new field In additive manufacturing has opened. The aim of the project is to develop a machine that can print parts for the next machine thus replicating itself. The machine itself actually is a rapid prototyping machine working on the principle of FDM. However, it is constructed with commonly available parts and most importantly construction schemes, electronics schemes and software is open-source and documented in order for others to follow the same process and build their own machines (RepRap 2012). Figure 2.28 shows the initial model of RepRap:

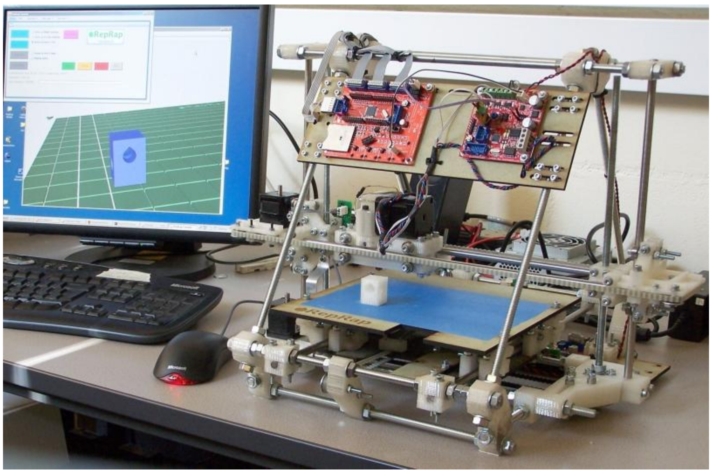


Figure 2.28 Reprap 3D printer (Reprap 2012)

Although the initial aim was to fabricate parts for another RepRap, it did not take long for the makers of the machine to use these machines to make other useful objects or replacement parts such as, iPhone cases, mounts, bathroom jugs, gears for personal toys or machines. After the release of the project, many early adopters of the technology started to build their own machines for the costs ranging $ 500 to $ 1800 including all of the structural, mechanical and electronic components. This led to others developing and selling their own versions. Some of the most successful examples are: Bits From Bytes, Makerbot, Ultimaker, PrintrBot, Up 3D printer, Fab@Home Project.

Around these personal 3D printers (in this section these machines will be named as 3D printers since it is the only used term in its user communities), especially RepRap and MakerBot, have formed strong communities on sharing development plans, toolhead designs and ideas, perfecting print quality and many more. Also, an online sharing place called Thingiverse (explained in Chapter 3) is established by MakerBot developers. This place involves designs that are free to download and modify. Although the website initially held printable STL files of 3D models, now any kind of data and files related with the design or just an idea can be shared. The system in the website also allows tagging of designs as derivations of each other providing a participatory platform. Toys, MakerBot toolhead attachments, personal accessories such as rings or bracelets, customizable hose adapters, gears are among thousands of examples that can be found in this online sharing medium.

Personal 3D printers usage has its roots in many developments such as open-source software and DIY, however since it is out of the scope of this thesis the details will not be included.

Besides personal 3D printers that is emerging as a powerful tool added to do-it-yourselfers' toolbox, personal fabrication started to have another place for growth, which is online 3D printing services such as Shapeways (see Chapter 3), Sculpteo, iMaterialise and Kraftwurx. Apart from professional rapid prototyping and rapid manufacturing companies, these services offer online marketplaces for users or designers to sell their designs as products. The designer can upload his model to the site and check the costs realtime and choose different materials and manufacturing methods such as abs plastic, color 3D prints, SLS nylon, 3D printed and glazed ceramics etc.

The complexity of the CAD software and their steep learning curves make it hard for an ordinary user to design and create 3D forms (Ben Hughes and Sinclair 2012). In order to overcome this problem, Shapeways and Sculpteo offer users customizable products through interfaces such as vases with custom typography, rings, bracelets, pendants, mugs and so on. Since these companies are collaborating with designers like Nervous System (see Chapter 3), the number of similar customization possibilities are increasing, thus empowering of users. Two of the greatest advantages of AM, form freedom and breaking free of the conventional manufacturing processes, facilitate the creation of products even by individuals who have little or no knowledge about the constraints.

Such emerging applications fostering personal fabrication and mass customization in a way exploits the potential brought by the AM technologies. There are no minimum order numbers since the products are manufactured on-demand on a tray that is full of several other orders of other users. Wohlers (2011) states in an online article that Shapeways is selling 12000 products per month all manufactured in additive manufacturing machines. Also, 10000 products are being added to the website each month. Another intriguing fact about this ecosystem is the average price of products for sale, which Is less than $14. Such prices make this technology more reachable by masses since some of the products sold in such websites can compete with their mass manufactured counterparts.

Regarding the developments mentioned above, spread of additive manufacturing opportunity to individuals have significant implications for industrial designers as well as consumers or users. Morris (2007) states:

> Personal fabrication empowers the industrial designer by providing the opportunity to bypass the traditional (and expensive) product development infrastructure. But it also empowers the amateur designer to design their own products and bypass industrial designers entirely.

Thus, users being able to manufacture and design with the democratization of design tools and manufacturing systems will require industrial designers to either gain new abilities or approach to the design process with a new perspective. According to Morris (2007), McDonald, Ryall, and Wimpenny (2001, 43) the designers will be designing forms that can be “shifted and transformed” instead of static models and for such applications to be possible and intuitive, collaboration between software programmers, industrial designers and engineers will be needed.

Empowering of users and amateurs together with the designers starts to blur the borders between the professional and amateur (Cascio, Soojung and Pang 2007; Pescovitz 2008, 8; Atkinson 2010, 142; Pfeiffer 2009, 5). Atkinson (2010) suggests that the empowering of the amateur with these tools improves their ability “act as professional designers do”. Thus, he asserts that rather than designing for consumers, giving them the ability to design for themselves would be a better option. A design professional according to him can benefit from “paying close attention to the driving forces for amateur design activity and the insights of users”. In such an environment the professional and amateur/consumer become “co-designers” (Atkinson 2010).

2.4.4 Designer as individual

It is seen that the democratization of fabrication tools empower designers as well as users. However, as mentioned before, these tools can empower users in a way that they can bypass industrial designers and manufacture products by themselves (Morris 2007). Although these arguments will be valid for most of the cases, there is another implication of this facilitation of manufacturing, which is the empowering of designers as individuals. Pfeiffer in her thesis titled “Digital tools, distributed making & design” (2009, 38) refers to the impact of this facilitation on designers as:

> Thus the designer-as- producer will plausibly become more common as digital tools facilitate the making of objects, and designers are more readily able to physically produce their ideas.

On an online crowd funding platform called Kickstarter, an industrial designer C. Sven Johnson has published a project called 100K Stray toasted Pull Toys (Johnson 2009) which is intended for CNC owners to be able to make their own wooden toys. Although this project does not relate directly with the implications of AM on industrial design, Johnson’s explanations in the project definition has a significant relation with the empowering of the designers as individuals. In the project definition Johnson states:

> Professional product designers like myself are hired by corporations. All our ideas - including the ones which never go into development - are owned by the corporations. In some cases, even those ideas which designers dream up on their free time is contractually claimed by their employers…
>
> … If you've wondered why there are so many other creatives on the internet but so few product designers, here's why. We're tied to corporations. We're tied to manufacturing processes... Until manufacturing processes become more fully democratized, the profession will remain largely beholden to the corporations who own the factories and can pay a salary; either directly through employment or indirectly through design firms.

Thus, the democratization of manufacturing tools, RM in this case, will break the professional industrial designer free from the corporations that hire industrial designers.

Apart from the industrial designer's professional field, the chance of designers experimenting these technologies is low due to the high costs of the AM machines. Then, if they are confined in corporations, as stated by Johnson, there remains no chance for the industrial designer to freely experiment with these technologies. Pfeiffer states that "it is the makers and engineers, the artists and entrepreneurs who have been most actively engaging with these technologies". Thus, if the professional designers are to escape from their professional practice long enough, they would be able to find new ways of using AM and "a new landscape of digital development and fabrication" (Pfeiffer 2009, 3).

According to Pfeiffer, clients will be given frameworks created by designers to create their own products in the future. Such things have happened in every medium like desktop publishing, music, video, fashion and user generated web content, as stated by Pfeiffer (Pfeiffer 2009, 40).

The empowering of designers as individuals will also be mentioned in the next chapter and illustrated through the products that individual or group of designers create which are manufactured on-demand in online RM services.

2.4.5 Mass Customization

Customization possibilities coming with RM has two aspects according to the explored applications. First one is the customization in industrial environment in which end products are manufactured to fit the user's needs. Figure 2.29 shows an example from the application in aerospace/automotive sectors. In MANRM project at Loughborough University a methodology has been established to capture the geometry needed to manufacture body fitting customized parts (Hopkinson, Hague, and Dickens 2006). Then these parts are manufactured using RM processes.

Figure 2.29 Customized body fitting car seat (Hopkinson, Hague, and Dickens 2006, 13)

Example provided above illustrates the mass customization potential exploited in mass manufactured products. In the Industrial Applications section before in this thesis, a similar example was the hearing aids application field. Especially medical field and products related with human anatomy has a huge potential that can be exploited.

Second possibility of customization is on the customization of products by the users themselves through interfaces that will be mentioned in Chapter 4.

2.4.6 Discussions

Among the implications of AM for industrial design, there are concerns on the direct and indirect effects of these technologies on the industrial design profession, designer, and design process.

Although it may not be perceived as a disadvantage for the general good, the democratization of design and manufacturing can have a devaluing effect on the industrial design profession since it opens the tools used by designers to the public. Atkinson gives examples from the graphic design profession and its opening to public by desktop publishing software (Atkinson 2010, 143). He suggests that the arguments made on the devaluing of professions on two-dimensional design (e.g graphic design) is now starting to be seen in three-dimensional design with the introduction of rapid manufacturing. In his argument he quotes an online debate about a published book on "DIY: Design it Yourself" by Ellen Lupton. In that debate, design historian Steven Heller argues that such guides make our work (design) so easy to do and devaluing the profession. Also, according to Heller, redefinition of the "amateur" by new technologies in the fields such as graphic design, photography, film and music causes a loss of the elite status of designers that provide them credibility. The counter argument of the author Lupton is that the credibility should not come from the elite status but "rather from its universal relevance to daily life" (as cited in Atkinson 2010, 144) and continues by stating "not everyone is a design 'professional,' a person dedicated to solving complex problems…"

There is a counter perspective put forward by Bathsheba Grossman (a world renown artist in 3D printing) in an online article published on RapidToday.com:

> If one looks at the graphic arts in relation to cheap image manipulation software and digital photography, those things lowered the barrier to becoming an image artist, and certainly more people do that type of work now than before, but it didn't turn vast swaths of the population into artists who weren't interested or lacked talent in the first place. I think that'll be even more true of 3D. I'm guessing that the difficulty of inventing and designing satisfying 3D objects is present in the problem itself, rather than being an artifact of problems with the tools.

The case for three-dimensional objects can be very similar to the desktop publishing example but with more important implications. The facilitation of desktop publishing and graphics design did not make pro graphics designers out of their jobs. But enabled the sector to be more accessible. For personal use, this situation increased average consumers abilities. Also these advancements made more designers to come into scene even if they are not professionals. When the case comes to three-dimensional world, accessible use of 3D printers can create a more dramatical advantage when compared to the 2d printers. Computer screens have been providing the 2D representation of the drawings done in 2 dimensions which are then printed on a 2D surface, paper. So principally in graphic design, what is seen on screen is directly printed on paper which does not include a dramatic shift in perception. Thus, this does not bring an advantage in design possibilities wise. However, in industrial design computer screens have been showing a 2 dimensional representation of a 3d object which is then converted into a 3d object. Then, even if the designer is very talented, s/he is always confronted with a limited representation of what s/he imagines. Professional designers can use RP more often than newly graduates, emerging designers or makers. However, the facilitation of home 3DP can bring a dramatic advantage to the home users or people who are interested in industrial design. Makers and DIY'ers are in a way designers themselves even if they have no design background (Atkinson 2010, 142). Continuous iteration of their designs via quick and cheap printouts can give birth to more usable products than the professional designers'.

Aldoy and Evans (2011, 345) put forward a problem related to CAD usage during the design process as loss of the ability to interpret scale and proportion. According to Pipes and Dorta et al. (as cited in Aldoy and Evans 2011, 345) the precise requirements of CAD software fails to match the speed of the "creative impulse" during the design process. The number of commands needed to be activated forces the designer to be too precise and diverts the designer away from design thinking. Although not directly related with RM, such problems have to be taken into account while exploring the implications of this technology on industrial design since CAD usage during the design process has become an inseparable part of design process (Aldoy and Evans 2011).

CHAPTER 3

EMERGING RAPID MANUFACTURING APPLICATIONS IN PRODUCT DESIGN

3.1 Introduction

This chapter explores emerging applications of rapid manufacturing in industrial design field which are later discussed with Barbar Designers in the following chapter. In order to gain a better understanding on the implications of these applications, not only the resulting products but their ways of design and manufacturing (if published by the designers) are presented. Some examples included in this chapter are not commercialized products rather being collector's pieces or products that are to be manufactured in limited editions.

Industrial applications of additive manufacturing gives a broad map of the approved methodologies in various fields of design and manufacturing. Although the developments in these fields are important for industrial designers, newly emerging applications in various contexts point to a new perception of the technology in which the designers are empowered as individuals. For example, most of the processes mentioned in the literature are only possible with companies having enough budgets to afford the machines for additive manufacturing. In such environments, designers are generally a part of a larger collective in which they are locked in boundaries of the company such as corporate identity, product segment, target consumer groups, marketing constraints. However, the applications presented in this chapter are mainly realized by individual designers or design collectives illustrating the empowering of designers as individuals liberating them from the various environmental constraints.

3.2 Brief History of Rapid Manufacturing in Product Design

Applications of rapid manufacturing in product design has started towards the end of 1990's with Janne Kytannen's Freedom of Creation (FOC) and their RP experimentations on processes such as stereolithography (SL) (Kytannen 2006, 276). At that time, SL resins were changing colors after a few months. By modifying the curing times and trying different resins they achieved a result that brought a nice amber color that lasts. Starting with lighting designs, FOC have been one of the pioneers in the usage of AM processes in the RM of consumer products. In the beginning of 2000's Materialise's investment into research on the manufacturing of products with SL resulted in a huge public interest in a very short time. The first editorial article on FOC was published by Icon magazine with the title "Lampshades that will change the world" (Kytannen 2006, 278).

Materialise is a company that has been providing rapid prototyping, additive manufacturing services and developing specialized additive manufacturing software (Materialise 2012). Their initial investment has turned into an international success and interest on the usage of RM for end use products .

Applications of AM in product design are also explored by Lionel Theodore (Future Factories). Starting as a research project in 2002 which is progressed into a practice-based PhD study. In Theodore's studies, systems that allow customized products like lighting, furnishings and decorative objects which are then turned into a commercial practice.

Another pioneer and world renown artist in 3D printing field is Bathsheba

Grossman who designs art objects mainly inspired by mathematics. She uses 3D printing to manufacture metal objects that are not possible in any other means of manufacturing.

3.3 Endless Series

Figure 3.1 Endless series furniture manufactured with FDM (Vander Koij 2012)

In Endless project by Designer Dirk Vander Koijj (for his graduation in Design Academy Eindhoven) a 5-axis industrial robot is modified. This 5-axis robot arm is used to manufacture Endless Series objects with an extruder attached to its head (Figure 3.1). The concept behind is exactly the same with fused deposition modeling technology in which a plastic filament is fed through a heated nozzle. Designer Dirk Vander Kooij has developed a screw extruder, which is attached to the robot arm and the pellets of recycled plastic (from refrigerator parts) is fed through a funnel (Figure 3.2). However the nozzle of the extruder is greatly thicker than these of regular fused deposition modeling machines. Large diameter of the extruded plastic combined with the huge build area of the robot arm results in a unique textured life-size and usable furniture. Actually this stair-stepped appearance of the resulting objects have been among the greatest barriers confronting the usage of the rapid prototyped models as finished products, since it decreases surface quality of the objects lacking the appearance of their injection molded counterparts. Although that has been the case for product prototypes, they are the representations of designs that are intended for different manufacturing processes. In Endless Series chair and tables, the intent is to design an object specifically for the additive manufacturing process, which in turn has given their forms and unique surface texture.

The endless chair and table are manufactured without any support structures, that introduces some limitations on the design. The angles of the hanging surfaces cannot have more than a specific angle since the filament in the bottom layer should support the one on the top enough to prevent overhangs in the construction. Although for additive manufacturing technologies there barely exists any limitation of form, this limitation in Endless Series is the source of its design's visual and formal appearance.

The designer's products collected under the title Endless Series are exhibited around the world and being sold to art collectors. Also, in many renowned media public attention is received. These products are being sold at prices beginning from 760 Euros (Vander Kooij 2012).

Figure 3.2 5-axis robot and its extruder head used in the manufacturing process of Endless series furniture (Vander Kooij 2012)

There is design for manufacture in Endless Series. Although the advanced additive manufacturing machines are capable of producing more complex forms, there is a limitation of the overhanging geometries in this project's procedure since there is no support structures. Although the stair stepped appearance of the RP models is undesired and directly related with the quality of the machine, the designer has used it in such a way that it has become a unique character of the product. The process used here implies that an industrial designer can be able to manufacture real size and end use objects or products individually without the need for an external manufacturer.

FDM models in RP are known for their strengths in physical stability since each layer in the x-y coordinate is made up of a continuous strand of filament that create very homogeneous distribution of the melted material thus, a strong structure. Knowing the different characteristics of different RP processes gives the designer the freedom to exploit the possibilities of the technology used. Even though RM technologies promise an incredible amount of design freedom and part complexity (as illustrated in Chapter 2), some limitations still exist that will inevitably cause design for manufacturing constraints such as the difference of part properties in x-y and z axis.

Being able to use recycled materials, in this case refrigerator plastics, enables the designer to directly produce environmentally friendly products. However, RP technologies are mainly based on industrial grade engineered plastics and polymers which in turn brings many more products made in plastics. Despite these materials, there are biopolymers used such as PLA that is derived from polylactic acid (Ichhaporia, 2008).

This application asserts the importance of knowing the constraints and the characteristics of the manufacturing process very well.

3.4 Freedom of Creation (FOC)

Kytannen (2006) states that the idea of using RP processes for end use products have been a hard to convince concept since "industry's leaders would respond that neither machines nor materials are ready for that yet" (Kytannen 2006, 276). However, design collective Freedom of Creation, pioneered by Kytannen rejected this perspective and argued "every technique and process has their own characteristics".

Their initial experiments with textiles have confronted the surface quality barrier which the users complained about the roughness of the textiles made with SLS polyamide. Then, inspired by this problem they have made a shower scrub made via SLS (Figure 3.3).

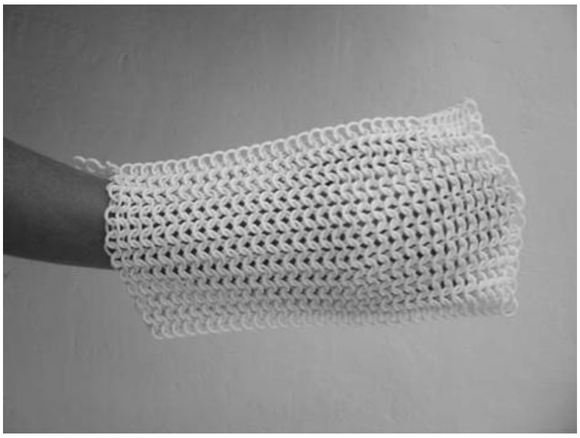


Figure 3.3 Shower scrub manufactured via SLS (Kytannen 2006, 279)

Figure 3.4 Commissioned chair manufactured via SLS and coated with glossy lacquer (Freedom of Creation 2012)

The chair in Figure 3.4, designed by Janne Kytannen of Freedom of Creation illustrates one of the most important benefits for industrial designers: form complexity involving Interlocking patterns and the manufacturability of impossible-to-mold parts. This product is designed for a comissioned project to be used in a 100 ft yacht. 23 unique chairs based on Kytannen's another design for FOC are manufactured via SLS as a single piece. Then the nylon part is coated with a high gloss lacquer which is then mounted on a swiveling metal base.

3.5 The Fall of the Damned Lamp

Figure 3.5 Damned lamp by Luc Merx (MGX 2012)

The Fall of the Damned suspension light (Figure 3.5) has designed by algorithmically deriving the figures within themselves and around a circular path. The designer, Luc Merx, exploits the form freedom brought by AM in a poetic way. In the definition of this product on MGX by Materialise website it is mentioned that:

> The Damned Lampshade is one of the works in which Gagat international reactivates historic imagery as a reference for their designs. The design of this lamp undermines several taboos imposed on design in the 20th century: it is figurative, ornamental, and narrative. The new questions about the possibilities of forms posed by this originate in a new understanding of technology. Technology no longer generates the forces, which determine the design of goods, but it enables an incredible range of possibilities and thus creates a new freedom of form.
> (MGX 2012)

In an online article on Dezeen Magazine, the form freedom is also emphasized by stating that the forces determining the design of goods are no longer generated by technology, instead it allows “incredible range of possibilities and thus creates a new form freedom.” (Dezeen 2012).

The fall of the Damned, with its form and ornamentation -that obviously contradicts with industrial mentality of the 20^{th} century- is a part of Luc Merx's Rococco Relevance research project (Rococco Relevance).

3.6 My Brain Lamp

Figure 3.6 My Brain Lamp manufactured via SLS (Lervik 2011)

My Brain Lamp is a 3D printed physical representation of its designer's brain (Figure 3.6). The necessary data for the digital model is obtained from a MR scan of the designer's brain. It is made from polyamide by selective laser sintering. My Brain Lamp was exhibited in an exhibition called Enlightenment in The Röhsska Museum of Design between 30 October 2007-27 January 2008. This combination of brain with light extends this design beyond its appearance giving a sublime meaning when considered in the exhibition's enlightenment concept.

Alexander Lervik explores new sources of inspiration for design and its meaning exploiting a huge potential brought by the technology of 3D printing. This technology introduces new sources of design data for inspiration. Since there is a continuously interconnecting world, with an increasing rate of digitalization of information - in this case a rapid digitalization of brain's form - exploitation sources and derivative ways of interconnecting different data sources will lead to unlimited potential in art and design fields. Although RM processes used to manufacture large parts still are not fast enough to compare with conventional manufacturing methods, it constitutes a segment that is between crafts and mass production.

3.7 Structural Ornament

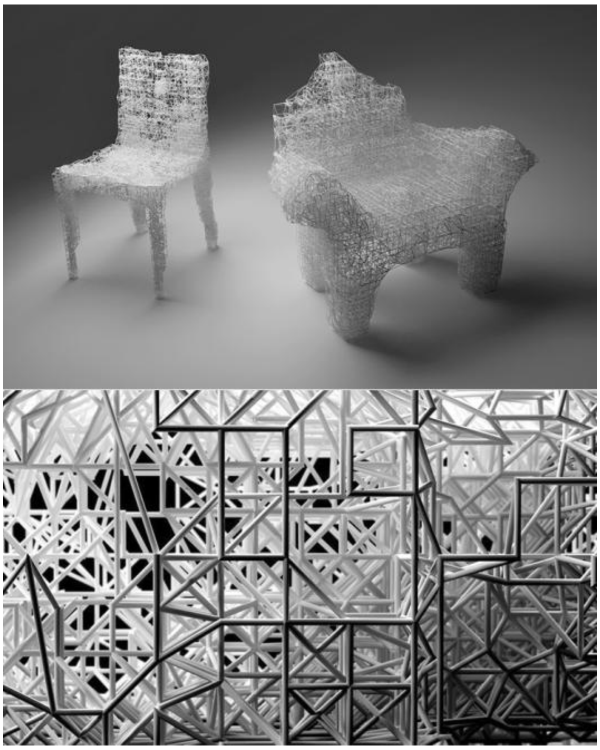


Figure 3.7 Structural Ornament chairs generated by software (Mozolewska 2011)

Structural Ornament is one of the generative design concepts realized by RM.

The concept is part of a thesis study conducted by Malgorzata Mozolewska. The algorithms for the generation of the chairs are programmed by Michal Piasecki, a designer who applies computational design in architecture, product and graphic design.

In the process, an initial model is given to the program (which is developed in an open source development platform Processing), as shown in Figure 3.8 step 1, that analyzes the model. Then by calculating the introduced stresses on the model it builds the necessary constructions - denser connections in the areas of greater stress - to support the given loads. The result of this process is unique every time the program is run giving a model of same chair with a completely different yet strong construction.

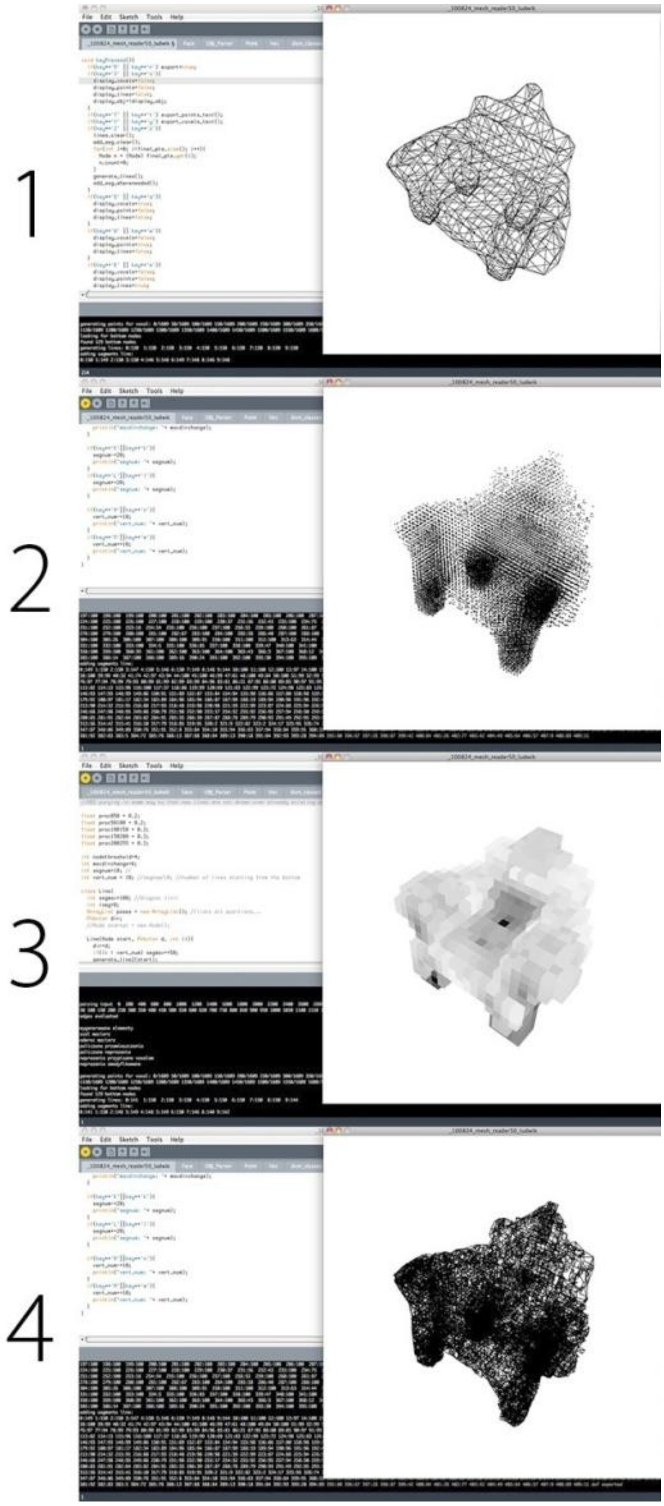


Figure 3.8 Calculation process of the internal structures according to the given initial model (Mozolewska 2011)

The resulting models illustrate an extreme complexity of internal structure, which cannot be realized by other means of manufacturing. Also the results of the generation process illustrates a different kind of ornamentation and intricacy as well as a solution to a sophisticated engineering problem on the carrying of loads.

3.8 Nervous System

Figure 3.9 Uniquely generated Hypae lamps (Rosenkrantz and Louis-Rosenberg 2012)

Nervous system is a collaboration between two MIT graduates having mathematics (Jesse Louis-Rosenberg), architecture and biology (Jessica Rosenkrantz) backgrounds. Their main focus is generative design by algorithmic and physical tools. The aim of the designers is to “craft a system whose result is a myriad of distinct creations” (Rosenkrantz and Louis-Rosenberg 2012). The result of the process is a different product each time the programs are run. The system they developed allows creation of unique objects based on the algorithms used, allowing customized and unique products to be made. Also, this allows very complex nature inspired patterns to be simulated and manufactured.

Another result of the process is production with limited editions like in the case of Hyphae Lamp (Figure 3.9) that is produced in a limited number of 28. Each Hyphae Lamp is unique which is generated by an algorithm that mimics natural growth patterns. The development of the algorithm and its visualization is done via an open-source development platform, Processing.

Nervous System uses SLS and 3D printing for manufacturing and polyamide as build material. For porcelain products like Reaction Cup, some intermediary casting processes are used. However, again 3D printing is used for the initial model, which later on used for the plaster molds. Afterwards clay slurry is poured into the plaster molds, which upon drying are fired in kilns giving the object its strength and stability. These porcelain products are also microwave and dishwasher safe as stated in Nervous System’s blog (Rosenkrantz and Louis-Rosenberg 2012).

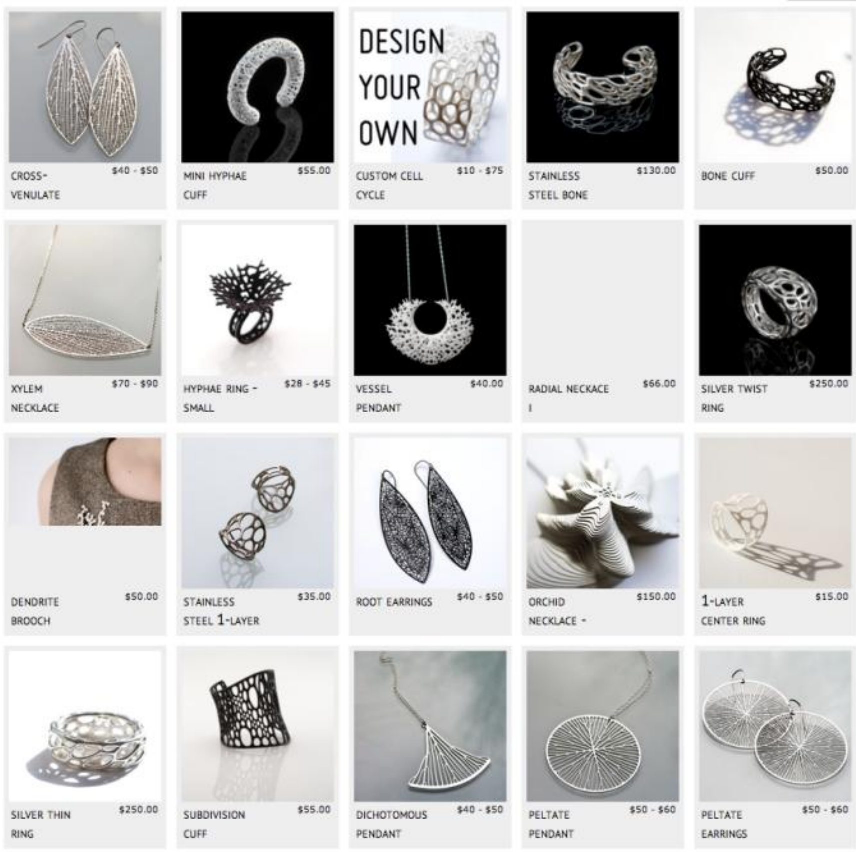


Figure 3.10 Various designs of Nervous System (Rosenkrantz and Louis-Rosenberg 2012).

The designs of Nervous System vary between jewelry, personal accessories, lighting and experimental areas (Figure 3.10) each design being an extension of the concept inspired by the biological growth patterns. Their designs are manufactured via an online 3D printing service called Shapeways (Shapeways 2012) and sent directly the customers who purchased them.

Another aspect of these designs made through algorithms is that the users can change the parameters of the design to get the results they like. This application, which is illustrated in the Figure 3.11, has parameters like: number of divisions, twist amount, radius, inside and outside roundness etc. Initially the user starts with a standard mesh and modifies several parameters according to their taste and the mesh rearranges itself according to the modified 2D shape that is to the upper right of Figure 3.11. However, the modifications on the design can result in unusable products since the interface allows extreme modifications to be done like in Figure 3.13.

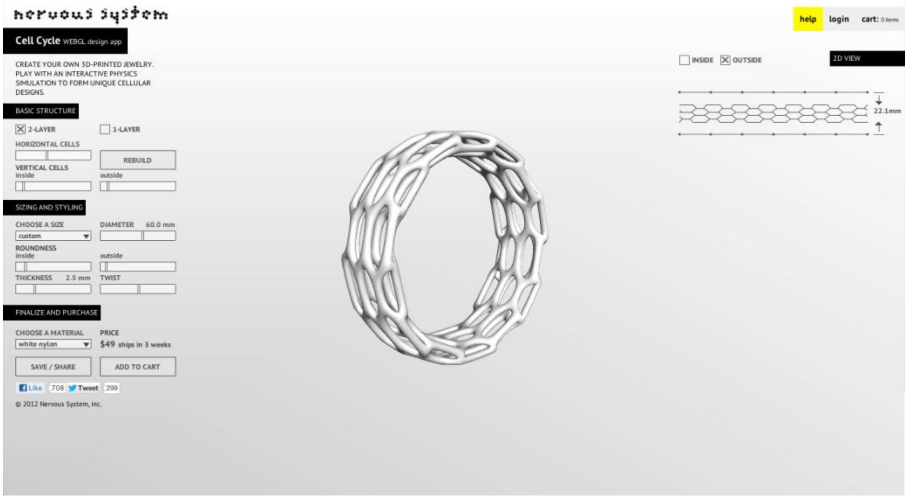


Figure 3.11 Customization interface of a bracelet design (Rosenkrantz and Louis-Rosenberg 2012).

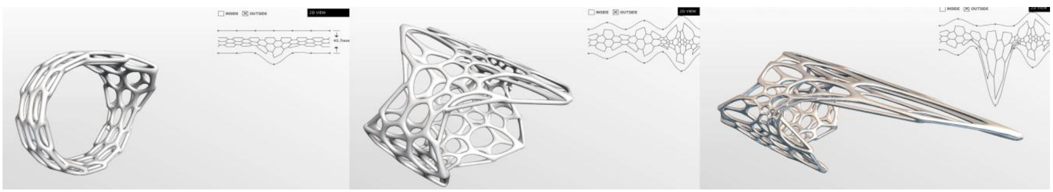


Figure 3.12 Customization of the mesh by modifying the 2D shape and material (Rosenkrantz and Louis-Rosenberg 2012).

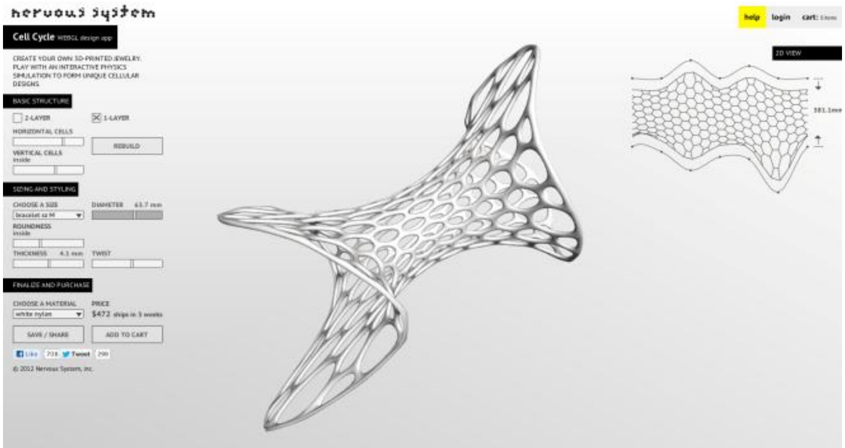


Figure 3.13 Mesh modified extremely by the researcher in the design interface (Rosenkrantz and Louis-Rosenberg 2012).

With the help of applications like these and manufacturing possibilities of 3D printing, designers' roles are changing. The designers state the value of their designs "comes from an intelligent and beautiful marriage of form and function".

3.9 N12 Bikini

Figure 3.14 Bikini manufactured with SLS polyamide (Huang and Fizel 2011).

N12 bikini, which takes its name from the material N12 Nylon, is another exploration of the boundaries of rapid manufacturing technology. The challenge in this design is to create a flexible "fabric" out of a solid material, polyamide.

Due to its biocompatibility and usage in most of the conventionally manufactured fabrics, polyamide is used as the build material. The vast number of application examples, flexibility and durability of this 3D printing technology (SLS) makes this type of application viable.

As mentioned above, the biggest challenge is to produce a flexible “fabric” out of a 3D printer. Figure 3.15 is a snapshot taken from a demonstration video of the N12 bikini that shows how the fabric bends. The main challenge of obtaining such a fabric is divided into two: packing of circles on a curved surface covering the form of human body, and obtaining enough coverage to hide the skin.

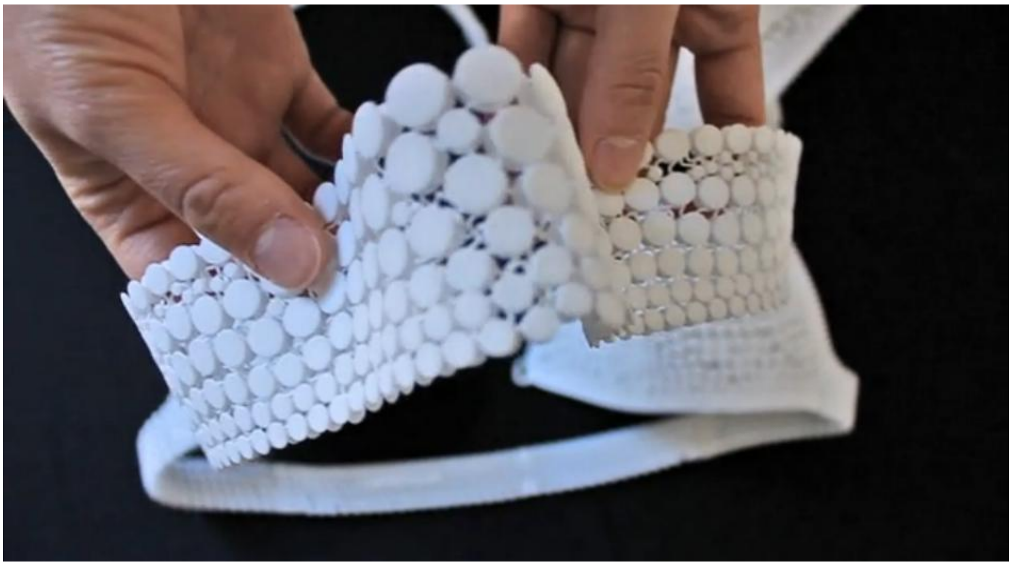


Figure 3.15 Flexibility of the 3D printed fabric. (Huang and Fizel 2011)

The process, which is expained in the designers’ website Continuum Fashion, starts with initial modeling of the fabric’s form. Then a specially written algorithm is used to place circles on that surface. On the surfaces with more curvature, the circles become denser and provide a more rigid structure. The algorithm scans the surface again to fill any gaps between the previously generated circles and fill them with smaller ones. There is no specific information given about the programs used, but the videos suggest that Grasshopper for

Rhinoceros 3D is used. To create a 3D geometry the circles initially generated are extruded at the minimum thickness that the selecte AM process allows. Then these are copied and offset which results in two layers of surfaces composed of circles. These circles in the offset surfaces are then joined with cylinders to form the structure illustrated in Figure 3.16.

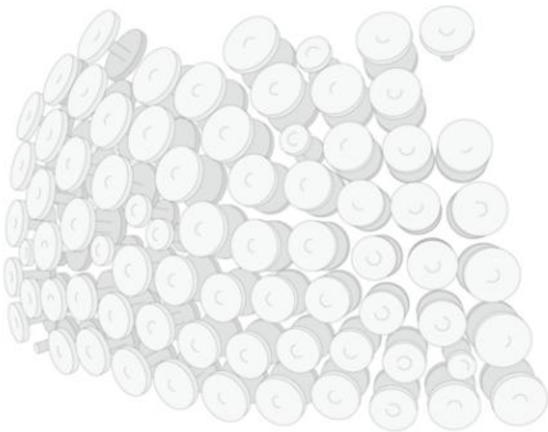


Figure 3.16 Two surfaces composed of circles which are connected with cylinder extrusions (Huang and Fizel 2011)

After the construction of these circular structures, centers of these cylinders are connected to each other with a mesh like structure holding the surfaces together (Figure 3.17). This mesh also helps to fix the form of the surface.

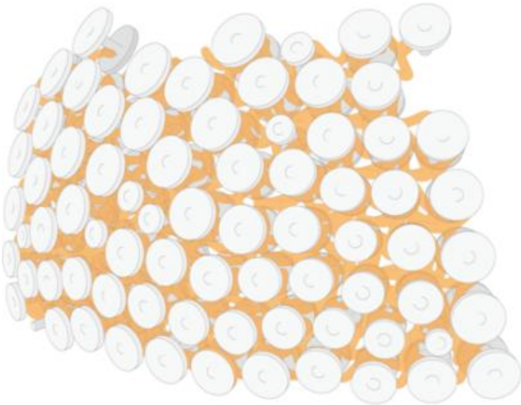


Figure 3.17 Mesh-like structure that connects the circular (Huang and Fizel 2011)

The result of the mesh and its coverage is shown in Figure 3.18. Although there still are gaps between the circles, the bikini supplies enough coverage to conceal the skin. It is also stated that use of nylon provides comfort in an out of water.

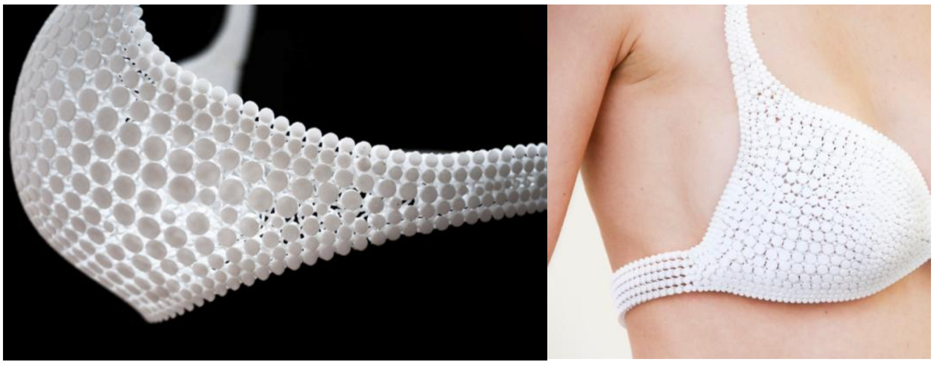


Figure 3.18 The resulting bikini and its coverage (Huang and Fizel 2011)

The designers of Continuum are selling these bikinis on the online 3D printing service Shapeways (Shapeways 2012) as well as other personal accessories designed with the same process of packing circles.

3.10 Fashion - Iris Van Herpen

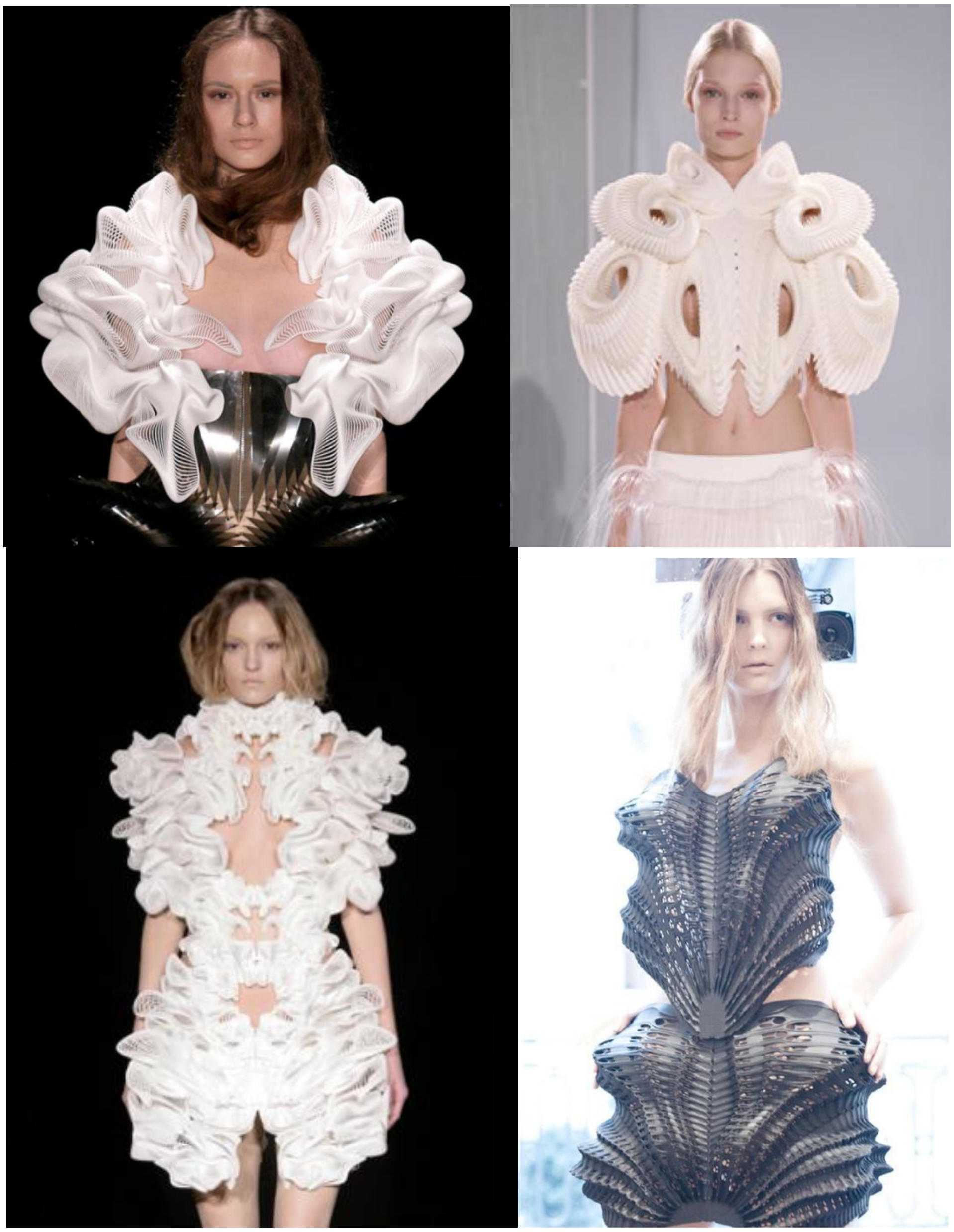


Figure 3.19 Various pieces made of polyamide manufactured with SLS (Irıs Van Herpen 2012; Daniel Wildrig 2012).

Iris Van Herpen is a fashion designer from Netherlands who uses AM in various collections of her own. Her collaboration with Daniel Wildrig (2012), an architect specialized in computational modeling, resulted in the forms seen in Figure 3.19.

Although there is not much information about the process, in an online interview (Wiegman 2011) Herpen explains that Wildrig's computational models are generated around human body. With continuous iterations and modifications these models are obtained (Figure 3.19) which are later manufactured in polyamide with SLS.

3.11 Online 3D printing services – Shapeways

Towards the end of the last decade, a new type of service started to emerge apart from the professional rapid prototyping and rapid manufacturing services. Websites like Shapeways, Sculpteo, i.Materialise and Kraftwurx present an online space where users or designers can upload their designs to the system and sell them as real products to the visitors of the website. The designs are then manufactured upon order via various additive manufacturing processes. The service can be used for professional prototyping reasons also.

The intriguing fact about such services is that they provide normal people (neither designer, engineer or a maker) access to the cutting edge technology by providing easy to use product creators (Figure 3.20). These tools enable the user to customize a bracelet or a ring, for example, according to his/her taste. The user can also upload a basic hand sketch of a pendant and that sketch is turned into a 3D model by automatically extruding the lines which is then manufactured and sent to the customers. Users of the website can open shops and sell their products in a gallery layout.

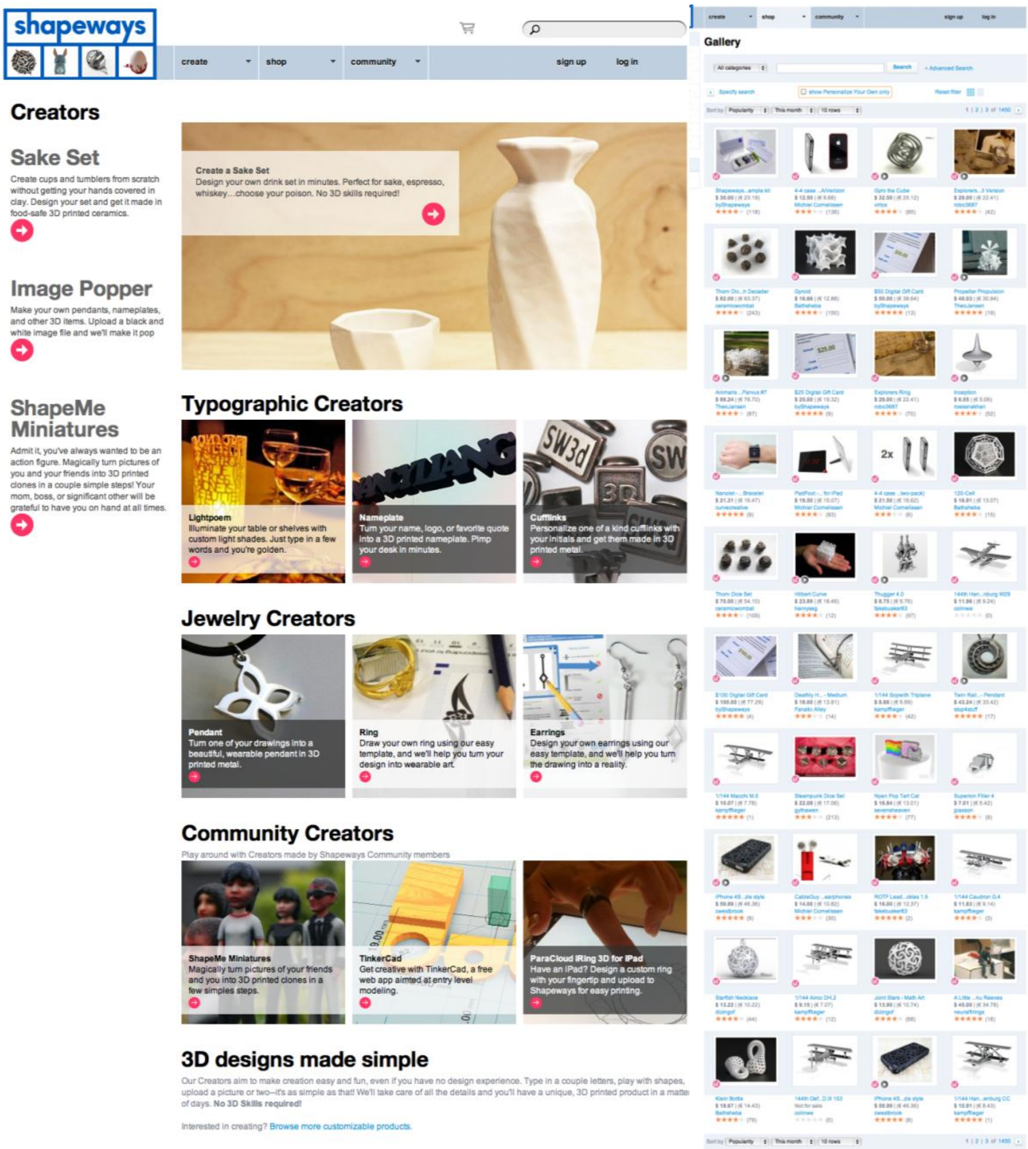


Figure 3.20 Shapeways' tools for customizing products (left) and gallery of products available for sale (right).

3.12 Participatory and open source design space – Thingiverse

Thingiverse is an online platform for sharing designs that are suitable for additive manufacturing. This online space is established by the founders of Makerbot 3D printers for the aim of sharing printable 3D models in these machines. However, it has grown into a collaborative platform in which many owners of the machine designed and uploaded 3D models of tools, toys, cases, gadgets, gears and even other 3D printers. As mentioned in section 2.4.3, Thingiverse has become an online laboratory of 3D printing experimentations and participatory design. Because the things uploaded in this space are free (open-source), people can download someone's model and build derivatives of it, developing it further or modifying according to his/her needs. The established system allows tagging 3D models which allows to track the derivations of an uploaded model. Figure 3.21 shows some of the designs that are shared on this website.

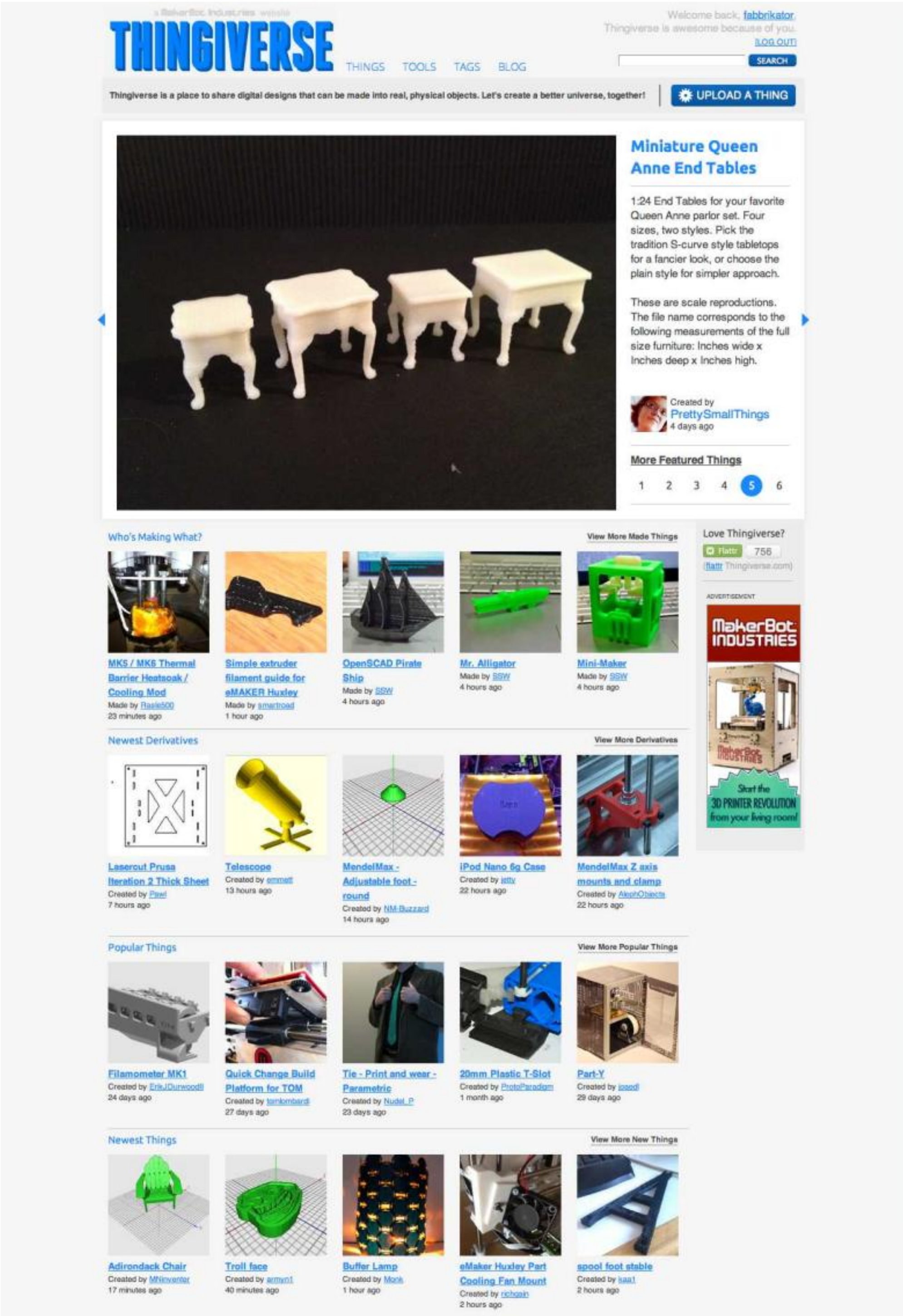


Figure 3.21 Thingiverse: An online sharing space for open-source 3D printable models and designs (Thingiverse 2012)

3.13 Summary of Emerging Applications in Rapid Manufacturing

Throughout the chapter, various applications of RM are illustrated in order to gain insight on the possibilities brought by the usage of additive manufacturing technologies for the manufacturing of end use products. Although some of the examples included are not commercial products, they are included to provide a wider perspective on the potentials and their realizations by the usage of RM.

It is observed from the examples in this chapter that the application fields of RM is diverse, ranging from lighting apparel to personal accessories. In addition to many application fields, advantages brought by AM are exploited by customized products as in Nervous System example that lets the users to decide the final form of the product through a parametric design interface. Also, online RM services like Shapeways make RM technology reachable by a wider audience while also allowing customizable products through their collaboration with designers like Nervous System. Similar to online RM services, Thingiverse establishes an open-source sharing space for designs related with AM.

From Damned Lamp and My Brain Lamp examples, it can be deduced that the border between a product and an art object is getting blurred with the usage of RM. On the other hand examples like Structural Ornament introduce the integration of engineering related generative design to the RM processes. Also, Endless Series project presents the importance of the designer's awareness of the AM processes and their limitations.

In the following chapter, these application examples are discussed with seven professional industrial designers who have experience with rapid manufacturing and prototyping processes.

CHAPTER 4

STUDY ON BARBAR DESIGNERS

4.1 Introduction

The application fields of additive manufacturing technologies are very diverse as illustrated in the previous chapters of this thesis. In addition to the industrial applications, newly emerging fields of applications create a labyrinthine system that is perplexing the analysis of the field from utilitarian and artistic standpoints as well as their relations with the industrial design profession.

In order to form a solid ground for the research and gain insight on the perspective of industrial designers to the current RM and RP processes, semi-structured interviews on the effects and implications of RP & RM technologies concerning their applications on industrial designers are conducted with professional industrial designers. The aim of this interview is to gather different perspectives from the professionals within the industry that have industrial design background, thus providing a grounded standpoint of industrial designers to the field of additive manufacturing.

4.2 Methodology

4.2.1 Aim

Initial aim for the semi-structured interview is to evaluate the emerging applications of RM presented in the previous chapter. Another aim of the interviews is to explore what these technologies mean for industrial designers in professional practice. The information on Barbar Designers and their works are to be mentioned in a very brief manner since the aim is not a case study of barbar designers initiative.

4.2.2 Selection of Participants

While selecting the industrial designers to be interviewed, a group of professionals that have experience with these technologies were needed to form a stronger and broader perspective. Also, the use of these technologies by the designers for the manufacturing of end use products would provide a better insight on the implications on industrial design and possible potentials in the profession. In order to achieve this aim, Barbar Designers, a collective design initiative located in Turkey is selected as the sampling group.

Among eighteen Barbar Designers, the ones with Industrial Design degree are selected with one exception of Mechanical Engineering. All of the seven selected designers were either graduated from an Industrial Design department or had a masters degree in industrial design. This diversity on the educational pathways of the designers enabled the researcher to map different approaches to the technology from a common background of industrial design. Also the researcher attempted to equalize the gender distribution among the designers to be able to reach conclusions that may result from the gender differences. For this reason, 10 designers (5 female and 5 male), were contacted for the interview. Although a total of 9 out of 10 designers accepted the interview, two of them were unable to come due to changes in their work schedule. Table 4.1 shows the demographics of the interviewed designers.

Table 4.1 Demographics of interviewed Barbar Designers.

Designer	Gender	Age	Experience	Education	Expertise
A	Male	37	14	Bachelor: ID	product design, retail design, interiors.
B	Female	49	26	Bachelor: ID	jewelry design, product design, graphic design
C	Female	49	27	Bachelor: ID	Jewellery design and metal smith
D	Male	47	18	Bachelor: Industrial Design, Masters: Graphic Design	exhibiton and information graphics design, book and periodic production design, typography, corporate id and graphic systems solutions
E	Male	39	15	Bachelor: Mechanical Engineering Design Masters: ID	Product design, graphic design, exhibition design, design management
F	Male	48	24	Bachelor: ID Master Certificate: Industrial Design	Electronics, sunglasses, packaging, academic
G	Male	39	16	Bachelor: Industrial Design	Industrial design, design management, part time instructor

4.2.3 About Barbar Design Initiative

Barbar Design Initiative is a multidisciplinary design collective based in İstanbul that gathers many renowned designers who are active in various fields such as jewelry design, industrial design, packaging, graphic design, architecture and glass manufacturing. The group gathers several times a year and designs around concepts determined in their discussions throughout these gatherings (Babadag et. al. 2009; Barbar Design Initiative). They define "barbarian" as:

> The term barbarian, which was used originally used by the Ancient Greeks to describe the peoples of the East and later adopted by the Romans into

its modern usage to describe a person in a savage, primitive state, is used by the Barbar group to poignantly provide a framework for what makes cultural production in Istanbul distinctive.

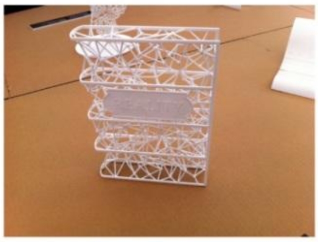
Below are the exhibitions of barbar designers up to date:

- Barbarbook (Istanbul Design Week, 2011)
- Barbaricon (Istanbul Design Week, 2010)
- Barbarlight (Istanbul Design Week, 2009)
- IMM (Cologne, 2008)
- Barbarian’s Banquet (Istanbul Design Week, 2007)

In each of the exhibitions, a certain theme is decided through open discussions in several meeting over years and all the designers realize their designs according to that theme. The resulting designs are manufactured with RP machines and either post-processed or used as is according to the AM process used. One of the concerns during the design process was to exploit the form freedom brought by AM, as stated by the interviewed designers. Also as stated in their manifesto, they are concerned about the cultural backgrounds and define their resulting designs as “object of an interactive and iterative amalgam” (Barbar Design Initiative). Their focus is a combination of environmental, social and personal realities that exist in İstanbul and Turkey.

Figure 4.1 in the next page shows various works of Barbar Design Initiative from several exhibitions.

Book of Reality (Kunter Şekercioğlu, Barbarbook 2009)



Trefoil (Kunter Şekercioğlu)

Hoş Gör Ya Hu (Kunter Şekercioğlu, Barbarlight 2009)

Roots (Taner Şekercioğlu, Barbarbook 2011)

Burning Turning (Ela Cindoruk, Barbarlight 2009)

Noor (Erdem Akan, Barbarlight 2009)

Barbaric Cut (Defne Koz, Barbarian Banquet 2008)

Nest (Alper Böler)

Figure 4.1 Various products realized by Barbar Designers

The diversified expertise fields of the selected designers provided a broader perspective on the effects and implications of additive manufacturing technologies on industrial design. Some of the designers natively use RP methods in their design process while some of them mainly have used the technology for this collective project. By this diversity of usage, a broad perspective on mapping the effects of these technologies on the industrial designer is established. From the general content of the interviews, it is observed that the designers' daily experience with RP and RM affect the way they approach to the technology. Designers who frequently use RP and RM in their daily workflow are observed to be more conservative in their approach to the presented application examples, whereas the ones having less experience are observed to be more interested.

4.2.4 Flow of the Interview

The interview with the Barbar designers is commenced with a general introduction on the RM and RP fields including what has been done in industrial applications. Although most of the designers are observed to be aware of these developments, a summarizing introduction is given in order to standardize the scope of the interview. General industrial applications are introduced such as medical, engineering and product design fields. Later, the application examples in the Chapter 3 of this thesis are discussed with the designers following the interview guideline in APPENDIX B.

Duration of the interviews ranged between 60 to 100 minutes. The general tone of the interviews were very cordial. All of the designers were interviewed separately either in their offices or in a predetermined place in İstanbul. However, designers B and C are interviewed together since they are working together in their professional life. The reasoning behind making the interviews separately was to prevent any probable biased opinions of the designers.

4.2.5 Analysis of the Interview

The semi-structured interviews are conducted in order to gather different standpoints of industrial designers to the field and create a unified perspective. Thus, rather than analyzing the interviews with quantitative methods, qualitative analysis is chosen. While constructing the collective standpoint of industrial designers, every criticism made on AM related fields are evaluated and included in this thesis.

All of the interviews are audio recorded and listened several times after the completion of interviews with the designers. In order to be able to search the interview contents and make correlations easier, all of the conversations are transcribed into text. Then these conversations are analyzed again and summarized under general topics. Throughout this process some irrelevant speeches are eliminated. The summarized statements are then collected under more general titles in a diagrammatic layout in order to facilitate correlation of common and contradictory point of views. Then, these statements are transformed into lists and rearranged the statements under the generated titles. Throughout these processes, following a linear order is hard to maintain. Thus, the researcher travelled in continuous loops between the audio recordings, transcriptions and diagrams in order to extract any possible correlation occurred in the interviews.

After the whole process is completed, the audio recordings are listened again and compared with the transcribed texts in order not to miss any relevant comments made by designers. Then, a unified perspective is established by combining individual comments made by every designer and collected under general titles presented in the following section.

4.3 Barbar Designers Analysis

The comments made by the designers throughout the interviews are collected under the following titles in order to make the analysis of the perspectives easier:

- Benefits
- Concerns
- Paradigm Shifts
- Personal Fabrication
- Customization
- Environmental Effects
- Potentials
- Empowering designer
- Design process
- Industrial design profession
- Industrial designer
- Innovation need
- Costs
- Applications

Since the aim of the interview is the gathering of as much divergent information on the relation between AM and industrial design as possible, the designers are not confined in specific themes during the discussions. This approach resulted in a more diverse standpoint and expanded the interview space which in turn created a perplexing map to organize. Different standpoints of designers are going to be unified in this section of the thesis under generalized titles mentioned above.

4.3.1 General Perspective of Designers

It is seen in general that the professional expertise of the designers have a significant effect on their attitude towards AM technologies and their applications. Designers that are more manufacturing oriented in their professional fields are inclined to evaluate AM technologies in a more literal manner. In other words, their concerns about the real applications reveal that despite all the advantages of AM, there is an innovation need in their usage for manufacturing of end use products. According to them these technologies are more useful for industrial designers in the design process of products in today's conditions.

Although these designers give these technologies more value in the design process, designer E stated that even the design process does not involve these technologies sufficiently in Turkish design industry. His main argument is the high costs involved in the operation of RM and RP machines and rejection of clients to pay for additional costs for prototypes.

Another comment of the designers is about the evaluation of products that are manufactured with AM as industrial products. There is a blurred general opinion that such products cannot be classified as an industrial product, yet, there is not a specific proposal for how to classify them. Rather, there arose a common standpoint that there will be a condition similar to the arts and crafts period in which the designers (craftsmen) were to design bespoke products. This standpoint overlaps with Campbell et al. (R. I. Campbell et al. 2003) stating that there will be a new type of industrial designer, “bespoke” industrial designer as a result of the empowering of the designer with manufacturing tools that enable them to manufacture bespoke products. The term used “bespoke” industrial design fills the gap which occurred in the interview while designers rejected these new applications as industrial but failed to offer a specific terminology for these applications.

Designer A propounded a perspective that fluxed between an industrial designer’s and consumer’s standpoints. Although in general he kept the perspective of an industrial designer, he questioned AM and RP technologies from an end user’s point of view. In general, designer A put forward a critical standpoint on the applications of AM technology and their meaning for industrial designers. Prior to the interview, he mentioned that he is interested in low-cost 3D printers and planning to buy one signaling his interest and excitement about the personal usage of the technology. However he also mentioned that the reason for buying such a tool is for experimenting or playing in other words. Despite his personal interest on these machines his professional approach in general was critical.

Designer A started with questioning why 3D printing technology has evoked such an excitement but not CNC machining and stated that there is not much difference between the two other than subtracting and adding material. When comparing with regular 2D printers, he asserted that the only difference is that you can hold the real 3D object rather than a 2D representation of it.

Since Designer B & C have professional expertise in jewelry sector, their manufacturing experience are more related with craftsmanship rather than industrial manufacturing methods. This aspect brings them closer to the usage of AM technologies in a more individualized manner serving in the empowering of the designer as individuals.

Designer D started the interview by stating although he does not see himself as a nerd or geek, he is fascinated with these machines' making of things by themselves. Also, his critical perspective on these technologies and relation with industrial design is more on the conceptual background rather than the practical side. Designer D is generally interested in how this technology is changing the way we perceive manufacturing, beauty and forms.

One of the major standpoints of designer D during the interview has been the changing of mankind's tool and object making process in a very short period. He stated mankind's toolmaking and object making process has millions of years of history and mankind has always had direct relationship with material. Even in today's and recent past's factories there has always been manual intervention by men. Also throughout these processes, there always existed trial and error. However, in AM, there is a computer screen and we try to perceive the drawings on the screen as much 3D as we can. We cannot be sure what will come out until the machine makes it according to designer D. He stated this transitional period from digital data to physical object interests him very much.

Despite the general perfectionism in AM systems, designer D is interested in the error and malfunction in such devices which leads to unexpected outcomes in the resulting model. He mentioned this concept of unexpectedness factor in these systems several times during the interview.

Designer E started with an example to introduce the changes brought by AM technologies. He, like designers A,B, C, and F, gave the example on the effect of digital photography on photography profession and stated his general concerns on the topic. In general he clearly stated that he is thinking positively about these possible changes and also indicates these changes' inevitability.

Designer E sees AM and RP technologies as a tool of industrial design profession and stated that industrial design should adopt these technologies and help it to develop In a proper way. He thinks that AM and RP technologies have strong connections with industrial design since the meaning of industrial is directly related with being able to manufacture. He also stated that he sees all of the applications discussed in the field of industrial design, either it is one of a kind product, a mass manufactured product or a product that is designed by a mathematical algorithm. He suggested to be aware of these technologies and adopt them.

Another remark of designer E was that with AM, the physical existence of a product starts to lose its importance and explained that only the data of a product is transferred from one nation to another. That data transfer has become same as sending the product itself. That digital data sent is enough to start the production of the product or part he stated.

Designer F focused on the general implications of AM technologies for the industrial design profession. In general he sees additive manufacturing technologies will open new horizons for the designers. These horizons according to him are participatory design processes, generative design applications that allow the user to design or customize products by changing certain parameters, and enable the designers to be the manufacturers of themselves that set them free of many dependancies.

According to designer F, industrial design profession's scope should not be limited. He asserted that the profession finds it's tools and meanings. Also he added the industrial designer's definition is not static but dynamic and believes that it will evolve over time. New production methods and materials will affect this evolution he asserted. Designer F's general perspective on AM technologies is that it may be opening new pathways in the profession.

Designer G's interpretations of AM technologies and applications were mainly from an industrial designer's perspective and when compared with the other designers, his standpoint was more literal. While discussing the applications for their implications on industrial design, he interpreted industrial design applications as usage for prototyping reasons only (rather than manufacturing of end use products) and asserted that since industrial means manufacturing in very large numbers its structure will remain mainly unchanged. Nevertheless, designer G also asserted that some updates and modifications in the definition of industrial design education will be needed.

In general, designer G rejected to classify the application examples shown to him under industrial design profession since they cannot be manufactured by mass manufacturing methods. Yet, he stated that some specialization fields under industrial design will arise and there will be an era similar to the arts and crafts period.

4.3.2 Benefits

From an industrial designer's perspective, designer A sees AM technology a great opportunity for the designers that will use it in the design process and later turn it into a product that will be accepted throughout the market. However, then he puts forward that if the product designed is really successful and will spread to the masses, then the designer has to turn to other manufacturing methods that allow him to manufacture it for masses. So the designer sees RM technologies a great tool for designers but in a limited scope which mainly is the design process. The most significant benefit for industrial designers, according to designer A, is **facilitation of idea to product transformation**. Yet, after the idea is transformed into a final product, **it is feasible to choose AM for the main manufacturing method only if the designed product is not manufacturable via conventional manufacturing methods**. When a product becomes very successful and beneficial for masses, even if the current manufacturing methods are not capable of manufacturing such a product, new methods are sought after that will enable mass production (Figure 4.2). **According to designer A, this would not be the case only if the forms are extremely complex. In that case, the complexity of the form must also have a meaning or function he stated.**

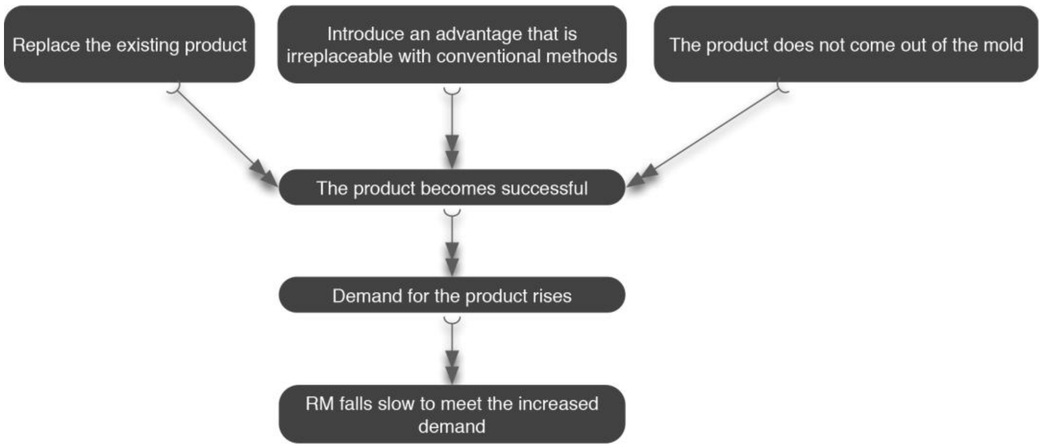


Figure 4.2 Designer A's reasoning for choosing RM for the manufacturing method of a product

Another distinction made by the designer is today only not so essential products such as lighting apparel, jewelry can be accepted as end products and completely manufactured with AM technologies (Because of fragility and surface quality). Designer A sees manufacturing of an object with only AM technologies as a different case and puts forward two criteria to be met in order to choose AM for the manufacturing method of a product: **The product should not be coming out of a mold and even if the product has to be manufactured for masses there should be such an advantage brought by AM that still you will prefer AM for the manufacturing method.** Since there are no such examples in consumer products, the use of AM for end use products remain in not so vital fields such as lighting and personal accessories. **He stated that there is an innovation need in the field of product design with AM technologies and some vital applications should be found.**

AM and RM are very beneficial if the form freedom brought by the technology is used in innovative ways according to designer A. He clearly stated that the exploitation of form freedom aspect of this technology without any meaning or function is useless. **He rather related such examples like FOC chair with designer's ego which, according to him, designer D and designer E is another way of saying "Look what I have done". The three designers' common standpoint on the benefits of form freedom was it is good only if it serves for a specific purpose.**

When compared with traditional manufacturing methods, AM provides flexibility in the process. In traditional manufacturing there may even be a machine for every single process, however in AM there is only one machine that does all the work and it is not necessary to change anything physically, as stated by designer A.

Designers B and C argued that this technology lets the designer to design and manufacture objects and products that were impossible even to imagine.

Major benefit mentioned by designer D is the possibility to create very intricate forms with these machines. Also he mentioned that this technology empowers the designer as an individual and with the invention of new materials for these AM processes amount of this empowering will increase.

Designer E mainly focused on the flexibility advantage of AM technologies. His professional experience throughout the field in which he designs limited runs of ceramic objects was probably the cause of this interest. In addition to the quality concerns, the quantity plays a very important role in the manufacturing process in Turkey he stated. Designer E mentioned this constitutes an important problem for designers.

He thinks that this manufacturing technology will open new horizons for the designers. He stated that there are some problems when designers decide to get their designs manufactured mainly being the product quantity and manufacturing facility's flexibility. To further explain the concept of flexibility, he shared his experiences while getting his designs manufactured in Turkey. Designer E stated that although there are many manufacturers in Turkey, it is not cheap to get your design manufactured if you need a high quality product. This is especially true for glass and porcelain products according to the designer's experiences. The manufacturing quantity is not flexible since the manufacturers neither accept low runs nor very large runs he continued.

The craftsmanship, technical knowledge, and manufacturing capability of companies vary too much and it is hard to find a manufacturer that satisfy the designer's needs he stated concerning Turkey as a case. For such cases, he thinks that this technology will liberate the industrial designer from such obstacles. He especially thinks that this will be the case for porcelain since he stated that manufacturing of a high quality porcelain is both hard and costly. AM technologies, according to designer E, frees the designers from the constraints caused by manufacturers.

On the manufacturing of ceramics, designer E stated that even a simple form is hard to get manufactured if it is needed in low runs. Furthermore, if the shape is complex, it is either too costly or impossible to manufacture. AM, when applied to the case of ceramics, provide great benefits to the designer according to him.

According to designer G, the most important benefit brought by AM when used to manufacture end use products was form freedom. In real applications of molded manufacturing problems resulting from the wall thicknesses, drafting angles, and quality appearance requirements limit the creativity of the designer stated designer G. AM, he asserted, gives the designer to play with forms without being concerned much about these limitations. With AM, the product comes out as it is designed and the only problem is related with the sizes of the product since as the dimensions increase the costs increase dramatically, he asserted. Yet, he also stated that it is not a real problem since it is a matter of budget. Despite the benefits he mentioned, he also questioned to what extent the speed of such manufacturing systems can be increased and stated that **AM methods are only feasible in the circumstances that conventional manufacturing methods remain insufficient in the manufacturing of the product.**

Another important benefit of AM technologies according to designer G is timing advantage. In order to explain this benefit, he gave an example from his professional experience. In the design process of a product that is going to be injection molded, a single tiny mistake in the mold can leave the designer or design team behind his opponent, stated designer G. Despite the advantages provided by AM technologies in time schedule of a design process, when designer G compared it with form freedom, he mentioned that form freedom advantage is more important than the timing advantage.

4.3.3 Concerns

Designer A refers to the usage of AM technologies by industrial designers and consumers continuously and in some parts of the interview. For this reason it becomes hard to differentiate the two standpoints from each other. As the initial excitement on 3D printing and AM gets lost, he stated, we will start to be concerned about what had been sacrificed by the usage of these technologies. The first sacrifice he stated was the surface quality of the objects manufactured. As the industry gets used to AM technologies and they become an industry standard in manufacturing, there will be compatibility problems he asserted. To further explain these compatibility problems, he made an analogy on computer operating systems that do not accept every program since they should be compatible with each other. This compatibility problems result in a loss of many great ideas since they are not compatible with the current widespread systems. Thus, the standardization of manufacturing systems with AM technologies, will decrease the survival chance of great ideas according to designer A. From his comments on the future of the AM technologies, it can be deduced that he sees the transformation to this technology as inevitable.

Apart from the compatibility problems, designer A used another analogy related with computer software used by designers. He mentioned that in the past not far from now, it was very hard to get photorealistic renders. Now however, he stated, it became easier with standardized software and readymade templates. So greater number of people can get photorealistic renders easily. Web design is also similar he stated. The standardization of such systems made it easier to find readymade templates and do things faster but at the same time, according to designer A, made the resulting outcomes more banal. Designer A's concern after making these analogies was standardized systems are killing creativity.

Designer A stated that these technologies will eventually make everyone a "designer" in a way. He gave examples from the impact of digital photography and applications like Instagram on photography profession.

Although designers B and C's general views of the technology were positive, they were concerned about the loss of error, coincidences and their contribution to design process that are intrinsic to hand sketches.

Other issues they mentioned as their concerns were increased amount of plastics usage and health issues when people start to be able to manufacture their own goods especially related with food. Since in a large percentile of RP machines plastics are the build material, designers B and C stated that if majority of these processes are continued to be carried on via the usage of plastics as build material, this can cause a great increase in waste plastics in the future.

Another standpoint introduced by designer G refers to the unscholarly designers' products that may lack safety features. Also, there are currently no safety guidelines on online 3D printing services like shapeways.com, the users can suffer from injuries due to the usage of faulty products.

Almost all the designers (A, B, C, E, F, G), mentioned that this technology will make everyone a "designer" as digital photography made everyone a "photographer". Designer B & C argued that when everyone becomes able to design and manufacture their own tools and products the perception of industrial designer will change. Similarly, designer F stated the when the users are empowered as designers then the meaning of "industrial designer" title will change. In an environment where everyone is a "designer" he added that he is concerned about to what extent the competition between them will be fair. Despite the general concerns of "everyone becoming a designer", designers' common standpoint was such problems will resolve throughout the natural flow. Industrial design and design profession will survive just like photography profession did, as stated by the interviewed designers. **However, the designers should reposition themselves according to the advancements in the system according to the general view of designers.**

Another concern stated by designer A is when ways of doing something is standardized, and the path becomes too easy, the creativity is lost leading to banal outcomes.

The main concern of designer E with the use of AM in industrial design profession is the isolation of the designers hands-on relation with the material as stated by him. "Designer's main issue is with manufacturing or material so I am not happy in a way that this technology isolates the designer from the reality."

he stated to communicate this idea. He added that since he is from a generation who worked with clay and hand sketches analog media is very and stated that we should be aware that all of these are tools but not a deliverance from reality. He pointed to the powerful existence of hand sketches and stated that apart from some specialized iPad applications nothing have replaced hand sketching. He compared hand sketching to clay modeling and stated that the power of clay modeling, in which you model by feeling and getting rid of the excess material like a sculptor, is mostly overlooked. In RP however, he stated the designer can only feel after the model is made. The designer then compared clay modeling to RP and said “RP is untouchable, a finished thing. In a way a finished end product. An intermediary product, but at the same time a finished product.” He identifies this as the main problem and then states that it is like a “verification product”. **Because of this, he explained, such RP models could not be used effectively in the product development process.** He sees these models rather suitable for reverse engineering, from designer to engineer and engineer to designer one to one proof models. He also asserted an example from the work experience he had that once he saw one of his colleagues working on a radius of a 1 mm area. He stated only RP is dealing with sub-mm dimensions however in manufacturing, such details (corner radius of a 1 mm area) are not important. This, he asserted, tears designers apart from reality. However, design process is completely related with reality and this is what makes a designer different from a filmmaker or an illusionist, he stated.

Designer G was not concerned about the future of AM technologies in general terms regarding the industrial design profession. Nevertheless, he stated that some serious problems regarding safety issues may arise in the future. These problems, according to designer G, will result from unscholarly designers' products. The spread of online 3-D printing services to the masses will cause many people to put their designs online stated designer G. In these circumstances the procedures for testing the quality of the product will not be used. These conditions according to him will result in greater number of unsuccessful products and health issues.

Although designer G did not state any other concerns, when he was asked whether if he has any concerns on the copyright issues or not, he stated if a product is wholly manufacturable with a single method, then it becomes easier to copy. However, he added, if the design of the product incorporates details that require special processes, then it becomes harder or even impossible to copy the original 100%.

4.3.4 Paradigm Shifts

Designer B stated as a concern on the future of this technology and it's implications for the industrial designer that in a society where everyone can design and manufacture, the perception of industrial design and designers will change. Designer C added after getting used to the new technology, good designs' importance will be understood better. Designer C also mentioned that since the machines and technology used for AM and RM cannot manufacture in an industrial manner, industrial design profession will be specialized or separated into product design and industrial design. She stated the main reason for this manufacturing processes not being industrial is that it takes time to manufacture with these machines.

Designer D mentioned that the conception of object creation starts to change in a very short period of time with this technology. Mankind's attitude towards object and tool creation is a result of millions of years he emphasized and stated that this technology changes this conception in a very short time. Traditional methods always involve manual intervention in which man interacts with material. He added that mankind loves to own and hold objects. Designer D continued by stating physical existence of objects and their interaction with men also develop intelligence. **The transformation of digital data directly to physical existence breaks mankind's relationship with material according to designer D.**

Such problems were also interpreted as designers' disconnection from the reality. This isolation causes the designer to loose too much time on unnecessary details and prevent them to see and interpret the whole (as designer E stated in Concerns section). Since design Is directly related with reality and it is what separates a designer from a filmmaker or illusionist, the connection of the designer with the real materials becomes an important aspect of the process. In the long term, usage of AM technologies being unaware of these effects would result in the isolation of industrial designer from reality, thus, destroying the most distinguishing factor of industrial design from fiction (as stated by designer F).

Apart from the relationship between material world and mankind, designer D proposed that the form freedom brought by the technology also brings new conceptions on the definition of beauty and elegance. Especially when he was talking about the Structural Ornament example, he stated that the intricacy of such forms and structures, the empty spaces within the overall structure, the thinness of the structures introduce new conceptions of beauty and elegance.

AM, by its nature, is a different way of manufacturing when compared to traditional manufacturing methods which involve trial, error, manual labor, intervention, lathes and cnc machines, according to designer D. He stated the process is happening by itself in AM.

Designer D proposed that there is a return to the essence of vernacular crafts existing in the beginning of 20th century.

Designer E compared the current condition the man shapes the tool and then tool shapes the man. He later stated that industrial designers should embrace the technology and steer the engineers or technical people working on these technologies and inform them about their needs . Later they should reposition themselves according to how these new manufacturing technologies affect their places in the society, he added. He asserted that these new methods of manufacturing will definitely cause some changes.

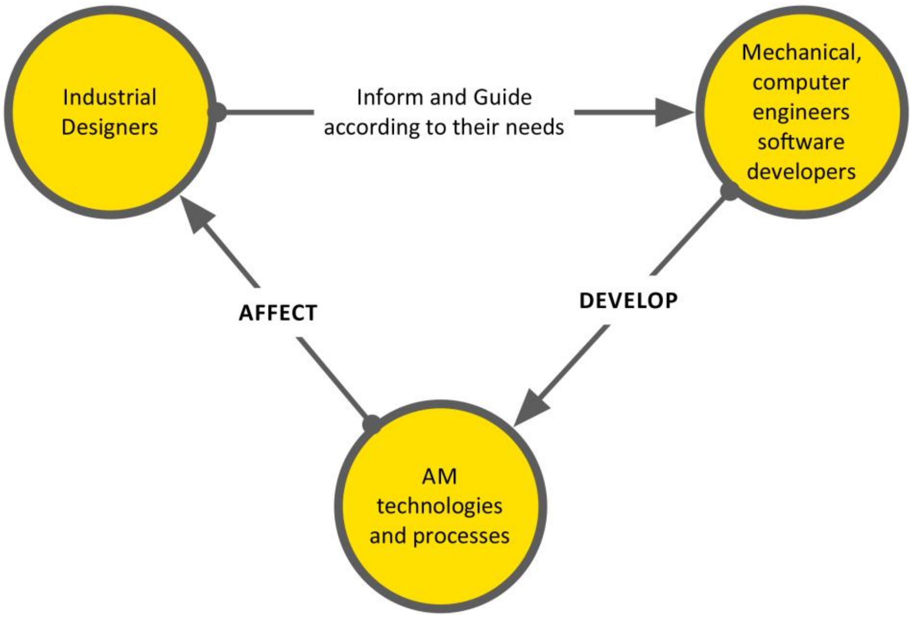


Figure 4.3 Interaction between industrial designers and the development of additive manufacturing technologies according to designer E.

Designer E stated that the industrial design profession will not be the same as today due to shifting paradigms and changing technological possibilities. Yet, he asserted the knowledge of the industrial designer on products, usability and function will play an important role in the existence of designers in the near future.

Designer F stated that he sees this technology as an opportunity to involve non-designers in the design process and design in collaboration with them. There are people who have many ideas but because they had not have design education they die with their ideas, he stated. This technology makes the process accessible to wider people and shortens the time that leads to a conclusion according to designer F. He thinks that when these machines become widespread like photocopying machines the chances of discovering what can be done with them increases. Because, according to him, when the technology comes closer to the users, it becomes easier for them to experiment and discover what can be achieved.

When commenting on whether the shown examples are industrial or not, designer F stated new pathways in design might be opening. Also the definition of industrial design can be discussed someday he added. However he mentioned that industrial design profession cannot be described between apparent borders like law or medicine. Industrial design had been the design of objects that are manufactured in series in the past and mentioned jewelry was not In the scope of industrial design. However today he stated, someone designs a ring, and can manufacture it in series. These advancements can cause some paradigm shifts in the definition of the industrial design profession he asserted.

Designer F also commented on the software tools used in design process and stated AM technologies should not only be perceived from the designers' view but also from the users' perspective. He stated that the facilitation of the modelling software and the methods of manufacturing the designed object changes design's adoption by the "clergy". "When such programs are well established and unscholarly designers start to design better than you, the meaning of the designer title you write on your business card may change." designer F asserted. He then stated that there has to be some modifications in the education system.

Designer G stated that there will not be paradigm shifts in industrial design, interpreting the definition of the profession literally. He argued that since products like Structural Ornament cannot be manufactured industrially, they are not in the scope of industrial design. Designer G stated that there will be further specialization fields under industrial design profession and gave the example of arts and crafts period. Concerning the latest condition of RM and RP he asserted that they put the designer in a situation in which one foot of the designer is artist and the other is designer. Between his legs, there is this technology letting the designer to decide on which leg to transfer his weight, designer G made an analogy. He added that also there is engineering involved in the process. He questioned to what extent the resulting methodology is industrial design. He accepted that it will be design but criticized its industrial part and stated that we will witness some updates, paradigm shifts in such areas.

All the Barbar designers interviewed referred to this technology as empowering everyone as a designer. The overall standpoint was referring to a paradigm shift in the definition and perception of design in the society. Although some designers seemed concerned about the outcomes, overall standpoint of the designers was all these shifts are inevitable and they will be resolved through the natural flow. While mentioning that spread of the usage of these technologies will make everyone a “designer”, it was observed that some of the designers interviewed used the term in an ironic manner. From this attitude, it can be deduced that the concerns of these designers about the future of industrial design profession might be more serious than their statements. Thus, a stronger paradigm shift in the industrial design profession might be expected.

4.3.5 Personal Fabrication

On personal usage of 3D printing by consumers or end-users, designer A thinks that instead of designing something from the beginning while there are already better designs on the market, it would be a better and more efficient pathway to modify existing designs according to their needs. Also, since today’s applications of personal 3D printing fail to exploit the potential of the technology in an innovative way, these applications will remain in a niche rather than going mainstream according to Designer A

Parallel to designer A's standpoint, designer D thinks that it is unnecessary to design objects from the bottom up. Instead he stated that ready-made templates are more logical for customized designs. This standpoint of the designer also corresponds with his ideas on the Nervous System's products which is mentioned in Applications section in the following paragraphs.

4.3.6 Environmental Effects

Designer A does not find AM's environmentally friendliness realistic. He argues that in the end we are not manufacturing toilet papers so there will still be a need for a serious logistics throughout the world. So his general view is that no matter what happens, we will still need traditional mass production line in many daily products. At the same time designer A stated that he wonders the results of the spread of home manufacturing to the masses. He again mentioned that such usages will remain in a niche area since there is not a good application of it.

Designer F stated there are more products than humanity can use throughout their whole lives and this excessive production is consuming all our natural sources, water being the first. Customized manufacturing he asserted, will bring a better way of consumption since sometimes a large percent of the mass manufactured products can be left unsold or unused. According to him, this technology is an opportunity to use industrial design profession in a more environmentally responsible manner.

4.3.7 Potential

In general, it is seen that the designers think that AM is not exploited well by industrial design profession. Most of the designs or products made with these technologies are like replacement objects and all reference to the objects in the past. However, there is much more potential in AM and it needs to be exploited. It is stated that since industrial designers are very affected by the technological limitations and got used to feed their creativity within that system, they should break these confinements and think outside of the box. The greatest need for the exploitation of AM's potentials by industrial design is the innovation in thinking patterns. Also, experimental usages of AM are more likely to exploit the potentials of the technology.

Applications of AM will be seen in many fields of design according to the general perspective. However, designer D stated that textile sector will be one of the fields that has the highest potential. Main argument for mentioning the textile sector is it requires customized products since anatomy differs from person to person. Although there is a need for customization in textile sector, rapid manufacturing of textiles still remains as an unviable option since they remain in very high price range which makes it harder for public to reach. However, with specialized software including parametric design interfaces when combined with specialized AM methods can lead the path to rapid manufactured textiles.

Another specialized field that AM has high potential was referred by designer E. Ceramics, porcelain and glass manufacturing according to designer E have the highest potential since their manufacturing process is not flexible in quantity and costs are generally very high if a quality product is desired. Also, form of the product acts as a very dominant factor in the production process. Even simple forms can be very hard or even impossible to manufacture as stated by designer E. The form freedom brought by AM plays an important role in such fields since these fields suffer from both formal limitations and inflexibility of production runs. In the interview, shapeways.com's ceramics and glass materials are introduced to the designer. Although designer E mentioned his concerns about health issues since there may be unglazed surfaces left on the resulting products, he got excited about the possibilities such applications of additive manufacturing brings.

Designer G stated that in all of the fields of industrial design the benefits of these technologies will be seen. He asserted there is no single field according to him that will carry the technology’s applications to a new level.

4.3.8 Empowering Designer as an Individual

According to designers B and C affordability problem of RP machines by individuals continue to exist when the designers are to use professional RP and RM machines. However, as stated by designers B and C, especially the low cost machines, although producing objects with lower quality when compared with expensive professional machines, empower the designers who try to design and manufacture their own products at the same time in a way that their dependency to other companies decrease. They gave an example from their process in which wax models are used for investment casting. They stated that machines that print these wax models are owned with very few companies in İstanbul and they charge high costs per a single ring. Since various sizes of a ring are also needed, this method becomes unaffordable by individual designers. If, they added, they owned such a low cost machine, it would enable them to realize many ideas they have. Personal 3D printers attracted their attention and they stated that with these machines they would be able to try whatever idea comes to their minds. Also, the researcher’s own experimental 3D models made of silicone drew their attention and they continuously played with the sample models given to them. It is also mentioned to them that these models are very cheap to make since it is made of regular industrial silicone used as sealants or for montages as well as the time required to print them is very short. Throughout the interview, it is observed that they played, stretched and ripped pieces from the models. It can be deduced that the reduced costs of an RP model, adds a playfulness to the model, and decreases the fear of giving harm to a very expensive object. In addition, they were interested by the TinkerCad software and its easy interface. The ability of the application to produce ready to manufacture models also grabbed their attention.

As mentioned under the Benefits title, designer E stated that AM technologies open new horizons for designers by adding flexibility to product development process and liberating designers from the manufacturers. He also asserted that these technologies should be embraced and exploited by designers.

According to designer F, the designer is returning to the days when s/he was also the manufacturer. He stated “at this point, we are talking about movement of the stones in the capitalistic system”. This transformation, he added, can cause some changes on the definition of industrial design profession in the medium term. He also stated this technology allows the designers to manufacture their own designs referring to a return to the arts and crafts period.

AM technologies increase the chance of designers to be the manufacturers of themselves in small projects according to designer F. Thus, he added, this newly emerging capability of the designer indirectly changes the dependance of them to the capitalistic system. He asserted that initially large companies will not care much about these designers who can manufacture their products in small amounts. However, he added, by the increasing number of material options and the decreasing manufacture times this will turn into a very big advantage. “When the rapid manufacturing really becomes rapid” he asserted the product that can be manufactured only 1 item per day will become 100 items per day and will transform the designer to a manufacturer at the same time. In a system where the designers are paid for their labor he stated, this will have a game changing effect on it.

Upon the examples of Nervous System and Structural Ornament, Designer F stated that parametric and generative design act as a time saver for the designer. He explained that solving engineering related problems by algorithms gives the freedom to think comfortably and create more iterations easily. He then shared his academic experience with students to further explain his ideas with a grounded approach. He stated that there are many intersection points between design and engineering but there are designers who want to play more with form rather than the engineering side of design. For those designers he stated, these technologies are very beneficial. He asserted that he meets many students that are interested In design but the engineering side like “does this carry that load” makes them get bored. It is apparent that their right brain lobes are working better, he added and the analytic side of design makes them feel exhausted.

4.3.9 Design Process

From an industrial designer’s perspective, designer E stated that it is more important to think how AM can be integrated more into the design process. He thinks that even for prototyping reasons, RP and AM technologies are not in the place that they deserve in product development process. The use of technology to produce end products (AM) excites him but he stated that he is more interested in usage of RP in the product development process.

At this point designer E shared his experience with the researcher on their attempt to integrate RP better to their product development cycle. He stated that initially they had been taking the prototyping service by outsourcing. However they realized that the costs remain high whatever they did to decrease it and they had not been able to make their clients to approve prototyping costs. He mentioned the importance of the RP models by stating that their clients wanted to see what the product will look like and they did not understand from CAD files on screen or renders and cannot be convinced about the products’ final form. They, he stated, generally want to hold the product in their hands. He added holding in their hands is like a verification process for the clients. In order to be able to give this prototyping service to their customers at a lower cost and also to keep the products confidentially in-house, he stated they purchased two machines one of which was Stratasys FDM and the other was Eden series of Objet Geometries. He stated that only some of the established companies agreed to pay additional costs for prototype models. Designer E also asserted that the costs did not decrease dramatically since they needed maintenance and the materials were not cheap. Also the process of producing these prototypes required a very good CAD knowledge and the machines sometimes get stuck and needed maintenance he added. The designer asserted that we need to be able to use these machines just like getting a printout from regular printers.

When design process is evaluated, it is seen that there are concerns on the possible loss of the value of chance and errors that are intrinsic to hand sketches. Designer E stated that since he is coming from a generation that used clay models and hand sketches, the process involved a hands-on experience with the material and form. This continuous interaction between the designer and material creates a continuous iterative process in which the designer feels the real object while shaping it continuously like a sculptor. This experience is being lost in current AM and RP processes since the out coming model is "untouchable" according to him. The resulting model is something that is finished, but at the same time unfinished. Designer's inability to manipulate the model by interactively feeling the form quantizes the analog and continuous nature of design. Thus, in RP, the designer has to print the model, check for errors, remodel or modify in digital media, then print the model again to verify. Because of these reasons, designer E refers to RP models used in the design process as "verification products" between designers and engineers.

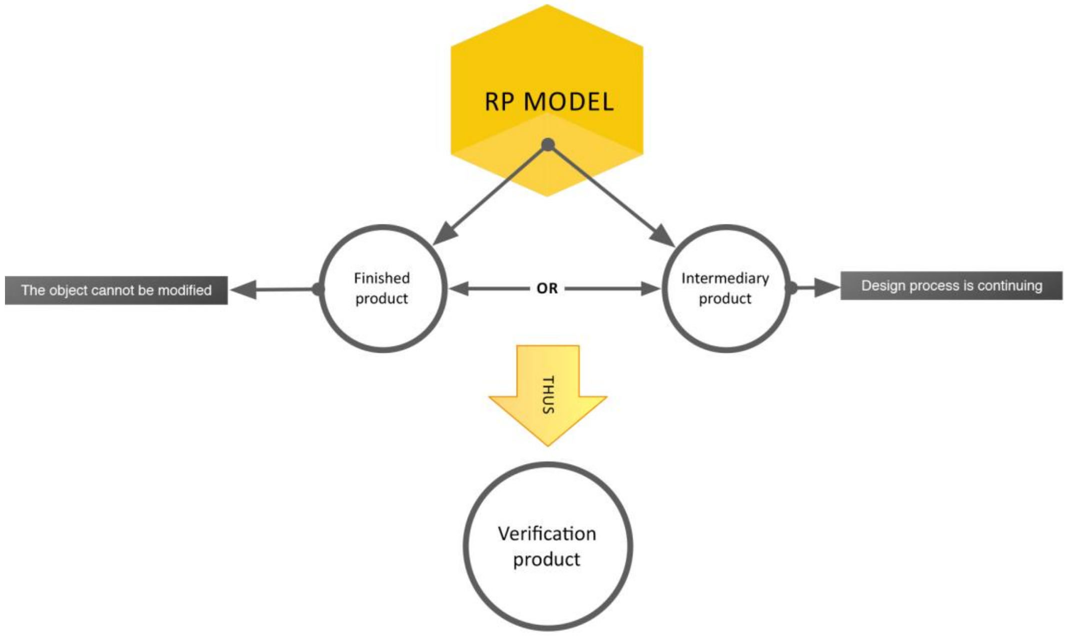


Figure 4.4 The nature of a rapid prototyping model according to designer E.

The loss of hands-on experience with the material also causes the designer to be isolated from the reality. In other words, since the dimensions and material properties cannot be experienced on the computer screen - although simulation software and haptic tools provide this to a some degree the degree of realism is another topic of discussion - the designer cannot always take the right decisions or get lost in unnecessary details such as sub-millimeter dimensions (as stated by designer E).

Designer F mentioned that throughout industrial design education there is a pre-existing problem with getting an object out of the mold that limits the designer's understanding of form. RP and AM technologies enable the designer to "play" with the forms he added.

4.3.10 Innovation Need

According to designers A and D, the usage of additive manufacturing technologies do not demonstrate innovation. First, designers are using the technology to manufacture or prototype products that were existing before. Designer D describes this attitude by stating that "it is used to make replacement objects that reference to past". Thus, according to his perspective, new types of products should be sought after. This standpoint of designer D also corresponds with designer A who stated that there are applications that additive manufacturing is the only option for manufacture and such application fields should be explored. Now, according to designer A, such applications are not much and they should be discovered to exploit the potential of the technology. Since most of the designers are very affected by the technological limitations, they are used to think within that boundaries. Therefore, in general there is a need for innovation in the way designers perceive these technologies.

4.3.11 Costs

Designers B and C are excited about the new technology and its artifacts, however also concerned about the high costs of the technology. During the interview, they stated when they try to integrate AM technologies to their manufacturing process, it adds too much to the product price that they become unsellable. One of the factors affecting the costs is the high prices of external RM services to manufacture the molds for their designs. Another factor is that they need 3D modeling services that are outsourced since the process of designing for additive manufacturing requires extensive CAD skills. In terms of this standpoint, they reach to a consensus with Designer E and A who especially mentioned the difficulty of proper 3D model generation to be used for AM. The high costs of integrating AM technology to the manufacturing process forces many new ideas to be eliminated from the beginning as stated by designer B and C. Upon their declaration of these problems, rising usage of personal 3D printers are mentioned by the researcher and examples on the outcomes of these personal 3D printers were shown to the designers B and C. They were asked if such a machine would change their design and manufacturing processes and both designers replied with excitement stating that they would be able to try and prototype whatever idea comes to their minds. They stated artists will also be using this technology when the costs go down significantly.

4.3.12 Applications

Rather then talking on specific applications shown throughout the interview, designer A preferred to make general arguments and they are included in the paragraphs below.

Designers B and C were generally aware of most of the applications of AM technologies. Although they had a general background on the industrial uses of the technology, they replied in excitement upon the examples shown on the emerging applications. Among the application examples shown, Structural Ornament project and the ones related with personal 3D printers drew their attention most.

Throughout the interview, designer D mentioned that unexpectedness of the AM process makes him to get excited. Although when looked from the engineering side of the process such thought is not true since the resulting model is one to one representation of the CAD model, it becomes ironically true since there is a missing link between the 2D representation of a 3D object and its real form. Designer D’s standpoint refers to this missing link that causes some unexpectedness in the resulting model. Yet, designer D also mentioned that he is much more interested in criticizing and breaking the perfectionist side of the process.

Designer E did not made extensive comments on the examples shown individually. Rather he constructed a general standpoint. Designer E stated that RP and AM technologies fall into the field of industrial design rather than other professions. Since industry means manufacturing, according to designer E, manufacturing of products by hand, by mass production, or even the manufacturing of one of a kind objects are in the field of industrial design despite general thinking. He added that today AM technologies are in the middle rather than being the ultimate tool for manufacturing. He asserted that it should be understood better to what extent this technology develops to manufacturing of end use products and to what extent it remains as a verification tool. As a concluding remark he stated that industrial designers should adopt and support this technology while maintaining its growth in the right direction.

Designer F examined the application examples shown and stated that the usage of the technology has gone very far from the moment they, as barbarians, had started the project. In general, he thinks that this technology, its applications and the changes it will cause are the messengers of new pathways in industrial design.

4.3.12.1 My Brain Lamp and MGX Damned Lamp

Designer A stated that this is not an industrial object and AM shows its advantage when we are manufacturing according to a individualized need or unique objects.

Designer G elucidated this example as a representation of designer's freedom and mentioned the feelings that this freedom can evoke in a designer. The disappearing of manufacturing limitations can trigger the free side of the designer letting him to experiment and innovate he asserted. Also, whether it is used for artistic purposes or not, it stimulates the inner artist, he added. Apart from these, according to designer G, since there is no one telling "This does not come out of the mold.", it stimulates the emotional side of the designer.

Although designers interviewed liked the conception of the brain lamp, they did not make comments in general. The reason for this, although not stated by the designers, probably is the acceptance of the product as an art object.

Similarly, the Damned Lamp by MGX was appreciated by most of the designers, yet received not much comments. However, designer E compared it with FOC Chair and stated that Damned lamp has an artistic meaning whereas FOC chair has neither artistic nor functional meaning.

4.3.12.2 Structural Ornament

These stress calculating softwares are very advantageous for designers, according to designer A. In this case, such a software helps the designer and manufacturer to realize a product with minimal material.

The usage of software tools and additive manufacturing, according to the designers B and C expands designer's abilities and enable them to realize things which were even unimaginable before. They further mentioned generation of purpose specific structures helps this expansion of abilities since design of such structures require a tremendous engineering knowledge and takes too much time even to calculate.

Designer D was interested in this example since it involves an automatic process that empowers the designer to solve an unimaginable structural problem. Also, he argues that the formal complexity and intricacy of objects created with AM bring new perceptions of elegance and beauty.

Designer E stated that this application is exciting for him both in the resulting forms aspect and the generation of automatic support structures.

Without the existence of software tools that we have today, such forms would be impossible to model by hand according to designer F. He also expressed his fascination of the intricate form of the chair and his predictions on the possible changes on the definition of industrial design profession came after this application example.

Upon the introduction of this application, designer G stated that industrial design profession will be more multidisciplinary, incorporating mechanical engineers, mathematicians, computer engineers, artists etc. However, he also stated that this is not an industrial product since it cannot be manufactured via mass production methods. Designer G accepted this as a design, yet not industrial. Then he asserted that there will be some paradigm shifts and updates on the definition and scope of the industrial design profession.

Among the newly emerging applications discussed in the interviews, Structural Ornament had the highest amount of comments from all of the designers. It was observed among the designers without exception that the images shown made the designers get excited on the intricacy of the chair. After explaining the procedure of the chair's design method, it acted as another stimulus to trigger their excitement. The differentiation of the application from the others shown can be outlined as follows:

- Extreme complexity
- Automatic and on purpose structure generation
- Randomness of the structure and the uniqueness of each generated chair

It can be deduced from the obtained comments and perspectives of the industrial designers interviewed that the use of additive manufacturing technologies do not simply mean a lot for industrial designers when used for the manufacturing of previously existing objects but objects that were not possible to manufacture before. Designer D clearly stated that the industrial designers are thinking additive manufacturing technologies as a way of making "replacement objects" and suggested that there should exist innovation in the way of using these technologies.

The strength of the discussed application arises from the strong correlation between the form of the chair and its function. They support each other but at the same time impossible to manufacture by conventional manufacturing systems. Although this manufacturability aspect of the resulting designs in applications of AM is important for designers, the results of the interview refer to a factor that these previously not manufacturable forms constitute a meaning to the designers only if they have either meaningful or functional properties. **If the meaning of the form is denser than its function, the product or the resulting object is interpreted to fall into artistic side of design. However, if the resulting forms, objects or parts have functional qualities denser than its literal meaning, then these have more potential of falling on to industrial side of design.**

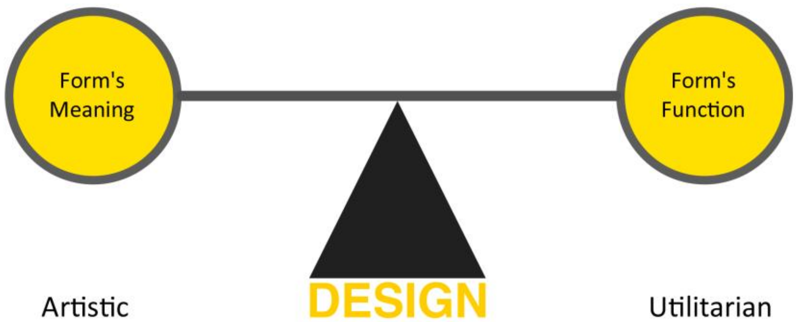


Figure 4.5 Evaluation of artistic and utilitarian side of design

Although these products are not interpreted as industrial by some designers, they have the same perspective on the future of additive manufacturing that such products will be in the field of industrial design. Especially designer E stated that this technology should be adopted by industrial designers and designers should be in the development process of it that will steer the profession and the technology to new paths.

Despite the concerns on whether if application examples like Structural Ornament is in the field of industrial design or not, designer F strongly argues that the scope and definition of industrial design profession is dynamic rather than static and many things that do not enter into the field of industrial design today can be in it after changing of environmental variables, technology in this case. He gave jewelry design as an example and stated it is possible now to design a single jewelry and manufacture it in large quantities.

4.3.12.3 Freedom of Creation Chair

Designer D criticized this chair design as a showoff relating it with the designer's ego. Although he clearly stated that such complexity without function or meaning does not mean anything for him, it creates a wow factor for the public and make the public show more interest to the technology. According to designer D, correlating such complex forms with a conceptual background will also make the product meaningful. Such correlations decrease the amount of wow factor for the public but at the same time results in a better product.

Designer E stated that this product does not have any benefits to the user but more related with designer's ego. He compared this example with the Damned Lamp (by MGX) and stated that the lamp has an artistic meaning while this one does not. Damned by MGX has artistic value according to designer E since there is a correlation between the form and the meaning.

4.3.12.4 Nervous System

Designer D was specifically interested In the unexpected results of the technology. The algorithms that generate a unique pattern each time the program is run interested designer D in its unique outcomes that result in an unexpected yet pre-designed ways. Although the system that generates these models are pre-designed, the resulting forms are completely unique since the program randomizes parameters and follows a different pathway each time.

The unexpectedness concept of designer D has to be explained in more detail since it can be deduced that there are two aspects of it. The first one, which is mentioned in the beginning of the interview is the unexpectedness concerning the relation between the CAD model and the machines output, 3D real model. He argues the designer or the modeler cannot perceive all of the features on computer screen since that shows a 2D representation of a 3D object. Thus, the resulting object coming out of the machine may involve some unexpected features. The second aspect of designer D's unexpectedness concept is more related with the design process of the object rather than its transformation into a real object through the machine. This aspect covers the uniqueness of the object resulting from the randomization of model's generation parameters in the software. Designer D stated that after feeding the program with data the uncertainty on where the outcome will go gets him excited and interested. Such applications can open new doors in design according to him. As a result of this uniqueness he argued, the products may have increased value to their users since it gives the emotion of being unique to a person, thus personalized. This upgraded state of the product transforms it into an object like jewelry he stated.

According to designer D's comments on Nervous System's products, designers will not design the ultimate form of the product but design systems that let users, consumers or customers to design products tailored to their own needs or tastes. Also he stated that with the use of AM technology, the manufacturing of an object start to have a different story.

Designer F stated that he thinks such applications show where this technology is going and he had similar ideas on the design of a product through a parametric interface. He added such applications enable an ordinary user to have customised products. Then he questioned whether if such applications will remain confined in specific areas or spread into other fields.

Such applications that involve parametric design attributes were evaluated as time savers for the designer to produce iterations of an idea. Despite its value for the designer, it was also evaluated as a very valuable tool for empowering the users to customize products. Designer G envisioned public booths on the streets that let an ordinary person to customize a product for his/her own needs.

Another implication arose from Nervous System's products was designing of a system by the designer to design or customize a product instead of designing a product's final form (as stated by designer G). Such parametric interfaces will enable an interactive process in which the users become the part of the design process. Designers A and D stated that designing products from the bottom up is an inefficient and useless process since there are better designs already. Also designer D stated that the usage of ready templates would be a better option. These comments support the idea of design of interfaces that let the users customize or design a product easier and in a more controlled environment that will prevent many errors and decrease the number of unsuccessfull trials.

Apart from the implications above, the uniqueness of the resulting product leverages the value of it giving the emotion of uniqueness to its owner (as stated by designer D).

4.3.12.5 Endless Series

The general reaction of the interviewed designers towards Endless Series was positive yet not all the designers made comments other than stating their interest. This application of RM was evaluated as the transformation of a disadvantage of a manufacturing method into an advantage. The exploration of a manufacturing method’s limitations enable the designer to exploit it to his/her advantage. In this case, one of the biggest disadvantages of AM methods, stair stepping effect, has turned to an advantage that gave the product its unique character.

Designer G stated that without knowing the limitations of the manufacturing method, the designer cannot use it to his advantage and added that one disadvantage of FDM method, which is the stair stepping effect, becomes the advantage of the product and gives itself the character.

CHAPTER 5

CONCLUSIONS

5.1 Overview

It is observed that RM has become a reality in several parts in design and manufacturing industries. However, AM is seen to be preferred in applications that can exploit the unique potentials intrinsic to this technologies' nature such as, **part complexity, weight and strength optimization, need for customized parts, time constraints (F1 races, product development cycles, proof of concept), and low runs of manufacturing**. In specialized industrial applications like dental aligner applications mentioned in Chapter 2, the process is unimaginable without the usage of AM that lets many unique products to be manufactured in the same build.

In general all of the designers interviewed in Barbar study agree that some serious changes in design industry and our daily lives will happen. Upon industrial design profession, there are two main standpoints: since industrial design is the design of products that are to be manufactured in thousands or even millions and AM technologies are not capable of manufacturing these numbers in a short time, the core industrial design will not be changed. The other standpoint argues that changes are inevitable so some updates in the industrial design profession and education should be made in order be able to exploit the potentials of this technology.

AM methods have the potential to change many paradigms including the way we think of an object. However, it is seen throughout the empirical study that, from an industrial designer's perspective, its applications will be limited and conventional manufacturing methods will continue to exist providing the products that we normally use in our daily lives.

5.1.1 Acceptance Rapid Manufacturing in Consumer Products

There are several issues on the acceptance of RM as a main manufacturing method. Most commonly apparent problems are resulting from the surface quality (stair stepping effect), material properties, machine accuracy and part accuracy over time. However, from the industrial and emerging applications explored in Chapter 2 and 3, it can be deduced that with purpose specific modifications and post processes there exists a great realization potential of RM. Especially when surface quality is not the main concern, rapid manufacturing of aerospace grade parts are possible. When surface quality is the concern, with the aid of post-processes, perfectly smooth surfaces can be attained as seen on FOC chair example which at the same time provides the required structural strength to perform its function. Yet, one of the problems with a wider usage and acceptance is caused by the lack of technical knowledge as stated by Gornet (2006, 126):

> The body of knowledge for the true mechanical properties of RP materials is quite small. Properties for all build orientations are not readily available from material or machine manufacturers. Material vendors rarely list the machine settings, build styles, or orientations of the ASTM (American Society for Testing and Materials) bars for the data that are available

This lack of technical knowledge can be overcome in large corporations by conducting studies on the required processes and even on the modification of devices used for AM mainly resulting from the financial opportunities. However, this cannot be the case In the case of individually working industrial designers or those who work in small companies. Thus, only viable option for industrial designers to explore the possibilities of AM is a hands-on experience with the technology.

5.1.2 Improvements in Additive Manufacturing Processes for Industrial Design

The isolation of the designer from reality and loss of interaction between the material and the designer refers to the need for systematical improvements in the communication between the designer and RM methods that are also used for product development cycles. Designer E's interpretation of RP as "untouchable" also overlaps with this notion of communication. From an industrial designer's perspective to the additive manufacturing field, it should not only be restricted to the manufacturing of prototypes or manufacturing of end products since the process of design realized by industrial designer embodies the continuous interaction of both processes. Although rapid manufacturing still has limitations caused by technical properties of the machines and materials, there are many fields that rapid manufacturing of end use products has become a reality. Thus, the ideal design process for an industrial designer in additive manufacturing fields should be a more interactive process which is facilitated by a continuous and easy transformation of design intend from physical to virtual and from virtual to physical medium which then makes the untouchable RP process touchable.

5.1.3 Industrial Designer Realizing the Potential of Additive Manufacturing

In the empirical study on Barbar Designers, designer E stated that the distinction between the designer and a filmmaker or illusionist arises from the relationship of the designer with reality. This connection between the designer and what is real starts to loose its validity since the AM and CAD processes in a way isolates the designer from the hands-on experience with the material. However, this is also caused by the working conditions of professional industrial designers which in a way are separated from the manufacturing process (R. I. Campbell et al. 2003). Thus, as Pfeiffer (2009, 38) states, in order to realize the potential of AM and digital tools, the “direct and hands-on access is crucial aspect for designers”. In that way, the designer is empowered by the ability to experiment and innovate with the tool.

As illustrated in the Endless Series example in Chapter 3, knowing the advantages and constraints of a manufacturing method thoroughly lets the designer to modify the process and design accordingly. Dirk Vander Koij’s process has been a continuous iteration between adjusting the design parameters and the manufacturing method (in his detailed explanations on the process he mentions unwanted the pulsating filament extrusion due to the screw extruders motion) he has developed a system of manufacturing products with a unique character and form. His experience throughout the process also let him to produce derivations of the product such as tables and lighting (Vander Koij 2012).

Functionally graded materials as seen in Chapter 2 provide very important benefits to the design process, yet remains unexplored. It is seen that such processes are used maturely in medicine such as manufacturing of implants that have porous ends to let bones to penetrate into the structure for a stronger connection between the implant and bone. The ability to control the material distribution inside a part opens a whole new horizon for industrial design since it allows the manufacturing of objects and products that were even unimaginable before due to limitations brought by the conventional methods. Moreover, the virtual independence of cost and complexity of parts manufactured via AM enables the designer to design without being concerned about increasing the cost of production. This paves the way to true innovation on how products and objects can be made since it does not force the designer to give up brilliant ideas just because “it does not come out of the mold” or the process becomes too expensive.

The facilitation of controlling the inside of an object combined with the flexibility of manufacturing inherent to AM, lets the designer to experiment with material in a way that is not possible before both due to financial and methodological reasons. The decreasing costs of AM processes, increasing accuracy and material selections let the designer to own the technological facilities of huge corporations like aerospace companies. Together with the democratization of manufacturing and availability of such technologies to a wider range of designers is likely to facilitate the innovation process in product design.

The field of developing medical imaging and 3D scanning technologies also create a unique potential in industrial design. The products that correspond to the user’s body shape can be realized by initially using these scanning methods to create 100% fitting products to the user’s anatomy which is followed by the manufacture of the unique product by RM.

5.1.4 Expansion of Industrial Designer’s Application Space

The usage of a common manufacturing system across many industries brings an advantage to designers by making these fields more accessible. Bespoke Innovations for example, combines a medical situation with a custom designed cover that is made according to the user’s needs. The expertise of an industrial designer on form and function plays an important role in such applications (as stated by designer F). Even previously unimaginable innovations may become a reality since the use of AM opens the fields it is used to a wider group of problem solvers, designers in this case. Pescovitz (2008, 8) gives an example from the power of collective problem solving existing in an online service InnoCentive:

> Jill Panetta, InnoCentive's chief scientific officer, says this R&D community has cracked 30% of the problems posted on the site, "30% more than would have been solved using a traditional, in-house approach."

Thus, it might be expected that the number of innovative applications in product design and other fields will increase due to the indirect effect brought by the involvement of industrial designers to wider fields related with design and manufacturing.

As the number of successful implementations of AM technologies in the construction of transplants, prosthetics and similar fields increase, it is not far from imagination that new kinds of prosthetics that can give new abilities to people who use them, although the modifications in the natural body parts may not be accepted throughout the society as a whole.

With the development of the parametric and generative software tools, the borders between the engineering and design starts to dissolve. Thus, this blurring distinction between the designer and engineer can empower the designers as individuals in new fields previously not possible due to very complex engineering problems.

5.1.5 Design Education

Explored applications and Barbar study points to a necessary update in industrial design education regarding the developing CAD environment and the RP processes which started to be used for RM. The experimentation of the designer with the form, materials, thus reality, has a strong impact on the design process itself since the AM technologies in short facilitates this experimentation. Therefore in design education, RP and its pathways to RM should be introduced to the students. However, without experiencing the process, the potential cannot be exploited because of the lacking of experimentation.

The researcher realized that among many universities, laboratory like environments are settled called Fab Labs that experiment with emerging technologies such as 3D printing. In these environments, the members of these fab labs, students generally, are provided with many tools like CNC routers, laser cutters, low cost 3D printers like Makerbot or RepRap and many others to make electronics etc. Such environments create a space in which participative innovation occurs by sharing knowledge or similar interests. Thus, learning in such spaces in a way becomes a game for researchers to play. Also, these environments bring together people, who are from different disciplines fostering the information exchange between different perspectives thus fostering innovative solutions.

The literature reviewed do not address the importance of these emerging spaces. Although there are some, they are very limited and none related with their implications on the design education. However, the researcher believes that such spaces should be encouraged alongside with traditional education. The formation of such spaces are not very hard or expensive to realize thanks to many low cost machines which can even easily be assembled by students.

5.1.6 Parametric Design and Design Systems

Parametric design changes the conception of a product which is used to be a static object. Now a system can be designed to let users to design or customize the final form and properties of the product. This opens a whole new horizon in which the products gain a fluid nature that can be modified according to the parameters designed by the designer.

There seems to be a consensus both among the literature and interviewed designers about the role of industrial designer in the future. That is the designers will no longer design static products but systems that let the users to design or customize their very own products (Morris 2007; Atkinson 2010). Since the most viable way of establishing such an environment is through the development of parametric software interfaces, need for a stronger collaboration between designers, software developers, programmers will arise. It might be a good option to integrate the software developing abilities in the industrial design education curriculum.

5.1.7 Concerns on the Usage of Digital Tools

Some designers in the interview specifically stated that the usage of AM technologies in the design and manufacturing stages cause loss of value that is intrinsic to hand sketches and hand modeling during the design process. This concern corresponds with the perspective of designers and educators as proposed by Lynn as cited in Aldoy (2011):

> Designers and educators who have made a career using traditional tools have concerns about the use of digital tools as they believe they have the capacity to somehow 'steal the soul' or degrade the quality of designing (Lynn, 2006). However, when industrial/ product design graduates apply for their first professional positions, the ability to use digital industrial design methods has become a key feature of the selection process (Lynn, 2006).

However, Aldoy also asserts that one of the main requirements for newly graduates to be accepted in professional positions in industrial design is the ability and experience in digital tools. Thus, the usage of these technologies have become a crucial factor in the professional experience of industrial design as well as in many other professions. Nevertheless, designer E's assertion of RP processes' untouchability refers to a problem that is related with the nature of the process used. The design process involved in the rapid manufacturing and rapid prototyping technologies do not involve manual intervention that is normally the main aspect of the design process. The survival of hand sketches despite all these digital drawing and design tools supports the need for a process that allows manual intervention. Thus, rather than having concerns on the usage of these digital tools, innovations in the pursuit of making the design and manufacturing processes that let manual intervention and more accessible by the designer should be sought after. A similar approach can be the design of systems that make the CAD data to real part and real part to CAD data transformation a smoother process that would let the designer to intervene or modify the design data easier.

The products that can be customized like Nervous System's and uploaded to online 3D printing services like ShapeWays may cause dissatisfied customers due to the chance of modifying the product beyond the usability limits. A user with little knowledge about the technology involved and no experience or knowledge on design can create a bracelet that can cost several hundred dollars to buy but not usable in real life due to extreme distortion of the model. Since these examples are the pioneers of such applications, the mentioned case will not be a problem in the beginning. But after the adoption by masses, some safety borders will probably be needed in such systems.

Although not much apparent in the literature except a fiction novel (Doctorow 2010) and designer G, RM of products, especially when multiple materials become more common and products with complex mechanisms or functions can be realized easier, will bring some health and safety problems. The probability of injuries or health issues brought by the usage of these products will be high due to unscholarly or irresponsible designs.

5.1.8 Personal Fabrication

Do-it-yourself (DIY) is described by Atkinson (2006) as an "antithesis of design" which is an “activity of professional designers and being part of an established cycles of the design, production and consumption of goods”. He asserts from the history referencing arts and crafts period, do-it-yourself boom and industrial design that DIY has always existed and and “enabled the consumer to rail against the prescribed design edicts, and indeed, prescribed social mores of the time”. Regarding the usage of RM by DIY communities mentioned in Chapter 2, the widespread usage of such online 3D printing services and increased usability of CAD interfaces may lead to a change that can transform the society in which nearly all of the products can be manufactured in a way similar to DIY. Then arises the question, if DIY and mass customization becomes the main route to manufacturing then what happens to the definition of professional design and its surroundings?

The emerging structure on RM via online 3D printing services and its spread on masses will cause changes in many of today’s paradigms ranging from the perception of an object to how we design, manufacture, buy and consume products together with making obsolete many jobs and creating new job opportunities. However, the difference from the previous industrial revolution, that has caused the birth of industrial design profession and transformed the crafts, is these technologies let anyone with a computer and related software make and sell products, giving power to the user / consumer’s hands.

5.1.9 Problems

Expansion of design space available to the industrial designers will bring some problems to the profession. The education curriculum is obliged to be very broad since more and more fields of design can start to enter to the field of profession. However, as Campbell et al. (R. I. Campbell et al. 2003) stated, the term industrial is used because the designers are to design products that are manufactured in industrial facilities with specialized machinery. In the case of

RM, there will be no mass production of the same product but either every product will be one of a kind or in small numbers. This shift of production space brings a shift in the paradigm of industrial design. The term industrial loses its meaning leaving more importance to the term “design”. On this issue, the perspective obtained from the empirical study is that core of the industrial design will not change since many products like shampoo packaging, and many other disposable products require mass production because of the need for massive quantities of production. Thus, specialization fields under industrial design might emerge or even separate from industrial design.

5.1.10 Limitations of Rapid Manufacturing

Despite all of the explored applications’ diversity, there are still problems with wider acceptance of AM for RM of products. For products that require glossy or smooth surfaces, the RM is still not possible since some post-processing Is required. However, there are many application cases in which the natural texture of AM are used as-is beginning from the works commercialized by the company Materialise. Despite the imperfections on the surface quality apparent in most of AM processes, some post processing can be done to establish a glossy look alike in FOC chair example in Chapter 3. However, since these processes are often laborious, becoming a mass manufacturing method for these processes without specialized applications needs time and there are problems that need to be overcome other than surface quality. Material strengths, for example, has been another barrier confronting the wider acceptance of AM for RM. However, the material properties have developed in the last decade and make it possible to use manufactured parts with AM in real life conditions like F1 races or aerospace applications.

Barbar Designers study resulted in many remarks that are parallel to the literature. CAD software usage for AM creates a barrier for the designer concerning the interaction and idea to product transformation process of designer with the object. CAD software or even a thorough process that facilitates this interaction is needed for the usability of RM by industrial designers.

5.2 Research Questions Revisited

What are the implications of rapid manufacturing technologies on industrial designers?

In addition to the implications mentioned under the Overview title the answers to the sub-research questions are summarized below:

How does additive manufacturing technologies empower the industrial designer?

One of the greatest benefits of AM processes is the liberation of the designer from the manufacturers and corporations which are mostly causes of many constraints that are cast on the designers. This liberation by empowering the designer with the advanced manufacturing tools that these entities own enables the designer to be their own manufacturers.

The CAD software used during the design process causes some arguments which were referred at Chapter 2 of this thesis. However, designers are also enabled to design software systems that let generative designs to be made. Parametric designs that can be modified to customize the resulting object create a new application field for industrial designers. The form freedom brought by additive manufacturing technologies can be exploited via these generative and parametric systems that result in the enhancement in the experimentation during the design process by evaluating iterations of the design idea. Since the complexity or shape of the forms generated virtually do not affect the build time, designers are empowered with a great experimentation tool for innovation. However, for this experimentation ability to be exploited, hands-on experience of the industrial designer with the machines and process should be facilitated by the availability of low-cost build materials, generative CAD software that has built-in structure generation capabilities, and availability of machines with lower costs.

Although indirectly related, AM technologies and 3D printers act as a bridge that connects the conceptual world that lies on a computer screen as two-dimensional representations of a three-dimensional reality. Thus, they help enhancing the communication between industrial designers and the outer world. These technologies empower the industrial designer in a way that it enables a rapid communication of the design idea to the client directly through a real object rather than limited representations of it. Aforementioned two-dimensional limited representations, as it can be deduced from Designer E's experiences, block the communication between the designer and the client or user.

What paradigm shifts do additive manufacturing technologies cause in industrial design profession?

As explored in the empirical study, AM brings new conceptions to the elegance and beauty due to the capability of incarnating very intricate and extremely complex forms. Also, functionally graded materials embody a field with a huge potential, yet unexplored. With the development of multi-material manufacturing processes, the applicability of these processes will increase. However, It is seen that this field is unexplored by industrial designers. The researcher believes that FGM can cause many paradigm shifts in our daily lives starting from the notion of how the matter and object responds to the user.

Another significant paradigm shift related with the spread of AM is personal fabrication. This phenomenon has a strong impact on the perception of industrial design, its role and designer in a society, since in a way that it will enable everyone with a computer and related software to manufacture their own products or goods as seen in Chapter 2 and Barbar Designers study. As stated by Barbar Designers, this shift will be resolved through the repositioning of the design profession and the designer himself. However, in order to take correct decisions, the implications should be well studied. Also, personal fabrication and democratization of tools opens the tools which were once possessed only by industrial designers to the public, thus empowering the users. This impact when compared with the desktop publishing example causes serious implications for the industrial design profession such as changing the role of an industrial designer in a society. Rather than designing a static product, designers may have to come up with interfaces and applications that let the users design, modify or customize according to their needs or desires. Also, literature review and the Barbar study refers to a point that the expertise of industrial designers in form, function and usability will have an important role defining this newly emerging conception of a designer.

The term industrial designer seems to be changing with the use of RM either towards product designer, or designer, rather than remaining as it is now. This is mainly caused by the customization and form freedom advantage brought by AM processes. Campbell et al. refer to this change as “bespoke industrial designer” and “hybrid” designer (R. I. Campbell et al. 2003). In addition to these possible changes, the use of RM brings a participatory design environment enabling users and designers to be able to work together.

How industrial design profession perceives personal fabrication brought by additive manufacturing?

Collective standpoint of industrial designers interviewed were mentioned in section 4.4 of this thesis. Although their general attitude towards discussed technologies are very positive, topics such as personal fabrication and personal 3D printers are observed to cause concerns regarding the status of the profession and the designers themselves. The main concern mentioned by 6 of the 7 designers was "everyone becoming a designer". Towards this concern, it is stated that by repositioning of industrial designers in the society according to the development in such fields, and some updates in the definition of the industrial design profession and education, these concerns will be resolved through the "natural flow". The main argument was the example of digital photography, desktop publishing and the survival of photography and graphic design professions. Although having gone through changes, these professions survived according to the standpoints asserted by the designers.

Nevertheless, the implications of the personal manufacturing requires further studies to determine the industrial design professions future. Toulis (2008) refers to the importance of personal fabrication as "Failure to appreciate DIY/Hack Culture is to risk having professional design become as irrelevant to the contemporary landscape as record labels and network television are in the age of iTunes and YouTube".

5.3 Limitations of Study

Interview method:

Although all the designers are interviewed individually, designers B & C were interviewed since they have the same background and working together in their profession apart from Barbarian projects. This decision however, may have limited their expression of their thoughts since one designer's opinions might affect the other's. Even though the interview was in a very cordial tone and the designers expressed their ideas in a relaxed tone and manner, the aforementioned reasons might have been the cause of collecting less data compared to other designers.

Point of views according to Gender:

Initial aim while selecting the participants was to interview with same number of male and female designers, nevertheless due to scheduling problems this could not be achieved. This prevented the researcher to make deductions according to gender differences.

Demographics and perspectives:

The resulting perspectives of Barbar Designers did not show a pattern neither directly relating with their experience In the profession nor their ages. This may have resulted from the quantity of the sampling group. Thus, further studies with greater number of participants are encouraged.

5.4 Further Study

The information on the additive manufacturing industry is seen to be very broad. Different processes, different terminology referring to the same concept, machine manufacturer’s non-standardized specifications, tests related with engineering, bio-engineering, machines capable of parts for different industries, rise of personal 3D printers, DIY, co-design are just like the top of additive manufacturing ice-berg. There, will be direct and indirect effects of AM in many parts of our lives and in many disciplines. Industrial design is among the ones that has not been explored sufficiently. In the diverse sources which this research is conducted, it is realized that the relation of industrial design and AM is not explored thoroughly. There are many attempts mapping out the effects of rapid prototyping on the design process, yet not much on the effects of RM and possibilities brought to the profession by it.

Another realization of the researcher has been the distance of RP related machines and industrial designers. Although the technology is used widely throughout the profession for product evaluation and verification purposes, studies relating to experimental usages are not observed throughout the literature and on-line sources. There are obviously research done on the design process such as the effects of haptic interfaces (Sener, Wormald, and Campbell 2002) and other fields, however, the industrial designers are observed to set themselves apart from these machines. Throughout the DIY communities and emerging personal 3D printer communities like RepRap, MakerBot and similar, presence of industrial designers can help this technology to advance into more usable products since the current examples lack ease of use both as design and software. This field seems to be an untapped source both for innovation and studies for industrial designers.

Although there starts to be many product designs that are manufactured with RM with emerging online 3D printing services, there has not been an evaluation towards the usability or quality of the resulting products in such sites. Related with the usability of these products, it would be a good option to conduct studies on participatory design with normal users using these tools and medium. Despite the fact that such acts do not seem to affect industrial designers now, the literature and the empirical study refers to a change that is not far away. Thus, in order to have insight on the future implications of these areas on the industrial design profession, better and thorough studies should be conducted.

Do-it-yourself culture is observed to be stronger than ever with the advancing manufacturing and design tools that are available to the average user. Thus, with the spread of RM and personal fabrication, DIY culture will have significant implications on the relation between industrial designers and the society. In a society in which individuals has the power to manufacture whatever they need, the meaning of industrial design and designers will inevitably change as the

Barbar Study and the literature refers to. Therefore, studies on the relation between DIY, maker culture, personal fabrication and industrial design would be beneficial for the industrial design profession’s future.

This study established a grounded perspective on the implications of rapid manufacturing on industrial designers and industrial design profession. The implications defined here need further studies to be conducted for a thorough understanding of their implications.

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APPENDIX A:

ADDITIVE MANUFACTURING PROCESSES

A.1 Liquid Based Processes

A.1.1 Stereolithography

Stereolithography, as introduced in the Brief History section of Chapter 2 of this thesis, was the first technology that was commercialized additive manufacturing. The main principle of stereolithography process is the curing of a photosensitive resin via ultraviolet laser. The laser scans the build platform according to the slice data coming from CAD file (Figure 5.1). Scanned portions of the resin solidifies. The platform is lowered with generally 100 µm increments and the process is repeated to form another layer of solidified material. For the structures that incorporate overhangs, the software creates support structures that generally form weaker bonds to the model. These support structures are then removed after the process is completed. When the model is completed by the machine, some post-processing is needed to fully cure the resulting model. For this, UV or thermal ovens are used.

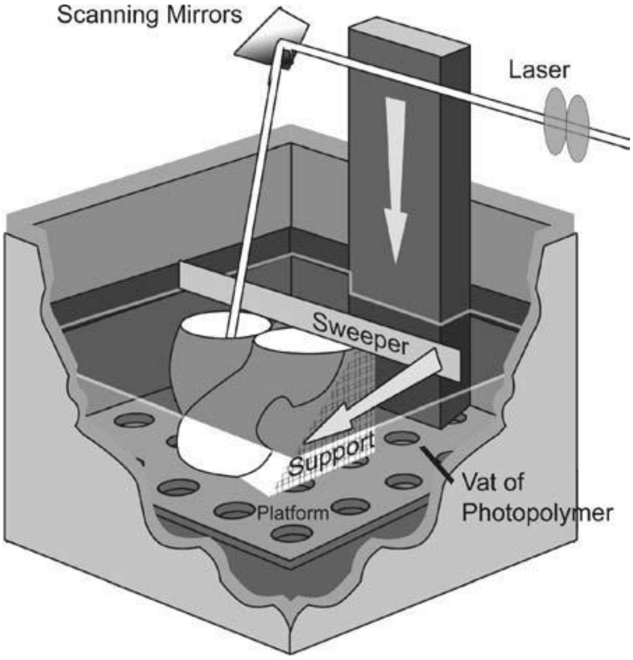


Figure A.1 Stereolithography process (Hopkinson, and Dickens 2006, 58)

A.1.2 Jetting systems

Jetting systems use inkjet technology to deposit material on the build platform. Print heads similar to 2D inkjet printers jet photopolymers or resins through tiny nozzles. There are two widely used commercial technologies: PolyJet™ and ThermoJet process.

In PolyJet ™ process, a photopolymer is jetted from multiple nozzles which are then cured by UV light placed on the print head. To support the overhangs, a gel like (upon curing with UV) support material is used which after completion of the model is cleaned by water jet. The machine can use multiple materials in a single build that lets the designer to incorporate materials with different physical properties or appearances. For example, flexible and tough materials can be used throughout a model to simulate over molding, or even to control material properties by heterogeneously mixing different materials (Objet 2012).

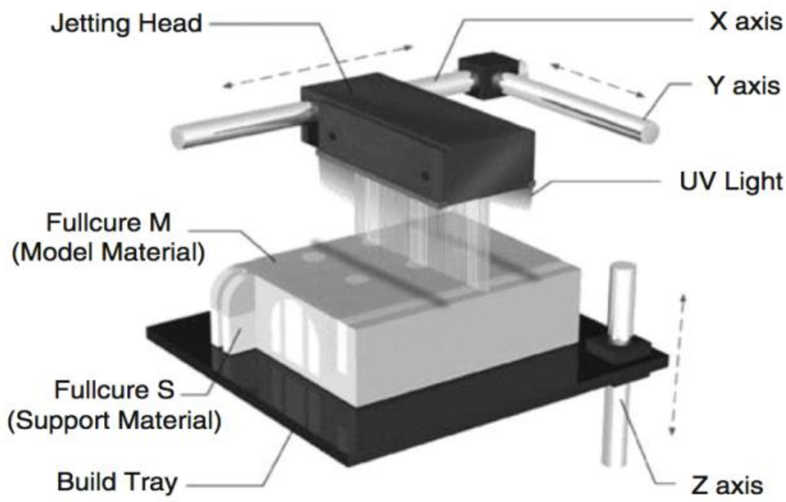


Figure A.2 PolyJet process (Gibson, Rosen, and Stucker 2009, 25)

Other process called ThermoJet uses wax as build material. Similar to PolyJet ™ process, the ThermoJet uses jets to transfer the build material onto the substrate. The supports are made from the same material with a lower melting point that can be washed away after the completion of the build. However, compared to the PolyJet ™ process, there is only one material available for the ThermoJet process, wax. This process produces models with high definition, yet fragile that can mainly be used for investment casting methods especially in jewelry fields.

A.1.3 Direct Light Processing

Direct Light Processing (DLP) systems use digital mirror devices (DMD) that can selectively reflect UV light onto the build area. This reflected UV light in the form of a matrix cures the photosensitive resin and the model is solidified layer by layer. In other words, the model's cross section image is projected onto a transparent contact window (Figure 5.3).

The advantage of this process is the speed since whole cross section is cured at once which also makes any scanning process or movable parts obsolete, thus less need for maintenance. However, since the resolution of the projected image directly determines the resolution of the model, this process only becomes efficient in the manufacturing of small objects, for example hearing aids.

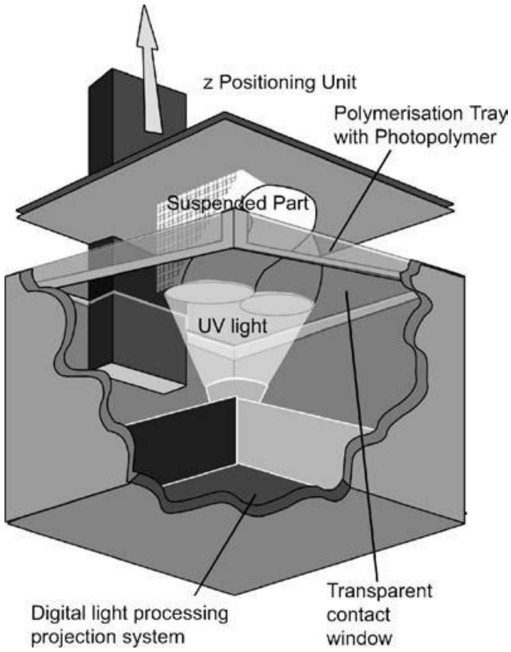


Figure A.3 Direct Light Processing process (Hopkinson and Dickens 2006, 62)

A.2 Powder Based Processes

A.2.1 Selective Laser Sintering

Selective laser sintering (SLS) involves the fusion of materials in powder form via a laser beam diverted by scanning mirrors (Figure 5.4). As each scan is completed, the powder bed is lowered and a roller covers a fresh layer of powder onto the fused shape. The laser beam scans the following cross section of the model and the top layer also bonds with the previous one.

This process is continued until completion of the model. Since the unused powder in the powder bed acts as a support material for the overhangs, generation of supports structures is not needed in this process. This advantage also decreases the labor needed in the post processing of the model since there is no support structures to be removed.

SLS process yields models with relatively good mechanical properties which makes it a good option for RM applications. Also, SLS models can be used in investment casting patterns that do not require high strength of master pattern.

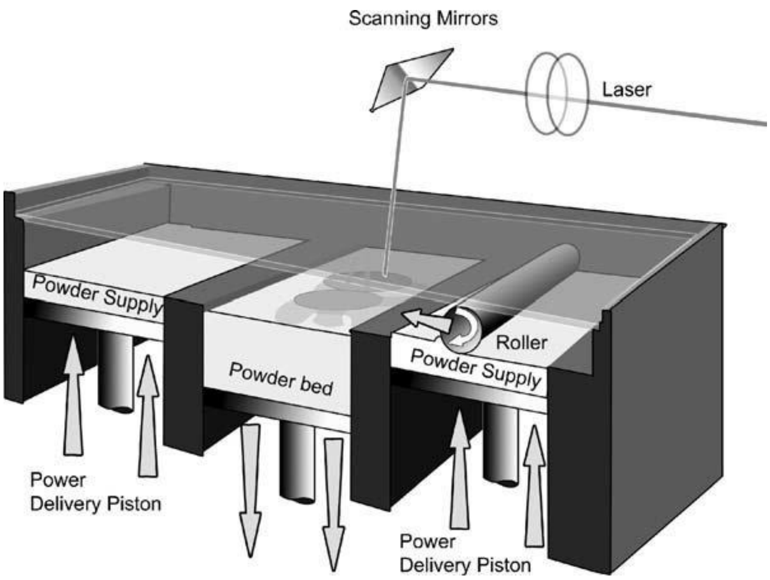


Figure A.4 Selective Laser Sintering process (Hopkinson and Dickens 2006, 64)

Apart from polymers, processes for selective laser sintering of ceramics and metals are also present. In these processes, the powdered ceramic or metal material is coated with a binder material which melts upon laser exposure and creates bonds between the particles of metal or ceramics. This process results in a green state part which is then post processed in furnaces that burns away the binder material while sintering the particles into a porous part which is then infiltrated with bronze.

A.2.2 Direct Metal Sintering

Direct Metal Laser Sintering (DMLS) is very similar to the SLS process. However, there is no binder material coated on the powdered metal particles. The laser power used in the process is much higher than SLS process since the process makes the metal powder into either melting or liquid phase. Although the process was developed initially to manufacture tooling, it is later aimed at rapid manufacturing of end use products.

A.2.3 3D Printing

3D Printing process is very similar to 2D inkjet printer technology in which a printhead consisting of tiny nozzles jets tiny ink droplets. In 3D printing process, the ink in the preceding technology is a binder material, and instead of paper sheets there is a powder bed. The binder material binds these powder particles to each other forming a cross section of the model. As in other additive manufacturing technologies, the build platform is lowered and a fresh layer of powdered material is spread by the blade over the powder bed (Figure 5.5). The process is repeated for each cross section layer of the object resulting in a finished model.

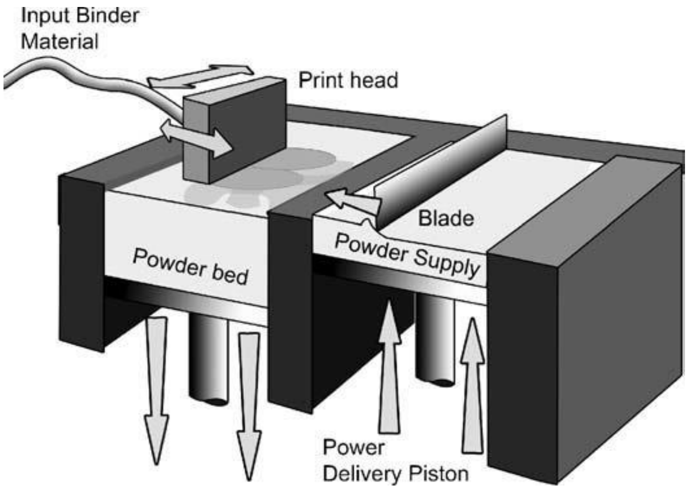


Figure A.5 3D printing process (Hopkinson and Dickens 2006, 66)

Powdered nature of the build material allows usage of different materials for the process. One of the commercialized applications of this process is owned by zCorp's machines that can print full color models. However, they are mainly for visualization purposes and mainly they can be used throughout the design process for visual testing. Since the parts coming out of the machine are fragile, they can neither be used as end products nor functional prototypes. Yet, there are some semi-experimental applications such as shapeways.com's ceramics printing. They use the same process but ceramic powder for the build material. The part coming out of the printing process is a green state object which is then glazed and kilned at high temperatures for the formation of porcelain.

Although Hopkinson and Dickens' classification scheme includes PolyJet ™ process under the liquid based processes, such systems are also collected under Printing title by Gibson, Rosen and Stucker (2009, 172). They put forward primary advantages of 3D printing machines as low cost, high speed, scalability, ease of building in multiple materials and capability of printing colors.

A.2.4 Fused Metal Deposition

Fused Metal Deposition process involves melting of metal powders in a melt pool established by a focused laser beam (Figure 5.6). Due to the nature of the process, the surface quality is very rough and speed of the process is low compare to other AM processes. However, since the material is supplied externally (rather than melting the homogeneous powder below), and very high temperatures can be attained this process allows the manufacturing of functionally graded materials (including titanium material) that will be explained later in this thesis.

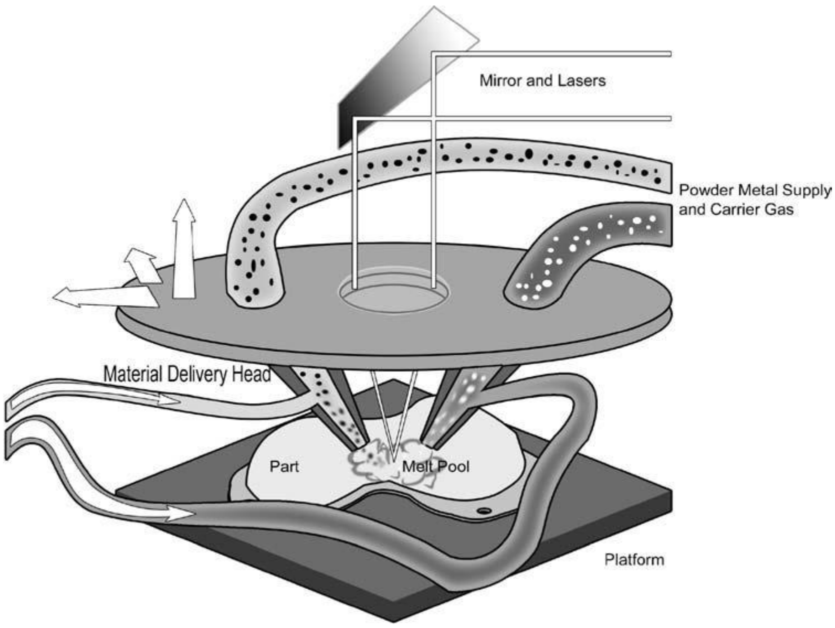


Figure A.6 Fused Metal Deposition process (Hopkinson and Dickens 2006, 67)

A.2.5 Electron Beam Melting

Electron Beam Melting process involves melting of a conductive metal powder by a focused electron beam diverted by a deflection coil (Figure 5.7) to control the x-y motion of the beam.

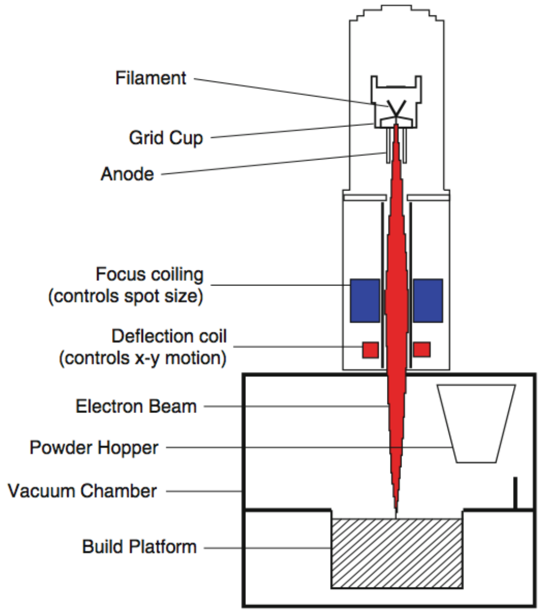


Figure A.7 Electron Beam Melting process (Gibson, Rosen, and Stucker 2009, 127)

Since the electron beam is controlled by the magnetic field in the deflection coil, scanning mirrors used in SLS process to control the laser beam position are not needed. This allows very fast scan speeds reaching 1 km/s. Although this process scans the surface of the powder with a single beam - which seems like a disadvantage in speed when compared to jetting systems that use array of jets or DLP process that projects whole layer in a single shot - extreme scanning speed of the beam results in a very fast speed of the overall process. The resulting models require post-processes for finishing mainly in tooling applications.

A.2.6 Selective Laser Melting

Selective Laser Melting (SLM) process resembles SLS process. However, rather than fusing the powder particles they are fully melted resulting a denser part. The commercialized systems of this process are especially aimed at small sized parts called micro-sintering process. The feature sizes of the parts can be as fine as 20 µm.

A.2.7 Selective Masking Sintering

In Selective Masking Sintering (SMS) process, a mask that reflects infrared radiation is printed on a transparent screen which is then placed over the build platform that holds the powdered material and heated by the infrared radiation that sinters the powder below the unmasked areas of the screen (Figure 5.8). This process is continuously repeated after the platform is lowered in increments alike other AM processes.

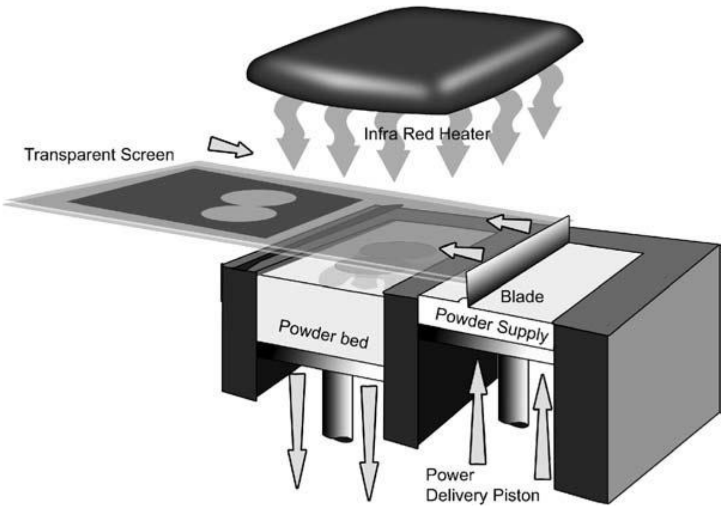


Figure A.8 Selective Masking Sintering process (Hopkinson and Dickens 2006, 69)

This process in a way resembles DLP process but instead of selectively reflecting UV light with micro mirrors, SMS process blocks infrared radiation via a reflective coating printed on a transparent screen. In this process, there is no need for lasers and moving parts (other than the feeding mechanism and positioning of the mask layer).

Exposing one whole section of the part brings the speed advantage independent from part complexity and quantity. Every layer is exposed to the infrared radiation and fully cured in 15-20 seconds.

A.2.8 Selective Inhibition Sintering

Selective Inhibition Sintering (SIS) process involves selectively inhibiting sintering of a powder based material that is later exposed to a radiant heat source. The process is like a combination of 3D printing and Selective Masking Sintering. A nozzle jets a material that prevents the contacted powder from sintering (Figure 5.9). Thus, the fusion of the parts that have not received the inhibiting material creates the object desired.

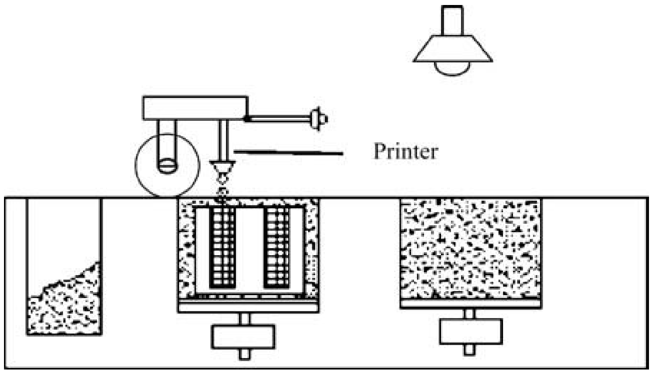


Figure A.9 Selective Inhibition Sintering process (Hopkinson and Dickens 2006, 70)

Since the unused powder receives the inhibiting material, it becomes useless thus creating a significant waste for manufacturing in low quantities. However, when rapid manufacturing is considered, the parts are generally stacked as close to each other as possible, thus decreasing the waste material.

A.2.9 Electrophotographic Layered Manufacturing

Electrophotographic Layered Manufacturing (ELM) works on the same principle of laser printers with toner drums in which a pre-charged drum is uncharged by a scanning laser forming the desired image that is then transferred to a sheet of paper. Although this is much more an experimental process, it has high potential in rapid manufacturing of small parts with high production rates.

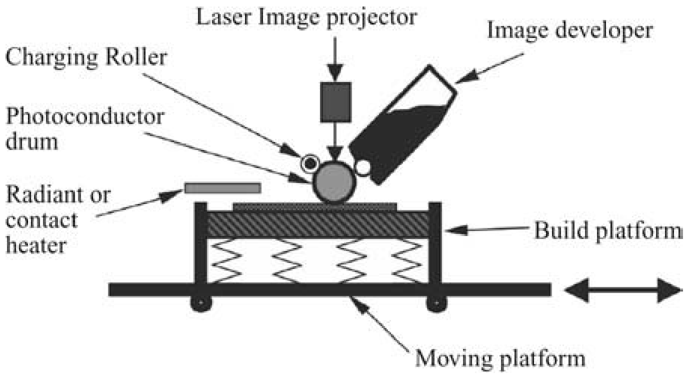


Figure A.10 Electrophotographic Layered Manufacturing process (Hopkinson and Dickens 2006, 73)

A.2.10 High Speed Sintering

In High Speed Sintering (HSS) process, a special ink is jetted onto the powdered material as cross sections of the desired object. Then an infra red heater scans the build envelope causing the inked powder to sinter. in a way this process is the reverse of Selective Inhibition Sintering.

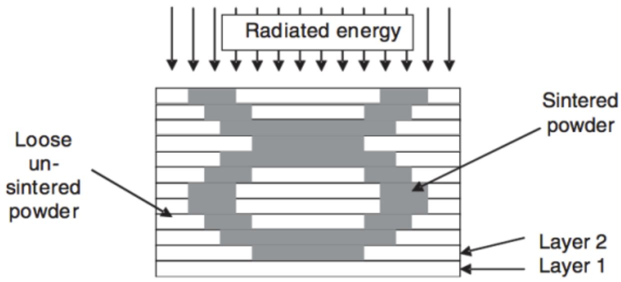


Figure A.11 High Speed Sintering process (Hopkinson and Dickens 2006, 74)

A.3 Solid Based Processes

A.3.1 Fused Deposition Modeling

Fused Deposition Modeling (FDM) process involves forcing a thermoplastic polymer in to a heated chamber (Figure 5.12) and through a precision nozzle causing an extrusion of a constant diameter. This hot extruded filament is traversed in x and y direction to create a cross section of the desired model. There are two nozzles, one for the build and the other for support material.

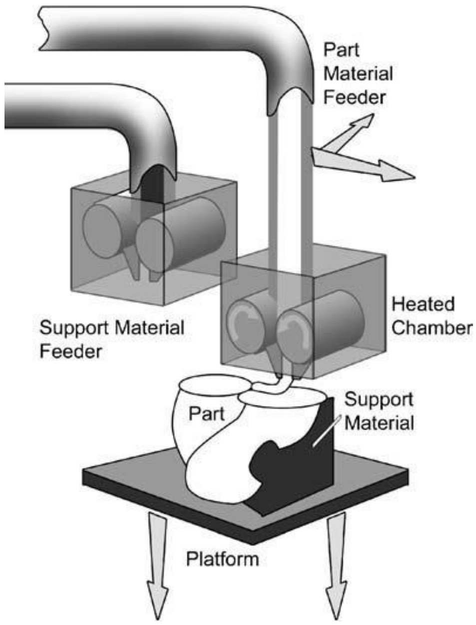


Figure A.12 Fused Deposition Modeling process (Hopkinson and Dickens 2006, 76)

There are some limiting factors such as speed and resolution caused by the necessity of traveling all the build surface and the nozzle's thickness. Despite these limitations, the ease of construction of the system and lower costs make this process one of the widest used methods available. Also, in the last years, the expiration of the patent of this process lead to many open source projects in which individuals or groups make their own machines either for personal usage or selling as low cost kits.

Although FDM process mainly uses thermoplastic polymers, wider experimental applications and derivations of the process exist, ranging from chocolate, ceramics, food, clay and more. Figure 5.13 shows a variant of FDM method, called Contour Crafting that incorporates a trowelling mechanism that smooths the outer surface of the build. Contour crafting is a process developed for construction in mind uses mainly construction ceramics.

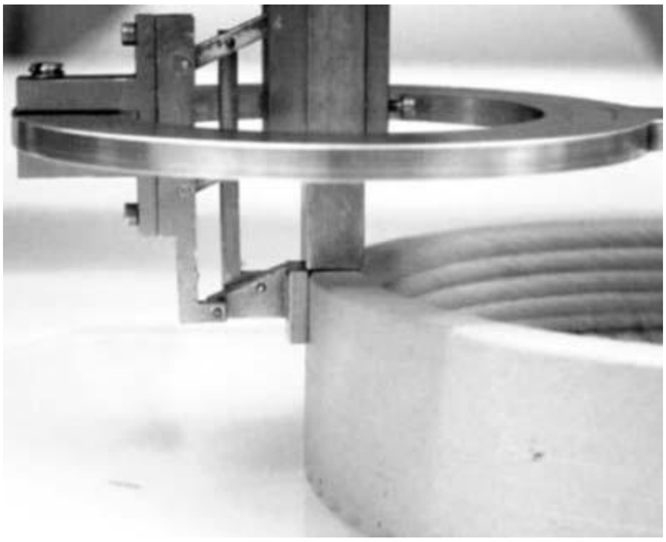


Figure A.13 Contour crafting extruder head **(Hopkinson and Dickens 2006, 77)**

A.3.2 Sheet Stacking

Although there exists several processes that are classified as sheet stacking technologies, the main principle involves cutting and stacking of materials in sheet form. Materials that are commonly used are PVC, paper, and metal. These sheets are cut via a laser or an ultrasonic knife, which is followed by a process similar to gluing each layer and stacking another layer of sheet material on top. For the removal of the part from the resulting cube (Figure 5.14) areas remaining outside of the desired part are sliced. After the build is completed, removal of the desired part is a manual operation which makes the overall process laborious.

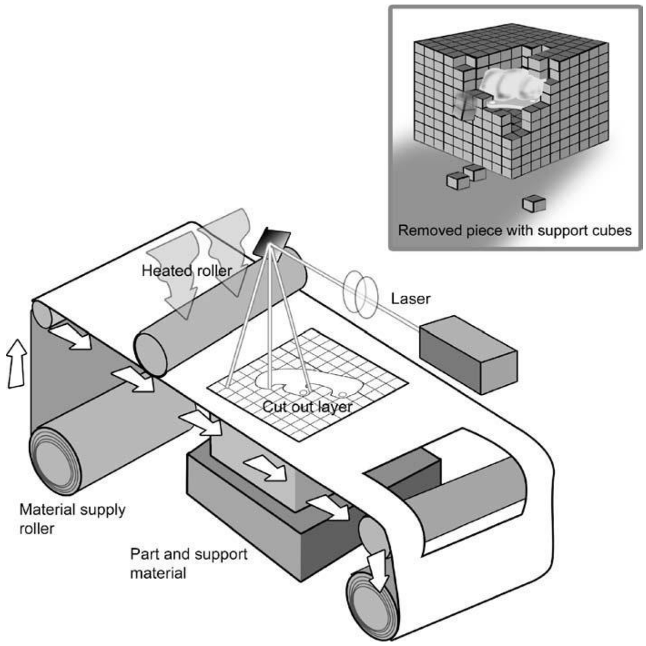


Figure A.14 Sheet stacking process (Hopkinson and Dickens 2006, 78)

APPENDIX B:

SEMI-STRUCTURED INTERVIEW GUIDELINE

Beginning the Interview

Start the interview by introducing the general application fields of additive manufacturing by giving brief titles:

- Visualization and verification
- Casting
- Aerospace Industry
- Automotive industry
- Medical and Bioengineering

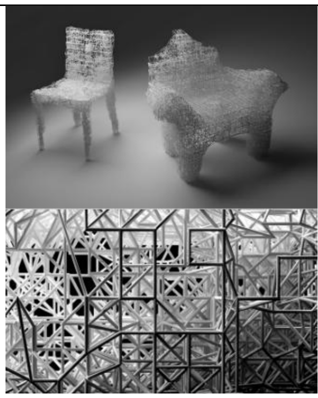
Questions asked before the introduction of emerging rapid manufacturing applications:

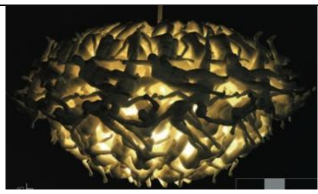
- How does this technology affect the way you think and design concerning the experience you had in Barbar projects and your professional practice?
- What possibilities are brought by additive manufacturing in terms of form creation, material selection, design process, manufacturing?

Introduction of Emerging Rapid Manufacturing Applications

Visuals of the application examples shown are included in table A in the order that is shown to the designers. These visuals are presented to each designer through laptop computer screen in the form of a slideshow which can be played forward and backwards. In addition to the visuals in table A, additional images that are included in Chapter 3 of this thesis are also shown to the designers while the details of these applications are presented verbally. They are expected to make comments on the possible implications of these applications related with industrial design and informed that they can make comments any time during the slideshow.

Table 5.1 Rapid manufacturing applications that are presented to the designers (in the order of appearance)

Order	Visual	Title
1		Structural Ornament
2		N12 Bikini
3		My Brain Lamp

4		Endless Series
5		Freedom of Creation Chair
6		MGX Damned Lamp
7		Nervous System

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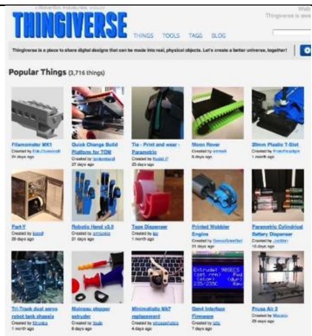
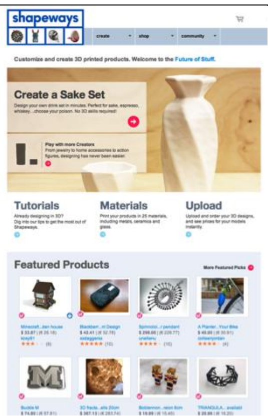
<tr><td>9</td><td>
</td><td>Thingiverse</td></tr>
<tr><td>10</td><td>
</td><td>Shapeways</td></tr>
</table>

Questions asked after the presentation of the application examples:

- In which areas of design can rapid manufacturing be exploited concerning your experience with the technology and discussed emerging application examples?
- How and in what ways does rapid manufacturing empower the designer concerning your experience and the discussed application examples?
- To what extent rapid manufacturing is acceptable as a manufacturing method for you?

- Do you have any concerns regarding the spread of rapid manufacturing services to the public?
- Do you have any concerns regarding a wider usage of rapid manufacturing processes in the field of industrial design?
- Concerning your experience with rapid manufacturing technology and the discussed application examples, do you think that these processes have the potential to cause paradigm shifts? If so, in which areas?
- Apart from the shown examples, in what fields of design in your opinion rapid manufacturing has a high potential?
- Concerning the future of this technology and its applications, do you have any further comments on the possible implications of rapid manufacturing for industrial design profession and designers?

VITA

Efe Alpay was born in Ankara, Turkey, on January 8, 1985. He graduated from TED Ankara College with a national and an International Baccalaureate diploma in June 2002. The following August he entered Bilkent University Graphic Design Department with full scholarship and received his Bachelor of Arts Degree as 2nd rank student in June 2006. He entered Middle East Technical University in September 2006 and his Master of Science Degree in Industrial Design is expected in September 2012. During his master studies, he co-founded Mirror Fabbrica and implemented a custom developed additive manufacturing process on mirrors and glass allowing custom made designs to be applied on glass and mirror surfaces as reliefs in the appearance of molten glass.

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