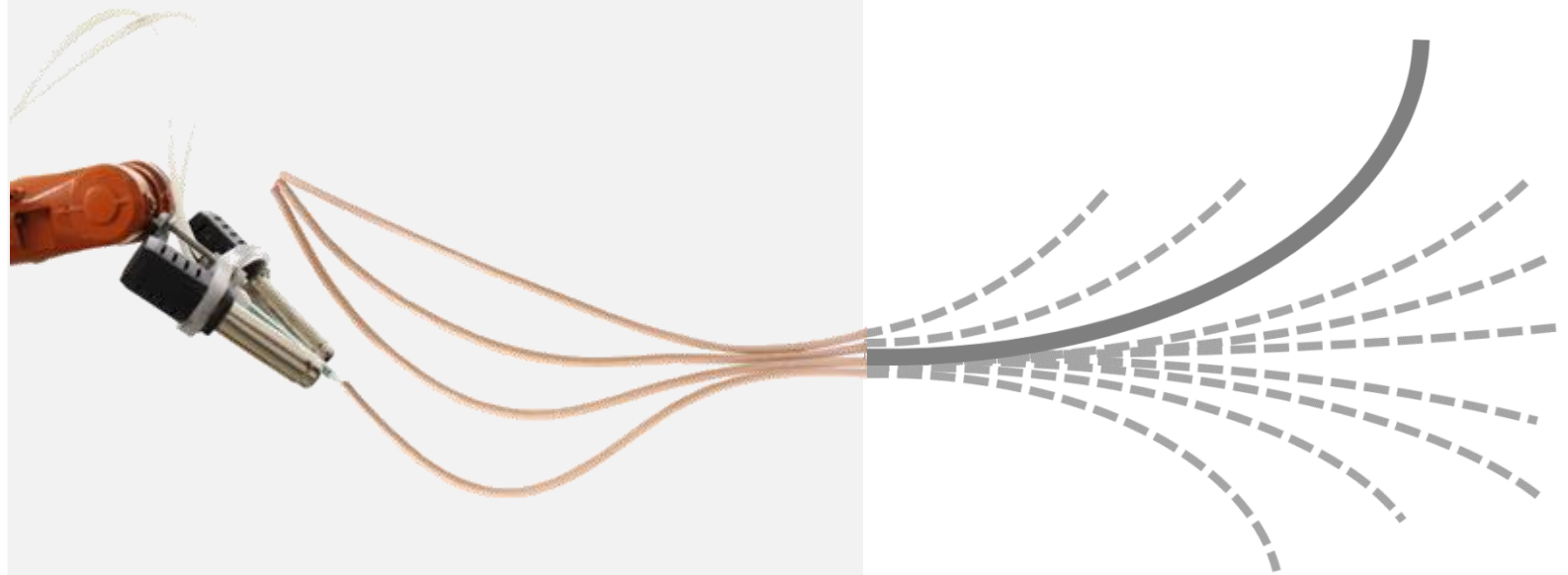


3D printing global value chains

How new technology is restructuring
production in the 21st Century



A Master Thesis written by Märtha Rehnberg

Supervised by Professor Stefano Ponte

MSc. International Business & Politics

Copenhagen Business School November 2015

Page count: 78

Executive Summary

From the steam revolution of the 19th Century, the containerization and ICT in the 20st Century, and the Internet that pierced into this century, the role that technology has played in enabling the globalization of production is well recognized. For some years now, 3D printing (3DP) has been debated as a technology that may revolutionize manufacturing by eradicating outmoded processes in global production. The technology promises to lower labor-intensity in manufacturing, the need for costly transportation, and wasteful use of raw material. For politicians in the Western countries, 3DP is a tool to bring jobs back home. For businessmen and women, it is a tool to optimize bottom-lines and bring new products to market faster.

While all these aspects of 3DP may be true for production, less attention is directed towards the implications of 3DP on value distribution and value creation in the global arena. In a critical realist fashion, the following thesis is built on the presumption that technology is a source of power to control and coordinate production. The way in which technology is applied, defines our ability to distribute and create value in order to transform, as opposed to reproduce, systems of production. Understanding the application of 3DP today is therefore important to understand implications tomorrow for politics and business internationally.

A theoretical framework is constructed from the approach of Global Value Chains, National Innovation Systems and an eclectic set of academic contributions to 3DP. A three-step approach to understanding impact from 3DP on global production systems and is proposed. First, a historical analysis of technology and production from the 19th to the 21st century shows that value chains of production are increasingly designed to respond to market information, flexibly and swiftly. This is followed by a desiccation of the technological conditions that make restructuring of GVCs from 3DP possible. Here it is argued that 3DP amplifies ongoing trends in production, such as mass customization. Two scenarios of GVC restructuring from 3DP are presented; one in which 3DP is used as a complement to traditional manufacturing technologies, and one in which 3DP is substituting traditional manufacturing technologies. It is argued that both scenarios generate an increased amount of

value in production, though the way in which this value is distributed will depend on the ability of actors to access 3DP. In the final step of the analysis, South Africa is analyzed as a suggestive case of an emerging country where both scenarios of 3DP are explored. The findings in this section suggest that a more nuanced view to technology access is needed. Here, it is argued that the technology promise of 3DP is not only determined by an actor's ability to import and develop 3DP, but also by an actor's ability to access market information.

In the light of a 3D printed reality, where transactions are digital, designers and buyers both local and global, and value both proprietary and free, a last reflection is dedicated to challenge the underlying assumptions of how value is defined in the global production of the 21st century.

List of Abbreviations

3DP	3D printing
AHRLAC	Advanced High Performance Reconnaissance Light Aircraft
AM	Additive Manufacturing
CSIR	Council for Scientific and Industrial Research
DST	Department of Science and Technology
DYI	Do-It-Yourself
EOI	Export Oriented Industrialization
GE	General Electrics
GVC	Global Value Chain
IBP	International Business and Politics
ICT	Information and Communication Technology
IP	Intellectual Property
IS	Innovation System
ISI	Import Substitution Industrialization
LEAP	Leading Edge Aviation Propulsion
NIS	National Innovation System
RAPDASA	Rapid Product Development Association South Africa
RP	Rapid Prototyping
RSA	Republic of South Africa
TiCoC	Titanium Centre of Competence
TMSA	Transformational Model of Social Activity

Table of Content

Chapter 1: Introduction	2
1.1. Motivations and Conceptual Delimitations	4
1.1.1. Global Value Chains	4
1.1.2. 3D Printing	5
1.1.3. South Africa	6
1.2. Structure of thesis	7
Chapter 2: Methodology	9
2.1 Philosophy of Science	9
2.1.1. Ontology: How I view the social world and my role in it	9
2.1.2. Epistemology: How I generate knowledge in a social world	11
2.2.1. Theory and Method: Understand the problem	14
2.2.2. Research Design: Develop a plan	16
2.2.3 Primary Data collection and interpretation: Carry out	19
2.2.4. Limitations: Look back.....	21
Chapter 3: Theoretical Framework	22
3.1. A tool for the “and” between International Business and Politics.....	22
3.1.1. History: Change from what?	23
3.1.2. Process: Is change possible?	26
3.1.3. Structure: Is change probable?	27
3.1.4. Agency: Change by whom?	28
3.2. Theoretical assistance in a ‘disruptable’ world economy	29
3.3. Chapter summary	32
Chapter 4: GVC Restructuring	33
4.1. The Steam Revolution and 19th Century production	33
4.1.2. Upgrading	34
4.1.2. Governance	34
4.2. ICT, Containerization and 20th Century production	34
4.2.1. Upgrading	35
4.2.2. Governance	36
4.3. The Internet and 21st Century production	37
4.3.1. Upgrading	38
4.3.2. Governance	39
4.4. Chapter summary and discussion	40

Chapter 5: 3DP and GVC restructuring	43
5.1. Technology Setting: The Innovation System of 3DP	43
5.2. Technology Access: The Global Value Chain of 3DP	47
5.3. Technology Promise: what and where is the value?	50
5.2.1. Extraction	51
5.2.2. Processing	53
5.2.3. Consumption	55
5.4. Chapter summary and discussion	58
Chapter 6: Technology Access & Exclusion: the case of 3DP in South Africa..	62
6.1 The National Innovation System of 3DP in South Africa	63
6.2. Accessing 3DP as local consumers: the GVC of 3DP in South Africa	67
6.3. Accessing 3DP as global suppliers: 3DP in the aerospace industry	70
6.4. Chapter Summary and Discussion	74
Chapter 7: Concluding Remarks	77
Bibliography	80
Appendix	89

List of Figures

Figure 1 Structure of Thesis.....	8
Figure 2 George Pólya's 4-step model to problem solving.....	13
Figure 3 Causation as applied in this thesis.....	16
Figure 4 Conceptual illustration of impact of 3DP on GVC restructuring.....	25
Figure 6 Ideal-typical GVC of 3D printing.....	48
Figure 8 2 Scenarios of GVC restructuring from 3DP.....	59
Figure 9 Organizations participating in the GVC of 3DP in South Africa.....	67

List of Tables

Table 1 The current state of ideal typical GVC Restructuring.....	41
Table 2 2 scenarios of GVC restructuring from 3DP.....	59
Table 3 The DST Roadmap for 3DP in South Africa.....	65

Chapter 1: Introduction

Goods and services are the elements that make up the global production and consumption we call 'the economy'. Through my line of study, I have been trained to observe these elements as being more than the input required to produce them or the resources needed to consume them. From the tangible good on which I write the following thesis, to the intangible service I use to protect my text, I have been schooled to reason, analyze and extrapolate relations of power that underpin the current state of our economy and that impact its development. The answers I have learnt, reside in the *and* between international business and politics. Here, policies and regulations are outcomes of market power while the business practices instead, a reflection of state power. My particular interest is in a gloomy area that lies somewhere in between: the role technology plays in bringing about change to the global economy.

Technology is the 'A' in our economic growth model, the variable that defines long term growth from the production and consumption of the goods and services that is our economy and therefore, a variable in which both business and politics hold a significant stake. The following thesis is about investigating potential change that may arise from 3D printing (3DP), a technology relevant for International Business and Politics because its existence in fact reflects the intimate nature of the *and* between business and politics, and because it is a technology that is currently changing the goods and services of our economy and the way in which we organize activity around their production and consumption. The impact of these changes on our economy remains uncertain, and the question of who will get what, when and where from 3DP remains open. So in exploring these aspects of 3DP I dedicate the following thesis to the strategic businessman, the accountable politician and the forward-looking academic whose focus lies in between.

Historically, technological advances have been crucial in changing the way in which we organize production across time and space. The steam engine broadly applied throughout the 19th century gave us control over space by making transportation and manufacturing so economic that for the first time spatially separating manufacturing from consumption was possible. This separation set

the stage for the era of globalization and for an understanding of production as being organized in global value chains (GVCs); chains of activities dispersed globally – from extraction, to processing and consumption – to bring final goods and services to the market. Information and communication technology (ICT) in the 20th century allowed even further steps in the globalization of production, as cheap communication for the first time awarded early adopters the ability to better plan production across borders and so a sense of control over time. The result of which was a global offshoring of manufacturing activities that previously had been centralized under one roof. The Internet in the end of this century shaped production into the next century even further, as its widespread application meant that even service activities became fit for outsourcing. But what is more is that the Internet today drives the digitization of supply chains that, combined with an automated manufacturing technology like 3DP ideally renders manufacturing free from the labor intensive nature of traditional manufacturing. The joke goes: “One man and a dog run the whole thing; the man to feed the dog, and the dog to keep the man from touching the printers!” (Mills 2011)

The EU refers to this technological reality as the “Factories of the Future”, Germany goes even further to call it “Industrie 4.0” and in the US, Obama (2013) referred to 3D printing as a tool to “making America a magnet for new jobs and manufacturing.” Further, “[a] once-shuttered warehouse is now a state-of-the-art lab where new workers are mastering the art of 3D printing that has the potential to revolutionize the way we make everything.” (ibid) So, where the 20th century production was about the de-industrialization of advanced economies that had industrialized during the steam revolution, and about the industrialization of less advanced economies that had not, the 21st century of production suggests a radically different picture in which the business case to bring manufacturing home is becoming attractive for both business and politics.

Whilst much attention is directed to the hype of 3DP and the technology promise presented for early adopters, less is written about what implications 3DP brings for emerging economies. Economies that may have to think long and hard about existing plans for industrial upgrading with manufacturing, as in its

future capital-intensive direction, it will not provide the same jobs as it previously has (Rodrik 2013). In fact, a totally new set of skills will become necessary with which to understand the impact 3DP may have on GVCs and the ability of less advanced economies to retain their positions in them and gain new sources of growth from them. Being concerned with this problem statement in this thesis, I formulate the following research question:

How does 3D printing impact global value chain restructuring?

To guide my research towards an answer I limit my analysis to three sub-questions, last of which is solely applied to a suggestive case of a emerging economy: South Africa. Choosing a case is a way to create constraints within which to direct my analysis, and create depth to an otherwise broad research question.

1. *What is the current state of global value chain restructuring?*
2. *What are the conditions that make global value chain restructuring from 3DP possible?*
3. *How probable is global value chain restructuring from 3DP in South Africa?*

1.1. Motivations and Conceptual Delimitations

1.1.1. Global Value Chains

The concept of Global Value Chains (GVCs) gained ground in both business and politics throughout the 90's as a tool to analyze i) how value is added from one activity to the other activity required to produce final goods and services, and ii) who gets what value across this chain of activities. The paradigm shift brought forth by the GVC framework was precisely that of taking as vantage point the value added to the goods and services that make up our economy. This, rather than value added to shareholders by the firm, or value added to the constituents of society by the industry, which often was the level of analysis for business and politics respectively. The GVC philosophy of placing goods and services at the center of analysis was in essence nothing new, as the same had been underscored by systems critics for a long time. As argued by critical scholar David Harvey

(1990) “[t]racing back all the items used in the production [...] reveals a relation of dependence upon a whole world of social labor conducted in many different places under very different social relations and conditions of production” (422). What GVC analysis brought to the table though, were methods structured around empirical rigor that granted the concept authority to make claims about value distribution and governance in global production. Doing so, the GVC framework became relevant for understanding one of the most fundamental concerns of international business and politics namely *who gets what, when and where*.

In this thesis, ‘impact’ and ‘GVC restructuring’ are defined along two qualitative analytical categories central to the GVC framework: the bottom-up category focused on processes as “trajectories of social and economic *upgrading and downgrading*” (Gereffi 2014, 28) and the top-down structural dimension focused on “multiple *governance structures* (international and domestic, public and private, chain-based and civic) that link different components of the system together” (Gereffi 2014, 29). Upgrading and governance as theoretical constructs are elaborated later in the methodology chapter. They are applied to the history of global production in a chapter called “GVC restructuring” to outline the current state of the same, and subsequently applied to 3DP in the “3DP and GVC restructuring” chapter to theorize about qualitative ‘impact’.

1.1.2. 3D Printing

Coincidentally the same month and year that Obama declared his support for 3DP, so did CEO of General Electrics (GE) Jeffrey Immelt declare his at the annual Atlantic conference in Washington: “[3DP] is worth my time, attention, money and effort”, furthering that “The tool is cheaper, the time is faster. If all I thought 3-D printing could do was shoes, I wouldn't be talking about it.” (Immelt in Thomson 2013). Within short, GE had gone from talking to walking when presenting to the aerospace industry its new LEAP Engine equipped with 19 3D printed fuel nozzles in alloyed metal. Using 3DP, GE had extended the product’s life time five times, made it 25% lighter and reduced its assembly by printing 18 parts in one (GE Reports 2015). The jet engines on which the fuel nozzles are fitted are sold next year and make up part of the GE’s bigger plan to 3D print 30% of its product portfolio by 2020. What is more, is that GE will

execute this plan in-house, in so doing joining fellow American business leaders such as Apple and Ford and their vision of a 'Made in America' (GE Reports 2015; Friedman 2013; Obama 2013).

It may therefore not be surprising that popular media couples 3DP with the word 'revolution' be it "industrial revolution" (Economist 2012) or "manufacturing revolution" (AT Kearney 2015) and that equity research institutes compete to provide the latest market forecasts. At JP Morgan the forecast is that the market will grow to 7B USD by 2020 whereas at Morgan Stanley the forecasts are closer to 22B USD (Forbes 2015). On the side of impact on other industries globally, McKinsey recently estimated that the economic impact of 3DP will exceed 550B USD by 2025 (2014). What these varying forecasts reveal is that there is a theoretical void in the understanding of 3DP as analysts of the industry seem to struggle with drawing the boundaries around what defines 3DP.

The aim of studying 3DP in this thesis is three fold. Firstly, the aim is to present GVC as a relevant framework with which to understand 3DP. By making a GVC of 3DP in this thesis, I hope to set the stage for future researchers to pursue impact analyses on industry specific GVCs, as such tasks lie beyond the limited remit of my thesis. Secondly, the aim is to challenge the GVC framework as it is clear from the GE case alone, that 3DP turns assumptions in the theoretical understanding of GVCs on its head; eliminating need for assembly and labor intensive processes and re-shoring manufacturing to only mention a couple. Thirdly, the aim is to provide stakeholders of global governance with a suggestive case of how the GVC of 3DP may impact GVC restructuring in an emerging economy namely South Africa.

1.1.3. South Africa

South Africa (RSA) is a case in question that seems to have thought 'long and hard' about their manufacturing strategy with regards to 3DP. Inherited with an isolated manufacturing industry from the apartheid years, RSA finds itself with a manufacturing industry in decline where costs are increasing while productivity on the other hand, is not (DST 2015). Furthermore, with generally sluggish growth rates, unimpressive employment figures yet with rich natural resources

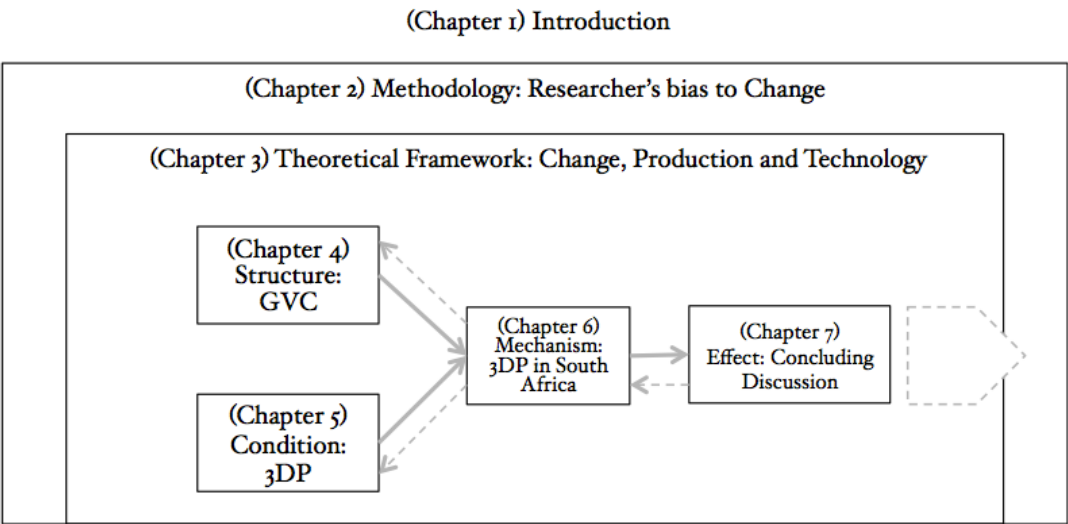
and existing technological capabilities, South Africa hold certain affordances that potentially make the case for 3DP both pertinent and relevant. And through its various research projects, the South African government is indeed investing in 3DP (RAPDASA 2015). The largest investment being with the Council for Scientific and Industrial Research (CSIR) that “is committed to support the South African Manufacturing industry through targeted, application-oriented research and development, to improve its global competitiveness as a primary driver for wealth creation, economic growth and a better life for all South Africans.” (Mzimasi 2012, 82). In a joint industry program, the CSIR is developing the world’s largest titanium 3D printer placing RSA on top of the list of “Emerging Technologies” that according to leading 3DP industry consultancy Wohlers Associates (2014) is worth noting (91). The vision is that “[t]he system [3DP machine] will make a major contribution towards achieving this goal, since it also addresses priorities such as the establishment of aerospace and titanium industries.” (Mzimasi 2012, 82).

1.2. Structure of thesis

With reference to the foundation for this thesis is my methodology presented in Chapter 2. This includes the philosophy of science developed as a student of International Business and Politics (IBP), and the research framework developed to guide my data collection and structure my interpretation of the same. Chapter 3 presents the theoretical framework I have constructed as a logical consequence to my ontological assumptions and epistemological demarcations laid out in the previous chapter. It is the backbone I draw from when generating insight to the concept of GVC restructuring from 3D printing: what change happens from, whether change is possible, who drives change, and finally whether change is probable. Chapter 3 is thus the theoretical backdrop for the subsequent chapters. By means of a historical account of production between the 19th and 21st century, I present the current state of GVC restructuring in Chapter 4. In Chapter 5, I put 3DP at the center of the analysis and present the technological conditions making GVC restructuring possible from 3DP. Chapter 4 is a theoretical chapter in which I draw from the rich GVC literature concerning historic events of GVC restructuring. In Chapter 5, I turn to both theory and

empirical work that has analyzed the technological possibilities presented by 3DP. As the GVC literature does not fall under this category, I turn to alternative theory hereunder including, but not limited to, innovation systems and supply chain management. Having presented the current state of GVC restructuring and the conditions 3DP presents to impact GVC restructuring, I then turn to the empirical part of the analysis in which I dive into the suggestive case of RSA. Chapter 6 presents the national innovation system (NIS) in the country as an outline of the technological capabilities in place and that may affect the adoption of 3DP. I then present and analyze primary data gathered from interviews with local practitioners of 3DP. Chapter 4, 5 and 6 are all followed by chapter summaries and discussions in which I contextualize my findings to those from previous chapters. For this reason, the last Chapter 7, is a condensed chapter in which I discuss the scope of conclusion for GVC restructuring presented by my findings.

Figure 1 Structure of Thesis



Source: Author

Chapter 2: Methodology

Conducting research in the field of international business and politics is a daunting undertaking. In this field, business is political, politics is business and above all, events occur in the international arena where nothing is certain and the only constant is change. More than 5 years into the field, generating thought-provoking yet applicable insights of a new phenomenon in international business and politics is still a daunting task for me. But it is one that can be overcome with a systematic approach to knowledge generation. The following chapter makes evident my view on change and semantics through which this thesis seeks to generate new and relevant knowledge. Accordingly, it is a strategic attempt to sidetrack some of the pitfalls associated with researching in, and concluding about, the “and” between business and politics.

2.1 Philosophy of Science

Since 3D printing (3DP) is an under-researched phenomenon and its role in regards to GVC restructuring to date completely uncovered, treading systematically is critical. The following section takes the first step in this direction by laying out the philosophy of science I have developed over the course of my studies; how I as a student have come to see the world, how I can gain new knowledge of it, and in it. “Underneath any given research design and choice of methods lies a researcher’s (often implicit) understanding of the nature of the world and how it should be studied” (Moses and Knutsen 2007, 2). As such, spelling out my ontological assumptions and epistemological demarcations here, makes more rational the research design presented later.

2.1.1. Ontology: How I view the social world and my role in it

Preparing for change

Technology, in the form of 3DP, the Global South in the form of RSA, and development in the form of GVC restructuring, are obvious and specific elements of my research. These are interests that disguise a less obvious yet more general sense of purpose I have to understand the role technology can play in changing a certain status quo. And my focus on change can be further derived from the critical view on power inherited from my line of study. A critical and at

times normative mindset that views the world as ‘could-be’ or even ‘should-be’, in contrast to a purely problem-solving mindset that views the world ‘as is’ (Cox 1981).

My view of the world is therefor a dynamic one: the world is made up of social agents and it is an *open* system which in contrast to a closed natural system, is subject to change (Moses and Knutsen 2007). My role as an academic is to be able to understand what change happens from and provide insight as to what a change brings for society. To live up to such commitment is to dare venturing into the unknown and investigate uncovered research topics like the one chosen for this thesis. Doing so, is an effort to contribute to predictive research and so fill the “research/practice gap” of business schools that has much debated over the past years¹ (Mingers 2015).

Uncovering change

Much like my academic commitment can be derived from observing my social activity, so do I view the world: as a set of events that if studied in depth can reveal purposes, embedded in deeper structures and underlying mechanisms that underpin the system in which they occur. In his Realist Theory of Science from 1978, Roy Bhaskar, often referred to as one of the founding fathers of critical realist philosophy of science ((Mingers 2015); (Buch-Hansen 2005)), describes the world as *stratified* and *pre-structured*. In a stratified world, an observer attributes purpose and provides explanation to agents’ behavior by means of discovering the underlying mechanisms – the deeper strata – that are responsible for the agents’ behavior. In his words, “[w]hen a stratum of reality has been adequately described the next step consists in the discovery of the mechanisms responsible for behaviour at that level” (Bhaskar 1978, 169). In this sense, agents are born into pre-existing, enduring structures, which makes change difficult but not impossible. And as a researcher, moving vertically between the different strata is thus key to understand where change is occurring and why. My view of the world is sympathetic to critical realism, in that it supports both Bhaskar’s understanding of i) structure/agency as being pre-structured and of ii) the world

¹ See Mingers (2015) or Wilmott (2012) for an account of, and current state of the debate

as being stratified. This adherence has implications on how I generate knowledge in order to both identify change and explain semantics.

2.1.2. Epistemology: How I generate knowledge in a social world

Distinguishing between transformative change and reproductive non-change

To identify change in a multilayered, stratified world, Bhaskar developed the Transformational Model of Social Activity (TMSA) in which he argues that social activity identified in one stratum should be juxtaposed not to other social activity in the same stratum, but to the underlying structures and mechanisms inherent in much deeper strata where transformation can happen. These structures embody the power balances in society which agents are subject to and thus have to distort to create a new status quo. “[Bhaskar] draws the distinction between the physical laws that may underlie the possible behaviours of say, a machine, and the actual causal factors that lead to it being used in a particular way on a particular occasion. The latter cannot be explained purely in terms of the former, but comes from higher-level human or economic systems.” (Mingers 2015, 321). In the context of 3DP, the ‘machine’ in itself may very well promise revolution and transformation, but in the end what will make this happen or not, is the power of the human on the other side to choose when and how to push ‘print’. Understanding the role of technology in bringing about real change comes from thorough observation of its users; why and how they apply it in the moment, and what effects – if any – this application has on pre-existing power balances: the deeper strata. The relevance of the TMSA lies in the explicit distinction between reproductive social activity and transformative social activity applicable to the research question at hand: in order for 3DP to impact GVC restructuring, the status quo must de facto be changed not only in its composition and input (reproduction) but also in its purpose and output (transformation).

Searching for observable and unobservable change

Further, to understand transformative social activity, critical realist epistemology directs attention to both what can be observed and what cannot. Mingers (2015) promotes critical realist philosophy of science to address “the research/practice gap” in business schools, hereunder the importance to research both the negative

and the positive space of events. “That which does not happen (when it was expected to) is causally as efficacious as that which does; that which is present is only so because of the gaps, boundaries and spaces which differentiate one thing from another; a lack of something (e.g., food or money) is as undesired as an excess (e.g., a tsunami)” (Mingers 2015, 322). In other words, the restructuring activities that are observed in the realm of 3DP are equally as important as the restructuring activities, which are not observed. By the same token, I have been intrigued by RSA as a case; though it is not amongst the leading nations in the sphere of 3DP, the country has a set of affordances, alluded to earlier and laid out later, that may probe the question ‘why not?’

Interpreting change

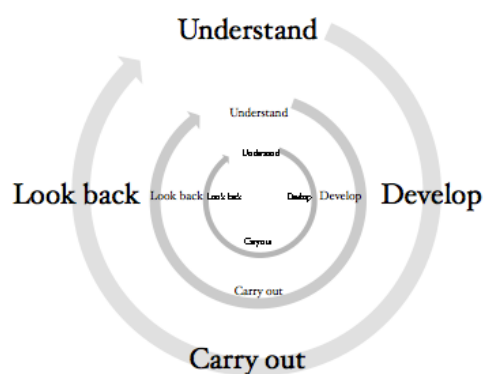
The challenge of working with the positive (what happens) as well as the negative (what does not happen) is that it is hard to know when to stop digging for deeper strata or where to stop drawing the picture as according to Bhaskar, [y]ou have to work at the totality, [...] if we have aspirations to change society.” (Buch-Hansen 2005, 58). One way to overcome this challenge is to be cautious about how and when to claim causality. This is particularly relevant for this paper in which a new topic is investigated and knowledge generated on the basis of little data. According to Bhaskar because of stratification, causality is *differentiated* meaning that an event observed in one stratum can be explained by several – observable and unobservable – underlying mechanisms and structures in deeper strata. To e.g. assert causality from observable empirical and quantifiable data only (as preferred by the positivist philosophy of science) is in Bhaskar’s view, to oversimplify causality and so to undergo epistemic fallacy (1978). At the other extreme, to not ascertain anything is to fall into epistemic relativism in which hyper-contextualization of research leaves the scope for conclusion minute. Differentiation means that some level of interpretation is not only acceptable but also required in order to get closer to Bhaskar’s ‘totality’. Social laws derived from empirical and theoretical analysis should thus be discussed along the parameters of probability rather than certainty, and seen as stepping-stones towards further knowledge generation (Mingers 2015).

In sum, I do believe in a real world independent of my activity and so I diverge from constructivist ontology. The challenge in understanding change and causality in this real world however, lies in my access to it. Because of its stratified, differentiated and open nature, I will epistemologically have limited access to the real world with its observable and unobservable power balances. And as such I will have limited ability to understand change in it, and limited scope of what can be concluded of it. In this instance, theory becomes my vital tool; my light and vision in the unknown. In the next section, I present the method through which I approach theory throughout this thesis in order to answer my research question.

2.2. Research Framework

This section builds on my epistemological demarcations in that it makes my discovery of 3DP, in a differentiated and stratified world, operational. As such I focus here on my *heuristics*, which in essence “denotes the study of how to find things out – the discipline, as it were, of discovery.” (Abbott 2004, 81) My discovery, that of answering ‘What is the potential impact of 3DP on GVC restructuring?’ rests on 4 steps advised by George Pólya in his infamous book ‘How to Solve It’ (1957): 1) understand the problem 2) develop a plan to solve it 3) carry out the plan 4) look

Figure 2 George Pólya's 4-step model to problem solving



Source: Author

back from the solution (xvi-xvii). In my view, these steps are crucial as I am approaching a new research area and as I am doing so with a complex worldview. Further, as illustrated in Figure 2, these steps should not be seen as linear and unilateral, rather in a stratified world, I see them as repeatable as I move vertically between the strata I study and so, much like my chosen phenomenon 3DP, I even see these steps as three-dimensional.

2.2.1. Theory and Method: Understand the problem

The circular approach used to move between different abstraction levels as presented in Figure 2 is not unusual to critical realism and is often reflected by the eclectic set of theories and methods used to understand problems. In fact, understanding a problem by means of working at what Bhaskar refers to as the ‘totality’, demands methodological pluralism. Laid out in my theoretical framework in the next chapter, the methodological pluralism applied in this thesis is reflected in choosing theories with different epistemological preferences and so theories that demand different sets of data. Doing so, requires of me to move interchangeably between chosen theories and gathered empirics, which I deem necessary to the discipline of discovery and in line my stratified worldview.

The reasoning behind this iterative method of theory application and empirical analysis is a trait of critical realism referred to as *retroduction* (Sæther, 1998, 242) (See Appendix 1 for a graphical illustration). According to retroductive reasoning I do not restrict myself to only inducing theoretical generalizations from empirics, nor to only deducing generalizations provided by existing theory to understand empirics. Retroduction is about challenging the dynamic that exists between induction and deduction. As such, it is not important whether the analysis takes as vantage point theory or empirics as long as I end up in the grey zone in between. It is in this space that differentiated causality is conceivable i.e. the critical reasoning whereby understanding the problem, like potential impact from 3DP on GVC restructuring, can be traced from multiple factors in underlying strata. But understanding the problem well also requires an acknowledgment of my own problems as a researcher such as those created by limits in time, space and capabilities. In this regard, I create artificial constraints within which to scope and design a feasible task.

Creating from constraint

In this paper I am inferring potential impact of one phenomenon, 3DP which is my independent variable, on another phenomenon, GVC restructuring which is my dependent variable. Having defined them as *phenomena*, I am buying into the Platonic notion that the knowledge I generate from observing 3DP and GVC is situated. It is not representative of the noumena, the real world, but is

representative of my view of my subject matter, the phenomena (Moses and Knutsen 2007, 173). My view, is limited to the time at hand to conduct research, the space in which to present findings, and the capabilities I have with which to understand the relation between these phenomena. Further, my phenomena of 3DP and GVC restructuring exist in a social system that is open, why I also accept the constantly changing nature of the objects I study. All these aspects in combination affect the way in which I approach my phenomena and the abstraction level at which I choose to present them.

As elaborated in later chapters, the rapidly evolving technology, and the dynamic molding of GVCs across time and space, makes ‘impact’ difficult to measure in quantitative and absolute terms such as money gained or lost from 3DP or number of jobs created or eliminated. When using published research on 3DP and its technological specificities there is a risk that by the time one article is published, months after the original research, the technology has developed so much that assumptions regarding its development and application have changed. For this thesis I therefore aspire to the Weberian method of treating my phenomena as *ideal types*. Firstly, treating 3DP and GVC as ideal types allows me to take the still frame needed to understand GVC restructuring and so change. This still frame is the structural baseline – the ideal type of GVC – that 3DP could potentially impact in terms of restructuring. Secondly this method facilitates the abstraction level needed to analyze impact qualitatively along two conceptual analytical categories provided by the theoretical foundation of GVCs: upgrading and governance.

The method of ideal types is a way to create width in the discovery of social laws relevant for answering the research question; social laws that I treat not as “knowledge about reality, but simply a means with which we can gain knowledge of reality” (Månson in Andersen and Kaspersen 2000, 79). In this way, escaping both the epistemic fallacy of realism and epistemic relativity of constructivism. But in order to add depth to my discovery, I scope impact according to its receiver – *impact for whom* – which is where my suggestive case of RSA comes into the picture. In order to detect whether impact on GVC restructuring is transformative or merely reproductive in accordance with Bhaskar’s TMSA, I

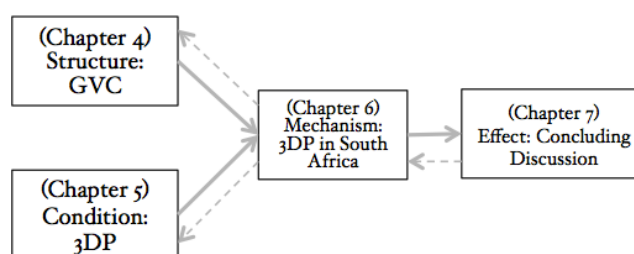
need to take a closer look at agency and purposeful social activities. Choosing a case is therefore an acknowledgement of the infeasibility of engaging with all actors implementing 3DP globally. Having now presented how I understand the problem, as well as how I understand my own challenges, I turn to developing a plan with which to answer my research question.

2.2.2. Research Design: Develop a plan

In this second step of problem solving, Pólya asks: “Can you restate the problem? Solve a part of it?” (1957, xvi-xvii). To restate the problem, I turn to a research design developed by Sayer (2000) and often used by critical realists to depict causation in a

stratified world. It is around Sayer’s model I have structured my analysis and the four sub-questions presented in the introduction (see Appendix 2 for original model)

Figure 3 Causation as applied in this thesis



Source: Author (Adjusted from Sayer 2000)

1. Structure: What is the current state of GVC restructuring?

Due to prestructuration, it is important to outline – as a first step – the structures to which agents’ purposeful activity is bound. It is here, in chapter 4, that I create the ideal type of GVC, the baseline which 3DP may have an effect of in terms of restructuring upgrading and governance. Presenting the structures in which my problem is embedded is a vital groundwork as it is the backbone for the entire analysis: it provides analytical boundaries within which to analyze 3DP later, and so the basis for understanding whether 3DP has a potential impact on GVC restructuring or not, and whether identified changes are transformative or merely reproductive. The latter of which is discussed in chapter 8, hence the arrow dashed arrows in Figure 3.

Answering what the current state of GVC restructuring is, I draw from and build on my theoretical framework that takes as vantage point an account of the GVC

approach: how it came about, its current state and where it may be heading in terms of theoretical advancement. *History* is here an important heuristic tool to not only “examine the question of what really was” in terms of GVC restructuring, but also “why” (Abbott 2004, 17). It is thus a theory driven section aimed at retroducting an ideal type of GVC by drawing from most prominent GVC scholars and practitioners. Aimed for width, the research here is rather *extensive* than intensive in nature (Sayer 2000, 21). Data is mainly drawn from theory but references are also made to the numerous international organizations that have incorporated GVC analyses into their practices.

2. *Conditions: What are the conditions that make possible GVC restructuring from 3D printing?*

The second sub-question aims at analyzing the conditions for GVC restructuring found in the independent variable, the technology of 3DP. I am here interested in the ideal material processes that make restructuring *possible* or not from a GVC point of view. *Interpretation* as a heuristic is a powerful tool to explain and translate the technology into a realm compatible with the GVC approach. This method of explanation is *semantic* in that I define “explanation as *translating* a phenomenon from one sphere of analysis to another until a final realm is reached with which we are intuitively satisfied” (Abbott 2004, 10). The final realm in this thesis is that of the GVC approach as that enables the analysis of potential impact of 3DP on GVC restructuring.

As in the previous chapter, the data collected here is secondary and mainly drawn from other disciplines that are further ahead of the research frontier of 3DP than IBP. As previously alluded to, I am dealing with the technology as an ideal type to sidetrack discussions about specificities of the technology. As such, I answer this sub-question by observing potential applications of 3DP into the ideal type of GVC, as opposed to explaining the technological specificities of 3DP that enable such application in sector-specific GVCs. I complement my theoretical toolbox with theory on Innovation Systems (IS) that puts technology organizations and technology policies at the center of the analysis – as these combined, constitute further conditions that have an impact on the probability of restructuring GVC from 3DP.

3. *Mechanisms: How probable is global value chain restructuring from 3DP in South Africa?*

Where I do extensive research in search for the width needed to answer my first two sub questions, I am here zooming in on the suggestive case of RSA to provide depth by means of more intensive research. Drawing from IS, I start by outlining the national technological organizations and policies that condition GVC restructuring from 3DP in RSA: the ‘National Innovation System’ (NIS). To this end, I am here working with the heuristic tool of *assumptions* (Abbott 2004) and more specifically the assumption that these mechanisms have an impact on the probability of transformation vis-à-vis reproduction. In other words I am assuming, in a critical realist fashion, that the events observed around 3DP in RSA, and effects analyzed from 3DP, can be explained by the underlying mechanisms – made up by the NIS – in the country. Explaining the relevant institutional environment for the dependent variable of 3DP in RSA follows the *syntactic* notion of explanation “focused on the logical pattern of an account, on the way its parts are put together.” (Abbott 2004, 12)

From the possibilities presented by 3DP (conditions), and the NIS in RSA that make those possibilities more or less probable (underlying mechanisms), I am at this stage knowledgeable of what 3DP strategies potentially could be observed in RSA and how those events may potentially impact GVC restructuring in the country. This includes an idea of central actors with an understanding of the space I am observing and whose viewpoint is valuable to my research. To answer the third and last sub question I therefore take a step further into my intensive research by engaging directly with actors connected to the GVC of 3DP in RSA. Engaging directly with local actors I am thus able to test and subsequently discuss plausible and most probable arguments developed thus far. As eloquently put forth by Cicero (in Abbott 2004) “[e]very systematic treatment of argumentation has two branches, one concerned with invention of arguments and the other with judgment of their validity” (v).

2.2.3 Primary Data collection and interpretation: Carry out

As I have incorporated my collection of secondary data into the development of the plan in the previous section, this section is chiefly concerned with gathering the primary data on 3DP in RSA. As a first step, I start by mapping all the actors I can find on the web that have a link to the 3DP space in RSA and so make up nodes in the chain of 3DP. Here I include economic actors that run a business related to supplying a product around the technology, as well as non-economic actors that work with the technology. By non-economic actors I refer to public actors that through the educational space or through state-funded projects work with the technology. To this end, pursue desktop research over the internet using the following search terms: “Additive manufacturing” “3D printing” and “Rapid Prototyping”. I then visit the websites to which select actors are connected in order to 1) validate that the actor indeed works with 3DP, 2) whether this actor is foreign/local and 3) analyze in what way they work with the technology e.g. supplier of service and/or goods (software/raw material/hardware). These categories are drawn from my analysis of 3DP in chapter “GVC of 3DP”. (For the full node analysis see Appendix 4)

Doing a this exercise is a way to get a first hand picture of the space I am researching and direction towards actors that potentially are valuable to engage with further in an interview. The selection process here is not straightforward as not all economic actors have published information regarding amounts of employees in the organization, financial situation or market share – criteria which in a mature industry would indicate relevant actors to interview. For this reason, and to the extent possible, I am using years of experience with the space as a selection criteria. I am intrigued by actors that have been working with 3DP for a long time as I am assuming a positive correlation between amounts of years working with 3DP and the amount and level of skills developed as a result of 3DP. Further, getting a hold of actors with numerous years of experience I hope to get a more realistic understanding of the effect of 3DP on GVC restructuring, in contrast to interviewing a late adopter with many technology ‘hopes’ and fewer technology ‘stories’. In addition to seniority in terms of years, I am also looking for seniority in terms of job function in order to get closer to Bhaskar’s

purposeful social activity. The assumption here is that proximity between the actor and firm strategies increases the more senior the job function.

These actors are subsequently approached via e-mail for interview requests, after which I interview those interested in partaking in a 30-60 minute interview. Finally, 8 people partook in semi-structured interviews; an interview style appropriate for my discovery driven research (Moses and Knutsen 2007) (see for an overview of the interviewees). Further, this method is an acknowledgement of practical challenges related to interacting with a social open system in which subjects respond to emails at different paces and are available at different periods of time. Given my own research agenda in which pausing my research is unfeasible, I am aware of the fact that each interview will be different not because the interviewees are different but because I am at different stages of enlightenment throughout the data collection stage. Turning such challenge into a strength is possible with retroductive reasoning in which I allow for an element of dialecticism between me and the interviewee and between interviewee and interviewee. In so doing, I am also testing Cicero's method here, of presenting new sets of *invented arguments* put forth by either me or a previous interviewee for the next to *judge according to their validity*.

As per the interview guide (Appendix 3) communicated to the interviewees prior to the interview, the interviews are recorded and subsequently transcribed. Conducting the interviews myself, transcription is vital in order to a) be present during the interview and open to pursue interesting venues that fall outside my interview questions and b) simulate the liberty of processing and interpreting the vast amount of input in my own due course – similar to the liberty I have when reading a text. Given my method of selecting and interacting with primary data there is a risk I am missing relevant nodes in the space such as actors that do not own a website. So in order to test the relevance of my voluntary sample and potentially complement the same, I pursue two strategies. Firstly, I ask my interviewees who/what organization they think I need to get a hold of for my research adding an element of snowball sampling (Moses and Knutsen 2007). Secondly, I conduct a network analysis feeding my original node analysis into the network tool Issue Crawler and Netdraw. In addition to mapping how actors

represented by URLs are linked to one another, I can see what URLs in the network are more central than others and so what actors are important to contact for interviews. As there exist many methodological pitfalls with concluding social laws on the basis of these tools only (Rogers 2006), it is important to pinpoint here that I merely utilize this kind of network analysis to validate and complement my already gathered sample of primary as well as secondary data. With regards to the latter, the network indeed presented some new actors in the NIS and new ways of applying 3DP that I had not found with traditional search methods. Find the network analysis in

2.2.4. Limitations: Look back

Looking back on my research design, there are two main limitations, which in contrast to the challenges and delimitations laid out above, I am unable to safeguard against with theory or method. The first limitation, is related to my own experience with 3DP. It is a technology, which I have studied over four years closely, and a technology which I have worked with directly in my previous position at the shipping conglomerate Maersk. Here, I worked as project leader with engines suppliers on the implementation of 3DP strategies for product innovation, as well strategies for process innovation within the supply chain and procurement division of Maersk. Though this experience may in fact make me more credible to theorize about the technology, my experience also brings several pitfalls. For one, I am biased to a technical and in depth understanding of the technology why I must be mindful of not internalizing or under-explaining 3DP to the reader. Further, I am also biased to a social understanding of the technology, having worked with the local maker community of 3DP enthusiasts. When investigating purposeful social activity of 3DP, I must therefore be aware of not assigning more values than what observed within the boundaries of this thesis. I have therefore made the deliberate choice of not including 3DP for home use, so-called “Hobby-printing” as such activity is dispersed, unmonitored and driven by numerous aims (Lipson and Kurman 2013, 46).

The second limitation is related to my suggestive case of RSA, which I, due to financial constraints, have been unable to visit. An ethnographic study on the ground of how 3DP is applied would needless to say have added insight to my

analysis. Instead, I make use of interviews and where possible, safeguard myself methodologically, by underlining that the case of RSA is merely a case in question used to operationalize and test arguments developed throughout this thesis. For the same reason, I take the liberty of not going into depths with the complex history of RSA, though undoubtedly this history has had an impact on aspects relevant for the current socio-economic situation of production and innovation. Related to my interviews, is also the fact that I was unable to get in touch with representatives of foreign companies with an interest in 3DP in RSA. These include, General Motors, Airbus and Boeing; none of which replied to my numerous attempts to create contact. Their strategic intents can thus only be theorized from official online statements and interviews with local actors working with them.

Chapter 3: Theoretical Framework

The theoretical framework presented here serves two needs: 1) to make clear why Global Value Chain (GVC) analysis is relevant to theorize and substantiate my understanding of 3DP and 2) to introduce additional theories that complement GVC analysis as I argue that in its current state it is unable to fully encapsulate the dynamics that technology can bring in a digital age and so what change its purposeful application can bring to society. The theoretical framework presented here, is the backbone to which I aspire when inducing theoretical implications of my findings later.

3.1. A tool for the “and” between International Business and Politics

At its core, GVC analysis is concerned with the very element of change so central to my thesis. Of a hyped phenomenon in the global economy like 3DP arguably is, GVC researchers would ask questions like “How novel are these emerging phenomena and world-economic patterns?”, “Do they indeed signal the emergence of a new international division of labor?” (Gereffi, et al. 1994, 1) and “How can economic actors gain access to the skills, competences and supporting

services required to participate in [this] global value chain?” (Gereffi, et al. 2001, 3). Judging events along the lines of novelty begs the discussion from Bhaskar’s TMSA on whether a certain change in fact is transformative or merely reproductive. Further, the bias GVC researchers hold towards international divisions of labor or what GVC scholars Gereffi et al. calls “spatial inequalities” (1994, 2), reveals a critical view on power similar to what I have developed as a student of IBP. Finally, providing recommendations to economic actors that are not yet part of GVCs alludes to the normative purpose I have in this thesis, namely to dare drawing conclusions about causality in order to provide practical insights applicable to the suggestive case of 3DP in RSA.

Four questions to understand change

Although the notion of GVC analysis is not based on one unified and coherent theory², its ontological foundation presented above has remained unchanged and so has its epistemological focus. As means to understanding change in the context of GVCs, 3DP, and RSA, GVC analysis would hunt for so called “*interventions and pressure points* that allow for change in this system”. (Gereffi 2014, 28-29) To this end, working at ‘the totality’, as encouraged by Bhaskar, seems to be a success criteria also followed by GVC researchers. Getting to grips with what potential impact 3DP has on GVC restructuring, is thus best done holistically by putting both structure and agency at the center of the analysis whilst combining an account of the past, in its focus on history, with an account of the current, in its focus on process. Doing so brings four questions to the table that are particularly useful guidelines through the first two sub-questions concerning the current structure of GVCs and conditions of 3DP.

3.1.1. History: Change from what?

On production in the open social system called the economy, one of the underlying assumptions is drawn from standard economic theory in which “the economy is an open system with three basic pillars – extraction, processing, and consumption.” (O'Brien and Williams 2010, 354). In line with Bhaskar’s stratification one could say that this three-pillared view of production is the

² See (Gereffi et al. 2001) for one of the first attempts at developing a “common thinking on value chains and contribute to the increased consistency and visibility of the value chain perspective”. (9)

deeper stratum of human activity that is rather constant and difficult, if not impossible, to change. What has changed throughout history however is the way humans organize production around these pillars, across time and space. GVC analysis is concerned with such organization and reorganization and uses a strong historical account to uncover underlying power structures, in deeper strata, that facilitate or prohibit equal change (Bair 2009).

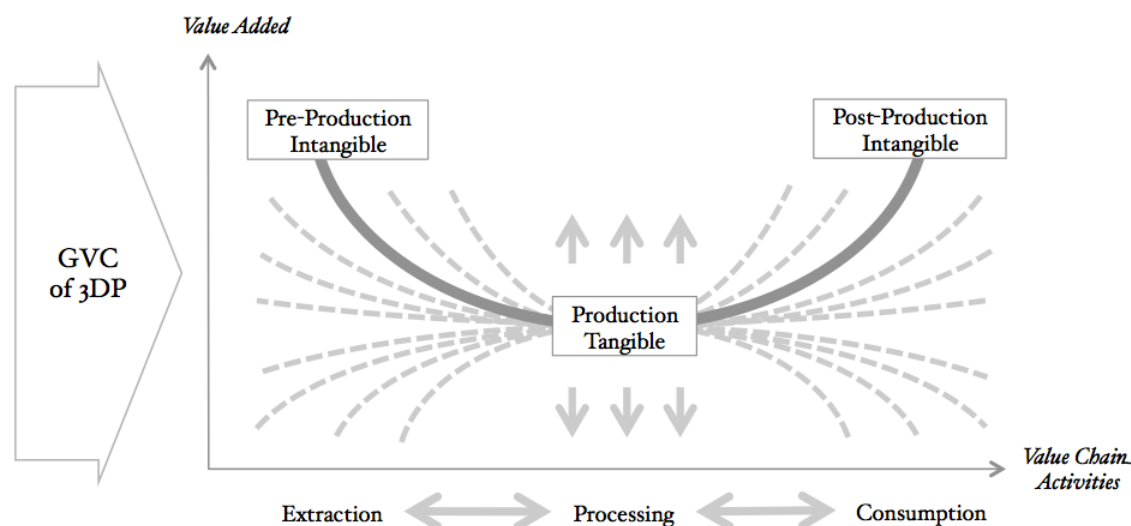
The GVC approach has aspired to, and developed from, theories that share similar credence in history. Two of them include trade theory and world systems theory (Bair 2009). To trade theory, the GVC approach is a critical response to the state-centric approach to world production and trade. To world-systems theory, the GVC provides several practical tools with which to analyze global production whilst maintaining a normative stance to global power relations and development (Gibbon et al. 2008). To this end, GVC analysis takes as vantage point the final products – be they of services or goods – to backtrack organization around extraction, processing and consumption: “take an ultimate consumable item and trace back the set of inputs that culminated in this item – the prior transformation, the raw materials, the transportation mechanisms, the labor input into each of the material processes, the food inputs into the labor. This linked set of processes we call a commodity chain.” (Hopkins and Wallerstein 1977, 128 in Bair 2009)

The GVC method of dissecting global production into sub activities at the level of the firm rather than the state has been used to analyze how value is distributed in a wide range of industries and across history. Such empirically rigorous exercise has produced an understanding of how global production changes as a result of international regulation provided by politics and technological advances provided by business and what impact these changes have on wealth distribution (Baldwin 2013). This exercise made GVC a useful tool to understand one of the most fundamental questions of critical realism namely *who gets what, when and where*. To depict this dimension, the GVC approach diverged from Michael Porter’s infamous value chain and developed the Smiley Curve; a concept which goes from a linear, value neutral understanding of the firm’s organization around production, to one able to capture where value is

added along the chain activities (Rabelotti 2014; Baldwin 2012; Shin et al. 2012). Throughout the 90s, the Smiley Curve gained relevance for the international community of business and politics: the OECD, the WTO, the WEF and UNCTAD to only mention a few institutions of the Global North³, and received “growing interest from economists, anthropologists and historians” (Gibbon et al., 2008, 316).

Due to its recognition and its visual ingenuity, I take as vantage point the smiley curve as 1) an account of enduring patterns of human organization around production (*change from what?*) elaborated in the chapter “GVC restructuring”, and 2) as backbone for analyzing the upgrading *possibilities* that 3DP holds for the ideal typical processes of GVCs (*is change possible?*), elaborated in the chapter “GVC of 3DP”. Accordingly, and as illustrated in Figure 4 the smiley curve (right) represents the dependent variable – the ideal state of GVC restructuring – which 3DP (left) as an independent variable potentially has an impact on, both in terms of curve shape and placement along the Y-axis.

Figure 4 Conceptual illustration of *potential impact of 3DP on GVC restructuring*



Source: Author (inspired by original the three pillars of production and the Smiley Curve)

³ For a thorough overview of the use of GVC analysis in IOs see (Gereffi 2014, 24)

The GVC of 3DP thus feeds into the ideal typical state of GVC restructuring represented by the smiley curve and not into specific GVCs. Such exercise would exceed the limited remit of this thesis, as well as that of my own capabilities. Instead the value brought forth by my chosen method, is to allow for industry-specific applications of 3DP to emerge organically as I approach one activity at a time along the three pillars of production. These emerging cases are only to illustrate and contribute to an increased understanding of 3DP, and inspire future research on the impact of 3DP on sector specific GVCs. Settling at this macro level, I adopt what Morrison et al. (2008) refers to the internationalist approach, in contrast to the industrialist approach: “*internationalists* privilege a macro perspective, in terms of both level of analysis and policy focus; conversely, the *industrialists* adopt a micro-founded framework of analysis”. (Morrison et al. 2008, 44)

3.1.2. Process: Is change possible?

In order to understand the conditions making GVC restructuring from 3DP possible, diving into what makes 3DP in itself possible, is necessary. To this end, mapping the specific functions and *processes* by which the technology can trickle into global production is a prerequisite. In fact, it is argued, “the greatest virtue of global commodity chains is its emphasis on process” (Korzeniewicz in Gereffi et al. 1994, 50). In contrast to the underlying structures of production induced by looking at history, processes make up more dynamic activity in higher strata, and represent activity specific to the product in question. Mapping the ideal typical value chain of 3DP is thus a useful way to not only introduce the technology in a structured manner, but also to verify that there indeed is access to the technology by other GVCs. On this presumption, it is possible to theorize about potential impact of 3DP on GVC restructuring and doing so along the parameter of the bottom-up analytical category of upgrading.

Upgrading is a term generically and widely used by the international community of business and politics to describe the purposeful activity of “innovating to increase value added” (Pietrobelli and Rabellotti 2006, 1; Giuliani et al. 2005, 552). In the GVC literature, upgrading is often applied at the level of the firm and refers to the ability of firms to:

- improve products: “product upgrading”
- optimize processes of production: “process upgrading”
- move into higher skilled activities either up or downstream in a given GVC: “functional upgrading”
- leverage developed skills to enter new GVCs altogether: “chain upgrading”

(Humphrey and Schmitz 2002, 1020).

These strategies of enterprise upgrading have in large become the foundation for the theoretical understanding of workforce development and for discussions at the World Bank and OECD in which workforce development is considered “among the most important economic development asset” (Psilos and Gereffi 2011, 2). Several upgrading typologies have been developed in the GVC literature and those that apply to 3DP, are furthered in chapter “GVC of 3DP”. As such, the GVC approach serves to provide structure to the currently scattered theoretical foundation of 3DP as well as a path to a more holistic and focused discussion regarding the impact of 3DP on global production as a whole; in so doing, shedding light not only on whether change to the state of global production from 3DP is *possible*, but also *where* in the production processes, illustrated by the smiley curve, change may happen.

3.1.3. Structure: Is change probable?

For GVC analysis, the ability of actors to change a certain status quo by means of entering GVCs is in essence a question of “access and exclusion” (Gereffi 2014, 28). According to GVC analysis, some actors have more power than others when it comes to either accessing a GVC, maintaining a long-term position in the same, or leveraging this position to access other GVCs. These actors are referred to as ‘lead firms’ (ibid) and identifying them, and their structural source of power in the GVC in question, can pave the way for interesting discussions as to who accesses the GVC of 3DP in RSA (the positive space) as well as who does not (the negative space). One of the key arguments of the GVC approach concerning upgrading for local firms is that it is strongly correlated with linkages to global lead firms and buyers. “Global value chain analysis emphasizes that local producers learn a great deal from global buyers about how to improve their

production processes, attain consistent and high quality, and increase the speed of response” (Humphrey and Schmitz 2002, 1020). From a classic resource dependence perspective, it is lead firms that are considered to have the power to affect the purposeful activity of other firms with which the lead firm is linked to, be it up- or downstream.

Therefore, for a substantiated analysis of change, GVC analysis couples the discussion of upgrading possibilities with governance – a top down analytical category that contributes to an understanding of the probability for upgrading (Pietrobelli and Saliola 2008). Where upgrading happens at the level of processes – within a process or from one to another – governance happens in the linkages between processes (Ponte and Sturgeon 2014, 211). By observing the nature of the inter-firm exchange that occurs between processes, GVC analysis induces what power relations are in play and so what probability actors that partake in GVCs have to actually change their situation by means of upgrading. Different approaches and typologies under the notion of governance have been developed in the GVC literature and reflect how the GVC method has shifted alongside its subject matter: the global economy of production. Gibbon and colleagues (2009) proposes a categorization between three types of governance, as “driving”, “coordination” and “normalization” (319; 324). In this thesis I apply GVC “governance as driving” which refers to the ideal typical types of governance structures that dominate in any given point in time (319). This abstraction level is thus suitable for the method of ideal types applied in this thesis. Here, generalizations are made around where the locus of power resides in the ideal GVC, represented by lead firms in a given process that chooses to control or ‘drive’ activity throughout the GVC. Next, to really come to depths with the concept of change, is to not only look at possibilities and probabilities for it but also demands for it.

3.1.4. Agency: Change by whom?

In addition to structural variables governing linkages between nodes in production networks, “the strategies of firms are deemed to be of critical importance in shaping the development of supplier capabilities.” According to Psilos and Gereffi (2011) “GVC participation requires deliberate “choice”.”(4). In

addition to *how*, it is therefore important to identify *why* agents organize in a certain way, because social activities whose purpose differs from those at deeper strata are more likely to bring about transformative change (Bhaskar 1978). With this epistemology in mind, it may be natural the choice of method undertaken by many GVC researchers namely that of conducting field work through which direct engagement with the subject matter's actions, and access to choices behind such actions, is made possible. A method, which furthermore explains the rich empirical data that lays the ground for most of the theoretical foundation of the GVC approach.

Based on what I have presented thus far, the GVC framework is a holistic theoretical framework suitable for working at 'the totality' to understand change as advised by Bhaskar. With an analytical eye directed towards history (change from what?) *and* real time processes (is change possible?), structure (is change probable) *and* agency (change by whom?), applying the GVC framework to 3DP can cover crucial aspects needed in order to understand whether there is potential impact of 3DP on GVC restructuring, and so set the stage for an understanding of whether such impact has transformative potential. I am however less certain about the ability of the GVC approach to in its current form understand the totality of 3DP; what Bhaskar refers to as *the higher level human and economic systems* (1987). As applied in this thesis this include 1) the capacity of local actors in RSA to utilize 3DP and 2) the strategies by non-economic actors, reflected by state funded projects, that may shape how and where 3DP is applied. What is needed here is theoretical assistance that by means of placing technology closer to the center of the analysis than the GVC approach does, can shed light on social aspects of technology application.

3.2. Theoretical assistance in a 'disruptable' world economy

The Externalization of Technology by the GVC approach

The technology promise of 3DP turns various underlying assumptions of GVC on its head. To only mention a few, what does localized production do to the unbundling world economy of production? Or to the elimination of assembly? What does 3DP on-demand mean for the spatial and temporal separation of the

pillars of extraction, processing and consumption? While digging into these questions are key for later chapters, I find it clear that 3DP – even in its ideal form – is an interesting mental exercise for the GVC framework. Yet to date, I have only detected one GVC reference to 3DP; by Baldwin in a report co-published with the WTO called “Global value chains in a changing world” (2013). Throughout the 436-page report, 3DP is mentioned four times to support the overarching notion that in a digital world, supply chains are disruptable. “Global supply chains, however, are themselves rapidly evolving. The change is in part due to their own impact (income and wage convergence) and in part due to rapid technological innovations in communication technology, computer integrated manufacturing and 3D printing.” (Baldwin 2013, 13). Other than the ‘may-s’ and ‘might-s’ after the word ‘3DP’, the report in itself does not dig deeper into its impact, nor does it suggest venues for future research into the field.

While the importance of technology indeed is recognized by the GVC approach, it is at best referred to as “technological milestones” or “technological advances” and only identified longitudinally by looking at history (Gereffi et al., 1994) (Gereffi 2014). As is elaborated in the next chapter, such approach has shed light on three main technological milestones: the steam revolution, information communication technologies, and lastly, yet still rarely applied, the Internet (Baldwin 2013; Gereffi 2001). In more recent work, Yeung and Coe (2015) frame technology as becoming increasingly important for the development of global production networks, making up the “risk environment” in which the networks are set (50). In their own words, “[t]hese risks range from market volatility to technological shifts and supply chain disruptions.” (ibid) Yet, no attempt is pursued from their end to incorporate technology into analytical categories directly applicable to understand the significance of technology such as 3DP. Though the importance dedicated to history is one of the main virtues of the GVC approach, it seems the other side of the coin – its vice – is its inability to understand present day technological trends like 3DP, with little or no history. I am thus looking for assistance in approaching technology with a less functionalistic view and as such, theory that can internalize technology into the analysis.

Internalizing Technology with Innovation Systems

Where GVC takes the goods as vantage point, innovation systems (IS) is about the environment in which the goods are produced. Yet, much like the GVC approach, IS is not one unified theory, rather an epistemological call for the researcher's attention towards the complexities coupled with technological adoption and so complexities that affect probabilities for change with technology. Broadly defined, an innovation system is "the network of institutions in the public and private sectors whose activities and interactions initiate, import, modify and diffuse new technologies" (Freeman 1987 in OECD 1997, 10). From the viewpoint of IS, technological innovation is key to bringing about change in the economy, but its adoption in terms of rate and direction is not solely defined by users in the firm, but by promoters of technology outside the walls of the firm (Lundvall 1992). With regards to economic development in a country like RSA, IS highlights the importance of access to superior technologies, which 3DP potentially is. But in contrast to the GVC approach that views the lead firms as most central to creating technology access and transfer, IS sees the local formal and informal institutions as what defines how a technology is adopted, and thus if the same will bring about change.

IS therefore focuses on general capacities to innovate as it is these that define change. To the notion of change by means of upgrading, Morrison and his colleagues (2008) make an interesting point that upgrading and innovation should be treated as two separate categories, critiquing the GVC approach for using the terms interchangeably by defining upgrading as "innovating to increase value add" (Pietrobelli and Saliola 2008, 951; Giuliani et al. 2005). In their words "the concept of upgrading suffers from some logical contradictions: it is used as a synonym for innovation, yet it is also intended as the outcome of an innovation process." (45) The capability to innovate thence presupposes upgrading, why it should be analyzed prior to upgrading as it is what makes or break sustainable upgrading strategies.

Further, where the GVC analysis looks at how technology in a given GVC affects local supplier capacity in the same GVC, the IS opens up for the "technological spillover" understood as effects that foreign technology import

can have on the national economy at large (Fu et al. 2011, 1207). As such, “[n]ations should not only acquire the achievements of other more advanced nations, they should increase them by their own efforts.” (Freeman and Soete 1997, 297.) Accordingly, understanding the network of actors in which a technology like 3DP is embedded is key to understanding change in the economy and so GVC restructuring. In this thesis, such network is delimited to the “technology organizations” that support 3DP globally and subsequently in RSA, and the “technological policies” through which the same promote a purposeful application of 3DP (Pietrobelli and Rabellotti 2011, 1264). By the same token, I restrict myself to overarching IS when discussing the ideal type of 3DP in Chapter 5, whereas when diving into South Africa, I apply the notion of National Innovation Systems (NIS).

3.3. Chapter summary

In Chapter 2 I presented my bias to as a researcher discover change in the field of IBP. Having chosen 3DP as a phenomenon to uncover, I limited my research objective to the field of production in this chapter. Here, I concluded that the deeper stratum of production evolved around the pillars of extraction, processing and consumption, and that transformative change or reproductive non-change occurs on top of such stratum. Because the field of GVC shares this epistemological demarcation, it is able through a holistic approach to identify ‘enduring patterns’ of human activity across the three pillars of production. To maintain relevant, I finally argue for a more dynamic approach of GVCs: one that can internalize technology and acknowledge the proactive role public actors’ play in shaping and driving innovation. In the next chapter I analyze the current state of GVC restructuring through a historical analysis of the role technology has played in shaping upgrading and governance. By observing history, I come closer to an understanding of what change with 3DP potentially occurs from.

Chapter 4: GVC Restructuring

For GVC researchers, today's globalized production is not a new phenomenon, rather one stemming from the early modern days of industrialization (Gibbon et al. 2008). Understanding historically how human activity has changed production across time and space is a foundation for the GVC approach and therefore also for this thesis, in order to understand the current state of GVC restructuring and later, further potential restructuring from 3DP. To this end, I take as vantage point technological milestones pre-defined in the GVC literature, and analyze these according to their effects on existing structures in terms of upgrading and governance. These milestone technologies include the steam revolution, information and communications technology (ICT), containerization and finally the Internet. Although the latter can be considered a tool under ICT, separating the two is useful to make clear the decisive spatial-temporal affect on GVC restructuring brought forth by digitalization and the Internet. Central to my research is thus the notion of technology as a phenomenon that can alter qualities of and relationships between time and space (Harvey 1990). In line with the method of ideal types combined with my internationalist lens of GVCs, the following chapter is outlining GVC restructuring at what Ponte and Sturgeon (2014) refers to as the 'macro level' focusing on 'overall' structures of GVCs (197).

4.1. The Steam Revolution and 19th Century production

According to Baldwin (2013), we have to date observed two major 'waves of unbundling' in production. The first unbundling came with the steam revolution in the 18th century, which significantly decreased the cost of transportation thus making it possible to spatially separate the two last pillars of production: processing from consumption. The steam revolution made the business case for large-scale manufacturing attractive, as well as that of international trade. A liberalized regulatory climate internationally, made the latter possible. However, while the cost of coordination and control across space remained high, so did the pillar of processing remain highly local in the Global North; what Baldwin refers to as "the globalization paradox" of the first unbundling (Baldwin 2013, 16).

4.1.2. Upgrading

Upgrading production activities during the first unbundling were strongly correlated with a high level of domestic industrialization. Policies for import substitution industrialization (ISI) were here prevailing to support the building and integration of entire supply chains at home, thus keeping most activities in the processing pillar in-house. In Baldwin's words (2011), "[m]ost of the necessary competencies had to exist domestically; no nation could be competitive without building a broad and deep industrial base – a hurdle that precious few nations could surmount." (6). The locus of power in this period of time consequently lied in the hands of the companies in the Global North, able to supply markets with products – a costly endeavor that held barriers of entry to manufacturing high amongst companies in the Global South (Baldwin 2011).

4.1.2. Governance

The first unbundling was associated with what Gereffi (1994) coined producer-driven GVCs, a governance structure in which the producer has the power to control and coordinate linkages in global industries (Bair 2009). Globalization of production was here mainly driven by the need for natural resources and/or new markets in which to expand. ISI in many countries in the Global South aimed at protecting local players from rivaling international competition, made it necessary for international companies seeking to invest in these countries to do so against conditions to upgrade local workforces (Gereffi 2001). This included the direct transfer of know-how in the form of managerial skills as well as technology (Baldwin 2011). Progress in communication technology made the setting up of international production networks possible – a trend that particularly took off throughout the 70's and came to restructure upgrading activities across GVCs and so also GVC governance.

4.2. ICT, Containerization and 20th Century production

The second unbundling happened throughout the 1970's and 1980's and changed the globalization paradox of the first unbundling, with information and communication technologies (ICT) gaining ground and reducing the cost of control and coordination. This, coupled with continued decreasing costs in transports associated with the break through innovation of containerization,

made the business case for outsourcing manufacturing inevitable (Baldwin 2008). In fact, outsourcing manufacturing became so cheap that activities within the processing pillar itself were separated and spread geographically (Baldwin 2011). This gave rise to trade *within* supply chains of intermediate, rather than finished goods (Cattaneo et al. 2010). The desiccation of the processing pillar increased the spatial separation of the three pillars of production even further with the second unbundling and globalization was not only furthered by natural resource intensive industries producing consumer durables and capital goods, but also and maybe even more so, globalization was furthered by the search for cheap labor by labor-intensive industries producing consumer, non-durable goods (Gereffi 2001, 34). This globalization trend was enabled by the rise of international standards and the codification of knowledge that made the activities in the processing pillar even more mobile (Sturgeon 2002). This in hand decreased barriers of entry to manufacturing, making the pillar of processing less costly and so also less valuable.

4.2.1. Upgrading

For countries in the Global North, the outsourcing of manufacturing enabled by ICT, meant that upgrading was pursued in the activities leading up to manufacturing such as R&D and design, and in the activities following up on manufacturing such as marketing and sales. Upgrading for western companies in essence meant focusing and developing internal intangible assets in-house and outsourcing tangible activities in the processing pillar to labor rich economies in the Global South. Upgrading for these economies, was no longer dependent upon building entire supply chains, but on joining existing supply chains (Baldwin 2011). International standards necessitated these countries to upgrade their existing functional skills in order to meet requirements related to the product itself and the processes by which the product was made (Sturgeon 2002). In terms of activities, upgrading chiefly occurred in tangible manufacturing activities, as the intangible activities in the pillars of extraction and consumption, remained within the boundaries of the firms in the headquarter economies (ibid).

4.2.2. Governance

The second unbundling was the era of what Gereffi calls the buyer-driven chain, referring to the rise of powerful companies in labor-intensive industries that supply consumer non-durables (2014). Power in these industries laid in the hands of the global buyer who defined the standards and who had a selection of manufacturing locations to choose from and so leverage power. The rise of buyer-driven chains is also associated with a regulatory shift away from ISI towards export-oriented industrialization (EOI) reflecting global political strategies to liberalize markets by bringing down trade barriers and providing domestic institutional frameworks necessary to attract FDI (Gereffi 2011). “Before the second unbundling, the political economy of trade liberalization was “I’ll open my market if you open yours”. After the second unbundling, the political economy was mostly unilateral: “I’ll open my borders and adopt pro-nexus reforms to attract factories and jobs” (Baldwin 2013, 25).

In contrast to the period of ISI where requirements were set for full technology transfer between host and home company, EOI meant that technology in the words of Baldwin (2011) merely was on “loan” (26). By means of foreign technology, countries under the second unbundling were able to set up manufacturing facilities swiftly, and so partake in the playing field of industrialization. However, within the same swift period of time could the demand disappear, and so also the technology. In order for developing countries to stay attractive in the eyes of global buyers, scale was of essence. This gave rise to export processing zones (EPZ) and global suppliers who upgraded by means of scale and by means of supplying goods to multiple GVCs. This however meant that upgrading from the processing stage, could in the long run not depend on the interaction of buyer-driven chains as “it is in these processing and assembly operations where companies see labour as a cost to contain rather than an asset to develop” (O'Brien and Williams 2010, 200). As such “[a]n unintended result of all this offshore-friendly policy was that it boosted the competitiveness of advanced-nation manufacturing firms.” (Baldwin 2011, 28) However, with the proliferation of the Internet, GVCs were to unbundle even further and trade go from trade in goods (first unbundling) to trade in intermediate goods (second unbundling) to trade in tasks – a trend that is shaping upgrading activities and

the governance of the same, and so restructuring GVCs even further (Gereffi 2001).

4.3. The Internet and 21st Century production

The steam revolution of the first unbundling enabled the separation of the pillars of processing and consumption and so decreased the barriers of entry to previously inaccessible markets. The ICT revolution of the second unbundling enabled the desiccation of the processing pillar of production and decreased the barriers of entry to manufacturing. In contrast to the 20th century ICT, the Internet made the distribution of information instant and free which set the stage for further unbundling of activities that, being previously intangible, were viewed as inappropriate for sourcing outside the walls of the organization (Gereffi 2001). By 1993 only 1% of information was shared over the Internet, whereas by the 2000's this number had increased to 51% and later in 2007, 97% of information was telecommunicated over the Internet (Hilbert and López 2011). Similar to how containerization was fuelling the ongoing trend of transportation of goods from the steam revolution of the 19th century, so did the Internet fuel the already ongoing trend from early days ICT, of outsourcing intangible activities by means of standardization and codification of knowledge. In Sturgeon's (2013) words, "computerization of work and emergence of low-cost international communications enabled a surprisingly wide range of service tasks to be standardized, fragmented, codified, modularized, and more readily sourced externally and cheaply transported across vast distances." (3)

In the start of the 2000's, supporting service functions such as IT, logistics and facilities management were increasingly outsourced to external firms. This in hand, gave rise to new players specializing in supplying specific services to a diverse set of GVCs. Across industries, this shift is manifested by the insertion of additional nodes in the chain; each new node representing a new specialized task that is being traded (Sturgeon 2013). Eventually, even manufacturing and aftersales servicing, which in most producer-driven chains were primary activities has in many industries now been outsourced (Cattaneo et al. 2010). The distinction between original equipment manufacturers, original brand manufacturers and original design manufacturers displays this shift; from trade in

goods and intermediates to the trade in tasks characteristic of the Internet era (Kadarusman and Nadvi 2013, 1025).

4.3.1. Upgrading

The continuous proliferation of international standards into more and more activities in the GVC not only makes offshoring possible, but with rising industrial capabilities in the Global South, standardization makes offshoring highly profitable (Baldwin 2013). In these countries, standardization and codification of know-how encourages upgrading of industrial capabilities necessary to take on the diverse and new sets of tasks demanded by lead firms. In this way, companies in the Global North gained confidence in outsourcing increasingly complex tasks, and in so doing, externalizing their own risks related to e.g. production planning and inventory management to specialized and more capable operators (Gibbon et al. 2008). Standardization has thus moved even producer-driven chains away from “manufacturer ‘push’ to consumer ‘pull’” (Gereffi 2001, 35) to reap the benefits of mass customization business models like build-to-order and lean retailing, similar to those enjoyed in buyer-driven chains. Standardization made possible with the Internet, accordingly enables even suppliers of capital goods and consumer durables to focus on brand building and customer satisfaction, and so further upgrade intangible activities.

These upgrading strategies of lead firms has taken de-industrialization in the Global North to new levels, making servitization⁴ the new norm. In the Global South functional upgrading enabled by the digitization of knowledge, also has spill-over effects into the adoption of technology – from transfer (first unbundling), to lending (second unbundling) to local technology development. In their investigation of the Indonesian electronics industry Kadarusman and Nadvi (2013) showed how local firms are “able to develop original product design and functionality by reverse engineering and improving such products and adapting them to the local market.” (1025). This suggests that upgrading in the Internet era becomes less and less dependent upon lead firms in the Global North. And it also confirms that an understanding for the local market is a competitive advantage. Here, the rise of E-commerce enabled by the Internet opens up for

⁴ For an overview of servitization in manufacturing see Ligthfoot, Baines and Smart 2013

cost efficient ways for new actors both in the Global North and South to partake in global and local industries. This is relevant both for B2B and B2C markets as well as for the new business model of the Internet era: the C2C model brought forth by powerful “infomediaries” (Gereffi 2001, 34) such as Ebay or Alibaba.

4.3.2. Governance

Gereffi (2001) argues that “the Internet intensifies a shift that is making all industries more buyer-driven in the sense that new consumer-oriented competitors are undermining the power of those manufacturers, retailers and marketers that do not take advantage of the Internet’s ability to facilitate mass customization.” (38) By new consumer-oriented competitors, Gereffi not only refers to the suggested convergence of producer-driven chains towards ‘buyer-driven -typed’ chains, but he also refers to the fading North/South divide reflected by the emergence of new powerful players from the global south: suppliers of specialized tasks, new technology providers or actors in the space of E-commerce. Joining existing GVCs which had been so important to the second unbundling in order to access knowledge in the hands of lead firms, seems now less important as more and more knowledge is codified and GVC activities commoditized by means of the proliferation of international standards (Gibbon et al. 2008).

“The rise of industrial capabilities in emerging economies has rendered static notions of permanent dependency and underdevelopment obsolete.” (Ponte and Sturgeon 2014, 196). At the same time, controlling and driving the entire GVC also seems less important for lead firms as the industrial capabilities in the processing pillar are increasing in quality and decreasing in cost. With the proliferation of nodes in GVCs, organization around the pillars of production in this era is less about control and more about networks and coordination of networked activities. Business operation here, is more about managing the immediate backward and forward linkages between the nodes in the network, rather than managing the entire network. In contrast to governance in the first and second unbundling, power is multipolar, dispersed and more complex to observe.

On an industrial level, the era of the Internet coincides with the post ‘Washington consensus’, in which ISI or EOI as waterproof upgrading strategies have proven faulty in the eyes of international policy makers. While we have seen a steady growth in world output during the period between 19th and 21st century production, and so an upwards move in the placement of the Smile curve, the same output has been unevenly distributed (Piketty 2014) (see Appendix 8 for an overview of global growth in GDP per capita and region between 1700-2012). Crises like the Asian crisis of the 90’s exposed such faults, as did the recent financial crisis – the aftermath of which policy makers still to date are concerned with. According to Cattaneo et al. (2010) the recent crisis exposed the downside of today’s networked GVCs that, because of their interconnected nature, can have major implications on entire global networks that make up global production. With regards to the trade collapse during the financial crisis, they argue that precisely because of the interconnectedness of today’s GVCs, “this collapse has been more severe, rapid, and persistent than trade collapses experiences in the past, including during the Great Depression” (Cattaneo et al. 2010, 23). The fragility of GVCs to economic cycles, along with the rising power of emerging economies, has according to Ponte and Sturgeon (2014), “opened a period of questioning and experimentation for policy-makers.” (198). During this period bilateral and regional agreements on trade have mushroomed, reflecting the need for GVCs to operate in a more dynamic and flexible regulatory structure than what is offered multilaterally under the Washington consensus (Baldwin 2013). As such, GVC restructuring in the 21st century is happening by means of global, regional and local networks.

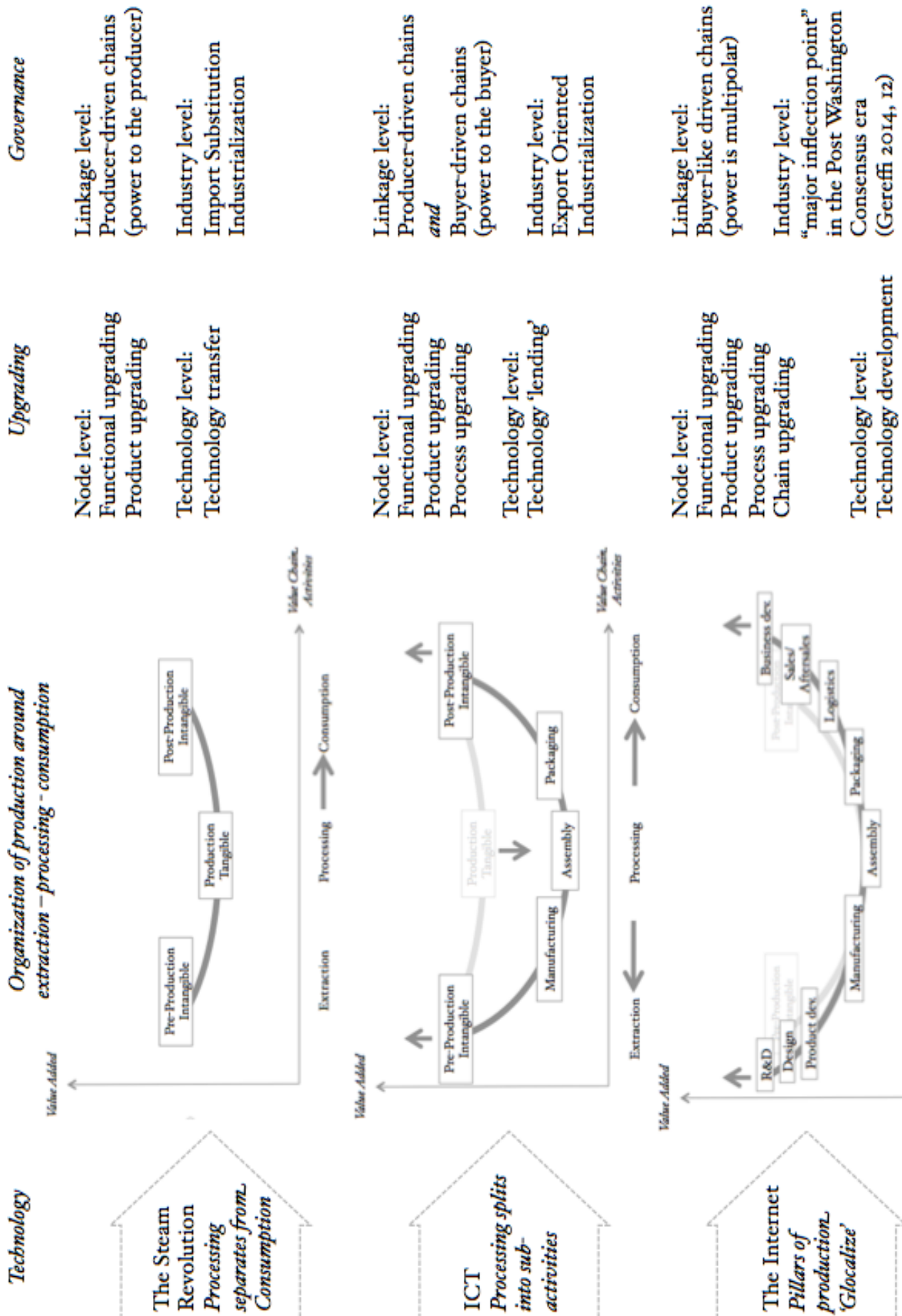
4.4. Chapter summary and discussion

Using history to detect underlying structures leading up to the current state of GVC restructuring, it is possible to tell an interesting story about how technology has played a central role in shaping the control over time and space in global production, as well as who has benefitted from such control. The Steam engine made transportation of tangible goods across space cheap. Those who benefitted from this control over space were those able to supply goods – the producers. As ICT gained ground however, the new paradigm in global production was that of carrying information cheaply, and close to instantly.

Those who benefitted from this control over time, were in hand those who controlled market information – the buyers. With the widespread use of the internet in the 21st century production, carrying information has become free and certainly instant. Much like containerization could be considered a multiplier for the ongoing trend of trade in tangible goods – final and increasingly intermediate – , so can the Internet be seen as multiplier for an ongoing trend brought forth by ICT, namely that of trade in intangible goods; trade in tasks.

The locus of power to control space and time in this current state of GVC restructuring, where both the control over time and space is affordable, is more and more granted to buyer-like actors. Further, the specialization of tasks, new technologies and new business models, has resulted in a proliferation of nodes, new GVCs and intertwining of GVCs on global, regional and local levels, which in hand has rendered the observation of ideal-typical chains increasingly difficult. For one, the notion of ‘buyers’ as a category has become highly diverse, and the spatial separation of the three pillars of production has become both local and global. In the field of GVC research, the fading divide in producer/buyer driven chains and North/South upgrading capabilities epistemologically means world production in this current state of GVC restructuring has become a more complex field to observe. The development of ideal typical GVCs from 19th century to 21st century production is outlined and summarized in Table 1. This table serves as an answer to my first sub question on the current state of GVC restructuring, and is also the backdrop to which I refer when discussing GVC restructuring in light of 3D printing. In the next chapter I take a dive into the conditions brought forth by the 3DP technology, and so the conditions making further GVC restructuring possible.

Table 1 The current state of ideal typical GVC Restructuring
(incl. dominant trajectories of upgrading and governance structures)



Source: Author

Chapter 5: 3DP and GVC restructuring

The following chapter serves to answer the second sub question of this thesis: “What are the conditions that make global value chain restructuring from 3DP possible?” The value of the following chapter is three fold. Firstly, I am seeking to provide structure to the currently fragmented theoretical foundation of 3DP by means of analyzing it through the lens of GVC theory. In doing so, I am also hoping to challenge the current theoretical state of GVC restructuring – understood as upgrading and governance – by proposing venues and trajectories of change brought forth by the technology. This allows me, to later on, qualitatively test the validity of such trajectories on my chosen case of RSA, and so lastly, move closer to answering my overarching research question regarding the potential impact 3DP has on the way we organize around the three pillars of production. To execute such plan, I approach the GVC of 3DP from three angles: The Technology Setting, Access and Promise. First, is an introduction to the prestructuration of 3DP defined as the Innovation System (IS) of informal and formal institutions that may be part of defining the future of GVC restructuring along with 3DP. Secondly, I look at the governance mechanisms that affect access to the technology and so affect the probability of identified upgrading trajectories. Lastly, I provide an account of the technological possibilities that 3DP holds for upgrading activities in the realm of business.

5.1. Technology Setting: The Innovation System of 3DP

As outlined in the previous chapter, production in the 21st century is now more than ever organized in GVCs that are highly networked and interlinked. How humans organize around extraction, processing and consumption, accordingly reflects purposive social activity aimed at best reaping the significant opportunities presented by networked GVCs, whilst also, navigating the particular risk landscape of this century. In this section, I outline mega trends in production that manifest this purposive social activity and as such make up the prestructuration, to which 3DP activity is bound. According to IS, the mega trends of a radical innovation, like 3DP arguably is, can indeed impact its diffusion: “[t]he success of any specific technical innovation, such as robots or CNC, depended on other related changes in *systems* of production.” (C. Freeman

1995, 11) By triangulating the current state of GVC restructuring presented in the previous chapter with contemporary literature on supply chain management and industrial development, it is possible to deduce megatrends of production at the level of technology, business and politics. After all, “competition in the global economy is forged by the interaction between three broad sets of factors: technological, institutional, and organizational innovations” (Gereffi 2001, 30).

From a technology perspective 3DP in manufacturing portrays a general trend towards a more and more capital-intensive manufacturing sector driven by breakthrough technological advances in the *automation* of manufacturing processes (Rodrik 2013). 3DP reflects such trend, as does robotics or the Internet of Things; technologies that often are coupled with 3DP (Gress and Kalafsky 2015). One of the first so-called smart factories in Europe, Amberg has worked with automation since 1989. Today machines and computers at Amberg handle 75% of the processing pillar (Zaske 2015) – automation that in hand is enabled by the proliferation of information and the next relevant technological megatrend: *Big Data Analytics* (Phillips, 2014; Stank et al., 2013; Woodward, 2015). Big data has been emphasized by supply chain literature as key to digitize supply chains globally, making them agile and apt to respond to consumer demands in real-time (Woodward 2015). Related to the digitization of supply chains is the trend of sharing information across the chain and the technological platforms that allow for such practice. In regards to 3DP, it is acknowledged that the *open source* platforms have played a key role in both developing the technology and facilitating its widespread adoption (Lipson and Kurman 2013). This, by means of the amount of software tools that are shared for free and thanks to the assisting mechanisms in place in the more bottoms up applications of 3DP represented in the maker and do-it-yourself (DYI) community (Berman 2012). Put differently, “[w]hile open-source communities are probably best known for software development, they are by no means restricted to software or even information products [...] such communities are also viable for developing physical products.” (de Jong and de Bruijn 2013, 45).

For the land of business, automation, big data analytics and open source platforms have driven three trends in the business of production. First is the

increasing focus on service, referred to in the GVC literature (and outlined in the previous chapter) as the increasing commodification of intangible activities. According to the World Bank (2012), the share of services in world GDP and in terms of value added has risen steadily over the past decades: from 53% in 1970, to more than 70% in 2010 (Low 2013). “*Servitization*” (Vandermerwe and Rada 1988, 314), “*Manuservices*” (Bryson and Daniels 2010, 88) or “*Servicification*” (Low 2013, 62) are just some of the many theoretical notions used to describe how services are “intimately intertwined with manufacturing in all phases, from design and innovation to recycling and waste management.” (Gress and Kalafsky 2015, 45). As such, it seems that the capital intensification of the manufacturing sector has not necessarily made it less labor intensive, as labor now is instead located in higher value added activities in the extraction and consumption pillar. Indeed, the Amberg smart factory has retained same amount of employees for the past decade (Zaske 2015). The drive towards servitization is due the profitability of *demand management* (Christopher and Ryals 2014, 29) and *mass customization* (Gilmore and Pine 1997, 91), the next megatrends driving business in production. Due to the richness of data and open source platforms in which the data can be shared between select nodes in GVCs, Gress and Kalafsky (2015) argue that the future of supply chain management will be about the ability “to anticipate, understand, and articulate demand” (47); what they coin “demand chain management” (ibid). Thus, by means of cost efficient automation and digitization of GVCs, businesses are able to steer full focus towards customer satisfaction, and in so doing, realize mass customization (Gilmore and Pine 1997).

From the perspective of industrial policy, the technological and business megatrends presented thus far have by large been supported by the public sector – discursively and financially. At Davos earlier this year Angela Merkel stated that “We must – and I say this as the German chancellor in the face of a strong Germany economy – deal quickly with the fusion of the online world and the world of industrial production. In Germany we call it Industrie 4.0”. (Merkel in Zaske 2015). Backing her words, is 200M EUR invested over the next two years to spur ‘the fourth industrial revolution’ across government, academia and business (ibid). In the EU, 1.15B EUR have been set aside to between 2014 and

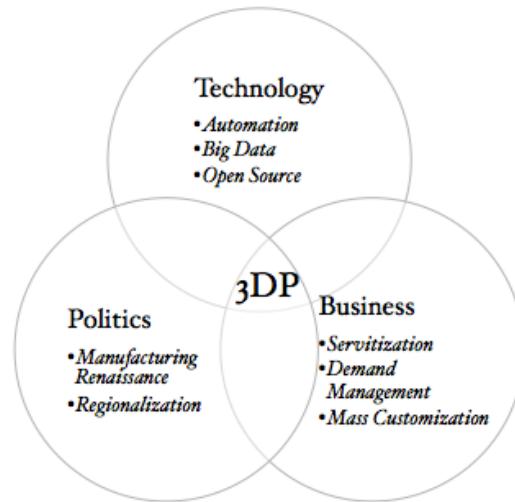
2020, support the “Factories of the Future” (FoF) in which the development of “high-tech manufacturing processes, including 3D printing” receive funding (European Commission 2013). On the other side of the Atlantic similar investments are targeted towards US manufacturing “to bring jobs back home” (Obama, 2013). Though more directed towards specific technologies, the US is e.g. earmarking 30M USD for research only within 3DP (Gress and Kalafsky 2015). By the same token, the public sector in South Korea, China, and as I elaborate later, RSA, are taking steps to ensure that also they are ahead of the technology frontier (ibid).

Though scattered and uneasy to get an overview of, the numbers behind the public interest in the 21st century production in which 3DP is embedded are indications of the post crisis era in which we currently are where the state has taken a driving role in manufacturing: “[t]he big difference is that Industrie 4.0 is driven by the government and is unmistakably part of industrial policy” (Bledowski in Seals 2015). In a way we see a move back to industrialization as a means to achieve global competitiveness where technology policies evolve around providing public funding to the manufacturing sector; funding which indeed has served great value to help the sector bounce back from the crisis (Cattaneo et al. 2010). Some rightfully argue that in terms of industrial policy, we are witnessing a ‘*manufacturing renaissance*’ (Mosconi 2015) in which insourcing manufacturing no longer means to not focus on “core competencies” (Cattaneo et al. 2010, 29). Building manufacturing capacities locally also seems to affirm the *regionalization* trend observed by GVC literature over the past decades which not only includes the advanced economies of the Global North but also emerging economies in the Global South (Baldwin 2013; Rodrik 2013). The latter that is manifested by the rise of “south-to-south” trade between strong lead firms in emerging economies (Bamper et al. 2014, 10).

Understanding such political push is useful to later on discuss probabilities for upgrading in a prestructured world: “[w]hile recognizing that international organizations do indeed influence economic outcomes, this is not as a result of pressure by lead firms but rather through the impact of regulation on the way that lead firms organize international production networks.” (Gibbon et al. 2008,

316) Figure 5 provides an overview of the IS that make up the prestructuration of 3DP at the level of technology, business and politics. Before diving into the application of 3DP in the extracting, processing and consumption pillar respectively, the following section presents the GVC of 3DP.

Figure 5 Innovation System of 3D printing



Source: Author

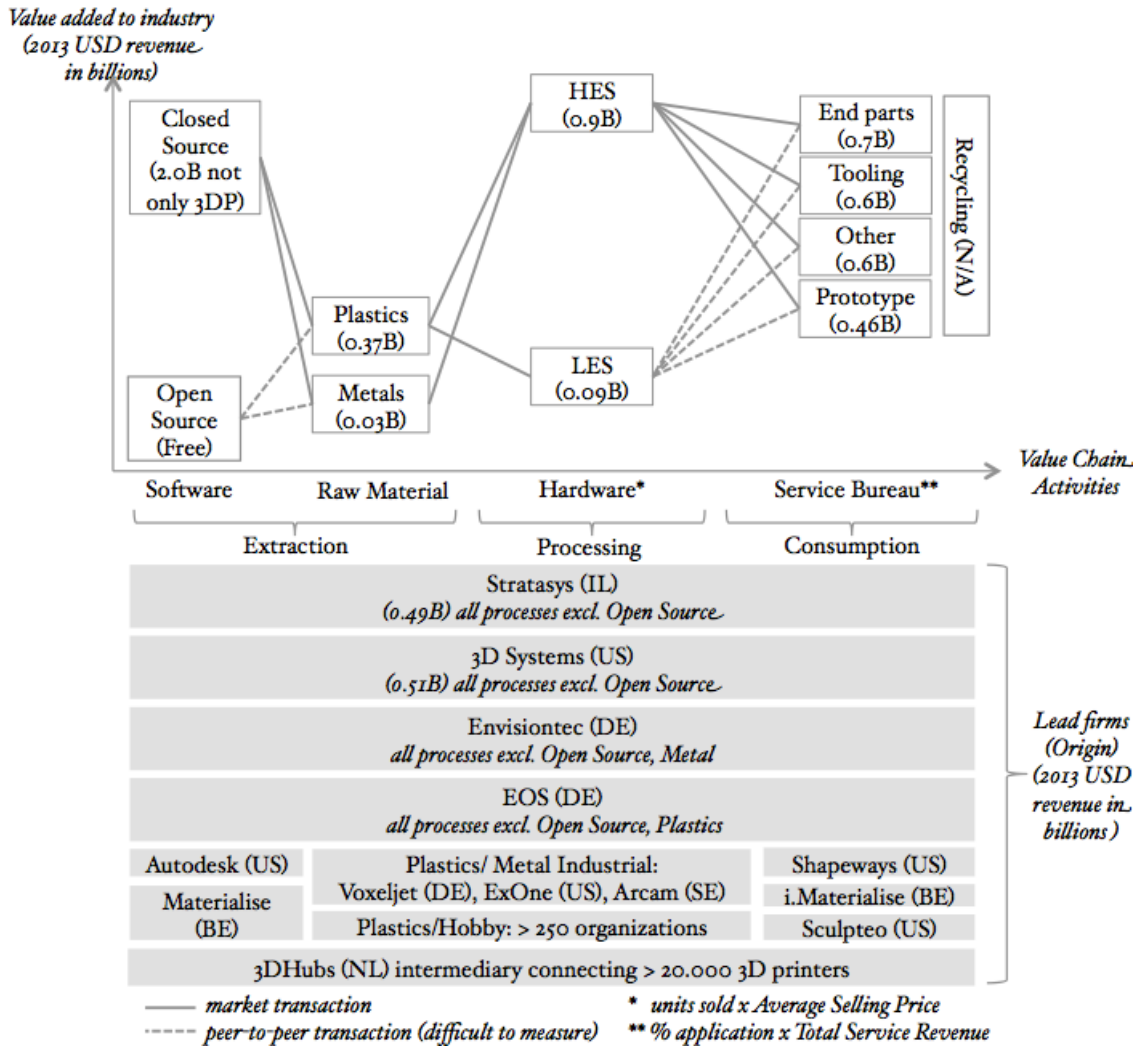
5.2. Technology Access: The Global Value Chain of 3DP

The first version of 3DP came out of a research project at the University of Texas in the late 1980's. At that time, and for many years to come, 3DP would be a technology only used by and for engineers (Lipson and Kurman 2013). Until somewhere in the mid 2000's when Peter Weijmarshausen founded one of the first C2C platforms for 3DP called Shapeways with the vision "to give anyone access to manufacturing" (The Creators Project 2013, 00:57). Around this time, the technology had become cheap enough to penetrate the early enthusiasts for home use, and designers in most R&D departments for prototyping purposes in the extraction pillar of production. By the time the technology was ready for metal applications the 3DP industry took off, and the success stories within the processing pillar of the ideal GVC started emerging too. Today, the market for 3DP final end-parts is growing at a 60% CAGR (McKinsey 2014).

Just like the consumption of 3DP can be broadly categorized into final end parts, prototyping or other, so can the entire production chain of 3DP be depicted through the three pillars of production: from the software required to design a 3D printable part, to the raw material and hardware with which to print, to the service bureau that undertakes the production, unless developed in-house as in GE's case. With regards to the hardware, I follow here Wohlers' distinction between higher-end systems (HES) with a market price above USD5000 and

lower-end systems (LES) with a market price below (Wohlers 2014). These processes are outlined in Figure 6 together with a presentation of firms that dominate each pillar – ‘lead firms’ in the 3DP IS that govern access to the technology, and so also impact the technology promise presented in next section.

Figure 6 Ideal-typical GVC of 3D printing
(incl. 2013 USD revenue numbers in billions)



Source: Author on the basis of categorizations and 2013 statistics from Wohlers Report 2014 (20, 99-129)

There are interesting analytical points worth noting from the ideal GVC of 3DP. Firstly is the youth of the industry, reflected in the number of dominant firms that have not yet gone public (Wohlers 2014); consequence of which is, that it is

difficult to get a picture of value added in terms of profitability of a transaction. Supporting claims of the low maturity level of the industry is the numerous smaller organizations developing LES or offering 3DP services by means of global platforms such as 3DHubs, which connects both owners of LES and HES to global demand in 3D printed goods. Intermediaries such as 3DHubs therefore opens up for a fifth type of upgrading introduced by Fernandez-Stark and colleagues (2011) namely “entry into the chain.”(in Bamper et al. 2014, 9). This type of upgrading seems relevant to 3DP as in contrast to inter-chain upgrading where actors who have been part of one GVC can leverage existing skills to access other GVCs, entry into the chain refers to the specific situation in which new actors gain access to GVCs where there previously was no access.

Second, looking at the origin of lead suppliers in the industry, supports megatrends of regionalization and re-industrialization driven by advanced economies with a strong history in manufacturing (Gress and Kalafsky 2015). The same trend follows on the production and demand side. Today, most of the production is kept in-house in the country of origin of the suppliers. And on the consumer side, 40% of 3DP systems in 2012 were installed in North America, 30% in Europe, 26% in Asia/ Pacific and only 4% in the category “other” where Africa is included (Wohlers 2014, 26). From the lens of IS, such representation is a logical output of the technology policies in these countries outlined in the previous section.

Thirdly, and valuable to a discussion of governance, is the fact that the largest players are vertically integrated; providing goods and services across the entire GVC of 3DP. Such integration may display that suppliers are competing to become the preferred supplier of dominant design in terms of technology and raw material. Taking a closer look at the product offerings, most of the HES hardware in fact requires of customers to use both the design software and the proprietary raw material provided by the same supplier of hardware (Berman 2012). But it may also suggest that a high level of control and coordination is required across the chain to maintain the quality of products or to protect intellectual property of the technology. Furthermore, it seems to support business megatrends that a high level of control and coordination is made

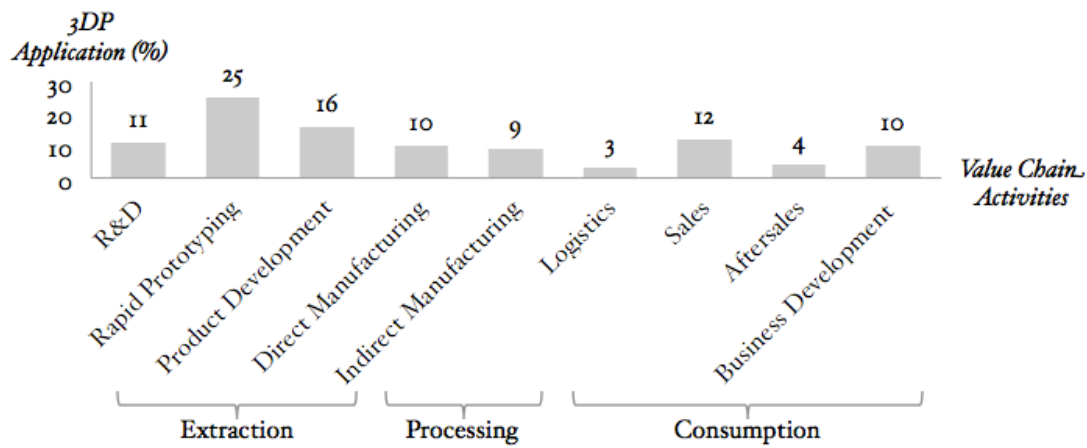
affordable with 3DP, either because of automation and digitalization in the bottom line, or because of the profitability of mass customization in the top line. To get a better understanding of this differentiated causality, I am in the next section zooming in on the application of 3DP i.e. the consumption pillar of the conceptual GVC of 3DP. It is here that 3DP feeds into the ideal-typical GVC of production presented in the previous chapter and it is thus here that I build an understanding of the value in applying 3DP in terms of upgrading, and the strategic intent of buyers pursuing such activity.

5.3. Technology Promise: what and where is the value?

The business case to adopt 3DP naturally differs across industries and in order not to deep dive into each sector-specific business case, I here make use of the data available that already has undertaken such task to induce overarching technological possibilities provided by 3DP. In an ‘internationalist’ fashion my task is thus to translate these into a format compatible to that of GVC, namely the ideal type of 3DP and its upgrading potential on the ideal GVC presented in previous chapter.

Besides the aerospace industry, the medical, dental, defense, education and now increasingly the automotive industry are amongst the top adopters of 3DP (Wohlers 2014). According to market analysts, these industries, along with the consumer sector of non-durable goods, will be the key drivers contributing to the double-digit growth of 3DP over the next few years (Forbes 2015, Wohlers 2014, Gartner 2015) (see Appendix 9). In terms of adoption of 3DP into GVCs, a survey from leading technology research advisory firm Gartner from last year, produced an overview of the select areas in which companies are currently investing, adopting and fully utilizing 3DP. As illustrated in Figure 7, converting these areas into activities compatible to the ideal GVC enables a structured presentation of the strategic intent driving investments in 3DP, and so an analysis of upgrading possibilities realized by practitioners under each pillar of production. (See Appendix 10 for original pie chart).

Figure 7 "Where do you apply 3DP?" Industry Survey by Gartner



Source: Author (interpreted from Gartner 2014)

5.2.1. Extraction

According to Gartner's understanding of the current field of 3DP adoption, most activity seems to be focused in the extraction pillar. Here, actors seek to pursue both product innovations under the new paradigm of freedom of design, but also to process innovation in product development and RP.

R&D: Providing endless possibilities in design to invent never-before-seen products

The additive layering process of 3DP enables the standardized production of complex structures, designs and creation of products never before seen (Lipson and Kurman 2013). The new paradigm of 'Freedom of Design' coupled with 3DP is about "creating new items that are impossible using traditional methods" (Gartner 2014). What we see emerging are complex lattice structures and inner hollows, in materials never before used: carbon infused plastics that are stronger than metal, nano, bio and active materials that even respond to their external environment (latter is called 4D printing) (Lipson and Kurman 2013; Wohlers 2014). (See Appendix II for MIT designer Nori Oxman's 3D printed wearable that creates structures from sunlight). 3DP in R&D is clearly about *product upgrading* i.e. "moving into more sophisticated product lines" (Humphrey and Schmitz 2002, 1020).

The challenge for established companies is 'not to design a chair, rather something one can sit on', why succeeding with 3DP in R&D is about developing new standards suitable for the new structures and materials that are 3D printed (Lipson and Kurman 2013). Such success criteria inevitably require abandoning

outdated ways of thinking about design. In many cases collaborating with new and atypical actors that possess a fresh set of eyes has been valuable. GE Aviation for instance, in addition to maintain close partnerships with leading suppliers of 3DP, holds yearly ‘hackathons’, competition in which they invite designers globally to partake in the re-engineering of existing GE products with 3DP; including the infamous fuel nozzle (GE Reports 2013b). On the consumer side, GE Appliances has set up a micro factory with Stratasys hardware, where new products will be invented using crowdsourcing (Stratasys 2014). With this in mind, there also exists a level of *inter-chain upgrading* and *entry into the chain* where, with regards to the latter, new actors can partake in GVCs that before 3DP were inaccessible to them.

Rapid Prototyping: Decreasing barriers of entry to design and development of new products

There are three main reasons behind the majority share seen in the adoption of 3DP in prototyping here called Rapid Prototyping (RP). First is cost savings where a 3D printer can cost as little as a couple of hundred USD, where a traditional “rapid prototyping machine can cost as much as 500.000 USD.” (Berman 2012, 156) Second is the ease of use of 3DP due the design software which is integrated and made accessible through open source platforms or design packages such as Google SketchUp and Tinkercad (Lipson and Kurman 2013). The low price and increased user friendliness of 3DP for RP has facilitated bringing a previously costly process in house which cuts design time and shortens the lead-time to market of new products (Berman 2012). “Today, the speed and convenience of rapid prototyping allows firms, small and large, to be more nimble and to produce different versions of a product overnight, test them, and produce improved versions without delay.” (Kietzmann et al. 2015, 211). Due to savings in cost and time, the *process upgrading* is relevant for established companies that adopt 3DP in RP as well as *functional upgrading* in bringing a previously outsourced process in-house. For new actors, *entry into the chain upgrading* is made possible by entrepreneurs that now can afford to create prototypes of their designs (Lipson and Kurman 2013; Herman 2014).

Product Development: Optimizing existing product portfolios

The purpose behind 3DP activity in product development is both about *product* and *process upgrading*. Well exemplified by the GE fuel nozzle, the strength to weight ratio was increased to extend the product life cycle five times which also, made the part 25% lighter (GE Global Research 2015). 3DP can be used both to improve properties in existing product portfolios and the processes by which to “transform inputs into outputs more efficiently” (Humphrey and Schmitz 2002, 1020). With regards to the latter, the very additive layering nature of 3DP, can on average save up to 90% of material waste, in contrast to subtractive, traditional manufacturing technologies (Khajavi et al. 2013). Even though the 3DP raw material is currently more expensive than that used for traditional manufacturing, material savings is nonetheless particularly interesting from a sustainability point of view, as well as to the overarching cost picture of parts production in expensive materials such as titanium, gold or other precious and expensive metals (Berman 2012; Wolthers 2014). (For an illustrative case comparing weight reduction in conventional manufacturing and 3DP see Appendix 13)

5.2.2. Processing

According to Gartner, a technology is mature once it has penetrated 20% of its target industry (2014). In manufacturing, the penetration of 3DP for volume production of final end parts was in 2014 11% (D’Aveni 2015). Compared to applications in prototyping the processing pillar has been harder to penetrate which for a long time was explained by technological limitations of 3DP. Today, the technology has reached a level where it is widely recognized as “ready to emerge from its niche status and become a viable alternative to conventional manufacturing processes.” (McKinsey 2014) And the conversion to 3DP can happen fast. The US hearing aid industry moved to 100% 3DP in less than 500 days and “not one company that stuck to traditional manufacturing methods survived.” (D’Aveni 2015, 43). The main challenge seems to be in realizing the cost benefit analysis that supports the selection of suitable parts for 3DP (Garrett 2014).

Direct manufacturing: producing complexity for free

Though the acquisition cost per high end system (HES) used for industrial manufacturing use is not insignificant, 3DP does not require economies of scale in order to return positive returns on investment why, compared to traditional manufacturing, 3DP implies a lower capital investment per manufacturing facility (Khavaji et al 2014; D'Aveni 2015). Here, economies of scope is what creates profits. As such, the cost of transaction specific investment of manufacturing is significantly reduced by the ability to 3D print high complexity in small and diverse batches at no extra cost per part. In GE's case, the full volume production of the fuel nozzle will save them 75% in manufacturing costs (GE Reports 2015). In the words of David Joyce, CEO of GE Aviation, "we no longer have to understand what the limitations of the machine are or the costs of what those limitations are." (GE Aviation 2013, 1:30). Another important explanation, and in line with the general megatrends of 21st century production, is how the computerization of the manufacturing process reduces the need for costly labor. Further, reducing human interaction also reduces costly errors (Garrett 2014). At the Amberg smart factory, the automation has reduced the number of errors "from 500 per one million actions to 12, and this year it dropped even further to 11." (Zaske 2015). According to Gartner (2014), when all benefits of 3DP in the processing stage are properly quantified, the mean cost reduction for final goods is 4%. At the same time, "53 percent of survey respondents indicated that managers of R&D engineering or manufacturing are the primary influencer driving any 3D printing strategy." (ibid). So where there are obvious theoretical possibilities for *process upgrading* in the manufacturing stage, *functional upgrading* to properly realize the business case for 3DP, as GE has, is the key to ensuring the former process upgrading (Appleyard 2015).

Indirect manufacturing: reducing needs for assembly, tooling, jigs, fixtures and packaging

An important opportunity space presented by 3DP is in indirect manufacturing activities where 3DP in fact, implies an elimination, or at least reduction, of several processes in the traditional smiley curve. One of the more obvious ones is the need for assembly, which GE managed to reduce with their fuel nozzle – printing 18 separate parts in one (Wohlers 2014). Actors who by means of 3DP

are successful in eliminating this node in the GVC, are those able to upgrading their skillsets to think of their prospect products in terms of systems rather than as sets of individual parts. Less visible to the naked eye though equally if not more important, is how 3DP reduces the need for machine tooling (Lipson and Kurman 2013). In the event that certain 3D printed parts indeed need assembly (e.g. for rotating or multi-material parts), the process of acquiring components and machines needed for post-processing is still significantly reduced with 3DP given its ability to produce high complexity instantly (Khajavi et al. 2014). Other processes eliminated with 3DP include molds to shape the part and various jigs, fixtures and gauges used to position and organize parts and subassemblies throughout the manufacturing process. These are all specialized and costly components that virtually disappear with 3DP; and so does its packaging (Lipson and Kurman 2013; Wohlers 2014; Khajavi et al 2014). For these products with high transaction costs such as high asset specificities and/or intensive and specialized labor, 3DP means *process upgrading* and even abandoning processes traditionally needed for production (Appleyard 2015).

5.2.3. Consumption

As the Amberg smart factory suggests, the capital intensiveness of 21st century production does not translate to a symmetrical trade off in labor. On the contrary, and in line with the servitization megatrend, it suggests that labor has merely been reallocated to crucial activities for competitive advantage with 3DP. In the pillar of extraction, this includes designing for 3DP, while in consumption, it includes mass customization of products and their delivery to increase customer satisfaction. Though the industry reveals little numbers on the price tags of 3D printed parts, it is here that we can theorize about end customer value, and consequently potential repositioning of the ideal GVC along the Y-axis, from 3DP.

Logistics: mastering time and space with decentralized, on-demand production

The vision of decentralized production is that “[d]esigns, not products, move around the world: digital files to be printed anywhere by any printer that can meet the design parameters.” (Garett 2014, 71). For logistics, this vision implies a decrease in transportation costs, inventory and warehousing costs, and in essence

shorter lead times across supply chains (Khajavi 2014). For industries such as defense or aerospace, 3DP on-demand and de-centralized, implies *process upgrading* attractive to alleviate the supply chain pains that may exist either due remote locations of operations, highly specialized equipment or due limited ability to keep high stock to mitigate risks of downtime. In the defense industry, the US military are currently printing the body of drones for operations in both Iraq and Afghanistan (D'Aveni 2015). And in aerospace, NASA is printing 21 spare parts whilst in orbit, a project that is intended to eventually scale up to metal 3DP (NASA 2015). Amongst third parties that are providing services around decentralized production using 3DP, a pre-requisite is that information is shared securely to protect the intellectual property of designs; a digital and cultural infrastructure that may explain the lower adoption of 3DP in this area (Wohlers 2014). Amongst established businesses that are upgrading existing product offerings are DHL, Amazon and UPS, are some established businesses that invest in 3DP to pursue *product upgrading*. UPS for instance, is turning several existing hub warehouses at airports into mini factories where 3DP is used to “produce and deliver customized parts to customers as needed, instead of shelving to vast inventories.” (D'Aveni 2015, 46).

Sales and Aftersales

Although the price tag of GE's fuel nozzle remains unknown, it is a case that demonstrates GE's understanding of their customer pains, which strategically translated into *product upgrading* to increase customer satisfaction, and presumably increase the product's price tag. Cutting 25% of the product's weight can be quantified into fuel savings for the end customer, as can stronger products be calculated in terms of amounts of overhauls saved during a product's life cycle. By the same token, aftersales products can be priced according to which supply chain pain is alleviated with 3DP e.g. lead-times of specialized parts reduced with 3DP, downtime saved, or risk of obsolete parts from low supplier base mitigated. On the B2C side, the mass customization aspect provides equal opportunities for higher value, capitalized by online platforms such as Shapeways where “[b]uyers can choose from endless combinations of shapes, sizes, and colors and this customization adds little to a manufacturer's cost even as orders reach mass-production levels.” (D'Aveni 2015, 44). But there also exists C2C platforms like

3DHubs in which, at the time of writing, over 22000 private 3D printers are connected in a Über-like global platform for private consumers with an idea but no printer. On this platform, the average order time is 2 days, making just-in-time production or even ultimate postponements an affordable reality. Both Shapeways and 3DHubs are platforms for private consumers to pursue *entry into the chain* by either supplying digital designs, or tangible products with their private 3D printer (Shapeways 2015; 3DHubs 2015).

Business Development

Across all stages of production in which 3DP is applied there are windows of opportunity for business development and *chain upgrading*; referring to social activity of which the purpose is to “enter into a new value chain by leveraging the skills acquired in the current chain.” (Gereffi 2014, 9) In the case of UPS, they pursue *product upgrading* by rethinking their product offering and tweaking their existing business model. Their core competency is to get products from destination A to destination B, but the question they seem to have asked themselves is whether such undertaking needs to be packaged in a physical transport. Put differently, what if they instead, created every product at destination B? Other upgrading strategies in business development include actors that have developed 3DP skills that can be leveraged to other industries. As example is Airbus, that in 2013 started a consultancy to “make proven aerospace technologies accessible in many different industries. In metallic 3D printing or additive manufacturing we cover the entire value chain, from optimized component design to the choice of suitable materials, from prototyping to qualified serial production.” (Airbus APWorks 2013). Like this, APWorks serves as delivery channel for Airbus’ patented technologies and so a means for Airbus to pursue *chain upgrading*.

And looking at the patents, several cases of well established companies that are tapping into 3DP for either product or chain upgrading are revealed: Xerox holds numerous patents together with Hewlett Packard, Siemens and 3M, GE holds 11 patents in software systems to support digital production and IBM holds more than 19 patents in what they refer to as the “software defined supply chain” (D’Aveni 2015, 45). But many emerging businesses are not captured by patents as

in the C2C space, most of them run on open source software and hardware protected by open source licenses (Lipson and Kurman 2013). For instance, the most widely used 3D printer, the RepRap, can either be bought fully assembled, in kits or its design can be downloaded for free for users to print and set up themselves (SSPP 2012).

5.4. Chapter summary and discussion

From the use cases presented thus far, there are numerous implications for GVC restructuring worth noting here to set the stage for the second part in which I investigate 3DP activity in RSA. First is the trend that producers are acquiring new capabilities, new actors are accessing GVCs both through chain upgrading and entry into the chain and lastly, transaction specific investments are decreasing, making control over time and space affordable and progressively possible. According to Humphrey and Schmitz, these aspects determine what they refer to as “governance change” (2002 in Pietrobelli and Saliola 2008, 951). The direction of such change can be debated, yet placing technology at the center of the analysis it is possible to identify two plausible scenarios with implications both for upgrading and governance restructuring. First, is the scenario in which 3DP and traditional manufacturing overlap and where 3DP is applied as a complement to traditional manufacturing technology. And second, is the scenario in which 3DP is used to substitute traditional manufacturing, often to create products that would not have been possible creating with traditional technology. In Figure 8, these two scenarios for GVC restructuring are presented along with a Table 2 which outlines upgrading trajectories that dominate across the three pillars of production pillar.

In the first scenario, 3DP is applied for RP in the extraction pillar or for the production of specialized machine tooling in the processing pillar; processes which are optimized both in terms of cost and time with 3DP. 3DP is thus here applied to decrease development cycles of products that are subsequently mass-produced using traditional technology and infrastructure. This suggests that a new level of control and coordination by means of re-bundling activities, is possible with 3DP. And further, that such control is not primarily driven by control over product quality or quantity, but by control over time and space to

respond to consumer demands with the right customized product, at the lowest possible lead-time.

Figure 8 2 Scenarios of GVC restructuring from 3DP

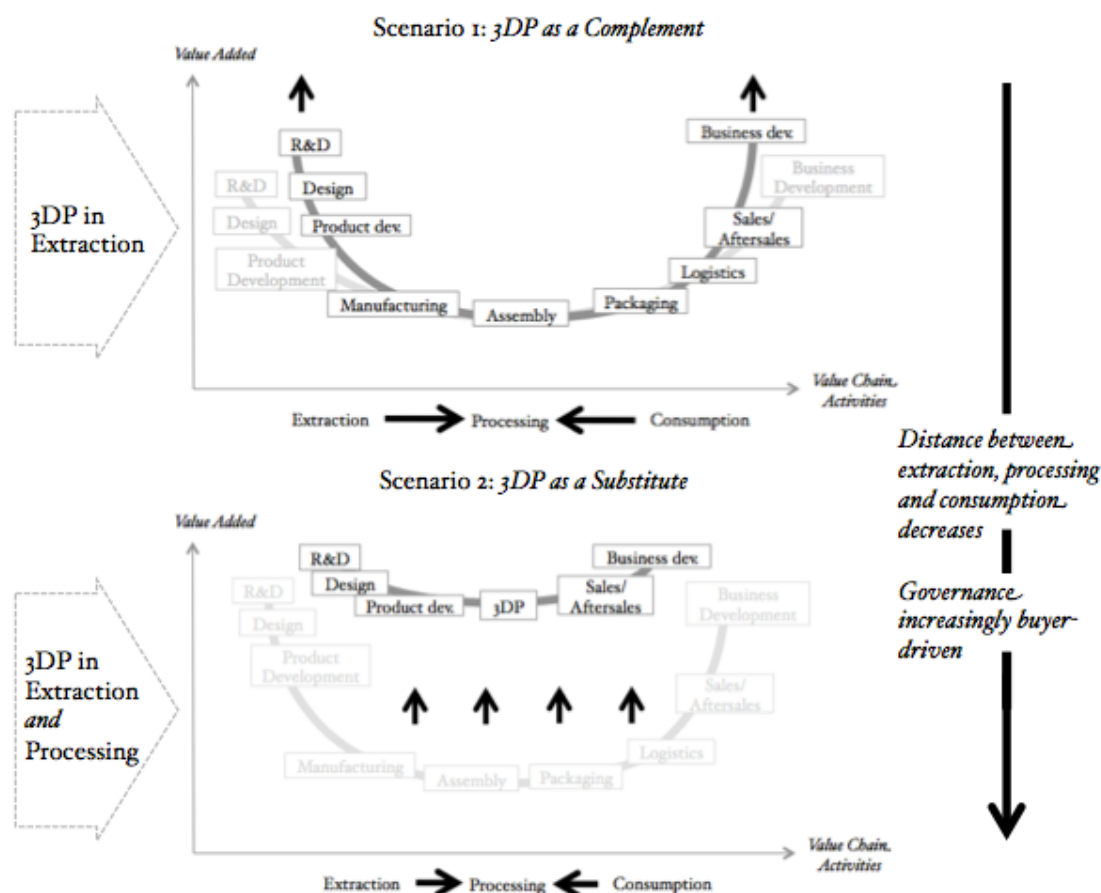


Table 2 Dominant upgrading trajectories in 2 scenarios of GVC restructuring from 3DP

	Extraction	Processing	Consumption
Scenario 1: 3DP as Complement	Process Upgrading: .) Product development cycles shortened	Process Upgrading: .) Tooling costs reduced	Process Upgrading: .) Lead times to market reduced
Scenario 2: 3DP as Substitute	(Additional upgrading) Product upgrading: .) Freedom of design and new materials .) Product life cycles extended	(Additional upgrading) Process Upgrading: .) Assembly reduced .) Economies of scope .) Material waste reduced .) Digitalization reduces errors	(Additional upgrading) Process Upgrading: .) Supply chain costs in packaging, warehousing, logistics and transportation reduced Product Upgrading: .) Mass customization

Opportunities for Chain Upgrading, Functional Upgrading and Entry into the Chain, present in each pillar

Source: Author

The spatiotemporal shift in the three pillars of production enabled with 3DP therefore comes with benefits that outweigh the low cost of economies of scale: profitable mass customization realized by a shorter production cycle. Therefore, 3DP “could transform industries in unexpected ways, moving the source of competitive advantage away from the ability to manufacture in high volumes at low cost and toward other areas of the value chain, such as design or even the ownership of customer networks” (McKinsey 2014). The power here is in the hands of actors that have access to information on the needs of the end customer. Unless 3DP as a complement is made accessible globally, one could argue that in this scenario, 3DP fuels ongoing trends in its innovation systems and so actually, it deepens the smiley curve of production.

The second scenario is a fully 3D printed GVC where the replacement of 3DP in many manufacturing industries removes low-skilled, labor-intensive and low-value added processes in the processing pillar. An automation process which in hand pushes the smiley upwards. Production could furthermore become decentral and move away from where it has been outsourced previously, to be located near the end consumer. In this way, production becomes even more on-demand than in the former scenario and control over time and space enhanced. Further supporting such claim is how 3DP also reduces assembly and so the amount of nodes in the ideal GVC. As such, 3DP seems to fuel ongoing trends observed in production namely a “radical “pull” business strategy that substitutes information for inventory and ships products only when there is real demand from customers” (2001, 35). 3DP can thus be argued to work as a multiplier and enhancer of the governance “shift from manufacturer “push” to consumer “pull” [that] appears to be a long-term trend in many industries”. (ibid)

Whether we see the second scenario trickling into an increasing set of industries already in the next 5 years or not, (as argued by D’Aveni (2015)), it may be safe to say that a governance restructuring is occurring regardless as a result of 3DP in both scenarios. The main difference between the two visions is in how value is distributed across the chain. In the first, labor-intensive and lower value added processes are still in play which may suggest that 3DP in fact reproduces current structures governing global production. In the latter however, the capital-

intensive nature of manufacturing eliminates labor in the processing pillar, moving labor instead forwards and backwards in the pillars of extraction and consumption much similar to what observed in the aforementioned Amberg factory. In this way, transforming the smiley into more of a 'smirk' where value is equally distributed across the ideal-typical GVC.

On the level of the chain and its position on the Y-axis, the increased control over time and space suggests that more value is generated by 3DP in 21st century production and so a vertical positive move along the Y-axis. But as theorized, increasing outputs in the world economy have historically not meant equal distribution amongst GVC participators. Relevant to the empirical data presented thus far, the IS literature argues that "the national origin of MNC matter quite a lot for the location of innovative activities." (Lundvall et al. 2002, 214). From a geopolitical point of view, the question is so to what extent the increased value along the Y-axis with 3DP is accessible for countries globally, as both lead firms supplying 3DP technology and lead buyers currently are from advanced economies. Access is thus not purely a matter of accessing the technology, but also the know-how that resides in its innovation system.

And so where it is clear that first moving lead producers and lead buyers in advanced economies are currently pursuing the technology promise of 3DP, it remains uncovered the role of less advanced economies, or even emerging economies whose access to 3DP technology and know-how is uncertain. I approach the last part of my analysis with a critical lens in which I use RSA as a case to problematize the technology promise of 3DP. I observe the strategic intents of public and private actors that support and adopt 3DP, and analyze the GVC restructuring scenarios they pursue in order to get a better understanding of the extent to which their purposive social activity represents transformative change to value distribution or reproductive non-change.

Chapter 6: Technology Access and Exclusion – the case of 3D printing in South Africa

“Nascent technological developments could lead to a slowing down of global value chain dispersion. The 3D printing and smart robotics bear the potential of reducing this cost advantage far enough to kick off a shift towards “re-shoring” of production activities towards the high-wage headquarter economies.”

- African Economic Outlook (AfDB, OECD, UNDP 2014, 128)

From a historical account, in Chapter 4, of patterns of upgrading and governance in global production I was able to understand that, in the current state of GVC restructuring, processes of production are organized in global and local networks and increasingly driven by the buyer. In Chapter 5, I provided a detailed still-frame of 3DP and a theoretical outline of its impact on GVC restructuring. Here, I argued that 3DP might fuel the ongoing trend towards buyer-driven governance, but doing so by means of reducing processes in the GVC as well as costs. This gives rise to numerous upgrading opportunities amongst established players, as well as entry into the chain by new players. As such, I have built the case that 3DP in its ideal form is a promising phenomenon for the stakeholder of global production to engage with. I have also introduced the hypothesis that being a technology of the advanced industrialized world, there is a risk that economies outside the IS of 3DP are excluded from its technology promise. In this event, 3DP may reproduce the pattern of uneven distribution of value seen thus far in the ideal typical GVC of production. As focus for this section is therefore a country that is arguably not ahead of the 3DP technology frontier, but whose economy is built on select industries that not only are embedded in the ideal typical GVC and thus will be affected by its restructuring, but also are highly relevant for the adoption of 3DP, be it in extraction only as in the first scenario of Figure 8 in the previous chapter, or in processing as well, as in the second scenario.

Building on the presumption that 3DP is worthwhile, the purpose of this chapter is not to ascertain why RSA should access the GVC of 3DP but rather how it accesses the GVC of 3DP as it is these “patterns of access and exclusion, which

help describe the connections between the development of firms and countries within the international system” (Gereffi 2014, 28). The value of such exercise is not an all encompassing outline of 3DP in RSA, but rather a demonstration of how the previous analysis based on ideal types can be applied to understand 3DP efforts in emerging economies and their impact on GVC restructuring. Findings from this chapter are not applicable to other emerging economies, but the suggested approach may be. Following the same retroductive method used in the previous chapter, I start by presenting the prestructuration of 3DP activity in RSA in the form of National Innovation Systems (NIS). Next, I analyze technology access and exclusion by outlining the GVC of 3DP in RSA before I discuss its impact vis-à-vis GVC restructuring.

6.1 The National Innovation System of 3DP in South Africa

RSA is an important hub for the GVC of mining, an assembly hub for the automotive industry, parts designer and manufacturer for aerospace and the tooling industry, and increasingly embedded in the GVCs of consumer goods such as the GVC of shoemaking that is estimated to double in size over the next five years (AfDB et al. 2014; DST 2015). Since its liberalization, RSA has steadily increased its export dependence in large through these industries that now combined almost make up 40% of the country’s GDP (Cattaneo et al. 2010; AfDB et al. 2014). In the light of an unemployment rate of 30%, hedging against disruptions in the ideal GVC is now more important than ever (ibid).

However, the NIS of RSA is young and was first defined in the post apartheid years throughout the mid 90s. Before that, strong ISI policies, followed by sanctions from the international community had isolated RSA from GVCs (Campbell and de Beer 2011). During this period of time, RSA built pockets of excellence in industries prioritized by the military government such as mining, aerospace, automotive and tooling (Barnes and Lorentzen 2003). With liberalization in the 90s, developing a strong NIS to increase productivity, and thereby gain and leverage international competitiveness was pertinent. A milestone for the NIS was the 1996 White Paper on Science and Technology aimed at opening up the public research agendas to social and environmental objectives, aligning them with the private research agenda to foster stronger

collaboration, and create more transparent funding mechanisms. The industries in focus were those of ICT, Biotech, and “Advanced manufacturing and new materials” in order to be “preparing for the 21st century” (OECD 2010, 1). Under the third priority industry, much of the stage was set for the public interest in 3DP.

To develop technologies and skills for advanced manufacturing, new centers of excellence were set up, anchored to existing ministries and leading universities. At the cusp of the 21st century, the Department of Science and Technology (DST) released a report denoting 3DP, here referred to as additive manufacturing (AM), as a central tool for efficient product development (Campbell and de Beer 2010). The pre-NIS years of RSA had however left the country largely excluded from access to 3DP technology, and with a lot “catching up to do”, focused government support and industry buy-in was presented as key to retain competitiveness in manufacturing (Campbell et al. 2011). Within short, the government had funded the foundation of the Rapid Product Development Association (RAPDASA) to access global know-how in the field of 3DP by working as “a platform for researchers and practitioners to share their knowledge and experience with others” (RAPDASA 2015) under the mission “to convince the South African industry of the importance of AM for maintaining international relevance and competitiveness” (DST; CSIR 2014, 64). Meanwhile the newly set up centers of excellence pushed for diffusion of the technology by investing on a national scale in the necessary skills to adopt 3DP.

Today, there are a number of particularly central technology organizations for 3DP in RSA. The National Research Foundation (NRF) is working closely with universities to support broad capability building and skills development for 3DP. On the technology development side, is the National Laser Center (NLC) launched the Aeroswift project in 2011 to co-develop “the largest titanium metal powder bed AM system in the world”, together with the aerospace industry under the Council of Scientific and Industrial Research (CSIR) (DST; CSIR 2014, 41). In part feeding into the Aeroswift project is the Titanium Centre of Competence (TiCoC) “focused on creating a titanium value chain entirely within South Africa”. (Wohlert 2014, 92). Since their foundation, the 3DP projects in

place have generated data that lays the ground for the several technology policies that steer public investments in 3DP. One of the more elaborate and concrete ones is the DST 2014 “Roadmap for Additive Manufacturing in South Africa” (DST; CSIR 2014). Herein, “four main priority focus areas” have been identified to steer public investments in 3DP from the DST (DST; CSIR 2014, 3).

Table 3 The DST Roadmap for 3DP in South Africa

<i>Focus Area</i>	<i>Strategic Intent of public sector</i>	<i>Dominant Upgrading Trajectory</i>
1. SMME* development and support	.) development of an AM based SMME industry in South Africa based on/strengthened by AM technology: - prosthetics, dental, hearing aids, jewelry, creative arts	Entry into the chain Functional upgrading
2. AM for Impact in traditional manufacturing sectors	.) improve efficiency of traditional manufacturing sectors through tooling development and improved product development cycles .) refurbishment of previously unserviceable parts for the local industry by means of powder deposition technology	Process upgrading
3. Qualified AM parts for medical and aerospace	.) use of AM for production of medical and dental implants .) use of AM for production of medical devices .) production of parts for the Aerospace and military markets based on current customers and collaboration agreements with OEMs	Product upgrading
4. New AM materials and technologies	.) development of AM systems .) development of materials for AM .) development of new AM technologies	Entry into the chain Product upgrading
Enabling capability development and education system		Functional upgrading

*Small, Medium and Micro Enterprises

Source: Author’s interpretation from original roadmap (DST; CSIR 2014, 45) in Appendix 14

Table 3 lists the four main focus areas along with an insertion of the dominant upgrading trajectories reflected by each focus area. From this policy, it is evident that the public sector in RSA, pursues both GVC restructuring scenarios induced in the previous chapter. In other words, public investments are steered towards applications of 3DP both to complement traditional manufacturing (as demonstrated in e.g. focus area 2) and to substitute traditional manufacturing (as demonstrated in e.g. focus area 3). The four focus areas also reflect an understanding that 3DP in the extraction and processing pillar of production can strengthen both the locally embedded entrepreneurial scene and the globally embedded corporate scene why ensuring broad technology access is key. Appropriately, focus area 1 and 2 chiefly promote 3DP applications for local consumption by entrepreneurs and the local manufacturing sector. Where focus

area 3 and 4 on the other hand, chiefly promote the strengthened position of RSA in GVCs in which 3DP can be applied to supply goods for global consumption; hereunder, not only 3D printed goods but also actual 3DP technology from RSA. The strategic intent of DST is thus for actors in RSA to access the GVC of 3DP as consumers of the technology, as well as suppliers of locally developed IP hardware and raw material.

This public strategic intent reflected in the roadmap seems in line with theory of NIS that stresses the “importance of indigenous innovation efforts for technology upgrading, and catching-up in particular.” (Fu et al. 2011, 1209). Moreover, “[n]ations should not only acquire the achievements of more advanced nations, they should increase them by their own efforts.” (Freeman 1995, 6). Related to the notion of governance in the GVC literature, local development of foreign technology is seen as a way to increase control and coordination of GVC activities important to steer upgrading in the desired direction such as what laid out in the roadmap. Technology access is therefore defined not solely by a nation’s ability to import 3DP from the advanced economies in which it is produced, nor by its ability to access the know-how in the same economies, but by the ability of economic actors to control and coordinate “what is to be produced” and “how it is to be produced” (Humphrey and Schmitz 2002, 1021).

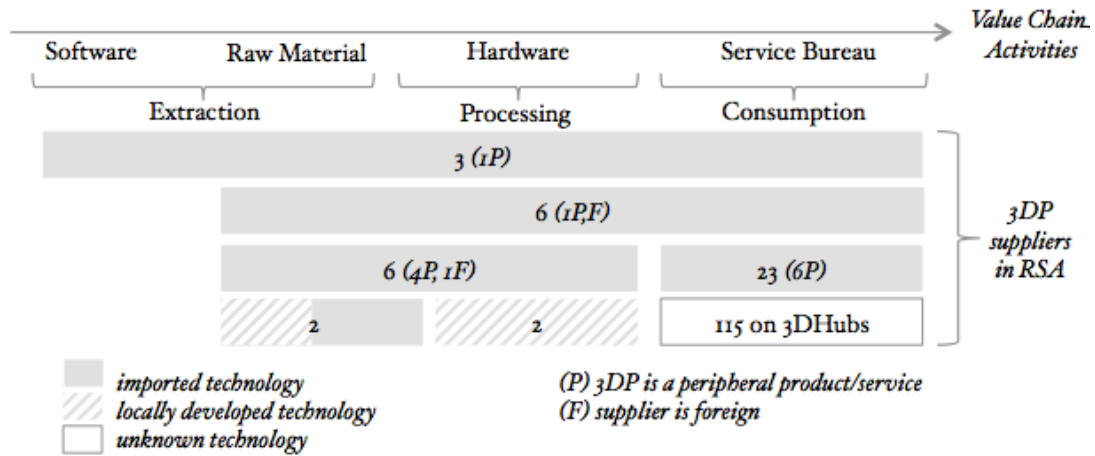
In the next section I investigate purposeful 3DP activity more in depth to understand i) how 3DP is accessed and controlled for local consumption by small medium and micro enterprises and the local traditional manufacturing sectors and ii) how it is accessed, developed and controlled to attract global consumption. With regards to the former, I take as vantage point an analysis of the local GVC of 3DP whilst for the latter, I limit myself to 3DP efforts observed in one industry, namely that of Aerospace.

6.2. Accessing 3DP as local consumers: the GVC of 3DP in South Africa

The public initiatives outlined above, only recently trickled into the private sector with most investment growth into the RSA installment base seen over the last two years (67%) according to an interview (Int.) with a public official at the DST (2015). In 2014, the DST roadmap estimated that 2375 3DP machines were installed in RSA, out of which 84% represent LES and out of the remaining 16% HES – only 6 systems able to print in metal (see Appendix 15). From these numbers RSA is a small player, owning a mere 0.4% of the global 2014 installment base of HES (79.602), and 1.5% of LES (139.582) (3DPrint 2015). Where the share of HES has seen linear growth since the early 90's, the share of LES on the other hand has grown exponentially since 2010 – a noteworthy development similar to the global one in which the number of LES grew from 66 systems to approximately 140.000 between 2007 and 2014 (3DPrint 2015). The share of public installations in universities was outgrown by private installations back in 2011, suggesting a market push towards the technology promise of 3DP in RSA (Campbell et al. 2011). But much like in chapter 5, revenue data to show the economics of 3DP activity in RSA is inaccessible and confirms the infant state of the industry. Nonetheless, mapping the firms established around the technology is possible and equally instructive to get a first glance of how the technology is accessed by other local actors for use in the extraction and/or processing pillar of production.

Figure 9 reveals analytical points relevant for an understanding of how 3DP is consumed locally. First, is the physical absence of lead suppliers of 3DP technology, who instead use local distributors to reach the local market. The foreign actors that do exist are e-stores where 3DP is a peripheral product in the product offering. Second is the dominance of local service bureaus as a node representing SMMEs that by owning 3DP technology can *enter chains* by supplying goods and services to across GVCs. The larger service bureaus do so by means of imported foreign LES and HES technology. In the case of HES used for direct manufacturing, most of this technology is proprietary in terms of the software used as well as the raw material. For this reason, becoming a distributor

Figure 9 Organizations participating in the GVC of 3DP in South Africa



Source: Author (for raw data see Appendix 4; 3DHUBS)

of foreign HES technology is better described as a partnership in which the distributor “has to be trained and certified on [foreign] equipment”. (Int. Bullock 2015, 17:39). For the sale of some HES, representatives from the foreign HQ are even flown down to RSA in order to train and educate both distributor and buyer (ibid). Given this, and the high customs that are in place for imports in RSA, purchasing HES has for a long time been a significant investment accessible to the few.

To circumvent the high cost of imports on raw material and hardware, locally developed technology has started to emerge. The Robobeast is a LES, developed as a more robust, cheap and accessible printer that today is famous for printing the Robohand – a prosthetic hand that in collaboration with foreign lead firm Stratasys has been printed in more than 200 customized copies. “Compared to the imports in this category, these printers are not only superior in many ways, they also are made in SA with local support and maintenance.” (Robobeast 2015). Another locally produced LES is the RepRap Morgan, an open source printer developed and later commercialized by Quentin Harley to make 3DP more accessible to RSA (Int. Harley 2015). On the topic of Harley’s customer base he

explains the importance of cheaper local LES for local diffusion of 3DP: “now that they can get the machine at a reasonable price they jump at the opportunity to get them cause it improvise their work chain in order to get to their final destination quicker.” (Int. 2/2 2015, 18:39) On the raw material side, an increasing amount of local plastic suppliers are emerging such as the Filament Factory whose founding story confirms the same proposition: “Shocked at the cost of filament for our beloved 3D printers, and knowing the prices of the raw materials, we set about to create an affordable, self contained, industrial strength filament creation system, and the Filament Factory was born.” (FilamentFactory 2015)

Going forward, local LES and local raw material that is cheaper than foreign alternatives, may very well be what to a larger extent is adopted in SMMEs that supply 3DP services and goods, and what is increasingly applied in the R&D divisions of local traditional manufacturing sectors for in-house RP and product development. In the case of the RepRap Morgan, “80% of customers are the ones wanting to use 3DP as part of their businesses to develop products that they will sell on to be manufactured and the rest, the other 20% are people that just want to play”. (Int. Harley 2015, 18:30). To fuel such move, the public sector is providing support in *functional upgrading* to build local design skills through various publically funded RP centers located across the country. In some events mobile RP projects have even been developed to promote 3DP access in rural areas. In one such project, where Quentin Harley was involved, “one guy developed a project: a better pump for getting water out of the well”. (Int. 2015, 14:00) With 3DP, the mold for the water pump was made cheaply for subsequent local mass production using traditional manufacturing technologies (ibid).

What these innovations imply for control and coordination in the local consumption of 3DP, is that within the implementation of LES in the extraction pillar, the decision of what is to be produced and how, can to an increasing extent be handed over to the local end consumer of 3DP that in hand can “determine how financial, material, and human resources are allocated and flow within a chain.” (Gereffi et al. 1994, 97). Demonstrated by the improved water

pump, 3DP strengthened local manufacturing, made product development cheaper and accessible to more, and potentially also increased the utility of the product. In Quentin Harley's words "the people with the actual problem are the people best able to solve that problem. So you need to get them the tools to do it." (Int. 2015, 14:23).

6.3. Accessing 3DP as global suppliers:

3DP in the aerospace industry

Project Aeroswift was founded in 2008 by the DST to develop RSA's first home grown 3DP technology as a collaboration between the CSIR, and RSA's largest aerospace manufacturing company and first tier supplier to Airbus and Boeing, Aerosud. According to a public official at the department, the "DST is funding the Aeroswift project because there are two revenue generating projects: one is the machine becoming a single large IP and deriving revenue from that, and then secondly, companies that have Aeroswift can manufacture, and become service bureaus on an industrial scale." (Int. 2/3 DST 2015, 05:00). As a HES with a capacity for larger volumes and higher speeds than foreign HES, the Aeroswift printer aims to both *enter the chain* of 3DP by addressing key technological limitations in the currently available 3DP technology whilst also, *upgrade processes* in manufacturing and challenges in the processing pillar of the local aerospace industry. In an interview with Marius Vermeulen who is engaged in developing the technology, 3DP presents the opportunity to reduce costly high skilled labor required in a highly regulated industry like aerospace: "the large driver for us is to reduce part count to reduce weight, to reduce assembling of parts, to get away from assembling hundreds of small parts, and to get rid of tooling." (Int. 1/3 2015, 14:40). Today the first machine has been successfully built, leaving next stage commercialization of the technology (ibid).

In tandem, the CSIR funds efforts from the TiCoC to beneficiate and so *upgrade products* from the local mining industry hereunder also, but not exclusively, for the purpose of raw material for 3DP (Int. van Vuuren 2015). As outlined in the roadmap "approximately 30% of the minerals used to produce the world's titanium is currently mined in South Africa, and finished titanium parts are

imported into SA at 100 times the price of the raw material that is exported". (DST; CSIR 2014, 40) In GVC terms, "the local production of titanium powder therefore presents a huge opportunity for local value addition through AM." (ibid.). According to the manager for future commercialization of the 3DP technology, the vision of these efforts are that "[b]y developing [3DP] technologies to manufacture titanium products, the country can become a significant contributor to the global aerospace market". (CSIR 2015).

With these pieces coming into place over the next couple of years, Hardus Greyling, manager at the CSIR, believes that "there are a lot of things that align quite well here in SA with respect to setting up a very strong value chain for AM" (Int. 3/3 2015, 14:00), further implying that once commercialized into a separate company, the Aeroswift "will be able to serve more than just the aerospace industry" (Int. 1/3 2015, 15:30). On the hardware side, Vermeulen explains that "as you increase production rate you start to address different markets which was typically not viable with traditional AM. And if you've got a large bed you can do 200 parts at a time and you can do that at 5-10 times the speed then there is potential for addressing different markets and applications than previously possible with AM." (Int. 2/3 2015, 02:48). And the similar argument for *chain upgrading* may apply for the development of titanium raw material. According to a public official at the DST "if you make it cheaper you can open up for new markets where titanium can be used where previously it was too expensive," (Int. 1/3 2015, 16:01), referring to expanding industries like automotive.

Since their foundation, foreign OEMs in the aerospace industry have shown interest in the RSA efforts to develop 3DP technology and raw material. In the words of Airbus Vice President Simon Ward, "[i]f the CSIR succeeds, that will be a major leap forward in technology, which will have major implications in terms of logistic costs and design of titanium products for the aerospace industry". (Defenceweb 2011) The leap from interest to support was manifested last year when Ward signed a collaborative agreement with Aerosud, in which Aerosud is allowed continuous access to contract bidding. In Ward's words "[w]hat we sign here is not a single order or a short term result, it is a roadmap to

develop the industry over the next ten years,”[...] “I’m here to confirm Airbus is in South Africa to stay,” Ward said. (Defenceweb 2014) By *entering the chain* as a supplier of unique and locally IP protected 3DP hardware and raw material that can be further leveraged for chain upgrading to industries other than aerospace, RSA may in fact gain control over *how* tangible products in the future will be produced. The question however remains with regards to DST’s second goal of 3DP for local industrial manufacturing i.e. *what* will be produced with the Aeroswift. Here there are certain governance challenges to overcome where long-term commitment with foreign OEMs may be proven either important or destructive.

First barrier is *control* over quality and the requirements of products designed by foreign OEM that future 3D printed parts will inevitably be subject to. As Vermeulen explains, “you need very advanced nondestructive testing methods to prove that what you did is according to specifications. I believe that’s an area where a lot of attention is being spent globally and I think that is still one of the main barriers for starting to sell parts to Airbus” (Int. 2/3 2015, 18:46). To this end, Willie du Preez, Member of the RSA Titanium association and Associate Professor at the Centre of RP and Manufacturing at the Central University of Technology (CUT), has “embarked on a longer term research program on AM with the intent [...] to eventually qualify [their] processes and materials.” In his words, “we want to make sure that the processes are so well developed that they can be transferred to industry players, empowering them to compete on the right standard internationally with this technology.” (Int. du Preez 2015, 10:28).

Second barrier is *access* to the digital designs from OEMs that are needed in order to successfully 3D print. According to du Preez, “the design authority doesn’t sit in SA”. Instead RSA is “mostly producing the design made in EU or US.” (Int. 2/2 2015, 04:00). Here, there is little to suggest that local manufacturing will get access to the designs digitally. Actually, the opposite may be the case, where foreign OEMs rather purchase the Aeroswift in order to re-shore more production, even away from RSA. On the topic, du Preez reveals from recent talks with Boeing that “if our Aeroswift project is successful [Boeing] would want to get a Aeroswift machine where they are, in the

laboratories to actually do parts for their aircrafts. These things are obviously confidential i.e. the geometries and the like so they will not send that over to us and have it done from here”. (12:45).

With the proven interest from lead buyers of the aerospace industry like Airbus and Boeing, the claim of DST regarding the Aeroswift seems promising: “this technology has the potential to position South Africa as a leader in high speed powder fusion AM technology.” (DST; CSIR 2014, 49). Yet with regards to upgrading current manufacturing and become “a major producer of AM products to the aerospace industry” (DST; CSIR 2014, 47), the DST may have to think again. If OEMs start re-bundling manufacturing processes, local players may be left unable to access designs to produce. According to du Preez, the notion that the foreign OEMs are in RSA ‘to stay’ (as confirmed by Ward at Airbus) is better explained by their interest in supplying for the local aviation market (Int. 2/2 2015, 11:35), without further knowledge of whether such supply would happen via local manufacturers or via in-house manufacturing. In the latter scenario, *functional upgrading* of local skillsets in the aerospace industry to instead design themselves what they print and supply for the aviation industry, may in fact be a viable way to transform governance structures in the industry.

In fact, an interesting spin-off to the Aeroswift project is AHRLAC (see Appendix 18) the first locally developed and manufactured airplane currently serving the military in RSA for areas like border control and military training (AHLRAC 2015). According to Vermeulen there are several opportunities for *chain upgrading* with 3DP from the aerospace industry to the aviation industry. “[T]hese developments actually work very well together because we have a new airframe mostly developed by us which we can also use to test new technologies such as the 3D printed parts. So we really have quite a number of polymer 3D printed parts on the aircraft and we are planning with the [Aeroswift] to produce metal parts for that plane which allows us to, early, step into the aviation industry.” (Int. 1/3 2015, 08:00)

6.4. Chapter Summary and Discussion

In this chapter I have sought to apply my understanding of the ideal types of GVC restructuring and 3DP respectively induced and analyzed throughout chapter 4 and 5. To add value to the debate of global value distribution so central to the *and* between international business and politics, I have chosen RSA as a suggestive case of an emerging economy that, faced with significant socio-economic challenges, is pursuing industrial policies relevant for the subject at hand. Displayed in the 2014 AM roadmap, which merely is one select technology policy, I have argued that the strategic intent for the public sector of RSA to pursue 3DP is to both support the scenario in which 3DP is adopted as a complement to the local manufacturing industry, and the scenario in which it is adopted as a substitute.

To understand the probability of GVC restructuring in RSA from the two scenarios, I have analyzed the notion of access to 3DP, and the way in which the technology is controlled and coordinated to direct desired upgrading trajectories in each scenario. Through the lens of NIS, I was able to find two aspects of technology access that are likely to have an effect on the rate and diffusion of 3DP in RSA. For one, the history of RSA as isolated from the international community of global production has resulted in RSA being a late adopter of 3DP. Putting in place technology policies to ‘catch up’ was therefore important to reap the benefits from 3DP observed in advanced economies – particularly where 3DP was applied in the extraction pillar to complement traditional technologies. Aside from being isolated historically, RSA is both geographically and administratively isolated from 3DP, which is manifested by the high costs in transporting imported foreign technology and getting it through customs.

Immediate consequences of this isolation are a small market for 3DP, and an absence of foreign subsidiaries of 3DP technology in RSA. Nonetheless, the exponential growth in LES observed over recent years reflect a need for 3DP amongst local entrepreneurs who adopt the technology to bring a product from idea to manufacturing – cheaply and swiftly. Access to the technology for this purpose happens either via the numerous local service bureaus or by purchasing cheaper hardware and raw material developed in, and specifically for, RSA.

According to Rick Treweek, Designer and Mayor of 3DHubs in Johannesburg, “because of this isolation, innovation in the hardware development of 3DP is really picking up.” (Int. 2015, 08:00). Whether the NIS of 3DP in RSA was intentionally designed to drive this type of local innovation in LES is not clear from the roadmap that, in terms of local technology development, instead is targeting HES and purposive social activity where 3DP is adopted to eventually substitute traditional manufacturing.

Strategically calculated by the public sector or not, the local development of foreign technology is undoubtedly a desired outcome in most development literature, including NIS. In this literature, “the importance of indigenous innovation efforts for technology upgrading” is due the acknowledgement that local – rather than foreign – technology is more likely to serve its environment well, as it is developed to address specific local customer needs often overlooked by foreign technology developers (Fu et al. 2011, 1209). “Although imported technology may contribute to economic growth, the South using inappropriate technology will grow at a lower rate than the North, and the income gap will persist or even rise.” (ibid) Drawing from this line of thought, one could argue that “appropriate” technology indeed is being developed both on the LES and HES side. Within LES, the aforementioned Robobeast or RepRap Morgan are LESs that not only are cheaper but also stronger and more rigid: in Treweek’s words “they’re built for Africa”. (Int. 2015, 24:30) Within HES, the Aeroswift was developed and customized to support the local aerospace industry and the eventual printing of parts using titanium mined and beneficiated in RSA.

The difference between the innovation in LES and HES however, is in their spatial-temporal relation to the consumption pillar. The LES innovation is currently only used for local consumption in the extraction pillar of production to complement traditional manufacturing technologies. While the HES innovation is purposefully funded in the processing pillar to supply the global consumption of hardware, raw material and 3D printed parts from and manufactured in, RSA. In the first scenario, LES is providing cheap product design for new and local actors to enter GVCs. As presented in the water pump example, these actors can design improved products cheaper and faster by being

close to the end customer and his/or her needs. As such, 3DP with LES can empower local entrepreneurship and manufacturing by moving the “source of competitive advantage away from the ability to manufacture in high volumes at low cost and toward other areas of the value chain, such as design or even the ownership of customer networks” (McKinsey 2014). Though the scale or impact of such activity in RSA is not known, it is an activity that speaks to the notion that when made accessible and affordable, 3DP can enable the realization of mass customization anywhere. In other words, when applied in the first scenario of GVC restructuring, benefits from the deepened smiley curve of GVC observed in the previous chapter, is therefore not necessarily restricted to advanced economies.

But in the second scenario, exemplified by the Aeroswift project, the prospect of access is different. Here, gaining control over designs to produce with 3DP, or accessing the needs of the end customer is far from certain as pointed out by du Preez. In fact, the proximity to end customers in the local aerospace industry is in this scenario not only constrained in geography and space, but also and maybe more importantly structurally, by consequence of the very GVC of aerospace in which RSA is embedded as a certified parts manufacturer and assembler, with limited design authority. On the relation between local firms upgrading in partnership with global lead buyers, the GVC literature underscores the empirically observed tendency that local firms “become tied into relationships that prevent functional upgrading and leave them dependent on a small number of powerful customers. In some cases, exclusive relationships with large buyers prevent them from diversifying their customer base.” (Humphrey and Schmitz 2002, 1024). Accordingly, policy makers and industry practitioners are well advised to denote the industry specific path dependency of aerospace that may challenge functional upgrading and access to the GVC of 3DP as a global supplier of 3D printed parts. Trajectories should thus be explored where local actors can leverage rare skills in order to gain access to information on the end customer so as to also, benefit from the mass customization trend of the 21st century production. This includes ongoing strategies to become a global supplier of unique 3DP hardware technology that can be customized to diverse industries and not only aerospace (like what developed under the Aeroswift project). Other

possibilities include commercializing cheaper titanium which can become affordable to industries where titanium has been too costly (as what explored in the TiCo) or, supporting capability building to design and 3D print parts for a local aviation industry (like what proven with the AHRLAC).

In conclusion, I have argued that 3DP is applied to decrease transaction specific investments in the extraction and processing pillar of production, it enables new actors to gain access to GVCs previously inaccessible to them and finally, I have argued that it is driving the acquisition of new capabilities amongst producers; all of which are central aspects to governance change (Humphrey and Schmitz). Drawing from these applications, numerous practical and theoretical upgrading trajectories emerge. Combined with an understanding of both the global megatrends of production that make up the IS of 3DP, and of the critical lens of GVC, it is clear that these potential outcomes, as proposed under two scenarios of GVC restructuring, are dependent upon access and control across all three pillars of production in order to transform power and value distribution in global production. Here I argue, that access is not only defined as access to the 3DP technology to control how a product is produced, but also access to information that resides in the consumption pillar to coordinate what is produced. Though only investigated in select applications, it seems probable that 3DP can bring about GVC restructuring in RSA. Moreover, 3DP is most likely to bring about progressive GVC restructuring, when combined with the right know-how of its end customer, be they global or local.

Chapter 7: Concluding Remarks

Like many critical social scientists, I am fascinated by the concepts of value, power and change, and intrigued by prospects of 'revolution'. It is therefore no surprise that 3DP caught my interest when portrayed in popular media as a technology able to 'revolutionize' global production. Equally frustrated was I however by the lack of depth of these claims, and when turning to academia, I found quite to opposite situation. Here, scholarly debates on 3DP are mostly separated between schools of thought that focus on particular aspects of the

technology. Within business, 3DP is argued to change supply chain management, while within engineering, change from 3DP is analyzed from the view of design, material science or specific production processes. In an attempt to understand the broader vision of change in production from 3DP, I have in this thesis defined a space in between many academic contributions, and here, formulated the question that has guided my research: *How does 3D printing impact global value chain restructuring?* I have then directed my attention to three layers of change i) the history of production to understand what change occurs from, ii) the processes in the technology to understand where change is possible, iii) and to specific structures and agencies in a given case where 3DP is applied, to understand the extent to which change is probable from the technology. These layers translated into three sub-questions, to which I present summarized answers here.

1. *What is the current state of global value chain restructuring?*

Enabled by the Internet, the codification of knowledge in the GVC has created a proliferation of processes and actors that can operate across chains. Chain upgrading makes GVCs interlinked and power amongst its participants multipolar. Value is defined by, and distributed amongst those who control customer information and are best able to coordinate production to address customers' needs swiftly and flexibly. In the current state of GVC restructuring, the three pillars of production are organized in '*glocal*', *networked* and *buyer-like* driven GVCs.

2. *What are the conditions that make global value chain restructuring from 3DP possible?*

By reducing the complexity and amount of nodes in the ideal typical GVC, 3DP makes it possible for producers to upgrade processes in order to address customers' needs swiftly and flexibly. It is therefore an 'amplifier' of an ongoing trend in its innovation system of mass customization and the governance trend towards buyer-like driven GVCs. The degree of such amplification depends on whether 3DP is used in the extraction pillar only, where it is a *complement* for traditional manufacturing technology, or whether 3DP is also applied in the processing pillar, where it is a *substitute* for traditional manufacturing technology.

In the second scenario, 3DP makes possible de-centralized production, near its customer, which arguably makes GVCs even more buyer-driven. It also makes manufacturing increasingly capital-intensive, eliminating labor-intensive activities in the processing pillar, and thereby also challenging the debated smile in the curve of production.

3. How probable is global value chain restructuring from 3DP in South Africa?

Having developed local 3DP technology suitable for local needs and resources, the probability of GVC restructuring in RSA from 3DP, will onwards depend on the industries in which local actors can secure access to information about the end customer and thus reap the mass customization benefits of 3DP. In the cases of adoption analyzed, this currently seems more probable where 3DP is applied as a complement to local manufacturing, rather than where it is explored as a substitute, to manufacture parts whose designs and standards are defined outside the country.

In sum, 3DP fuels the ongoing trend towards buyer driven governance in GVC restructuring. It reduces the amount and cost of GVC processes, which, for established GVC players permits re-bundling processes, and for new players, access to GVCs previously inaccessible to them. Networks in a 3D printed reality, are ideally bound together by digital transactions, rather than physical products. Here, transactions include customer-specific information for mass customization, 3DP-specific information for capability building in the open source maker community, or product-specific information for printing locally and on-demand. Access to these networks determines whether 3DP may transform or reproduce production. As suggested by the case of RSA, access is not only a normative concern to democratize GVCs but it can also be a realistic catalyst in driving the development of products that represent new innovative solutions, to problems yet unidentified by established GVC players. Should the number of users grow at the exponential rate observed today, I imagine 3DP holds the potential to transform value distribution, value creation, and more importantly, the way in which we define value, transactions, products and buyers in the 21st century of digital production.

Bibliography

AfDB/OECD/UNDP. "South Africa." *African Economic Outlook 2014: Global Value Chains and Africa's Industrialisation*, 2014.

3DHubs. 2015. www.3dhubs.com (accessed 25 07 2015).

3DPrint. *3DPrint.com*. den 25 June 2015. <http://3dprint.com/76140-3d-printing/> (accessed 04 08 2015).

Abbott, Andrew. *Methods of Discovery*. Vol. 1. New York: Norton and Company Inc. , 2004.

AHLRAC. *AHLRAC - Home*. 2015. <http://www.ahrlac.com/> (accessed 17 10 2015).

Airbus APWorks. *AP Works*. 2013. <http://www.apworks.de/en/who-we-are/profile/> (accessed 03 09 2015).

Appleyard, Mathew. "Corporate responses to online music piracy: Strategic lessons for the challenge of additive manufacturing." *Business Horizons*, 2015: 69-76.

ArchDaily. *ArchDaily: The world's most visited architecture website*. den 12 July 2015. <http://www.archdaily.com/769818/neri-oxmans-mushtari-is-a-3d-printed-wearable-that-makes-products-from-sunlight> (accessed 30 08 2015).

AT Kearney. "3D Printing: A Manufacturing Revolution." 2015. <https://www.atkearney.com/documents/10192/5992684/3D+Printing+A+Manufacturing+Revolution.pdf/bf8f5c00-69c4-4909-858a-423e3b94bba3> (accessed 04 09 2015).

Additive Manufacturing - The Next Industrial Revolution. <https://www.youtube.com/watch?v=loSXLkrmzyw&feature=youtu.be>. GE Aviation. 2013.

Bagheri, Behrad. *imscenter.net*. 15 12 2014. http://www.imscenter.net/IMS_news/cincinnati-mayor-proclaimed-cincinnati-to-be-industry-4-0-demonstration-city (accessed 17 08 2015).

Bair, Jennifer. *Frontiers of Commodity Chain Research*. Stanford, California: Stanford University Press, 2009.

Baldwin, Richard. "Global supply chains: why they emerged, why they matter, and where they are going." i *Global value chains in a changing world*, av Deborah K. Elms and Patrick Low, 13-59. Geneva: WTO Publications, 2013.

"Globalisation: the great unbundling(s)." *Fondazione Rodolfo De Benedetti*. den 26 March 2008. http://www.frdi.org/upload/file/presentazione_baldwin.pdf (accessed 03. 08. 2015).

Baldwin, Richard. *Trade And Industrialisation After Globalisation's 2nd Unbundling: How Building And Joining A Supply Chain Are Different And Why It Matters*. Working Paper, the National Bureau of Economic Research, Cambridge: NBER, 2011.

Bamper, Penny, Karina Fernandez-Stark, Gary Gereffi, and Andrew Guinn. *Connecting Local Producers in Developing Countries to Regional and Global Value Chains*. OECD Trade Policy Paper No.160s, OECD, OECD Publishing, 2014.

Barnes, Justin, and Janden Lorentzen. *Learning, Upgrading and Innovation in the South African Automotive Industry*. SODS, Department of International Economics and Management, University of KwaZulu-Natal, Copenhagen Business School, JEL, 2003.

Berman, Barry. "3-D printing: The new industrial revolution." *Business Horizons*, 2012: 155-162.

Bhaskar, Roy. *A realist theory of science*. Hemel Hempstead: Harvester, 1978.

Bryson, J, and P Daniels. "Service Worlds: The 'services duality' and the rise of manuservice economy." i *Handbook of Service Science, Service Scienc: Research and Innovations in the Service Economy*, av P Maglio, S Kieliszewski and J Spohrer, 79-104. New York: Springer, 2010.

Buch-Hansen, Hubert. "Critical realism in the social sciences: an interview with Roy Bhaskar." *Scandinavian Journal of Social Theory*, 2005: 59-69.

Bullock, David. *Founder and CEO, Rapid3D* (2015) (Interview).

Campbell, R.I, and D.J de Beer. "Rapid prototyping in South Africa: past, present and future." *Rapid Prototyping Journal*, 2005: 260-265.

Campbell, R.I., J.I. de Beer, and E. Pei. "Additive Manufacturing in South Africa: building on the foundations." *Rapid Prototyping Journal*, 2011: 156-162.

Carlström, Ralf, Höganäs *General Manager* (2015). (Interview)

Cattaneo, Olivier, Gary Gereffi, and Cornelia Staritz. *Global Value Chains in a Postcrisis World: a Development Perspective*. Washington: The International Bank for Reconstruction and Development, 2010.

CBS Library . 2015a.

http://libsearch.cbs.dk/primo_library/libweb/action/search.do?v1%28freeText%29=3D+printing&fn=search&v1%2814133430UI%29=any&v1%2814750036UI%29=all_items&ct=search&vid=CBS&indx=1&dum=true&reset_config=true&op=Search&form_build_id=form-JrN6pZzDpseracSSzi-ac9vEyHoNLxUnhiREoCHEMAk&form_id=cbs_section_frontpage_library_search_form# (accessed 5 August 2015).

CBS Library. 2015b.

http://libsearch.cbs.dk/primo_library/libweb/action/search.do?fn=search&ct=search

[ch&initialSearch=true&mode=Basic&tab=default_tab&indx=1&dum=true&srt=rank&vid=CBS&frbg=&vl%28freeText%29=additive+manufacturing&scp.scps=scope%3A%28CBS%29%2Cprimo_central_multiple_fe&vl%28997619790UI%29=all_items&vl%281UIStartWith%29=contains&vl%28432460814UI%29=any&vl%28432460814UI%29=title&vl%28432460814UI%29=any#](#) (accessed 05 08 2015).

CBS Library. 2015c.

[http://libsearch.cbs.dk/primo_library/libweb/action/search.do?dscnt=0&scp.scps=scope:\(CBS\),primo_central_multiple_fe&frbg=&tab=default_tab&dstmp=1443115988993&srt=rank&ct=search&mode=Basic&&dum=true&vl\(997619790UI\)=all_items&indx=1&vl\(1UIStartWith\)=contains&vl\(432460814UI\)=any&vl\(freeText\)=Rapid%20prototyping&fn=search&vid=CBS&vid=CBS&backFromPreferences=true#](#) (accessed 13 08 2015).

Christopher, Martin, and Lynette, J. Ryals. "The Supply Chain becomes the Demand Chain." *Journals of Business Logistics*, 2014: 29-35.

Cox, Robert W. "Social forces, states and world orders: beyond international relations theory." *Millenium - Journal of International Studies*, 1981: 126-156.

CSIR. *www.csir.com*. 16 10 2015. http://www.csir.co.za/enews/2015_Oct/21.html (accessed 20 10 2015).

D'Aveni, Richard. "The 3D Printing Revolution." *Harvard Business Review*, May 2015.

de Beer, D.J. "Establishment of rapid prototyping/additive manufacturing in South Africa." *The Journal of Southern African Institute of Mining and Metallurgy*, 2011.

de Jong, Jeroen P.J, and Eric de Bruijn. "Innovation Lessons from 3D printing." *MIT Sloan Management Review*, 2013.

Defenceweb. *Airbus, Denel Aerostructures, Aerosud agreement strengthens local industry* . 17 09 2014.

http://www.defenceweb.co.za/index.php?option=com_content&view=article&id=36296:airbus-denel-aerostructures-aerosud-agreement-strengthens-local-industry&catid=7:Industry&Itemid=116 (accessed 06 09 2015).

Defenceweb—. *www.defenceweb.com*. den 25 February 2011.

http://www.defenceweb.co.za/index.php?option=com_content&view=article&id=13809 (accessed 30 09 2015).

DST, Department of Science and Technology. *Anonymous Public Official* (Interview) (29 09 2015).

DST; CSIR. "RAPDASA ." *A South African Additive Manufacturing Roadmap*. October 2014.

<http://www.rapdasa.org/docs/AM%20Roadmap%20for%20SA%20over%201-2028%20Oct%202014.pdf> (accessed 14 08 2015).

du Preex, Willie, *Director, Assistant Professor, CUT, RAPDASA* (2015) (Interview).

European Commission . "Factories of the Future PPP: towards competitive EU manufacturing." *European Commission*. 2013.
http://ec.europa.eu/research/press/2013/pdf/ppp/fof_factsheet.pdf (accessed 10 07 2015).

Forbes. *2015 Roundup of 3D printing forecasts and estimates*. 31 03 2015.
<http://www.forbes.com/sites/louiscolumbus/2015/03/31/2015-roundup-of-3d-printing-market-forecasts-and-estimates/> (accessed 17 04 2015).

Freeman, Chris, and Luc Soete. *The Economics of Industrial Innovation*. Vol. 1. Great Britain: MIT Press, 1997.

Freeman, Christopher. "The "National System of Innovation" in Historical Perspective." *Cambridge Journal of Economics*, 1995: 5-24.

Friedman, Thomas. *When Complexity is Free*. 14 09 2013.
http://mobile.nytimes.com/2013/01/15/opinion/sunday/friedman-when-complexity-is-free.html?pagewanted=all&_r=0&referrer=http://www.ge.com/stories/advanced-manufacturing/ (accessed 15 03 2015).

Fu, Xiaolan, Carlo Pietrobelli, and Luc Soete. "The Role of Foreign Technology and Indigenous Innovation in the Emerging Economies: Technological Change and Catching up." *World Development*, 2011: 1204-1212.

Garett, Banning. "3D Printing: New Economic Paradigms and Strategic Shifts." *Global Policy*, February 2014.

Garrett, Banning. "3D Printing: New Economic Paradigms and Strategic Shifts." *Global Policy*, February 2014: 70-75.

Gartner. *Gartner Newsroom*. 9 12 2014.
<http://www.gartner.com/newsroom/id/2940117> (accessed 17 08 2015).

GE Reports. *Jet Engine Bracket From Indonesia Wins 3D Printing Challenge*. den 11 December 2013b. <http://www.gereports.com/post/77131235083/jet-engine-bracket-from-indonesia-wins-3d-printing/> (accessed 03 09 2015).

Gereffi, Gary. "Beyond the Producer Driven / Buyer Driven dichotomy: The Evolution of Global Value Chains in the Internet Era." *IDS Bulletin*, 2001: 30-40.

"Global value chains in a post-Washington Consensus World." *Review of International Political Economy*, 2014: 9-37.

Gereffi, Gary, John Humphrey, and Timothy Sturgeon. "The governance of global value chains." *Review of International Political Economy*, 2005: 78-104.

- Gereffi, Gary, John Humphrey, Raphael Kaplinsky, and J. Timothy Sturgeon. "Introduction: Globalisation, Value Chains and Development." *IDS Bulletin*, 2001: 2-14.
- Gereffi, Gary, Miguel Korzeniewicz, and Roberto P. Korzeniewicz. "Introduction: Global Commodity Chains." i *Commodity Chains and Global Capitalism*, av Gary Gereffi and Miguel Korzeniewicz. Westport, CT: Praeger, 1994.
- Gibbon, Peter, Jennifer Bair, and Stefano Ponte. "Governing global value chains: an introduction." *Economy and Society*, August 2008: 315-338.
- Gilmore, J., and B Pine. "The four faces of mass customization ." *Harvard Business Review*, 1997: 91-101.
- Giuliani, Elisa, Carlo Pietrobelli, and Roberta Rabellotti. "Upgrading in Global Value Chains: Lessons from Latin American Clusters." *World Development*, 02 01 2005: 549-573.
- Gress, Douglas R., and Ronald V. Kalafsky. "Gepgraphines of production in 3D: Theoretical and research implications stemming from Additive manufacturing." *Geoforum*, 5 February 2015: 43-52.
- Greyling, Hardus, *Manager, Aeroswift CSIR* (2015) (Interview).
- Harley, Guentin, *Founder and CEO, RepRap Morgan* (2015) (Interview).
- Harvey, David. "Between Space and Time: Reflections on the Geographical Imagination." *Annals of the Association of American Geographers*, 1990: 418-434.
- Hilbert, Martin, and Priscila López. "The World's Technological Capacity to Store, Communicate, and Compute Information." *Science*, 2011: 60-65.
- Hopkins, Terence, and Immanuel Wallerstein. *Commodity Chains in the World-Economy Prior to 1800 Review (Fernand Braudel Center)* . Research Foundation of SUNY, 1986.
- Humphrey, John, and Hubert Schmitz. *Governance and Upgrading: Linking industrial Cluster and Global Value Chain research*. Institute of Development Studies, Brighton: University of Sussex, 2000.
- . "How does insert in global value chains affect upgrading in industrial clusters?" *Regional Studies*, 2002: 1017-1027.
- Kadarusman, Yohanes, and Khalid Nadvi. "Competitiveness and Technological Upgrading in Global Value Chains: Evidence from the Indonesian Electronics and Garment sector." *European Planning Studies* 21, nr 7 (2013): 1007-1028.
- Kawakami, Momoko, and Timothy J Sturgeon. *The dynamics of Local Learning in Global Value Chains*. New York: Palgrave & IDE JETRO, 2011.
- Khajavi, Siavash, H, Jouni Partanen, and Jan Holmström. "Additive Manufacturing in the spare parts supply chain." *Computers in Industry*, 19 September 2013: 50-63.

- Kietzmann, Jan, Leyland Pitt, and Pierre Berthon. "Today, the speed and convenience of rapid prototyping allows ." *Marketing and Technology, Business Horizons*, 2015: 209-215.
- Kozinets, Robert, V. "The Field behind the Screen: Using Netnography for Marketing Research in Online Communities." *Journal of Marketing Research*, February 2002: 61-72.
- Lightfoot, Howard, Tim Baines, and Palie Smart. "The servitization of manufacturing; A systematic literature review of interdependent trends." *International Journal of Operations & Production Management*, 2013: 1408-1434.
- Low, Patrick. "The role of services in global value chains." i *Global Value Chains in a Changing World*, av Deborah K Elms and Patrick Low. Geneva: WTO Publications, 2013.
- Lundvall, Bengt-Åke. *National Innovations Systems: Towards a theory of Innovation and Interactive Learning*. London: Pinter, 1992.
- Lundvall, Bengt-Åke, Björn Johnson, Esben Sloth Andersen, and Bent Dalum. "National systems of production, innovation and competence building." *Research Policy*, 2002: 213-231.
- Månson, Peter. "Max Weber." i *Classical and Modern Social Theory*, av Heine Andersen and Lars Bo Kaspersen. Oxford: Blackwell, 2000.
- McKinsey. *3D Printing takes shape*. January 2014.
<http://www.mckinsey.com/insights/manufacturing/3-d-printing-takes-shape>
 (accessed 18 07 2015).
- Mills, Mark P. *Manufacturing, 3D printing and what china knows about the emerging American century*. den 5 July 2011. <http://news.yahoo.com/manufacturing-3d-printing-china-knows-emerging-american-century-165336327.html> (accessed 22 8 2015).
- Mingers, John. "Helping business schools engage with real problems: the contribution with critical realism and systems thinkin." *European Journal of Operational Research*, 2015: 316-333.
- Mosconi, Franco. *The New European Industrial Policy - Global competitiveness and the manufacturing renaissance*. New York: Routledge, 2015.
- Moses, Jonathon, W., and Torbjørn, L. Knutsen. *Ways of Knowing*. Vol. 1. New York: Palgrave Macmillan, 2007.
- Mzimasi, Gcukumana. "Seeing South Africa through a manufacturing LENS: specialised technical services and support to industry." *CSIR Science Scope*, 2 April 2012: 82-83.
- NASA. *Special 3-D Delivery from Space to NASA's Marshall Space Flight Center*. 7 February 2015.

<https://www.nasa.gov/centers/marshall/news/news/release/2015/special-3-d-delivery-from-space-to-nasa-s-marshall-space-flight-center.html> (accessed 17 04 2015).

Nordås, H. K, S. Miroudot, and P Kowalski. "Dynamic gains from trade." *OECD Trade Policy Papers*, den 24 November 2006: 1-53.

Obama, Barack. *State of the Union Address*. 12 02 2013.
<http://www.whitehouse.gov/the-press-office/2013/02/12/remarks-president-state-union-address> (accessed 09 06 2015).

O'Brien, Robert, and Marc Williams. *Global Political Economy*. 3rd edition. London: Palgrave Macmillan, 2010.

OECD. "OECD Science." OECD Publications. 1997.
<http://www.oecd.org/science/inno/2101733.pdf> (accessed 03 09 2015).
—. "South Africa." *SMEs, Entrepreneurship and Innovation*, 2010.

Pietrobelli, Carlo, and Federica Saliola. "Power relationships along the value chain: multinational firms, global buyers, and performance of local suppliers." *Cambridge Journal of Economics*, 03 June 2008: 947-962.

Pietrobelli, Carlo, and Roberta Rabellotti. *Upgrading to Compete, Global Value Chains, Clusters and SMEs in Latin America*. New York: Inter-American Development Bank, 2006.
—. "Global Value Chains meet Innovation Systems: are there learning opportunities for developing countries? ." *World Development*, 2011: 1261-1269.

Piketty, Thomas. *Capital in the Twenty-First Century*. Vol. 2. 2 vol. Padshow: TJ International Ltd, 2014.

Ponte, Stefano, and Timothy Sturgeon. "Explaining governance in global value chains: a modular theory building effort." *Review of International Political Economy*, 2014 (2013): 195-223.
—. "Explaining governance in global value chains: A modular theorybuilding effort." *Review of International Political Economy*, 2014: 195-223.

Psilos, Phil, and Gary Gereffi. "Workforce Development in the Global Economy: Linking skills and capabilities." RTI International; Duke Center on Globalization, Governance and Competitiveness , 2011.

Pólya, George. *How to Solve It*. New York, Doubleday: Garden City, 1957.
Rabellotti, Roberta. "Roberta Rabellotti." *Presentations*. 20 March 2014.
<http://sites.google.com/site/robertarabellotti/home> (accessed 10 August 2015).

RAPDASA. *RAPDASA Who is*. 2015. <http://www.rapdasa.org/whoisrapdasa.aspx> (accessed 10 09 2015).

Reports, GE. *GE Reports: the first FAA cleared 3D printed part to fly in a commercial jet engine from GE*. 14 April 2015.

<http://www.gerreports.com/post/116402870270/the-faa-cleared-the-first-3d-printed-part-to-fly/> (accessed 28 05 2015).

Research, GE Global. *Global Research*. 2015.
<http://www.geglobalresearch.com/innovation/3d-printing-creates-new-parts-aircraft-engines> (accessed 03 07 2015).

Robertson, Natalee, *Makerbot Product Manager* (2015) (Interview).

Rodrik, Dani. "www.sss.ias.edu." *Global Citizen Foundation*. June 2013.
http://www.sss.ias.edu/files/pdfs/Rodrik/Research/GCF_Rodrik-working-paper-1-6-24-13.pdf (accessed 4 09 2015).

Rogers, Richard. "Mapping Web Space with the Issuecrawler." 2006.
<http://www.govcom.org>.

Sayer, Andrew. *Realism in Social Science*. 1 vol. London: SAGE Publications, 2000.

Seals, Tara. "German, US Tech Consortiums Aim at Smart Manufacturing." *Web-scale networking*. den 24 September 2015.
<http://www.webscalenetworking.com/topics/webscalenetworking/articles/410368-german-us-tech-consortiums-aim-smart-manufacturing.html> (accessed 5 09 2015).

Sæther, Bjørnar. "Retrodution: An alternative Business Research Strategy?" *Business Strategy and the Ennvironment* , 1998: 245-249.

Shapeways. 2015. www.shapeways.com (accessed 17 08 2015).

Shin, Namchul, Kenneth L. Kraemer, and Jason Diedrick. "Value Capture in the Global Electronics Industry: Empirical Evidence for the "Smiling Curve" Concept." *Industry and Innovation*, 2012: 89-107.

SmarTechPublishing. "SmarTechPublishing Markets." August 2014.
<https://smartechpublishing.com/images/uploads/general/AerospaceWP.pdf> (accessed 10 09 2015).

Solow, Robert. "A Contribution to the Theory of Economic Growth." *The Quarterly Journal of Economics*, February 1956: 65-94.

Statistical Studies of Peer Production. *Manufacturing in motion: first survey on 3D printing community*. den 12 May 2012.
<http://surveys.peerproduction.net/2012/05/manufacturing-in-motion/3/> (accessed 12 08 2015).

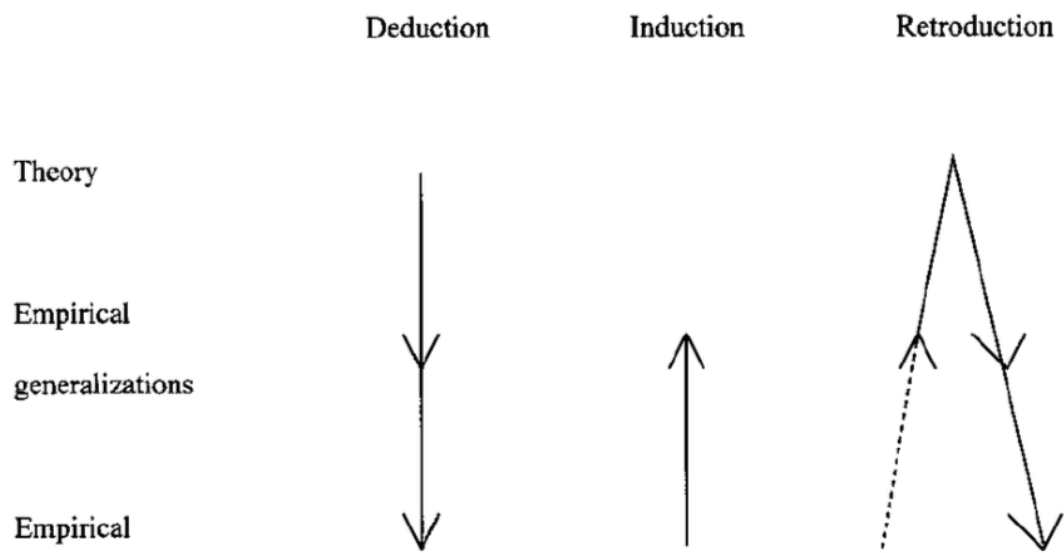
Stratasys. *Investors Stratasys*. den 17 September 2014.
<http://investors.stratasys.com/releasedetail.cfm?releaseid=871371> (accessed 20 09 2015).

Sturgeon, Timothy. *Global Value Chains and Economic Globalisation: Towards a new measurement framework*. MIT, Industrial Performance Center, Eurostat, 2013.

- The Creators Project. *youtube*. The Creators Project. 14 January 2013. <https://www.youtube.com/watch?v=IS4Xw8f9LCc> (accessed 28 05 2015).
- The Economist. "A third industrial revolution." (The Economist Newspaper Limited) April 2015.
- Thomson, Derek. "Is 3D Printing Overrated? Not at All, Says GE's Jeffrey Immelt." *The Atlantic*. 7 February 2013. <http://www.theatlantic.com/business/archive/2013/02/is-3d-printing-overrated-not-at-all-says-ge-jeffrey-immelt/272965/> (accessed 30 06 2015).
- Treweek, Rick *Founder African Robot, 3DHubs Mayor Johannesburg* (2015) (Interview).
- UNCTAD. *Trade and Development Report 2013*. United Nations Conference on Trade and Development, UN Publishing, 2013.
- US Department of Energy. "Unlocking the potential of Additive Manufacturing in the fuel cells industry." *hydrogenandfuelcells.energy.gov*. den 02 November 2014. http://www1.eere.energy.gov/hydrogenandfuelcells/pdfs/webinarslides_additive_manufacturing_021114.pdf (accessed 22 08 2015).
- van Vuuren, Dawie, *Manager, CSIR, Ti Plant* (2015) (Interview).
- Vandermerwe, Sandra, and Juan Rada. "Servitization of business: Adding value by adding services." *European Management Journal*, 1988: 314-324.
- Veblen, Thorstein. *The Theory of Business Enterprise*. New York: Cosimo, 1904.
- Vermeleun, Marius, *Project Manager, Aeroswift Aerosud* (2015) (Interview).
- Willmott, Hugh. "Reframing relevance as 'social usefulness': a comment on Hodgkinson and Starkey's 'not simply returning to the same answer over and over again'." *British Journal of Management*, 2012: 457-469.
- Yeung, Henry Wai-Chung, and Neil M. Coe. "Towards a Dynamic Theory of GPN." *Economic Geography*, 2014: 29-58.
- Zaske, Sara. "Germany's vision for Industrie 4.0: The revolution will be digitised." *ZDNet*. 23 February 2015. <http://www.zdnet.com/article/germanys-vision-for-industrie-4-0-the-revolution-will-be-digitised/> (accessed 3 08 2015).

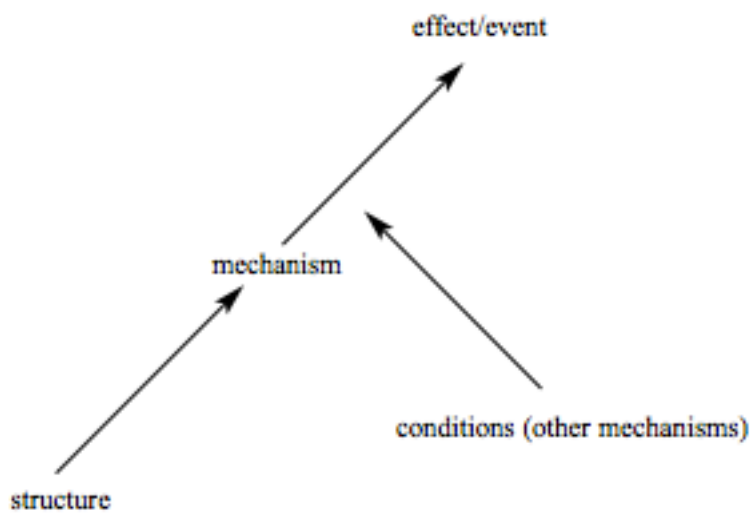
Appendix

Appendix 1 Retroduction



Source: (Sæther 1998, 246)

Appendix 2 Causation in Critical Realism



Source: (Sayer 2000, 15)

Appendix 3 List of Interviewees for 3DP in South Africa and Interview guide

Name	Organization	Title	Place
Dawie van Vuuren	CSIR Tl Plant	Manager	Skype
Willie du Preez	CUT, RAPDASA	Director, Ass. Proff	Skype
Hardus Greyling	Aeroswift CSIR	Manager	Skype
Marius Vermeulen	Aeroswift, Aerosud	Project Manager	Skype
Rick Treweek	African Robot, Trobok,	Founder, 3Dhubs Major Johannesburg	Skype
David Bullock	Rapid3D	Founder, CEO	Skype
Quentin Harley	RepRap Morgan	Founder, CEO	Skype
Ralf Carlström	Höganäs	General Manager	E-mail
Natalee Robertson	Rectron	Makertbot Product Manager	E-mail
Anonymous Public Official	Department of Science	Advanced Manufacturing	Skype

Interview guide

1. Purpose: Investigating 3D printing activity in South Africa

Thank you taking the time for this interview in which you will be a highly valuable source of primary data for my research set forth to answer:

How do actors engage in the GVC of 3DP in South Africa?

The final Masterthesis will be handed in in November 2015 and be made available to the public through Copenhagen Business School's thesis bank (part of university library). If interested you will receive a soft copy upon its completion.

As a student of International Business and Politics, I have been trained for the past five years in the field of International Political Economy. This is a critical field concerned with global distribution of wealth and power and which in contrast to its predecessor International Relations, observes economic actors in the business sphere, as well as non-economic actors in the public sphere.

I find RSA as an interesting case for several reasons a) little research on 3DP in RSA as most research on 3D printing is focused on the global north b) lot of endowments in RSA that could lend the business case for 3D printing compelling such as a rich mining industry (particularly for titanium) and already being a technological hub in the continent (for automotive and aerospace).

You have been invited as you are either representing an actor associated with:

- i) a local entity directly engaging with the technology (e.g. as a supplier/sub supplier/customer/ user)
- ii) a local entity indirectly engaged with the technology (e.g. as a regulator/researcher)
- iii) a foreign entity directly engaging with the technology (e.g. as a supplier/sub supplier/customer/ user)
- iv) a foreign entity indirectly engaged with the technology (e.g. as a regulator/researcher)

2. Consent: A recorded interview, part of the final Master Thesis

By agreeing to partake in this interview you agree to be recorded and quoted in my Master Thesis. In the event that you do not wish not to be recorded, I will instead, post interview, email the quotations I wish to include in the thesis for your approval. You will thus approve quotations on a case-by-case basis.

The purpose of recording the interview is for the interviewer to better focus on guiding the interview towards insightful content in the limited time available, rather than having to transcribe while interviewing.

The interview will be transcribed post interview and handed in alongside the thesis and the original recordings.

You can choose to be anonymous in terms of person and/or in terms of affiliation (organization).

Please let me know your decision regarding recording and anonymity prior to the interview.

3. Interview questions for a semi-structured interview of 30-45minutes

Kindly note that the following questions are only guidelines for a content rich interview. Being semi-structured, I will take the liberty to step outside of the questions in the event that you direct my attention towards other valuable areas that I have not identified prior to the interview. This, confirming the purpose of the interview and my research at large to uncover new knowledge and not to merely confirm what I already know.

Needless to say, you can refrain from answering my questions at any time during the interview. You are also welcome to ask me questions at any time throughout the interview.

Introduction:

- Introduction of interviewer: current position, affiliation and duration
- Introduction of interviewee: current position, affiliation and duration

Core Questions:

- How did you journey into 3DP?
- How would you describe the 3D printing space in RSA? E.g. Is it young/mature space? a collaborative/competitive space?
- Who are the key actors in this space?
- In case you are directly engaged with the technology:
 - o What 3DP technology are you working with?
 - o Access to technology: where did you get the 3D printer from? (Local or Distr. Or import?)
- What are the benefits of 3D printing?
- What are the risks related to 3D printing?
- How would you describe RSA in this field v. rest of the world?
- What does to future of 3D printing in RSA bring in term of opportunities and threats?

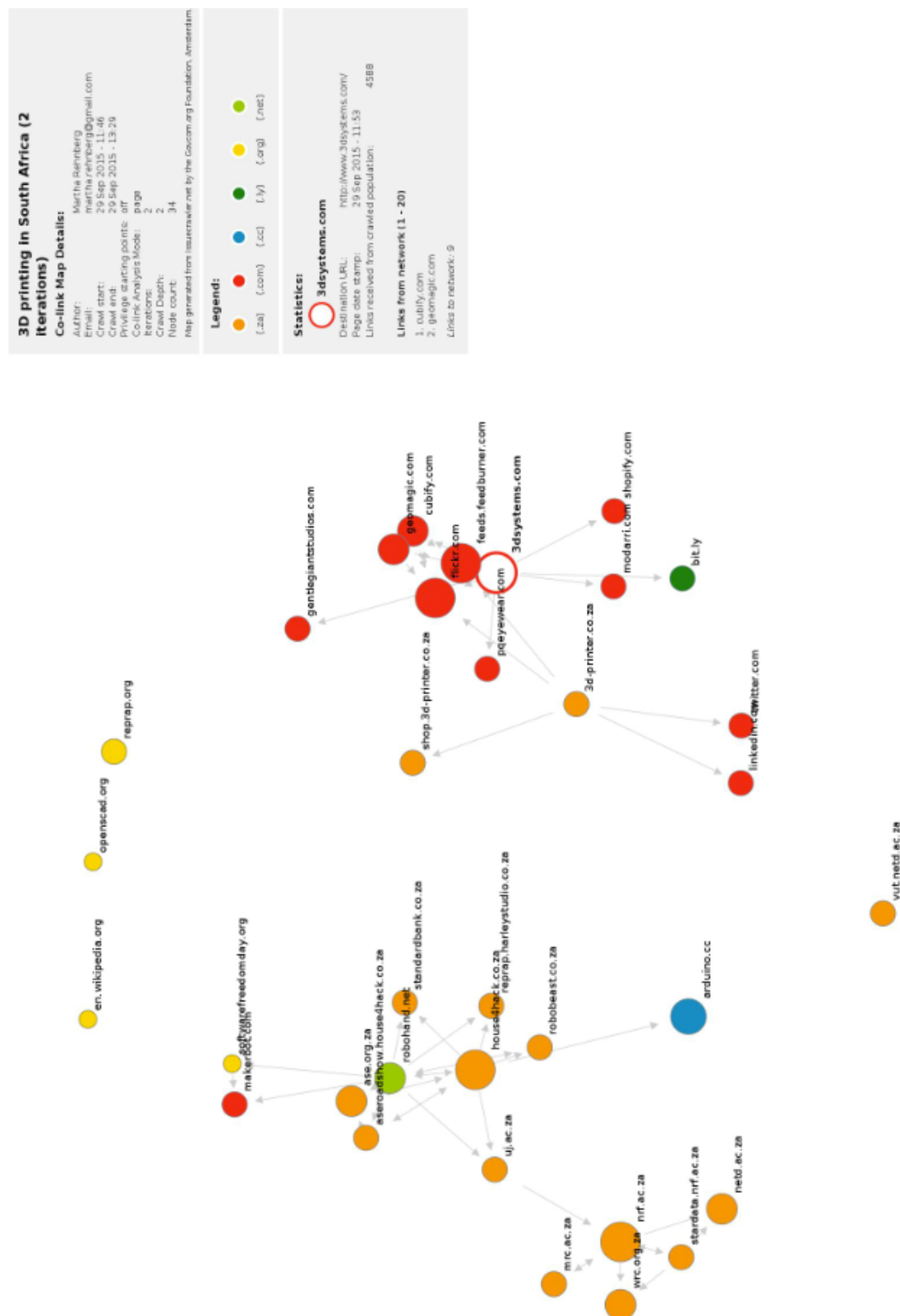
Closing questions:

- Is there anyone in the field you think I should talk to?
- Can I contact you post-interview if further elaboration or clarification is needed?

Appendix 4 Node Analysis of economic actors in South Africa

Node	Local /	Location	Product Portfolio	Website
ABS-filament	Local	E-store	Raw Material	sales@abs-filament.co.za
Filament Factory	Local	Johannesburg /E-store (and di	Raw Material	http://www.filamentfactory.co.za/
3D printing	Local	E-store	Raw Material/Hardware	http://www.3d-printing-sa.co.za/pages/cor
3D printing store	Local	E-store/Centurion	Raw Material/Hardware	http://www.3dprintingstore.co.za/filament
Netram	Local	E-store/Cape Town	Raw Material/Hardware	http://netram.co.za/812-filament
Rectron	Local	Johannesburg	Raw Material/Hardware	http://www.rectron.co.za/contact-us/
RS	Foreign	E-store	Raw Material/Hardware	http://za.rs-online.com/web/generalDisplay
Riecktron	Local	E-store/Centurion	Raw Material/Hardware	https://www.riectron.co.za/en/category/2
3Dprintingsystems	Foreign	E-store	Raw Material/Hardware/Service Bureau	http://3dprintingsystems.co.za/products/3d
3DUnique	Local	E-store	Raw Material/Hardware/Service Bureau	http://3dunique.co.za/product/3d-construc
Rothco	Local	Kempton Park	Raw Material/Hardware/Service Bureau	http://rothco.co.za/prototype/stratasys/
Solid Edge Technology	Local	E-store	Raw Material/Hardware/Service Bureau	http://www.setech.co.za/products/
Delta 3D printer	Local	E-store	Raw Material/Hardware/Service Bureau	http://deltaprinter.co.za/filamentextruder/i
DIY Electronics	Local	Durban	Raw Material/Hardware/Service Bureau	http://diyelectronics.co.za/store/index.php
3D Echo Tech	Local	Cape Town	Service Bureau	http://www.3dechotech.co.za/about/
3D Print Lab	Local	Pretoria	Service Bureau	www.3dprintlab.blogspot.com
3D Rapid Prototyping	Local	Johannesburg	Service Bureau	www.3drapidprototyping.co.za
3RD DIMENSION PROTOTYPING	Local	Durban	Service Bureau	www.3rd3d.co.za
DMS Rapid	Local	Johannesburg	Service Bureau	http://www.dmsrapid.com/
Illusions 3D	Local	Johannesburg	Service Bureau	http://www.illusions3d.co.za/
Liquid Edge	Local	Cape Town /E-store	Service Bureau	http://www.liquid-edge.co.za/about.asp
Nanitech Complete IT solutions	Local	Genoni	Service Bureau	http://www.nanitech.co.za/home.html
PRK Design	Local	Cape Town	Service Bureau	http://www.bizcommunity.com/Companies
Productprint	Local	Durban	Service Bureau	www.productprint.co.za
Protoform	Local	Cape Town	Service Bureau	www.protoform.co.za
Protogrow	Local	Pretoria	Service Bureau	http://www.protogrow.co.za/industries_we
Realise Product Design	Local	Centurion	Service Bureau	http://www.bizcommunity.com/Companies
Rohland Industrial Design	Local	Johannesburg	Service Bureau	http://www.rid.co.za/About-us/
Seswa 3D	Local	Johannesburg	Service Bureau	http://www.seswa3d.co.za/
She, Bear and Joao	Local	Midrand	Service Bureau	http://www.shebearandjoao.co.za/
Snowflake Marketing	Local	Johannesburg	Service Bureau	www.facebook.com/snowflakemarketingsa
StudioX	Local	Cape Town	Service Bureau	http://www.studiox.co.za/home
WWW.SIGNAGEWORLD.CO.ZA	Local	Pretoria	Service Bureau	WWW.SIGNAGEWORLD.CO.ZA
CRPM	Local	Free State	Service Bureau	http://www.cut.ac.za/crpm/
VUT (AM Service bureau)	Local	Southern Gauteng	Service Bureau	http://www.vut.ac.za/index.php/service/un
VUT (Innovation Hub)	Local	Southern Gauteng	Service Bureau	http://www.vut-research.ac.za
African Robot	Local		Service Bureau	http://africanrobot.com/
RepRap Morgan	Local	Centurion	Hardware	http://reprap.harleystudio.co.za/store/
Cad House	Local	Johannesburg	Software/Raw Material/Hardware/Service Bu	http://www.cad-house.co.za/
OLX	Local		Software/Raw Material/Hardware/Service Bu	http://www.olx.co.za/nf/search/3D%20prin
Rapid3D	Local	Dennis Shepstone /E-store	Software/Raw Material/Hardware/Service Bu	http://rapid3d.co.za/
Robobeast	Local	E-store	Hardware	http://robobeast.co.za/

Source: Author



Source: Author

Appendix 6: Reversal of Industrialization/ De-industrialization trend



Source: Adjusted from (Baldwin 2013, 23)

Appendix 8: Overview of Journals in which articles on "3D printing" / "Additive Manufacturing" / "Rapid Prototyping" have been published between 1980-2015 YTD

“3D Printing”

Refine Search			X
Include	Exclude	Journal Title	
☐	☐	Acta Biomaterialia (21)	
☐	☐	Advanced Drug Delivery Reviews (21)	
☐	☐	Advanced Functional Materials (27)	
☐	☐	Advanced Healthcare Materials (8)	
☐	☐	Advanced Materials (51)	
☐	☐	Architectural Design (9)	
☐	☐	Assembly Automation (13)	
☐	☐	Biomaterials (87)	
☐	☐	Biotechnology and Bioengineering (9)	
☐	☐	Computer-Aided Design (39)	
☐	☐	International Journal Of Advanced Manufacturing Technology (27)	
☐	☐	Journal of Materials Processing Technology (28)	
☐	☐	Journal of Materials Science: Materials in Medicine (14)	
☐	☐	Materials Letters (13)	
☐	☐	Materials Today (16)	
☐	☐	Metal Powder Report (143)	
☐	☐	Microelectronic Engineering (18)	
☐	☐	New Scientist (36)	
☐	☐	Rapid Prototyping Journal (128)	
☐	☐	Trends in Biotechnology (16)	

Source: (CBS Library 2015a)

“Additive Manufacturing”

Refine Search			X
Include	Exclude	Journal Title	
☐	☐	Acta Biomaterialia (20)	
☐	☐	Acta Materialia (41)	
☐	☐	Additive Manufacturing (41)	
☐	☐	Advanced Engineering Materials (10)	
☐	☐	Assembly Automation (17)	
☐	☐	International Journal of Advanced Manufacturing Technology (105)	
☐	☐	JOM (76)	
☐	☐	JOM: Journal of The Minerals, Metals & Materials Society (73)	
☐	☐	Journal of Applied Polymer Science (10)	
☐	☐	Journal Of Materials Processing Tech. (111)	
☐	☐	Journal Of Materials Processing Technology (99)	
☐	☐	Materials and Design (68)	
☐	☐	Materials and Manufacturing Processes (22)	
☐	☐	Metal Powder Report (205)	
☐	☐	Physics Procedia (83)	
☐	☐	Procedia Cirp (81)	
☐	☐	Procedia Engineering (47)	
☐	☐	Rapid Prototyping Journal (151)	

Source: (CBS Library 2015b)

“Rapid Prototyping”

Refine Search

Include	Exclude	Journal Title
☐	☐	Acta Biomaterialia (96)
☐	☐	Acta Materialia (32)
☐	☐	Advanced Engineering Materials (13)
☐	☐	Applied Surface Science (73)
☐	☐	Assembly Automation (74)
☐	☐	Biomaterials (123)
☐	☐	Biomedical Microdevices (32)
☐	☐	Computers in Industry (107)
☐	☐	International Journal of Advanced Manufacturing Technology (275)
☐	☐	International Journal Of Production Research (132)
☐	☐	Journal Of Materials Processing Tech. (297)
☐	☐	Journal Of Materials Processing Technology (256)
☐	☐	Materials Letters (43)
☐	☐	Procedia Engineering (109)
☐	☐	Rapid Prototyping Journal (630)
☐	☐	Robotics and Computer-Integrated Manufacturing (62)
☐	☐	The International Journal of Advanced Manufacturing Technology (81)

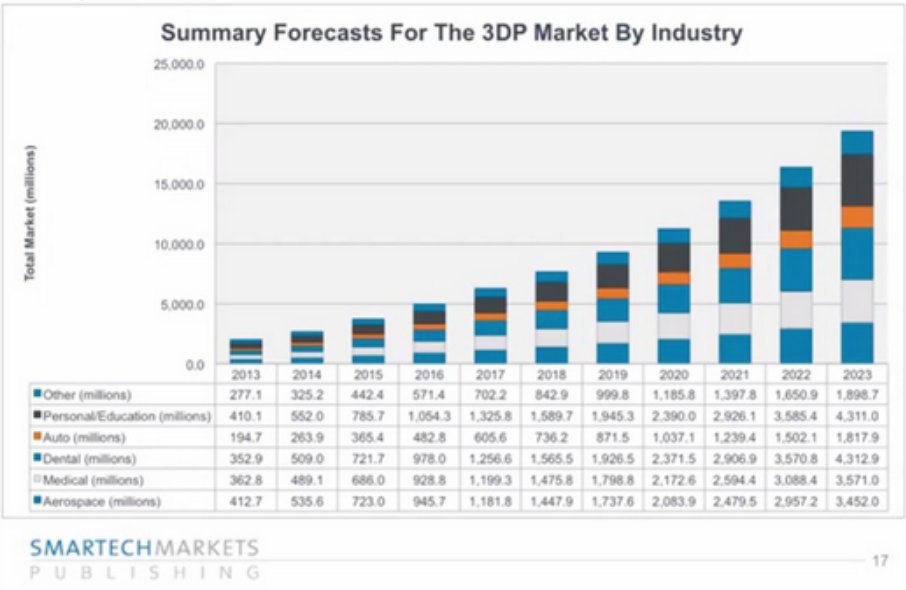
Source: (CBS Library 2015c)

Appendix 3 World growth in output per capita (GDP) between 1700-2012

Average annual growth rate	Per capita world output	Europe	America	Africa	Asia
0-1700	0.0%	0.0%	0.0%	0.0%	0.0%
1700-2012	0.8%	1.0%	1.1%	0.5%	0.7%
incl.: 1700-1820	0.1%	0.1%	0.4%	0.0%	0.0%
1820-1913	0.9%	1.0%	1.5%	0.4%	0.2%
1913-2012	1.6%	1.9%	1.5%	1.1%	2.0%
1913-1950	0.9%	0.9%	1.4%	0.9%	0.2%
1950-1970	2.8%	3.8%	1.9%	2.1%	3.5%
1970-1990	1.3%	1.9%	1.6%	0.3%	2.1%
1990-2012	2.1%	1.9%	1.5%	1.4%	3.8%
1950-1980	2.5%	3.4%	2.0%	1.8%	3.2%
1980-2012	1.7%	1.8%	1.3%	0.8%	3.1%

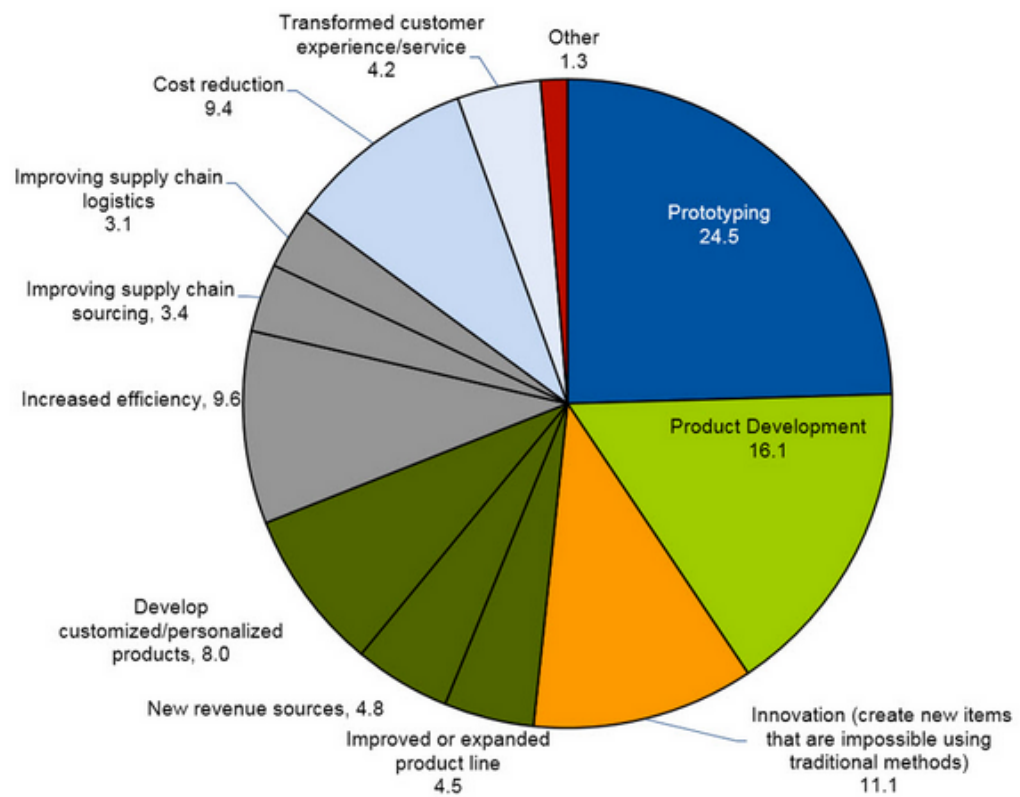
Source: (Piketty 2014, 94)

Appendix 9 Summary Forecast for the 3DP market by industry (2013-2023)



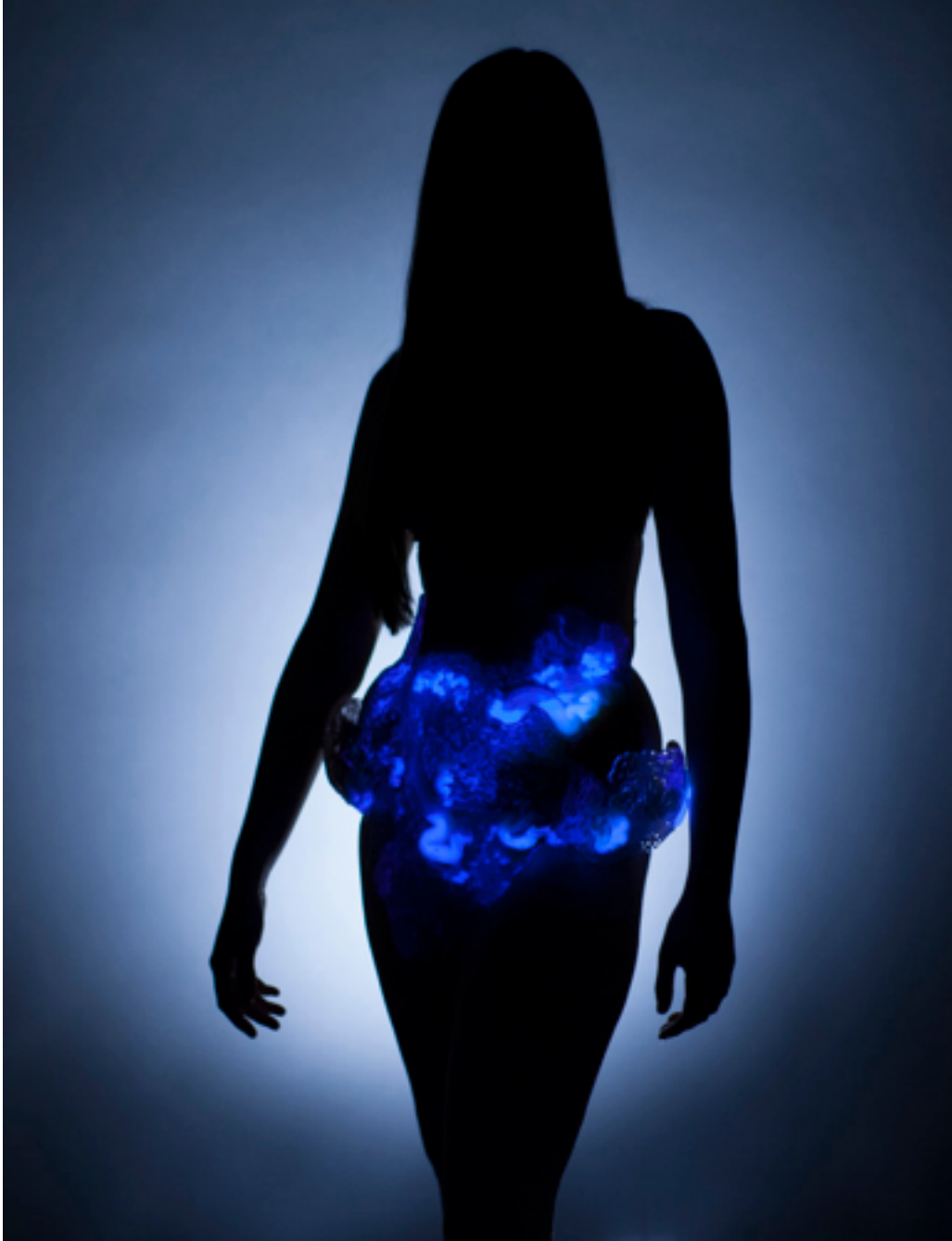
Source: (Forbes 2015)

Appendix 10 3DP Adoption per business activity (%)



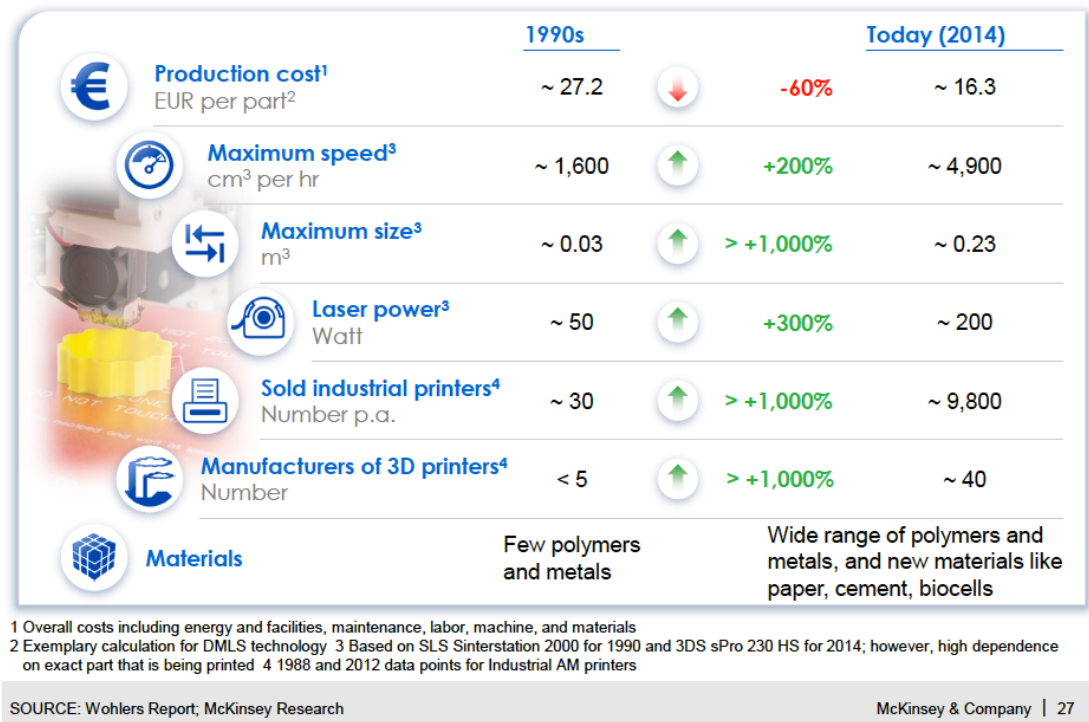
Source: (Gartner in Forbes 2015)

Appendix 11 "The Mushtari" a 3D printed wearable that creates structures from sunlight

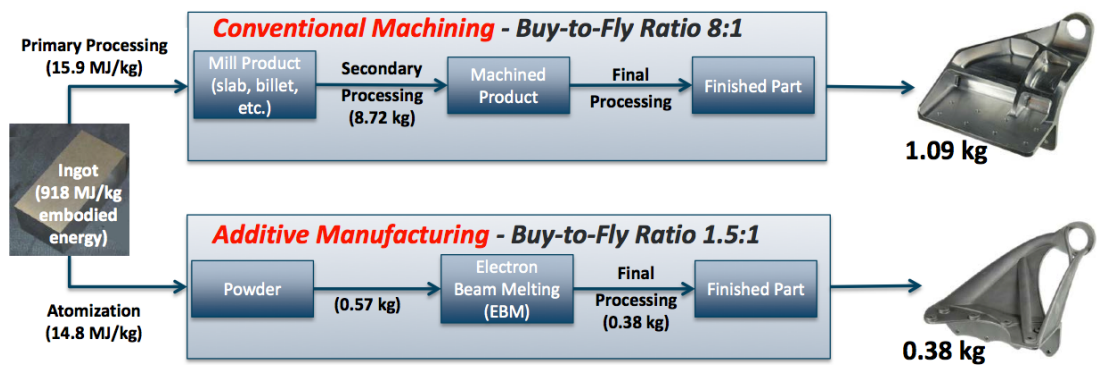


Source: (ArchDaily 2015)

Appendix 12 Technological Development of 3DP between 1990 and 2014



Appendix 13 Titanium bracket for Aerospace: Comparing Conventional and Additive Manufacturing



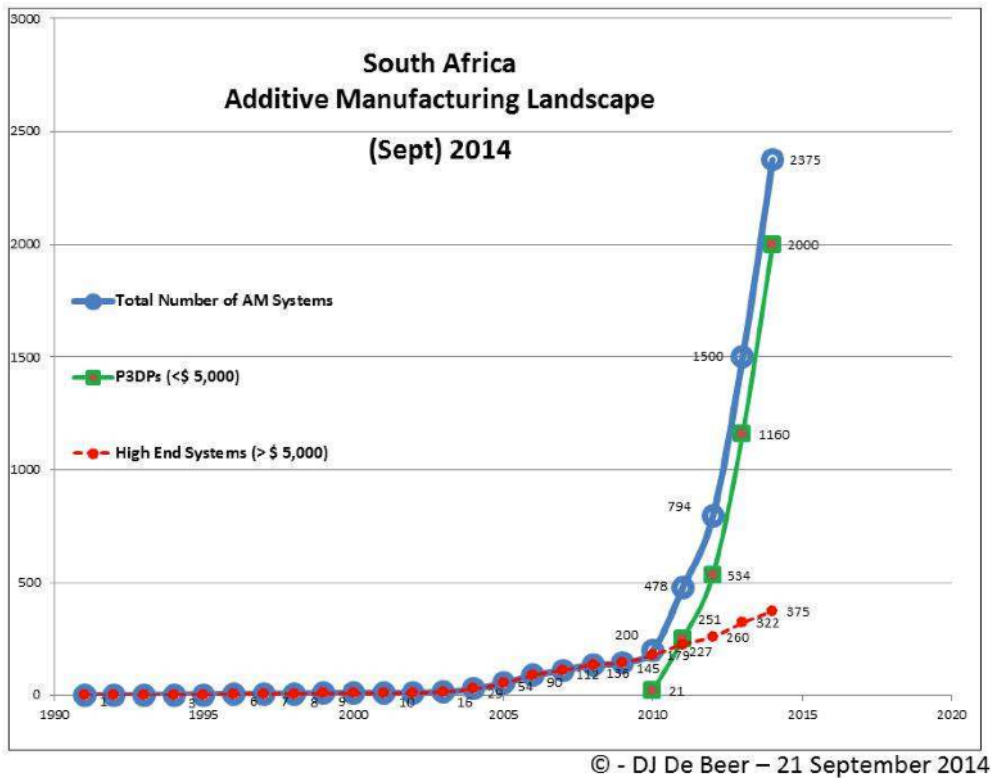
Source: US Department of Energy 2014

Appendix 14 Original Roadmap Additive Manufacturing South Africa

• Use of AM for production of medical and dental implants • Use of AM for production of medical devices • Production of parts for the Aerospace and military markets based on current customers and collaboration agreements with OEM's	Qualified AM parts for medical and aerospace	Enabling capability development	Education system
• Improve efficiency of traditional manufacturing sectors through tooling development and improved product development cycles • Refurbishment of previously unserviceable parts for the local industry by means of powder deposition technology	AM for Impact in traditional manufacturing sectors		
• Development of Additive Manufacturing systems • Development of Materials for AM • Development of new AM technologies	New AM Materials and technologies		
• Development of an AM based SMME industry in South Africa based on/strengthened by Additive Manufacturing technology – Prosthetics, Dental, Hearing aids, Jewelry, Creative Arts	SMME Development and support		

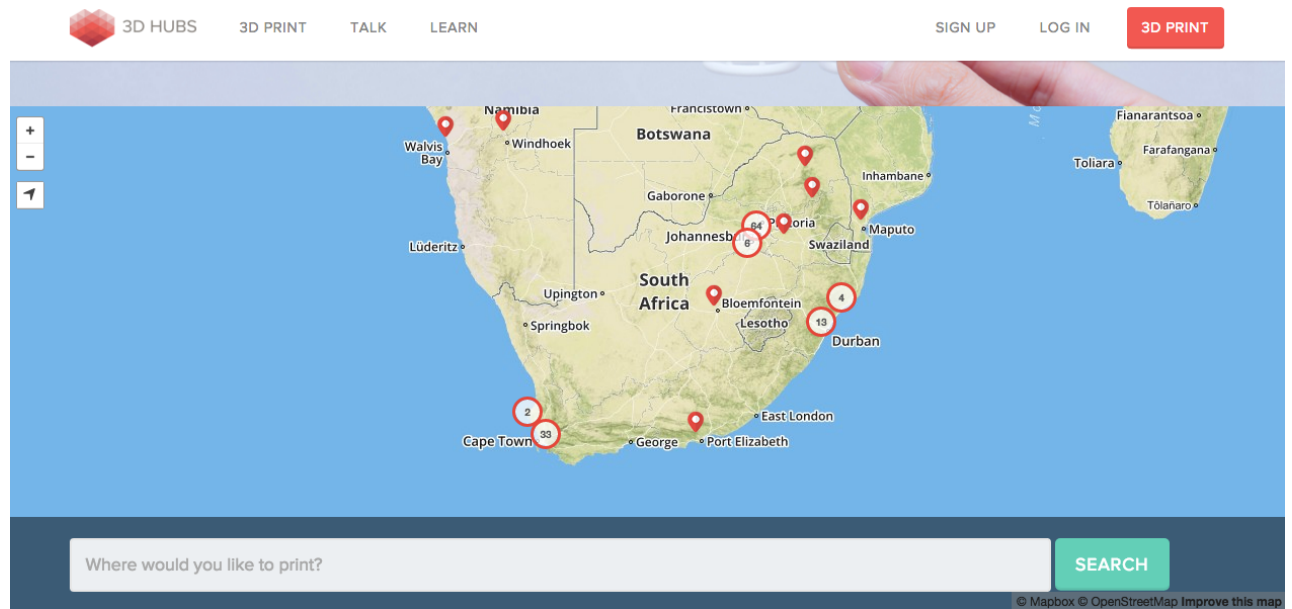
Source: (DST; CSIR 2014, 45)

Appendix 15 3D printing in South Africa (1990-2014)



Source: (DST; CSIR 2014, 30)

Appendix 4 3DHubs in South Africa



Source: (3DHubs 2015)

Appendix 5 The AHRLAC



Figure 17: Locally produced AHRLAC aircraft with some components produced by AM technology

Source: (DST; CSIR 2014, 37)

Transcribed Interviews: 3D printing in South Africa

I. Focus Group Interview (15.08.15) on the Aeroswift Project

Participants:

- Hardus Greyling (Manager, CSIR National Laser Centre)
- Marius Vermeleulen (MV) (Program Manager, Aerosud (AS) ITC)

NB: OK to be recorded but quotations to be approved afterwards.

Martha (M) introduces scope of thesis and why South Africa

MV: Marius here from Aerosud, and Aerosud are actually our industrial partner to develop this high speed large AM system called the Aeroswift Project (ASP) so Marius and his team is actually sharing building space here with us and are sharing the facilities with us.

M: how many are you in the team?

H: as the National Laser Centre (NLC), which is now part of CSIR we are in total 60-65 people but this group is focused on doing three main activities, the first one is laser-based manufacturing R&D, the second looks at laser source development what we call model lasers, new laser sources, and then there is a third group that looks at photonics in the biomedical field. So the ASP is part of the laser based and laser source manufacturing as the development happens both from the viewpoint of how lasers work and are developed as well as the optics of it, so how it is built and set up to operate the beam correctly so the team collaborating on ASP from NLC side there are 15-20 people in total, but it varies. On a full time basis 8-9 people and then as the work changes we bring in more people. And then from the Aerosud (AS) side 9 people or so.

MV: yeah 8 people full time and we also bring in specific colleagues as well.

H: the total I guess is just below 20 on a full time basis

M: we jumped into it right away that's great! [Introducing the structure incl. quotations to be passed by him first]. How did you venture into 3DP?

MV: Marius speaking from the AS ITC (Innovation and Training Center). Historically we were part of AS as a bigger company and AS is a aerospace design and manufacturing company so they produce quite a number of parts for Airbus and Boeing etc for the aerospace industry this includes structural parts, composite parts of the wing, metal parts, aviation racks quite a number of things. We produce 1.4 Mio parts/annum. AS ITC was a separate company that was started initially (7:01) to do development for the main company but has in the meantime moved off as now a separate company completely from main company and AS ITC looks at technology development as more as process development for the aerospace industry. We've got a no of things running. Notably 2 large projects: one is the ASP and then we have the other airplane development program. So we developed a local airplane called ARLAC (advanced high performance lightweight aircraft). You're welcome to google that its another development in this company and these developments actually work very well together because (8:06) we have a new airframe mostly developed by us which we can also use to test new technologies such as the 3D printed parts so we really have quite a number of polymer 3D printed parts on the aircraft and we are planning with the new 3DP machine to produce metal parts for that plane which allows us to early step into the aviation industry and of course then we also have ties with some of the main OEMs as you've read with the Boeing and Airbus with 3D technology and planning to supply into those rooms as well.

M: so they fuel into each other these two projects?

MV: correct

M: and would that be to develop design skills that are on par with let's say Airbus or Boeing or how would that make you a competitive player to these guys?

MV: as part of AS group we are already a design and manufacturer partner Airbus and Boeing. So for example of Airbus 400 AS is already an associated partner being a full design and engineering partner (9:45) with quite a number of

components on that aircraft of large components. So we're already designing for this industry but as you know AM is with a new design space, new rules and yes we are planning and actively look at improving our design skills for AM and ASP is one of the ways in which we do that. (10:14)

H: from our side I've been involved with lasers for many years, we established the NLC in year 2000. It was based on R&D activities that happened previously in the country but focused more on two aspects propulsive laser technologies and on let's call it laser term separation technologies laser based separation technology but in 2000 we set up the NLC with the focus to set up laser technologies for the manufacturing sector and niche areas in terms of laser source development (10:55) so since 2000 we focused a lot of efforts specifically on laser cladding which as you know is a precursor to AM (called indirect deposition technology) since 2000 we've spent a lot of time on developing this and we've actually had to spend a lot of time on developing this so its really market ready and we are in the process of setting up a new company that provide laser based refurbishment services to the industry. And it's interesting that you mentioned Man Diesel and Turbo as they are our largest clients at present (11:33) a part from the power generation utility they are currently our largest client in SA with respect for the refurbishment services. And in 2008 we started thinking about new research and development programs and that was just when AM was really in terms of metal starting to get maturity level that one can start considering developing technology for metal applications so we started the program and at that same time AS approached us with the suggestion to look at (12:11) large area high speed AM systems so the initial concept and idea came from AS and we teamed up from day 1 to develop this technology so since 2008 we've done what we call proof of concept where we basically develop the rudimentary lab demonstrator with very limited funding and the point was that we actually could demonstrate the concept that we had in mind for the ASP technology and with that we successfully demonstrated and took that to our main founding agency the DST and then since 2011 they've basically funded the development of this program and now 4 years into the program and so what we have at present is that we have the machine which we have designed and built from scratch and the first phase of our work is now complete (13:09) which was machine design and construction and then we just passed the development process so the last two years the ASP team when we started building the machine

which is constructed with CSIR, they've moved in with us so we have a full integrated team collaborating with us in this program.

M: CSIR you've been focused on being a technology provider so developing the actual technologies.

H: So CSIR was established by an act of our government 70 years ago and the task we're the primary government funded research laboratory in the country focusing largely on industrial type applications there is a medical research council, a agricultural research council there is human science council and the CSIR is an acronym for the Council for Scientific and Industrial Research (14:19) so the focus is really on working closely with universities but taking technologies to the point where they can be introduced to the industry or vice-verse with industry to develop technology that can improve the competitiveness so as such the CSIR is not into the business of developing products or designing products or offering services that can – we develop technologies to the point that they can transfer this (14:45).

M: you are considering to set up a separate company to launch the technology was that correctly understood?

H: yes so there are reasons for that. One way of commercializing this technology ASP specifically would be to either license it out to an existing company playing in this field, a model which we have for all commercialization activities or alternatively is to set up a new entity that will use the technology for commercial gain and the ASP case we will most likely follow the latter cause we want to (15:30) set this company up so that it is able to serve more than one market. So currently when you think of AS you think of the aerospace industry whereas we from the ASP side and the technology side, our believe is that we will be able to serve more than just the aerospace industry.

M: Which other industries are you considering?

H: defense, transport concerning talks we've had about constructions in large metals for transport industry. I believe automotive industry in the future will also become a player they are not there yet but we do believe that there is potential for

the future. The nice thing about ASP is that it's a large frame machine so it allows to do a little bit of batch processing which is not typically what you will see from conventional AM. (16:30)

MV: in terms of industries of course that is also very typical is space which is fairly typical for AM and then also car and motor generation which is the other industries which are already having quite a lot of activity in terms of refurbishment (16:52) that for ASP is also a viable industry.

M: then the NLC is connected to the technology that you have developed to large scale AM and then Marius on the AS side you are focusing on the design skills – again me trying to contextualize here?

MV: not exactly look at our teams for example. So for our machine development (17:55) some of the base patents were developed by Aerosud and then we are responsible for the design and development of the actual design and hardware of the machine and we also look at the process that actual material process and from the CSIR side there are also process engineers that looks at material actions and they are also responsible for the laser and optics systems so in terms of the doing and manufacturing it's very much an integrated approach for the machine development itself. Of course, we from Aerosud 's side we have direct links to the OEMs in the Aerospace industry so when you get to part design and part manufacture that would be from either the AS side or the new company that will be established and then the machine side its very much a combining approach. (19:02)

M: in the event that a separate company is set up who owns the patent and the royalties is that too early to say or how should that be shared between the NLC and Aerosud?

MV: we of course are fairly busy with our commercialization strategy but I think it's a little bit too early for us to share that bit of information (19:26)

M: presented the Maersk project

Part 2/3 Recording

MV: that is of course one of the things we are trying to address with ASP technology. A number of years back AM of metal became more known and more accepted by a large no of industries and at the AS side we looked at the potential of using AM for the aerospace industry and identified two main limitations: one is part size and one is print speed and the cost of many parts is typically driven by manufacturing speed and that capital investment of that part and that to a large extent is we believe is why AM is so good for as you mentioned low volume high value parts. So one of the things that AS technologies is doing is that we are building parts at much higher production rates which means we reducing the time of printing and therefore reducing the part cost so typically medical and aerospace are the two main industries for this and as you mentioned automotive being at the other end of the scale in terms of this and now with AM the ASP we don't foresee making parts for Volkswagen or any of those companies but the point is that as you increase production rate you start to address different markets which was typically not viable with traditional AM. And if you've got a large bed you can do 200 parts at a time and you can do that at 5-10 times the speed then there is potential for addressing different markets and applications than previously possible with AM (2:48)

M: Airbus said back in 2012 that one of the high level managers at Airbus that the large scale AM was really unique. How would you describe this space in SA? 3DP in general? And SA towards the rest of the world? I mean these are big questions but any top of mind input there?

MV: sure. There is sort of two questions there and one being the collaborative or competitive space in SA and at this point it is highly collaborative space and I think largely because it is so research focused still and a lot of research is happening and the funding is centralized in the research field which is typically much more collaborative scenes and even on industry scale we see quite a bit of that. On the other question on if this technology is mature or young its very difficult to call 3DP mature anywhere in the world, just because it's only 20 years old but I think (4:42) there is very specific niche areas where we have made quite a number of advances in SA where I think we can at least call ourselves mature relative to the rest of the world. I can maybe pull up a few examples one I'm not sure you've seen the website but we have a very mature industry association called

RAPDASA so myself and Hardus are both part of RAPDASA committee but its been around for quite some time now, we are having our 16th annual conference this year which gives you an indication of the amount of or the length of AM in SA – how long it's been around and how long we've seen this technology. Another ex. In SA at the CUT there is a very good research community, a centre for RP and manufacturing. The center has got a wide range of technologies and the center has been around for quite some time and they are doing substantial work in the medical industry to the extent that they have already implanted a number of large facial implants. (6.14)

M: the titanium jaw implant yes

MV: correct, and that is being designed and manufactured implanted all locally so its not new in terms of the ... but there are many players internationally that are already doing that .. the 4 main research centers are CUT as I mentioned, VUT who has quite a number of systems, also Stellenbosch university which have a metal system and doing a lot of work in the tooling industry and then at the CSIR of course there is the ASP but there is also the refurbishment work and even manufacturing in powder blown technology. (7.16) so quite a number of research areas. Also other universities that got smaller competences but these are really the main ones with the main research facilities. Then the amount of investment that goes into this I think is actually fairly substantial specially if you look at the size of SA and the total stream, but the last number of years it is about 30 million USD that is being funded from our government towards AM equipment alone so its fairly large investments for SA in this area. And then there is also a number of projects which you may have read about one of them is Richard van us with the Robohand and RoboBeast which is well known. You might have heard about the Reprap Morgan which was developed by Quentin Harley which is another variation of low cost 3D printers and there is an artist that is doing quite a bit of work in SA called Michaella Janse van Vuuren her work is quite well known and I believe some of her artifacts are in a science museum in London. In general we are a small community but we are focusing on a number of niche areas and I believe in the niche areas we are very well situated for that. (9.09)

M: I think you mention 30 mio USD , I agree that it's a substantial amount and I wonder what's the breakdown between the bottoms up and top down approach if

you want – so how much funding goes into developing industrial capacity and how much into local entrepreneurship. You mentioned this designer and so on.. if you have any thoughts as to where there is more potential?

MV: the biggest portion of this funding comes from the DST which means it's mainly based on research of course there the KPIs are very much focused on human capital development, on job creation, as well as impact on industry and a large portion of that funding is going to research but with those things in mind. Our DTI is more and more becoming involved in this technology as well. We haven't seen large investments from their side up until now but we have developed a roadmap for this technology in SA which we can discuss later, but in that it is clear that a number of these technologies are getting to a maturity level where we believe that we will see quite large investments in industrial funding as well in the future (11.02)

M: investment from the private sector as well?

MV: for sure. There is quite a number of industries involved and I believe the funding is mainly from the industry sector – very little has been funded from the government for those sectors...

H: currently there is not a lot of funding coming from the industrial sector except for the people that play within the lower commercial end side basically using 3DP to set up small companies and so on but with respect to large industrial involvement it is still limited but i think there is a strong push from the government to support R&D and specifically as our DST phrases it industrial led R&D so there is strong emphasis on not funding fundamental R&D but to see that there is a good collaboration with industry and in many cases to ask industry to lead R&D questions. (12.09) also just make one correction regarding the 30 million USD Marius mentioned there is specifically regarding equipment investments and that doesn't talk to funding that was actually invested to establishing capabilities in terms of human capital – so that is only the value of installed equipment of 3DP.

M: and I think this is the big point from an academic point of view the risk when you research the space – is that you need complementary technologies in software,

skills and equipment so only looking at 3DP will really silo the space that you're researching where as you need to take all into account as one is not possible without the other. (13.11). Marius what would you say how do you think 3DP has impacted the role and work that you do now?

MV: if I can answer from an aviation hat of course it's very much different to what you would receive from David in that regards- for us we need to look very closely as manufacturing technologies and aerospace industry has unique challenges in contrast to e.g. automotive – very high value very low volume – so from that perspective alone it make very much sense to do this (14.40) we also have very skilled competencies in people that we require for the manufacturing of aircrafts a lot of parts are being manufacturing yearly and you can't use low skilled labor for that manufacturing because of the stringent qualifications of the aerospace industry so some of the large driver for us is to reduce part count to reduce weight to reduce assembling of parts to get away from assembling hundreds of small parts, to get rid of tooling. If we produce 28 aircrafts a month it means you need a tooling shelf to make 20 small brackets per month and that's very high cost drivers for us. So a lot of advantages that AM has in terms of design freedom I believe plays very well into our hand so that's why we identified the technology fairly early on as a possible (15.51) technology for manufacturing in SA. And for us the issue was really the limitations of what the tech can do and if you have very high cost process it limits the number of applications you have in your business case. If we can reduce the cost of the tech or the manufacturing cost then you increase the number of applications that is viable for AM. (16.19) also I don't see this as a technology that will replace traditional manufacturing technologies but as a very specific additional tool in the box. Another manufacturing tool sometime you cast, sometimes you 3D print whatever the case may be for your application.

M: so that was a bit the technology promise- what would you say is the peril, what you have not seen yet? In terms of risks?

MV: one of the big risks of AM is that you are creating material properties on the fly. If I need to compare this with another technology it would probably be composites where aviation industry has got a fairly big issue: they do a manual lay up and they've got someone that puts resin on the material and it influences the

properties of that material. And if you look at the aviation industry a lot of the manual lay up is being replaced with very costly highly controlled processes for automated layup for making this technology viable. In aerospace terms its called special processes – special processes anywhere where you can influence the material properties and for any such process you need very very tight process control to make sure that the material properties is as you need it and also you need very advanced NDT methods to prove that what you did is according to spec. so I believe that's an area where a lot of attention is being spent globally and I think that is still one of the main barriers for starting to sell parts to Airbus and for metal at least a lot of funding will be spent and we will focus a lot of our attention as well. (18.46)

M: the real time monitoring of the printing process?

MV: that is one part of it yes, but process control in general is a big topic not just

Recording part 3/3

M: We've been going a bit off the script here, but there are two areas that I'd to cover before we end and one is the raw material – and I'd like to hear your thoughts on the SA titanium industry if you think that will play a role in the AM? And the second one is the role of SA on the SSA region of 3DP.

H: so the titanium is obviously part of the success story that's why I think there's a lot of focus from local government to support beneficiation of local resources and we are rightfully quoted the second largest producers in 2015, the US geological survey, of ilumite and til from which the titanium mineral is extracted so the point is that we are not a metal producing industry so it's a real shame and a pity and that's why the government started funding a program to look at new ways to produce titanium metal from this minerals. This program started also about 2010 and roughly at the same scale and level as the ASP is and it sits with a sister division to the NLC another unit within CSIR material science and manufacturing but its also part of a larger network (2:43) and we haven't really talked about networks in AM which exists and I can talk about. Within titanium there is a centre called titanium centre of competence and it really talk to the entire value chain for titanium metal from primary metal production to things like

AM and then to final products, machine vending actually also producing sheet material from the metal side. So these guys similar to us, they have demonstrated proof of concept and they are now busy with setting up a pilot plant they've been at this for 2 years in terms of running tests and I think their target s to produce a couple of kilograms per hour on a continuous basis and once that is done then they will really take this to the next step which is the industrialization of this plant to produce titanium metal. Now I'm not the expert in this field, im coming from the laser and Am perspective. But you could talk to Dawie (send you his contact info).

M: fantastic!

H: the point I raise is that I think we generally believe... because their (4.18) general focus is to reduce the price and develop a process which will produce cheaper titanium metal. That process has been patented and they've been basically use some kind of powdering material pure titanium metal powder and what needs to happen to use that powder is obviously alloying of the powder to make it compatible with requirements of the aerospace industry and we also need to look a the morphology of the powder to ensure that its compatible to AM: but it's very close to what one can use in AM if these questions are addressed so based on the fact that we have a large mineral base that there is a strong intent from government to fund and development of technology in this field I think we are ideally situated to put SA on the map with respect to titanium AM and components made from titanium. (5.12). and hopefully in the next five or six years we should be able to put all these technologies at a maturity level to the point where we can really make an impact on the market. (5.20) the other important element here is vanadium we are also the second largest mining and also very important for tTi 64 and obviously for a couple of our aluminum smelters as well

M: but now you are getting your raw material from the hardware producers?

H: correct so right now we buy from global powder suppliers. Typically we have a couple of powder suppliers we work closely with cause we are still in the R&D phase so we have in certain project and certain areas we work with certain suppliers. Höganäs is one of them yes.

M: mainly foreign?

H: only foreign! There is no local SA powder producer.

M: and also for polymers?

MV: yes at this point it is the case. As you know most of these machine manufacturers actually force you to use raw material from them which in many cases is an interesting business case but that's a different discussion. On the lower end of the machines, the 3DP kits, there are some local producers of material. But very limited. There is potential in SA. We have Sussel which is a very large producer of polymers which has potential for local manufacturing of raw materials but at this state there is really not a lot of attention being put on local production of polymers. As Hardus mentioned (7.09) SA, because of the remoteness, the size of the country we need to make sure we invest in the correct niche areas and not try to do everything.

H: and then you asked the question of our role in the region. That's unfortunately the disappointment I would guess. The problem is that Africa in general is really very underdeveloped with respect to manufacturing technologies so we have very little collaborations with African countries- you can really only call them research collaborations. Part of my responsibility here at the CSIR is to manage a program which we call the African laser center which is a virtual network of research institutions across Africa that would utilize laser based technologies that covers anything from manufacturing to medical applications to remote sensing to agriculture whatever you can think of with this lasering. So the main activity is right in the north of Africa- there is some activity in Egypt and Algeria (8.46) Marocco, Tunesia. SSA is very limited. Some in Kenya which means that opportunities for us to work with AM with SSA is zero. Obviously I hope to see that if Africa becomes more industrially focused and programs are developed to stimulate the manufacturing environment we would be ideally positioned to work closely with the region to show the lead but Africa has really got some unique challenges which is from a manufacturing point of view very difficult to manage. (9.36) so unfortunately there is little happening. Maybe one area where we have something is that SA has very good universities and quite a number of them and BREAK. And typically we fund about 20 students to study at SA universities and

there is very little funding for them apart from the specialized programs from the SA gov. to support outreach into Africa. And I think it is something really want to dearly change but it's a long and difficult road.

M: at Maersk we were interested in the geographical location. What if we could print in Angola and cut customs time?

H: the challenge is not just taking the technology but seeing that the technology is taken care of and actually adopted by the local community and that's the bigger challenge. For us its not really thinking about working on a project in Angola or in Congo doesn't really matter for that sake, the problem is that the partners on that side might take some time to develop to the point where you can work in a fruitful collaboration and that's the challenge. And that's why the African laser center really supports the way we fund projects currently is to support research mobility.

M: the role technology plays to increase absorptive capacity across borders....

H: correct

M: I think we're getting to an end (12.54) unless you have any comments... last points?

H: I think you've touch really on the titanium and importance of local mineral resource and I think I've touched upon the point that there are a lot of things that align quite well here in SA with respect to setting up a very strong value chain for AM. Obviously you must know the economics of the country we are sitting with a huge unemployment rate at the present so I think the government understands that there needs to be strong programs on job creation and any way that you fire the economy is really to ensure that manufacturing industry is built and supported strongly. (14.09) so I think those things plus that we have resources and there is willingness to fund the projects in manufacturing technologies puts us in a very good position so that one can build this technology to really be globally competitive. Then I think Marius mentioned the SA AM technology roadmap and the DST actually commissioned us to develop this road map and the final draft form, there is a version on the RAPDASA websites – look at that. With the

view that we develop a plan with the funding requirements that support AM R&D – industry led R&D. And so we are really lucky that DST is very committed to AM specifically. So I think funding is not the big issue from the technology development point of view as we are also quite fortunate with respect to that. (15.51)

M: very useful. And similar to DTI's action plan.

H: yes to DTI is focused more on how to make industries more efficient, talking about incentives they are interested in elimination of trade barriers and these kind of programs.

MV: I think maybe just from my side who else you should talk to: I mean we have a good general view as we were the main drivers behind the AM roadmap but other people you should speak to are ill put them on email.

- Closing -

2. Interview (18.08.15): With Rapid 3D, integrated local supplier of goods and services in entire GVC of 3DP.

Participant: David Bullock (D), founded Rapid 3D 11 years ago.

Martha (M) introduces scope of thesis and why South Africa

D: South Africa is an interesting case in that we are removed from the global picture in some case but I think we also, we are fairly, advanced in some areas as well.

M: Yes I understand that too and particularly in metal within the aerospace and defense space

D: Yeah

M: Tell me about your background

D: Our Rapid3D story I have along career in Engineering from development point of view, machining and the design aspect as well. I stumbled across 3DP in 2002. We managed to get our first machine and start a small print service and shortly after that we were approached by Zcorp to represent them in South Africa. After some time that relationship has grown and we are continuing the collaboration with 3D systems who acquired Zcorp but also some of the other major machine manufacturers in the 3DP space and on top of that for the past 11 years we have spent a lot of time understanding different technologies, we have accumulated a fleet of machines and also done a lot of work in enabling technologies like 3D scanning, software and we have been fairly lateral in our approach to that in terms of using software and perhaps not always mainstream software in taking different approaches. An interesting ideas obviously ten years ago the level of education in the industry very very low and that has improved dramatically but it is still very much a case of educating people on how the technology can be used, what technology works for what application and so on.

M: What is hard to get capital in the beginning?

D: Yes it was incredibly difficult because people didn't know what we were talking about and thought it was risky. As it's become known it's certainly much easier but, it can still be a challenge in certain areas but it has improved a lot for sure. The South African market is interesting cause there are sectors that have been using the technology for a long time for at least 10 years. So it is really a case about working with those sectors.

M: Which sectors?

D: The jewelry sector in particular was very pioneering in terms of adopting 3D printing for us a good market. And the real difference there is that they use it as a production tool and not as a prototyping tool. And then the medical sector especially some of the universities CUT has really done some amazing work in the medical field with implants etc.

M: Titanium jaw etc.

D: Yes that is the team that I am referring to.

D: And then of course the aerospace industry have interesting projects happening with airbus and the national laser center. That is also quite pioneering in terms of what has been undertaken there.

M: I have interviews for the Aeroswift project. You all seem to know each other?

D: Hehe, I guess that is another interesting thing about the SA space the rapid prototyping associating RAPDASA has been in existence for 15 years this years, I sit on that committee, my wife too, the guys from the aeroswift project, it is quite a small community and pretty much everybody know each other. But we are starting to see other people now, other people who are starting to make an impression now in the SA market.

M: You then touch upon the space – it has been collaborative but maybe changing or what to you think?

D: I think in a lot of ways it has been collaborative, in a way a lot of the universities and a lot of individuals Pr. De Beer for ex. Has been very instrumental in introducing the technology in SA at the universities and that has in a lot of ways helped to kick start the awareness of the use of 3DP and AM. I think that has matured to a point where it now can start to move out of the university into the commercial env. But having said all of that it is still and certainly are, from a Rapid3D we still have a very good relationship with all the unive. And we kind of know all of these people and have a good working relationship with them and supply software, scanners etc to the universities. Having said that, its definitively starting to get more competitive. You know we have other players that are competing. The business sector is much more educated now so you have to compete to get business in terms of business sells and things like that.

M: E.g. CAD House?

D: Yes. In the SA context its quite interesting cause we ended up with 3D systems via Zcorp and they did directly with 3Dsystems and ended up with Zcorp as well. There are two of us, and if it hadn't happened that way, the market size is probably not really big enough to necessarily support two resellers at this stage. We tend to be in slightly different sectors but there definitively is some competition from a 3Dsystems point of view but we have other equipment where we have exclusivity to the south African market.

M: Can you tell me a bit about your business model?

D: Our main value/differentiators is technical drivers (we're all engineers) and have always taken a lot of time and pride in understanding the technology and being able to use it effectively and through that be able to provide really good technical support and provide solutions in terms of technology to recommend the right 3D printing tech for the right application. The market is starting to become a bit more discerning but in the earlier days that definitively wasn't the case and even with different manufacturers, everybody was trying to prove that their particular technology was the be and or (the only one) and that obviously isn't the case there are definitively different technologies that work in different applications.

M: So it's about understanding what technology works for what purpose?

D: Yeah exactly and a solution we consider ourselves to be solutions providers rather than just boxmovers. Having the understanding for the right tool for the job (16:48).

And that you also are providing enabling technologies like software – could you talk about the Geomagic and the software in general?

D: Geomagic was acquired by 3Dsystems and has been around for a long time specifically designed to deal with 3D scan data and also into the reverse engineering and the design base and also some really interesting tools that use heptic devices and also use a voxel based engine which is a very good peering with 3DP because you basically are guaranteed a printable model. Yeah so geomagic is a really interesting product range, and we use that extensively for our scanning service.

M: So it's a full package solution couple with the hardware?

D: Yes for some applications but not all of them, some of them are coupled with scanners but primarily it's a software offering.

M: Could you describe your relationship with e.g. 3Dsystems? How you collaborate as a distributor?

D: OK so we are one of two companies representing them, in SA. We have reseller agreement with them and what that means is that we have access to their product range. What that requires in a lot of cases is that we have to have and operate demo equipment and obviously to be trained and certified on their equipment. The relationship is not exclusive but it's fairly typical of that type of relationship in the industry. In the personal and professional range of printers we are the first line of support so if we sell a piece of equipment we do the installation the tech support, the service etc. we obviously have back up for the 3D systems service team. And then on the production machines it's a more of a partnership arrangement where the direct support comes from 3D systems so we kind of just enable that in SA. The thing about the SA market is that we are so far from everywhere that it's difficult for anybody to operate without some sort of presence locally.

M: So they have to give up some level of control with local distributors like yourself?

D: Yes

M: I remember from your portfolio that you have "personal" "professional" "production" categories. Could you talk a bit about that? Maybe where you have the most business?

D: If you look at our history, we've come out of the professional space so what we consider professional printers are typically desktop printers less than USD 5K and we do those machines but tend to sell them into professional kind of space to engineers, design officers, sort of freelance designers. We don't really focus on the

home market. Professional machines tend to be loosely class. As mid range machines, we don't really put a price point on that but that would cover everything from concept modeling, prototyping, certainly in the jewelry space you could classify as production machines as well. Although price wise we rate them as professional. And then production machines is the high range stuff SLA machines etc. and here the SA market is very very new. We are starting to see more and more interest in this kind of sector where people are starting to look at laser sintered machines and direct metal machines as full production tools but that is very young market and that is where the growth is gonna come from but its still early days.

M: So you're starting to talk here opportunities, what would drive that opportunity?

D: I think the things that drive those opp. Are the call for short run production people wanting to do more and more customized components, lots of people that are entering markets where previously there were large barriers of entry because you had to tool up to make a particular product and obviously with AM that takes this need away. So there's def. opp there and there are opp. In the medical space, direct metal, the SA era, the aviation sector is small in SA. Very specialized and I don't really see too much opportunity there. I do see opportunity in the more traditional tooling areas traditional machining shops and basically just moving away from mass production to mass customization.

M: Locally or globally?

D: Those drivers I would say are true globally, and in SA we probably lag a bit you know behind places like Europa and the states but they still apply and there are niche sectors like I mentioned jewelry and another one which is really interesting is the hearing protection, as well as dental are starting to show quite a lot of interest but the real opp is moving into production and manufacturing as opposed to consumer market.

M: It seem that the hype around the hobby printers, home printing is a bit further away than the more heavy industry/ cap intensive industry. And I recently saw

that you were a speaker at the FESPA conf on printing in Africa. Can you talk a bit about that and the role SA has in 3DP for the continent? If any?

D: Yes that was really a 2d print conf and was part of our efforts in terms of education. we see a lot of opportunity in the rest of the continent, a lot of countries north of us that are very keen on getting into the technology and tend to look south to do that so we do have initiatives to move into those areas. We already service places like Zimbabwe, Mauritius, Botswana, Kenya.

M: With hardware or as a service bureau?

D: We do have some equipment in those areas but definitively starting to see more interest and from a manufactures point of view its much easier to deal with a route that is through us and that's what tends to happen.

M: How many systems installed in the region? Who would I talk to?

D: Good question, know that Prof De beer would know. He keeps track on this, not sure how updated but he tends to this exercise every year for the Rapdasa conference. He's probably the best place to go to get those numbers.

D: Good to know.

M: OK, so tell me about your raw material?

D: It's all imported. All coming from, pretty much without exception all are proprietary so they all come from the manufacturers.

M: Do you think that SA has a chance in terms of beneficiaries in e.g. titanium. Do you think there's a market for that?

D: Probably a bit too early. There are in the hobby market there are some guys that re making filament but in terms of powder and polymers I think its way off. I don't really see that happening, not enough machines in the country at this stage to support this business.

Break. (phone rings)

M: Two closing questions: who you think are the key actors both public and private? And then what are the risk for 3DP in SA?

D: There is quite a lot of activity from a government point of view to try to drive the technology and there are initiatives specifically focused on advanced manufacturing and so the projects like Aeroswift project where they are combining a whole lot of things like titanium and try to leverage our expertise and our resources in that kind of area and they are definitely are hectors and the government departments of science and technology is a guy there Garth Williams who is very involved in those. Then the Aeroswift project you have. In terms of academic Gerry Boysen, Johann Els, Rapid3D is a fairly significant player as a print service so we are I would say amongst the top 3 resellers and certainly after the CUT the biggest commercial print service in SA. Having said that we are nowhere close to the scale like Shapeways but we have a reasonably size in terms of range and technologies. And then I should probably also mention the jewelry industry and there the Jewelry council of SA is important and the industry as a whole having really embraced the technology. So if you are to identify an industry sector which has the largest number of equipment installed that probably would be the jewelry sector in the SA context. "

M: That is so interesting for me as I've gotten across it but it hasn't gotten that much attention and is one of the key take aways for me here.

D: Yeah they tend to fly under the radar and it's probably because it's not about 3D printing it's about the product and the jewelry and that's what it's supposed to be in my opinion. I think that's probably a fair summary. I'll drop you a mail if I think of something else.

M: But I think you're spot on here and in a way it make a lot of sense with the jewelry having a lot of precious metals and so on in SA.

D: Yeah it makes sense

M: Academically I look at so called GVC which are focused on how value is distributed and it's quite tricky to get a hold of how value flows profits etc. its quite hard to find business cases.

D: Just to talk a bit around that a bit more there are a lot of jewelers world wide that employ design skills world wide and a lot of SA manufacturing jewelers obviously use a lot of local design skills but they also use a lot of global skills located elsewhere they might be in India, the states or Thailand and then that design moves and get brought to life in SA (38:05). And in a lot of cases there are SA design that goes into basically designed around diamonds and jewels and a lot of that stuff goes into the Chinese market and a lot of these things is enabled but the 3D printing technology.

M: So you're saying that there's more designers globally that can take part in this place and then the end customer is also global you mentioned China for e.g.? And so SA having the raw materials both the gold maybe but particularly precious stones it's like a manufacturing hub?

D: Yeah absolutely. I mean its not as big as it should be and that's another government initiative to try to boost that and take advantage of those local researches so yeah that's another player in the game in terms of getting added value to the precious metals and actually creating jewelry rather than just exporting gold or platinum or whatever the case is.

M: And how would they do that is that about the local expertise in terms of the software as a designer or?

D: Yeah absolutely I mean jewelry is very very creative and it's about expertise but not only that it's about style and you know design and I think we have some world-class jewelers and artists. One guy I can think of, almost the entire line of products is exported and the 3D printing story is there: it's definitively an enabler and it allows these guys to do all sorts of things that 10-15 years ago would have been practically impossible.

M: Do you have someone there you think I should talk to?

D: There are a couple of guys in the jewelry space that would be interesting to talk to: Andrew Stevens, Chris van Rensburg who is the current chairman of the jewelry council. Talk to them as my perspective is specifically as a supplier of 3D printing.

M: Final question: what do you think are the risks for 3DP in SA; we talked about the role of government, also the role of accessing capital?

D: I think there are lots of general business risks that apply to any general business situation but from a 3D printing point of view, one of the biggest risks for people getting into 3DP is the lack of understanding and that is very closely linked to the media hype. The hype tends to be very very misleading and you know people put things into a box and make all sorts of assumptions based in a hype. This can be a real risk from a business point of view and we see it. People going into something only to realize that they didn't really understand the costs involved, the materials, the technology and then ended up with something that wasn't really fit for purpose or really didn't make a good business case and that was basically all due to the hype or misunderstanding really.

M: So the general hype that its' plug and play etc. I've crossed upon that from my work too that the hype helps to demystify but then there's the other side of the coin too. And it comes down to your first point mentioned at the start of the interview – the importance for education. So what are your next steps at Rapid3D?

D: We have recently in the last 6 months to a year we have partnered, basically created a new company with some share holders that were quite a lot bigger than we were and so we have expanded our footprint quite a lot and are working hard to build our team to transfer skills etc. from our experience. That's a big part of what we're busy with now to take it to the next level and also to decide and work on focusing on particular areas where the business case for AM and 3DP makes business sense. So to continue with our basic philosophy but stepping it up a notch.

M: I really look forward following you guys in the next couple of months and I myself hope to stay in this space after the thesis too.

- closing -

Offering to send the case to David Bullock who is interested in receiving the same.

3. Interview (26.08.15): Participant in the local maker space as Mayor of NL platform 3DHubs in Johannesburg, Designer and Founder of Trobok Toys (3D printed toys), Education Service provider of 3DP and Founder of African Robot.

Participant: Rick Treweek

Martha (M) introduces scope of thesis and why South Africa

M: How did you journey into 3DP?

Rick (R): I was living in Singapore for 8 years and move there initially to develop mobile games ten or so years ago and in SA at that time developing mobiles games was completely an alien thing so what happened is that we were one of the first guys to develop flash light games which was Adobe software for mobile and we made a game just for fun and that took off and went all over the world and because of that Adobe asked us to talk about their software at their conferences and the last one was in Singapore and there we realized that everyone was already playing games on their phones and people were really asking intelligent questions that weren't used to hearing. So we ended up doing a big project there and long story short we ended up getting funding for our project and all that but then... what I have always love to do is character design, I ve always loved drawing and made little characters and stuff and when developing games I used to get off the computer to develop these little characters in clay – to use my hands (3:15) and not be starting out the whole time. And then I saw a little add on the internet for the little Makerbot replicator 1 and it had a little toy car, rabbit and so on and that got me into buying my first 3D printing. The idea that I could actually draw my stuff from the computer! And through that I started playing around and because of my

gaming and character past I started designing a lot and I did a little character for free that I put up on Thingiverse and Ultimaker got a hold of this model and they printed a little character on their Ultimaker. And then I got a hold of them cause I was blown away by the quality of the print and through that I got a relationship with ultimaker and they sent me free machine in exchange for little toys set I did with them. And that's how I've funded my self with the printing. Same in Singapore I did a little mascot for them cause every time they were at a trade show or something so for them to be able to print out a toy with there logo and website on it was huge and they also gave me a printer in exchange for doing that for them.

M: have you also done the Marvin mascot for 3Dhubs?

R: no, but with 3Dhubs I'm the Johannesburg mayor. I think SA and Africa in general was pretty much off the map, they knew me through my work online and when I chatted with them they were quite surprised that I was from SA. That's how we started and just a year ago we were 5 listed in J-burg and now we are like 40 people. So just in a year (6:17) it's really started to pick up a lot.

M: in SA in general if you look at the 3Dhubs map there is around 80 hubs. And if you look at the rest of SSA there is basically nothing why do you think that is?

R: SA is definitively more technology advanced. We have a stronger economy and out of everywhere in SSA, SA is definitively more on the map in that sense with a lot of international business and J-burg is a hub for a lot of African countries. There have been some interesting stories of guys building their own 3Dprinters from ewaste that gets sent out there to get stripped out. In essence a lot of the guys can't afford their printers and if you look at a printer which is about 2000dollars when you convert that for SA rands and have to pay for your shipping and customs its actually a very expensive thing for your average person to get into.

M: Makerbot recently opened a distributing channel last year.

R: yeah so they have but I think that because of this isolation, innovation and the hardware development of 3DP is really picking up. Guys are making machines, which is very cool. (8.20)

M: so you are talking about local development of actual hardware?

R: yeah.

M: still FDM tech? Or do you refer to the CSIR large-scale titanium printer?

R: Still FDM but also I think myself and a few others, FDM for SA and SSA is quite a still important thing because of the usage cost. Like I was saying how expensive it is to print especially as you start buying material. Material costs at the moment and other technologies are still too expensive for the general person to use. The printers that are being developed are FDM but guys are looking at scale here. We are looking at China here with what happens with the big 3D printers but still sticking with FDM cause that is more accessible to everyone. (9:47)

M: so yeah when you're talking about costs- what do you think is the high level cost benefit analysis of 3DP? Opportunities v. risks

R: What do you mean?

M: well for you I understand there are a lot of opportunities presented because of your history with the gaming industry and you have a designing background and it seems that the opportunities for you are quite evident but do you think there are other opportunities and for whom? So a bit open question here – I just want to hear you sort of

R: I think again the big opportunities are in this unknown space that is happening. We see like the big bridge in Amsterdam or the big houses in China. I think the big opportunities here are looking at the housing market.. And stories like there 's this guy living in a village he has all this e-waste but for him to get basic items is a mission, he doesn't have a car transport so for him to get to a local (11:09) village where they sell plates or something like that is an absolute mission, whereas if he bought his own 3D printer and started printing functional stuff for his village and that's important. Africa is such a big place and you have so much rural areas and I think the opp. can come especially in the housing sector cause we have so many people that are in need of (11:39) housing so I think its about looking at this and about looking at new ways of construction and 3DP is opening those

channels. Not saying the technology is ready yet but for me what is really exciting longer term is that we can actually start doing things that have never been done before only through 3DP as a method. Same with what they do with the space station where a tool goes missing and they need another tool. Pretty similar here because we are completely isolated from the rest of the world and the problem is that when we want to get stuff in an item might cost you 40 dollars but its going to cost another 40 dollars just in shipping alone. The idea of 3DP that we don't actually need to post stuff anymore – I'm really interested in that aspect. And I explore that through my toys and characters because (12:41) it's a way to get to know the technology. It's the same with the games, I've always been interested in the technology in itself but we used games to explore the technology. So by getting the younger generation here into technology I use toys and characters to break down boundaries so kids will see the toys and get all excited about the toys but then that opens up the introduction like "OK this was actually produced on a machine and you can design it on your computer" – it's a great way with makerfairs to start engaging with the younger generation so its not a big boundary between tech and someone who think the don't understand.

M: I really like that description cause when I talk to the industrial side – 3DP is just a tool, functionalistic view of the technology. For them it's a tool to work with an industry they are passionate about and for you it's the other way around – you are passionate about the technology and for you the industry and the subject is just a tool for you to explore the technology further. So it's really the other way around.

R: Exactly!

M: so what do you see actually happening? I can only come from the outside, reading all these sucesstories but hard for me to get to the field... so what is happening and what are the challenges to get to this grand vision like you are saying of the "Democracy of manufacturing movement"? (14:24)

R: I think it goes hand in hand with what is happening with the maker movement in the grander scale especially in S. Africa. We have a serious problem with education; our education is amongst the bottom in the world so with 3DP in my head I clump it into the maker movement with this new way of learning and

reaching people. For us the important thing is accessibility to 3DP, to YouTube, to things like that because we have maker spaces in our main cities and people could potentially get there but the majority of the people and the majority of the education where it really needs to matter is out in the rural areas. And its really tricky for these people to get the cities and I think where this is going and where this excites me is for example getting a mobile maker space together. So actually creating a maker space on wheels that you can actually drive around to different rural areas, show these kids and get them that experience and then for me it's the idea of the way we teach has completely changed. If you can get a kid excited about something they will teach themselves so its more about getting someone excited and then say OK he has the tools – here is how you search YouTube 16:10. And the he has the toolbox to really teach himself. Going back to the toy idea: if you show a kid a Spiderman – and get him excited about that and then with that excitement you need to kind of ride on. On a bigger picture in SA I think the opp. With the maker movement has big opportunity in that sector (education) and where I think it's really going to change and people realizing that you don't have to spend a fortune on traditional education and things like that because the opportunities the internet has brought with YouTube and things like that – the teachers are out there but the problem is access to that – getting people in from of the internet to experience YouTube, or in front of a 3D printer.

M: Whom would you target to enable access?

R: I think for us it's about going to the people. Even if we created a maker space that is totally free, the fact that they have to get from a rural village hours out, to the cities causes all these things so it really is about getting the big corporate sponsors and stuff that can actually help us with this idea – physically building these busses and taking them where they need to go as opposed to going to market an all of that because again the people in the rural areas – its impossible to reach that audience. But with these busses you can set up like pop up mini universities and through that you might go through 500 people and you might identify one person that is really into it and he would go back to his community and hopefully that would cause a snowball effect. That is the general idea at least (18:58)

M: I read there is a lot of public funding especially to the big universities how is public funding to a guy like you? Like how do you fund yourself?

R: I think that's the big problems here and something we've identified quite quickly that you have these traditional education systems that have build up their network where they have access to money and funds but the problem that is happening here is that you get a university that hears about 3D printing and they go buy a 1M rand 3D printer but then none knows how to use it. So what happens is that someone will use it and then the next thing it becomes a white horse – its broken and none knows how to fix it. So there is access to funds but the guys that can get it don't understand and cant adapt quick enough to adopt new technologies of 3DP and look holistically at 3DP to see how it could be used. So that's what we are looking at the moment. Guys that have a lot of funding, they build innovation labs that are open to everyone but none actually comes because there is none there that uses the equipment, know how to fix the equipment when it breaks, and on the flip side of it – me as an individual its very hard to go out and get funding from our government unless you have a big track record, unless you are a big corporation (20:52). But again the problem with the big corporates is that they don't understand you have to be so interested and involved in the technology. They know they have to use the technology that they are given, that they have to spend money on innovation but the thing is that they don't actually really know what they are doing with that money – just ends up being a bit of a waste.

M: guys like 3D hubs are quite important then to ensure access, which you are talking so much about? And then maybe foreign actors are s important if not more than local actors in ensuring access?

R: yeah. And I think that's the thing with local things- like the robohand project. That was actually started by a South Africa Rich van Us, and then makerbot picked this up. And they sent him a free 3D printer and for them being these americans they were like yeah we're supporting Africa. But it wasn't free. (22:43) By the time it had landed on his desk he had to pay the shipping costs, customs and that ended up being the same amount as it costs to buy the 3Dp! So it's really quite tricky in those scenarios. I also recently won a 3Dprinter in a design competition but it cost me 5000Rand just to get it in the country. I was lucky enough to spend that money but I asked the customs what happens when

someone who can't afford it is in the community and wins something there is no way he can get the printer here.

M: the local technology . I'm starting to understand the business case for developing local FDM technology. How far long is that?

R: it's flying! So the same guy who did the robohand now built the printer called the robobeast and it's built for Africa – strong and rigid. You can throw it on the back of the truck and for the maker fair he latterly drove it from J-burg all the way from cape town. He threw the printer on his truck and it was literally bouncing around. What he also is doing is adding battery packs and solar panels because we have this thing here called “Load shedding” (?!?!?) (24:36) so every now and then our government will completely cut our power and for two hours none in the country has power cause there is not enough power for the country. So someone like Rich is quite far ahead now and even exploring bigger volume stuff now because to actually start to make actual functional stuff a chair for example, or doing more his prosthetics he is looking at bigger build volume but still FDM technology.

M: and I also heard about local filament?

R: yeah the filament factory. And already since returning last year I have had three companies approaching me as traditional plastic manufacturers and they have been asking me about printing and stuff and I think its going to pick up really quickly. Most people here have heard about 3DP (26:02) but when I arrive a year ago none had heard about it And with the maker fair now this year suddenly you have a lot of the public has been exposed to it and I think its going to start snowballing in a big way. And I think not just 3DP but the maker movement in SA really needs this new way at looking at education. With our corruption, the old system doesn't work and I think people are really looking at new ways to improve education systems here and I think the whole democratization of manufacturing, the whole maker movement, shared economy idea is very exciting for a place like South Africa. (27:01)

M: just to go back to the plastic manufacturers that had reached out – were they SA suppliers?

R: yes, these are guys that are traditionally in the plastics industry and that are creating material for bottling plants and they are thinking that maybe its an idea to start creating filament to sell locally. So the filament factory seem to be the only one at the moment but I think a lot of guys are starting to look at it now. The same thing with the hardware, when I was here originally there were only a couple of guys selling printers but now from the maker fair, it was amazing how many guys are starting to distribute and sell locally. So in only one year it's really amazing (27:55)

M: tell me more about the Maker fair then!

R: initially last year we had this thing called maker fair Africa which wasn't officially part of maker fair (makerfair magazine) and it was the first time there was an event for makers to attend and there were makers that attended but there was really zero attention from the public. It was a bunch of makers standing around and none came from the public cause the marketing was really bad. So then Makerfair came and everyone was burned the first time around thought "ah it's going to those typical Americans coming to Africa and have no idea of what's going on" so we didn't expect much in terms of turnaround. But it was fantastic and I think we had around 4000 people turning up! And for our first time it was amazing – a lot of kids, a lot of schools and a lot of public from all kinds of walks of life. It's very hard to pinpoint who the majority of that was. But it was interesting that a lot of guys at the show were selling 3D printers and redistributing printers so we had all the SA 3DP companies in SA at the same time. quite a few crafts and stuff – but there was a lot of 3DP – almost too many printers. But a lot of them came from the business side trying to get into the space – not only makers per se. So amazing to see so many. And when I say many I mean around 4 but it's a lot for SA.

M: which hat did you wear?

R: I took completely all my business hats off and was there as Trobok Toys – so not selling anything – I had a tiny display of my toys and it was a way to start

talking to people about the technology when they approached me. Giving away little prints to little kids who got really excited about 3DP. And seeing the kids get so excited when they walk away with their first print is quite special.

M: when I got my first Malvin I got super excited too and I m not a kid so I get that! But did you try to sell African Robot then as a company?

R: the reason that I started African Robot – I started trobok toys just (31:40) just as a passion brand and it still very much is and then moving back to SA, if you talk about toys here – there is really no toy culture. When you say toys they are like “oh kids” whereas in Asia toys are part of adult life and is art. So for me I was getting really tired living in Asia they asked where I was from and I said SA they asked “so how did you get there”. They think we still live in caves, run around barefoot so for me because I was quite known through Trobok Toys I wanted to call myself African Robot to show people that “look I’m from Africa but I’m just as tech as anyone using the internet”. I think South Africans also have this mindset that whatever happens overseas it takes 2-3 years before it comes to SA (32:51). And that is what we want to change here through the makers here cause we have amazing technology I mean if you look at a lot of the big things : Elon Musk was a South African, a lot of development that you wouldn’t know are from South Africans and I think from an international level I think people have a very big misconception about SA -they think we have Lions running around and stuff. So for me African Robots was to keep Trobok Toys purely as a toy character brand but I wanted to still engage corporates, doing things like hackathons, workshops so I started that as a brand that could be more generic. Still evolved around 3DP and stuff but still let me keep Trobok Toys as a passion project untouched by the corporate world (33:50). As it does have a way of poisoning your passion

M: so your saying that your customers at African Robot are mostly form the corporate world?

R: we have been working with the banks – doing hackathons and idea generations with them. Doing a lot with schools and talks at schools. Just showing people that 3DP does not only exist overseas. Its about showing people that is exists right here, on their doorstep, its affordable and not this crazy mysterious thing out there. But yeah – mostly money wise its coproates doing consulting, banking but

then a lot of the work that isn't monetization is doing work at schools. (34:56) and just generally spreading the word about the maker movement.

M: Love when the corporates all of the sudden want to have hackathons! What's in it for the banking industry?

R: they've started to realize that they need to just inspire their workers a bit more. and what we do is internal showcase days. And because they are so huge they'll have these showcase days where people can come and meet and talk with other bank people. And we'll come in as outsiders with 3D printers – and when you've never seen a 3D printer before it's really exciting. They feel like they are being all cool and hip, and up to date with tech. so their employees should feel inspired when they go back to work to start creating. So the banks realize that people need to have fun and instead of being boxed up and sitting in front of a computer all day – they show here that they are interested of what is going on outside in the world of tech (36:44). It does lead to potential client jobs as well for us. I have found the case of three banks here already that all have these super expensive 3D printers and none is using them and then they hire me to do 3D printing for them. They have these 3D printing machines sitting in their warehouse but none knows how to use them.

M: I talked to David Bullock for Rapid3D and he mentioned how hard it was for him to get capital in the beginning. Maybe what you are doing with the banking sectors helps demystify the technology and get people better access to capital?

R: yeah I definitely think that has a big part cause a lot of the people here they think of 3DP and they think it's science fiction, exists overseas and they're not going to research it further. Whereas what we are doing a talk or a workshop is to show that it's here!. They see that it's this little machine that melt plastics into products. And once they see that they see potential. (38:29) and that definitely helps grow the industry here.

M: Closing question here – what are your next steps?

R: so that's a big thing for me at the moment having these different ideas – not sitting on only one. So I don't want to do the mistake of jumping into something.

I do believe that the right way forward hasn't shown itself just yet. But what I am working hard towards with Trobok, African Robots everything kind of comes together in the maker movement. So especially with this mobile maker space not only in SA – but taking it through Africa, show people that it is possible and changing the nature of education in this country. (40:02) because we have so much potential but unfortunately our government, our currency and the data costs are completely killing us so the only way for us to grow as SA is to reinvent what people think education is and I think the maker movement and other disruptive technologies is the only way to win that fight. 40:39. So all that we do in the bigger picture, getting together as makers, making these events, making people realize that they don't have to have a corporate 9-5 job... but I'll always make characters one way or another whether it is monetized or not- its important to keep that creative flow going no matter how exciting your thing is – as soon as money gets into the picture it gets less fun and it changes completely. It's tainted by old school money

M: you are clever in that sense in keeping Troybok 'free' 41:39

R: I've learned that from the games yes.

M: Just before leaving here – what do you think 3D printing has done for the gaming industry?

R: I don't think its done anything super phenomenal at the moment little things like people making little characters of their avatars that they have created themselves as all very cool but I rather like to see what 3DP will do to toys, collectibles and merchandizing (42:57). For example our last game we developed – at each level you win a 3Dprinted toy when you reached it and for us to merchandise our game its quite a cost to create these merchandized items so with 3DP its like you almost create merchandize but you don't have to spend actually money on it and I think going down the line I think its going to have a huge impact on games. You know you like download a phone game and little phone case comes with that game that you can put on your phone that actually ahs your character on it. also for board games like monopoly just being able to customize the look and feel of the game that you bought. (44:04). It's that customization that is going to be unique and special for the gaming world.

M: interesting!! Look forward to follow it! what do you think of 3D hub's strategy to get corporates on board like Nike to reach the mainstream and not myself sure they are going to succeed...

R: I know what you mean but I am myself quite surprised in the attitude of corporates who are starting to realize that individuals have the power to create themselves. I really believe that the days of having huge advertising agencies or huge corporates is over. It still needs to happen but the way these people work are no longer, its no longer about boss and employee it really needs to be about a team and people enjoying what they are doing. People are starting to wake up to that in the corporate world and things are happening real fast.... Education can't even write curriculum about 3DP cause it's happening so fast that by the time the curriculum is approved its already old school (46:27). It's almost like you need to be small and agile to network with someone that is small and agile with complementary capabilities to get a head of the game. So the building arm at the moment is actually backed by university and they have the foresight to see that it is happening, they can see that it is moving so quickly so they just need to expose their students to it but they cant themselves actually create a printing lab. They are slowly realizing this that there are so many people like us wanting to do stuff and looking for funding and before there was no way we would get funding cause they would be like "oh you're not a big corporate what are you going to do" but I think that money is better spend with small groups of people that know what they are doing with that money instead of creating these giant white horse things that none uses. You can't depend on schoolbook mentality because the rules change and you need to be flexible enough to be able to dot those changes. But not everyone likes change – many people are scared of it but I think again it's about changing the perception of people. (48:58)

M: closing

4. Interview (1.09.15): Ti Pilot Plant (CSIR)

Participant: Dr. Dawie van Vuuren, Director Ti Pilot Plant (CSIR)

Martha (M) introduces scope of thesis and why South Africa

M: What is the impact if any of AM on the titanium market of South Africa?

D: at the moment the titanium market in SA is really from the metal side we produce a lot of the metal and we extract about 30% of the mineral in SA, we're the 2nd largest producer of the mineral. As far as the metal is concerned, we don't produce it ourselves but import the metal that we in hand use in special applications. Especially in the pure alcoline industry and I think there is some used in the platinum industry as well to extract platinum in the chemical process. so we don't make the metal we only go to beneficiated slack that we export. The vision that we have is that we want to establish a titanium metal industry in SA and the metal industry should cover the production of metal and also the fabrication of downstream products from the metal, of which AM is one of the markets. The other markets is to go into molding products from powder which is not an AM application. It's a different technology.

M: a more traditional technology?

D: yeah so the AM market is in our horizon but that's on the downstream side, but we also have colleagues that work on the downstream side and work upstream. And I am working upstream and going downstream. So on the downstream side we have people that work on the aerospace industry and you spoke to Hardus Greyling from the aeroswift project and so hopefully in some time in the future the two ends will meet. But that is in the longer term and not the shorter term. Which will probable be on the 5-10 year horizon. This is when I talk about it commercially (4:07). When we talk about research, we are talking already. My responsibility is to produce Ti metal in powder form so we are talking to each other to make sure that eventually the powder we produce might be applied in AM as well, there are 2 problems to do that: 1) the morphology of the powder (for most AM processes you need spherical powder and we procure angular powder so there is some work we do to spherinize the powder) . the other obstacle 2) is that for the aerospace you need pre alloyed powder and mostly titanium 6 aluminum acium. We are at this stage only looking at pure titanium powder and not the alloy but its on the horizon to further down the line look at pre-alloyed powder as well. But still a lot that has to be done. So that's' the kind of gap between the upstream

work that I am doing and the downstream work that they are doing in the Ti market.

So currently people in SA that work with AM with Ti are basically using imported Ti powder and then they produce specialty components (5:49) with it and you are going to speak to Willie who is the correct person to speak to with regards to that.

M: let's go a back to the upstream segment then- How does the industry look in SA for Ti? Private vs. Public? Foreign vs. Local? And how does your research affect that space if at all?

D: OK so the upstream mineral extraction and mineral beneficiation belongs to the private sector and there are basically 2 companies doing this the one is Exato which is part of Tronox which is an international company and the other company is Richard's bay mineral and both these companies are large international companies. On the metal side, the metal and not the AM (here we import it and its basically traders that import the Ti products and distribute locally. The market is really small and it's specially for special applications (7:38)). However on the development of the Ti metal industry it is the government that are taking the lead and it's the government that are stimulating the downstream Ti metal industry in SA there is private sector interest in it specially you've spoke to Hardus Greyling, there's Aerosud. On the other side we do have potential commercial partners but Im unable to disclose any names because there are no formal partnership agreements in place yet.

M: I understand that when in this research phase, it's a very collaborative space still.

D: yes . when you speak to Willie, they manufacture specially for the medical industry, implants for patients that need it and that is done on a semi commercial basis. But I do believe that the patients that receive these implants cannot afford it. at the end of the day its really the government that funds it 9:08. But its real parts that are being used and real people getting the benefits from

M: the Ti jaw for example?. My perspective is industrial upgrading a concept that we use in Political economy and the central element here is to look at change and when you have a government initiative such as the CSIR investing in the metal side of the TI industry, what would you say that change implies – does it imply a significant change to the status quo? The market players? Impact?

D: Well, eventually the private sector would have to take it over. The different government bodies and the work that they have done is not structured to do commercial operation so somewhere down the line there would have to be commercial investors and it has to be privatized. This is my view about it. but currently the both the technical and the financial sector to do it is simply too large for the private sector to accept in SA. And that's why the government is stimulating it but eventually the idea is to hand it over in some sort of way. (10:53)

M: would you have an idea of what the size of the investment is for Ti?

D: for the research or for commercial investment?

M: overall?

D. Not sure, the funding is in the form of different projects. But I would take a guess that it is around 2-3M dollars per year for Ti projects.

M: this is not to quote you here , its' more for my intuition here. What are your thoughts on the opportunities long term? And who would take over the commercialization?

D: the objective is to stimulate our industry, our manufacturing industry cause there is a need for earning foreign revenue and for creating jobs for our people in SA has a large no of people, 30% without work and that creates all sort of problems so a lot of the work that the project is stimulating is with the objective of establishing economic activity and to create work and not just manual labor but high skilled labor for our work. And we don't see a large no of jobs coming out of the Ti production side, cause that is capitalist intensive in nature (13:49) but if we can establish a manufacturing industry where AM comes in, there are a lot more

people employed in that kind of activities than in the bulk commodity side of the Ti Industry.

M: so it's not to only look at Ti per se, but the spillovers to manufacturing. Willie talks though of 700-950 people, what would you say about that?

D: I haven't looked at the downstream side of things so not sure. But I have looked at the upstream side of it and here we are only talking of hundreds and not thousands.

M: what do you think are the enabling institutions needed for the objectives to be met? E.g. human capacities needed, risks over all.

D: Good question and I would need to shoot off the hip. There's a lot of work with do with R&D but that is mostly lets say scientist and engineers on the academic level but once you start building factories you need different skills. Now there are people that can run factories but they are not involved, we need operators, technologists and technicians and to some extent we are not giving enough attention to that. But its also a question of timing at the moment it is more about getting the technology right. Eventually we also need people that can sell and manage the technologies.

M: soft skills I see.. and what are the capacities, current existing capacities that the industry would build on in SA?

D: well we do have fairly large engineering segment both on the metallurgical and chemical engineering side but also on the construction side and some of it can be diverted at its needed. We have a strong construction industry.

M: it's a challenge to look at AM cause there are so many industries it fuels into...

D: I think with AM you need people that are creative and that can imagine things and design things and come up with new products. But then you need people that can sell it and market it and make a business out of it (18:42).

M: I talked to David Bullock from Rapid 3D who talked of the Jeweler industry which was a great surprise to me as being in the fore front in terms of 3DP application point of view. What would you say are interesting industries affected by AM?

D: I think on the one hand the products that we can make are limited by our imagination we can make all sorts of products from AM, but I think the area where SA can play, it would not be in the large volume components or products, it would have to be more design or knowledge intensive products. Because if you get into large volume products we cannot compete with the east its really as simple as that – Asia is taking over the world in that sector. If you take the medical industry where we make medical implants, these are customized products and there its not a mass produced thing and those are the kind of area that I think and also with the RAPDASA there I think SA became to a large extent involve with RP and there SA could be involved – every product needs a prototype, but I think that once it needs to become mass produced I don't think we are well positioned.

M: and it doesn't seem either that that is sought for by the government

D: if you take the work that Hardus Greyling spoke about – there they are trying to develop a competitive advantage by developing large scale Ti technology machine which will be it and that will provide some kind of barrier of entry. But if we buy an expensive machine from Germany and we buy the expensive feedstock and we try and sell the expensive product back to Germany it doesn't make sense.

M: would it be long term something that you are hoping that the powder could be used for the large scale technology developed by Hardus and the guys?

D: I think would be nice. (2248) for the vision that we have for the metal industry it's a subsector, not the important one because the volumes are relatively small I think its still a while before AM will take over from conventional mold and fabricated parts.

M: also a lot of standardizations and certifications involved.

D: Yes! And those are all hurdles or risks!

M: the more you look into them the more cert. you need and so on. Talking about Höganäs that are getting their powder from manufacturer in Canada that makes powder from thread. But not sure where they get the thread from either...

D: not that I know of whether they get it from SA or not.

M: well, as you can hear I m asking quite specific questions and I think it is because the Ti part is really a sidetrack where I am looking into to see whether there is something there or not. And what I hear from you is that there is something there but it's not your core research and it's a bit far in the future and therefore limited about one can say of the opportunities. Any top of mind from your end if not a big thank you for your time!

D. a pleasure- just let us know when your thesis is available as I'd like to have a look at it!

- Closing -

5. Interview (04.09.15): supplier of local open source hardware "ReprapMorgen".

Participant: Quentin Harley, founder and developer of RepRap Morgan

Märtha (M) introduces the research objective.

Q: I entered into 3DP because I basically saw a Aprils fool joke on the internet I was busy with video recordings and orchestras and in this space where I like to chat in I found a fool joke about machine that can print the records. Of course it's a fake cause you can't print records but I was the machine and thought that it was interesting and thought- I can do that. Before that I've always like to build stuff, for the recording I did I built my own microphone, I used open source Linux software so I had been active in the open source free making community before

and when I saw 3DP I immediately wanted to get one. And when I couldn't get one I started building my own. (3:11)

M: That's fantastic and when did you start doing this? and are you fully dedicated to the rewrap project or are you also working with music

Q: I still have a little bit of contact with music but actually now fulltime with the Morgan.

M: Congratulations! How many are able to do that in this space in SA? To support themselves

Q: I know of two other groups... most of the guys have day's jobs and do this as a hobby. About a year ago I decided to leave Siemens. I've been a medical engineer working with imaging equipment, and I decided to leave the company after 15 years. (4:21)

M: wow! That's scary leaving the corporate net. But at that time you had become known in the 3DP space right?

Q: It is yes and yes that's it. Obviously I built the Morgan cause I wanted a machine for myself and I couldn't afford some of the machines and at this time the linear elements were quite expensive and that's where the scissor arm came into the picture. As with all money saving projects I set out to save money but ended up spending about 3,4 times as much than just buying the thing. But its part of the fun and part of what makes this space so exciting to do this.

M: could you describe the tech linear vs. not? I'm tech rookie

Q: the linear elements are all those rails, in a normal 3D printer the gantry based machines you have these long linear bearings, tubes or system that run along a linear line. So you have your XY axis that run on these linear rails. At the time, maybe I don't look hard enough but I could only find stuff that was quoted per millimeter and it was really expensive. As a hobby I couldn't afford that. So I used scaffolding for the bearings instead of the linear bearings. And parts I could find

and get access to. And the bearings held quite well cause they are designed to hold a human up!.

M: how would you describe the space of 3DP in SA? I talked to David bullock that mentioned that 10 years ago there was none and now businesses are mushrooming. Same I hear from Rick Treweek... same opinion? (7:11)

Q: I do agree. There are quite an amount of companies doing the kits and then a couple service bureaus. I see myself as I'm still trying to feel the water and cater for select market. It is quite competitive people are starting to find the edges of their special niches and then branching out to the others. And its quite nice to see that people are starting to realize that 3DP is a viable tool to use in their workflow and there still a lot of growth and capabilities but I think its starting to grow, although it s still a young space.

M: and it seems similar to the top down industrial applications side.. I understand that it has been collaborative but that it is starting to break up and move into a more competitive space

Q: it still a very collaborative I and in the maker community it will always be. I'm in a house called House4Hack, which is a maker space but is very active in the open hardware and software space in SA and my workshop is in the back if this workshop so then we have our weekly eating we meet here and others will tag along. So it's still very nice to move in that free making society.

M: all this open source and collaborative space is generally vey rich. I was in Maersk and am now myself in the start up scene. Now, tell me about your business! (10.20)

Q: we are really small company for a long time just a young engineers and myself but recently as in two days ago he decided to move from one company to here. On the business side we just finished the development of the latest range of the Morgan – the Morgan 2 with a carbon arm and everything, so we are just starting to sell them now and people are very excited about it. We might see a couple of larger deals coming through soon but I Cant mention them at this moment. But it could be quite nice but also quite scary deal that it coming up. So at the moment

we are really tiny and selling our machines through WoM, not active advertising. Mainly because we couldn't produce the machines to serve such a market but we are getting our production line in place at the moment.

M: both kits and fully assembled?

Q: no not quite we don't do the kits anymore. The kits turned out to be quite a good way to loose your money. It's a strange market because providing kits actually ends up being more expensive for us and so also for the customer. Because the amount of work that goes into procuring a kit is more than assembling up for the machine because you have to make sure all the parts are there, label them and put them into bags and then invariably when it arrives at the customers, they throw away a couple of bags and then the service – you spend so much time over the phone and in the workshop helping them to do it. so you could have built the machines for them in half the time and charged them less. For us it makes more sense financially to build theses machines and sell them as complete unit. And if they want to they can use these machines to print and make new ones (13:30).

M: how high % can you reprint?

Q: basically on the machine there are a couple of metal or plastic pieces that you can easily buy for low cost – so you don't print those. But in the open source version of the machine ; the complete arm, the wheel kit, the motor covers, the bed support – everything is 3DP. So you could in terms of filament kilograms print most of the machine (14:29).

M: could you take me downstream and upstream?

Q: We import motors and some of the electronic components we import from China because as far as I now they are the only high volume producers of these parts. There is no factory in SA that can produce these parts at the moment – the cost to build them here and with the material that you have to import from China anyway would probably make no sense. (15:16) then we do the full assembly and plastic manufacturing at our workshop here.

M: and the plastic from filament factory?

Q: yes we use them to print and to sell with the machines and we use them for the master molds we use to make our machines. 3DP is a wonderful technology cause it allows you to create something out of nothing in a very short time and at very low cost but if you want to use 3DP especially if you want to go into high quality it takes a lot of time to get those parts printed so for instance the heads on one of my machines would take from 4-6 hours to print so if I have to keep a machines busy for 6hrs to build 10% of the machine you can imagine how long it would take me to print the entire machine (16:40). What we have done is that we used 3DP parts we finished them manually, created molds and now we are casting our machines in injection molding quality using 3DP as a source of the mold, so its actually closer to the factory of the future than I imagined it to be because now we can produce (17:00) high quality parts that are really strong in shorter amounts of time we can cast parts of the machine in about 2 hours instead of two days.

M: who is your customer then? Young entrepreneurs or is there a common denominator amongst your customers?

Q: 80% of customers are the ones wanting to use 3DP as part of their businesses to develop products that they will sell on to be manufactured and the rest, the other 20% are people that just want to play. They want a machine that is reliable to print stuff around the house- these guys are hobbyists (18:29).

M: from an analytical point of view its very interesting ratio – that most people are using it for prototyping – as tool to empower local entrepreneurship in a way

Q: yea I think most of the people just wanted to play with 3DP already built them themselves – they are the thinkers that use it to print whatever they like to make – other 3dp for example. But most of the people that come into the market now are people who have seen the printers, they don't have necessarily the skills to make them, or not the time cause they are too busy with their own ideas and now that they can get the machine at a reasonable price they jump at the opportunity to get them cause it improvise their work chain in order to get to their final destination quicker.

M: two elements I need to ask you 1) what are the risks? 2) what are your linkages to foreign players in this space?

Q: in terms of risks its basically 3DP is not as easy as people imagine it to be – especially with the tech that we are using. People buy the machine with the idea that they will fly away and make stuff immediately. But it's a tool you have to learn like any other tool. Even a hammer and a (20:39) angle is not an easy thing to use if you don't know how to handle it. and 3DP is a tool you also need to learn how to use (21:38). My main risk as a manufacturer is so the fact that people don't know what to expect from the machine. One of my clients had to return the machine to me because they couldn't grasp how to use the machine. And it's not about the machine but about the perception people have of the machine (22:02) they want to see it like a desktop 2D printer where you just press print! I still remember where we had the diametric printers and you had to place the paper exactly right for it to print properly. And people don't remember time when it used to be harder to use e.g. computers where there was a whole process just to get them booted, **now when you open your computer everything is just there! And unfortunately we are developing technology in this time of everything working like tablets** (22:52).

And in terms of the foreign players I don't have a lot of collaboration at the moment – I used to work with the guys from RoboBeast and Robohand – Rich van Us came to House4Hack about a year ago after I started with the development of the RepRap Morgan – to set up a workshop here. And of course he needed to get some 3DP to build in strange places and he saw what we had here and saw that you could really build what you wanted and then he started building this huge metal framework 3DP that he called the Robobeast. And I helped him with the electronics and the implementation of the software and implement it to the Robobeast to get the product from a DIY product into a more professional product (24:31). And that collaboration ended in January this year when they moved to a new factory in south of J-burg and most of my work on the change over was done and so I decided to start developing the Morgan again.

M: I'm investigating the role of foreign technology versus local technology – which is your story as well – that because the foreign tech was so expensive local people had to develop their own technology. And I want to know if some foreign players

have monopoly of some technology which restricts access. I understand that this is more prevalent on the industrial side but still curious what you think in terms of your space, more bottom up space. Kind of open question here on the relation between local and foreign players?

PART 2

Q: the only collaboration I have with foreign players is in terms of the firmware that I am using on my machine and the source ware that is developed with open source so a lot of the development is done in the world as a community. I contributed a lot of source ware to this project but because it's open source all the advances I give to the community – for everyone that I do this (1:50) there will be 5 or 6 other guys that develop on top of that into other projects. So the firmware is really a living organism and the software always fresh and new – so you will always get the latest and freshest upgrades. So everyone is so grateful that they can get this stuff for free that they will give whatever they can do for free. It's a very fast developing environment to be in. but other than that I have tried and worked on sourcing as much as I can locally. So in order to empower the local manufacturing space as well. There are a lot of people with great skills but not a lot of people using them because of the low cost of imported products. But because we are manufacturing this machine ourselves we need special things made so I believe and hope to think of myself as a job creator myself!

M: and that seems to be the KPI for the government as well... and I am wondering how much attention they are giving to your space when they are funding this other industrial and big projects..

Q: I think it's easier for them to fund one big project than to fund thousand small ones. But I am part of a (3:29) Gauteng accelerator project which is a government funded, tech space funded organization that caters for entrepreneurs in the Gauteng region of SA. And basically what they do is that they run small competitions every now and then – looking for small business entrepreneurs to find a couple of ones to support with free training, they introduced us to proper book keeping systems. I m horrible with paper work but I have now a proper book keeping system cause I was forced to do it so they could look at my books (4:42). Now everything is easy to maintain cause everything is kept in a computer.

So that is happening but its not a lot of money – depending on where you are, at what state in your company but I found it very valuable to support I got in real terms it just makes running a company – especially for someone like me that spent half of my life in a corporate where everything like that was done for me. So it's definitively getting easier now as I go along.

M: so maybe not in terms of money but in terms of knowledge there is some sort of support system. What about demand from outside of SA?

Q: (5:57) there are some that asked me if I would send it to them. But it boils down to the cost of export killing the deal. Sending one of our machines the volumetric weight of our smallest machine is 25KG, and that is very expensive to send especially from SA to anywhere in the world because it seems that we are down in the very tail-end of the whole world – far away from everything else!

M: reading utopian and visionary people talking of 3DP and its role for Africa in general.. though SA is incomparable to other countries in the region I can't help but that that the geography matters and that the geographical (7:02) proximity has some kind of the role for the region. If 3DP is gaining ground in SA that you indeed would become some kind of hub for the region at least the SSA region. Do you see that happening?

Q: yes absolutely! It's already starting to happen. We have quite active 3Dhubs collective in SA – when people want stuff 3D printer but not buy a printer they can just order it on 3D hubs and because SA is slightly different than the rest of SA in terms of the economy.. you really have to see SA to understand it. to me the feeling I get.. I used to work for Siemens and where I worked in SA for them, had the same feel as their medial HQ in Germany. It's a young city with lots of new buildings and lots of people staying here – almost a European city. Even though we are made up of different ethnic groups. It's not like other parts in Southern Europe or other parts of Africa where people are really more alike.

M: that's why it's so difficult to from an academic point of view induce learning for other countries cause its such a special case. (9:30)... can't help to ask you about the manufacturing revolution though. Talked to Rick Treweek about his mobile fablab..

Q: I'm actually busy working on a deal with the innovation lab that is part of the Gauteng accelerator project they have a project – at my house or something like that – it means that bringing the works to the homes. We have a lot of migrant labor in SA. People staying far away from the industrial parts and have to travel very far to work because they simply cannot afford to stay (11:19) in the city and people who are staying in the city build their own shacks in the slum townships. The government is trying to develop them slums but they are growing so fast so its really tough to get the people closer to their work places without trouble because the places are so strangely laid out because of the apartheid thing that happened in the 80s. o what they are doing now and the idea here is that they get some of my 3D printers and put them in these labs, large trailer with some tools, computers, 3DP and facilities to do basic work related, office space a little bit of internet connectivity... basically to empower the local community to start building their own (12:37) projects close to home and not just away in the cities and basically bring innovation in these areas instead of away.

M: and they wouldn't print prototypes but fully functional end parts?

Q: yes, actually I had a talk with one of these directors in the project and spoke to him about having some molding and casting workshop that I have to make my printer parts, to use the 3D printers at their disposal to make molds for the parts that they want to make in bulks. So for instance one guy developed a project – a better pump for getting water out of the well, then he makes one with a 3D printer, then he molds it and then he makes hundreds and then the mold is done but he can make another mold and in that way you can use one 3D printer to enable a lot of small businesses to develop their product in a professional way without taking that machine out of commission its just developed for the next guy and the next project.

M: so these guys that have an actual idea of the customer demands?

Q: yes and only they know what they want that's the thing. Only the people with the actual problem are the people best able to solve that problem (14:23). So you need to get them the tools to do it.

M: but they would have to have some basic software skills no?

Q: that's right but what happens normally is that the trailer gets parked there is one or two staff members that know how everything works and when there is someone who comes with an idea they can get the basic training on how to use the software and the printer. And if they are uncomfortable using them they have the staff that can do it for them (15:03). So that they can get their stuff and their designs out there without having to go through the steep learning curve required to get the machines going

M: fantastic! So then I hear that a lot of the potential is in manufacturing equipment. What other industries do you think are interesting for 3DP in SA?

Q: as you know there's a lot of focus on prosthetics because of the high strength and low cost of the printed prosthetics and if you take the Robohand as an example it opened up a whole industry on non medical devices with people start fixing themselves because they just cannot afford to be helped by somebody else (16:18). There are a couple of guys who came here from a town far away and they have an idea to make medical equipment using 3DP on one of my machines. I'm quite excited about that so we'll see how that turns out. But that is medically trained people who want to start printing because **they are being replaced by people who don't necessarily know how to do it properly and now they are going to ride the same train into making it done properly 16:55.**

M: people that are close to the problem again.. Are there other industries you think?

Q: I think jewelry is one... interior decoration is another (17:07) – I've seen a lot of interesting things there. My introduction to these molding technologies really brought me closer to 3DP in a strange way because I have seen a lot of people that use 3DP to create the molds for whatever industry they want to go into so you get these decorative cornices for instance. Now instead of manually having to make one you design it on your computer, print a section of it, you mold it, you cast it, and then you have these cornices you can put anywhere in your house. Or you can make decorative pieces that people put on buildings- they cast it out of concrete and then they put them up. So 3DP is a stepping-stone to get to different

manufacturing technique and it basically democratizes (18:21) the process. you don't need to be a really good artist, you can put the capability of making really artistic into the hands of people who lack that because of training or whatever.

M: you make these molds then with 3DP and then would you produce these using capacities in SA using traditional manufacturing technologies?

Q: yes so 3DP for me has a great value in prototyping and for the pre-manufacturing of the molds and masters for other products so there's a couple of guys I know that use traditional 3Dprinted molds to make things like custom chocolate for clients (**merchandise**). Because 3DP chocolate is trickier and hard to get the resolution but using a mold it's easy and to make the molds now gets easy with 3DP (19:56) .

Another area is dental where we see a lot of movement into the direction that some of these plates that people used to do to make corrections, will now be scanned and 3D printed instead of cast and then manufactured.

M: we have a big supplier in Denmark who does that exact thing. So how I see it now top of mind. I'm really enjoying the information that you're coming with that is quite unique in the sense you are describing it thank you so much it's a pleasure to hear your very practical point of view which is very important to not only hear these success stories here and there and how I hear it is that the technology that is more bottom up FDM tech. enables the molding and prototyping to decrease the barriers of entry to traditional manufacturing whereas on the industrial side that is where we are talking about the visions of freedom of design understood from the view of the end part – to print functional , very customized, no assemble 3D printed end parts.. and titanium.. inspired by the GE nozzle but these are products that are in low quantities, long time horizons, and very specialized where it make sense to run these 3DP factories. Whereas the space that you are in then it's more let's create the molds, the prototypes close to the people who know the problems, and then let's take that to factory.

Q: absolutely! I think that's a 100% correct. So for instance you could use one of my machines to make shoes where you get a shoe that is just right for, you take 3D scanner of the foot of the lady and design one that fits perfectly every time. That is something you could do and you can charge a lot of money for it. but we are in

Africa! There are a lot of things that need to be done here that shouldn't cost a lot of money so we should use these tools that can help more people than just the rich – that can help people in need. Those people are also important! Especially people that are (23:19) limbed and or people that don't have fresh water. If you now have this guy that has designed a new compact system that you can use to help people living in these slum like environments to get cleaner water that is something that is more valuable and if you **can use 3DP to speed up development of this product and put it to market quicker**. This is better for the entrepreneur (24:02) that gets the money quicker and also for the people that it helps.

M: it's really a different reality which makes SA very interesting and not too many looking at that and although a smaller space than the US or the EU it's an important information so thank you so much for the information it's been great.

Q: we see elements of everything that is happening in 3DP here in SA. (26:15)

- Closing -

6. Interview (08.09.15): RAPDASA, Titanium Association, & Center for Rapid Prototyping and Manufacturing (CUT)

Participant: Dr. Willie du Preez, Member of RAPDASA Board, Member of Titanium Associate, Associate Professor CUT. Previous: Director Titanium Centre of Competence; Manager National Product Development Center (both CSIR)

Märtha introduces the research objective (M)

W: OK so thank you for this opportunity I am currently appointed as ass. Prof. at CUT free state and also the director of research at our centre for RP in manufacturing (CRPM). This center has existed since 1997 and the key player in establishing it what Prof. Deon de Beer- if you haven't spoken to him I really recommend that you do! In our center here which is the research part, is linked closely to our mechanical engineering department and we have decide since a

couple of years ago that our main research would be AM. In this center we have a good assortment of different technologies and what we have embarked on is a longer term research program on AM with the intent that we can make sure to eventually qualify our processes and our materials in other words if we say we produce titanium components, we want to be able to say that our processes are repeatable and reliable and as far as the material goes it will comply with the accepted specifications for such components incl. mechanical properties physical properties, micro structures and the likes. And the same we want to do for the polymer materials we are working on. We also are working in collaboration for the national collaboration program. Its called the collaborative program for AM. In that program, in addition to a focus on titanium and polymers we also have a subprogram on design for AM as we do believe that it is important to understand the design aspects very well and to also share that with people around us in the industries and the like (4:14) to ensure that one really makes the most of the advantages that AM gives you.

M: where do you get your funding from?

W: this was part of my task since I joined the university here in April last year was to negotiate longer term funding for us and we've been successful in securing funding from our national department in science and technology. Our current contract extends up to March 2017 with an expected year to be added on but the actual business plan is actually a longer term one – 5-10 years for going through this process of qualification. And then we also get funding from our national research foundation. We have recently secured a research chair in medical product development through AM. (5:28) in fact this chair was launched on the 14th of august which was a prominent event for us and that comes with funding for 5 years and if we do well it will be extended for further 5 years.

M: that's a long batch of years to work with!

W: yeah it really gives us the horizon to really develop more in depth competence and also develop our people for future.

M: when you get these funding, I understand your holistic approach incl. design and these other areas – do you get funding for this full package program or a specific aspect?

W: firstly the program for which we got the funding is a national collaborative program with 5 universities as well as the national laser center at the CSIR and Aerosud so there are 7 players in this program. The universities are Stellenbosch, University of Cape Town, the Vaal University in Gauteng, North West University.

M: I'm investigating both the bottom up (maker community etc) and top down perspective (the heavy industry e.g). Does the government see the potential in both? Does the government fund both? What do you think the relation is between the bottom up and the top down approach if it makes sense?

W: I think I'm with you, (8:43) I just need to check if you've taken note of the AM Roadmap over the last two year shared in the RAPDASA forum. That development was sponsored by the Dep. of Science and Technology. The intent with this roadmap was essentially to create this document to inform future decision making around investment in this technology and its applications so by referring to that I wanted to say that I believe the government sees this, not only as a R&D type of thing but that they are very keen on seeing the technology be fully taken up by the industry. So our intention especially with the qualification is that we want to make sure that the processes are so well developed that they can be transferred to industry players, empowering them to compete on the right standard internationally with this technology (10:28)

M: when the titanium centre was established, airbus and Boeing were active players in supporting this center. Who do you think are key actors in your point of view to make or break your project?

W: firstly then as far as the actual execution of the program the partners in the collaborative program other players such as airbus and boeing. Boeing btw, just around 2006 -7 played a prominent role in encouraging the SA government to invest in Titanium with further value addition to our titanium mineral resource so that was a fairly strong intention to get that program going at the time (11:51).

Since then Boeing has been keeping contact with us in SA, and during my recent visit with them in the states they confirmed again that they do see the particular strategic importance of what we are doing also in AM and they are even went so far as to say that if our Aeroswift project is successful they would want to get a Aeroswift machine where they are, in the laboratories to actually do parts for their aircrafts. These things are obviously confidential the geometries and the like so they will not send that over to us and have it done from here. (12:45) and then from airbus side as well there is a similar interest and these interests have been confirmed through agreements between theses actors and CSIR. Formally signed in 2013.

M: the LOIs and MoA

W: exactly, so they are important players in the aerospace.

M: what do you think the value is of this partnership? What does this commitment imply in monetary terms? Is that even possible to talk about?

W: so far in real monetary terms they have not invested direct funding with money into the program. But what they are, and what Boeing at least definitively are committed to doing is to support what we call human capital development of students so they have also confirmed to me that they have identified 5 projects that they are willing to directly invest in supporting the students and these projects are very well aligned with our own programs. (14:42) Apart from that the real value for us, big players like those being willing to give us direction regarding the way we should be going, the real needs that they face in aerospace. We could easily sit as academics or researchers and sit in our research environment and think that we know what is needed but what we do need are the real, the actual information from the industry players. In that sense we have been fairly successful and aligned our research programs accordingly.

M: how do you think, what is the role of Denel and Aerosud as local players here vis-a.-vis Airbus and Boeing?

W: both Aerosud and Denel (16:04), particularly Denel Aerostructures, they are providing to airbus and being components that they are manufacturing so they are

also from a manufacturing point of view very aware of the requirements from these big COEs. For us it is valuable to have them onboard, Aerosud very directly in the collaborative program. But also very ongoing collaboration with Denel aerostructures and there is also Denel dynamics business unit that is also interested in working with us. With Denel it is more an alliance but not directly as aerosud

M: so arms length with Denel and more integrated with Aerosud. Do you have any thoughts on other industries where there is interest in AM in SA?

W: again for the moment if we just stick with titanium there is a local company, southern implants that are very prominent in the field for dental implants – globally as well. They have been working with us for a number of years. Here at CUT as far as the application field goes our immediate strong focus area is on medical implants, most of them titanium implants for reconstructive surgery. And also joint replacements in certain cases. There is also a group in Univ. of cape town that mainly focus on joint replacements but we have done some very interesting projects with them too. From that perspective a player like southern implants has been very valuable for us to be kept aware of the needs from an industry point of view (18:52)

M: that's the medical industry.

W: we also have a center for RP with a very broad customer base that we are servicing with short term types of contracts. This will be a week or two a month at most where they could send us a design and say make us a model. So we are talking here of a broad base of industry players. Our total customer base is over 700 not all of them just industry but it gives you an indication that we are also in good contact with smaller companies and their needs in this regard.

M: when you get customers asking for models, is that drawing from your competencies in design side to try to build conceptual models?

W: yes we also have the product development technology (20:07) station here at CUT which has existed since 2002 and this technology station – its real mandate is to work closely on product development and things like design, reverse

engineering, creating prototypes and so on. And these 2 centers are working very closely together. And often they come with a concept and we come with a design and take it further for a company.

M: is that something that generates cashflow?

W: we have a fairly solid annual turnover from these contracts. Again it's a short term things so a couple of 100 contracts per annum at the turnover of roughly 2-3M rand per annum. So for us it is also great to generate income, but it also opens up opportunities for technology transfer and commercialization

M: are you tracking what happens with these models? do they go to market?

W: normally when these go further we are able to keep track of them, where relevant we would also enter into agreements if there is any IP we go into agreement around sharing IP or maybe just some form of technology transfer.

M: is it on the titanium and polymer side?

W: yes that is across the range. Actually many of those are polymer related or we also have AM machine for steel components. We also have machine for building sand.

M: interesting when the different materials coincide. From my own categorizing I've looked at metal versus plastics and what I see on the plastics side in SA is that it allows a diverse set of players to engage in product development and go to market using local manufacturing capabilities. Whereas on the industrial side, you need partners, capital, 3D printing is your end tool here in contrast to plastics where it is a means to go to market faster.

W: you're right in that sense in that there are already in this point in time quite a number of players in the industry working on the polymer side because those machines are more affordable to do those kind of models of prototypes. The metal machines tend to be more expensive. In the future hopefully we'll get to a point where these also are more affordable. But also from the R&D point of view our approach has been that in the polymer (24:52).....

PART 2

.... people are moving forward with the technology so from our perspective there is not much research intervention to be done whilst on the metal side the challenges are still much stronger but on the plastics side we do believe that we need to look into the repeatability of producing these parts and eventually also transfer to the players out there so the quality gets to the right level

M: I guess now that if you want plastics to be used for end use products but currently it seems that it is mostly for doing molds or RP.

W: yes although (1:54) one should be aware that in the Aerospace industry they are using polymer parts quite extensively for parts that are not structural let's say internal parts like airducts, or brackets in the cabin. They are already being used quite extensively by Airbus and Boeing and even on commercial aircrafts nowadays. The number are lower that for instance automotive and that is where AM comes to play quite well.

M: you mention automotive, what do you think are the prospects for AM here if any? (2:50)

W: I think firstly in the field of product development it could definitively play a strong role as you know RP allows you to get to models quickly but as far as components go for product the potential is there to do parts for the internal vehicle the thing is just that the numbers are so much larger than any others and this technology is not as rapid. You would need a whole line of machines to produce parts which is a serious capital investment. But I do believe the potential is there so we'll have to see how it develops (4:03) in SA at the moment because we don't have the OEMs here the design authority doesn't sit in SA. We are mostly producing and the design made in EU or US or whatever.

M: that's the case for aviation and automotive, but when talking about equipment. I had a talk with Quentin Harley from RepRap who mentioned equipment suppliers who made prototypes, mold it and produce larger batches using local manufacturing capabilities.

W: definitively and that is a very good example. Again it's essentially a product development process where this comes in strongly and then production yes.

M: (5:46) I like what you said about automotive that they need to a large amount of parts. So working in Maersk, we had similar pains as the guys in aerospace – low quantities but low level of standardization or high level of customization. SO what we looked into was whether it could alleviate supply chain pains – e.g. getting parts into Angola where it takes 6 months to get stuff through customs. DO you do work on that?

W: it's a very exciting field where as you say, you can actually do your production at the point of use and you could address these kind of problems like spare parts and so on. But what you need is essentially the design which you could put on a disk or whatever for future and when you need it you just bring it back to the system and print. That is the kind of area that we refer to in the roadmap as addressing the existing conventional manufacturing industry in how to be more competitive in particular cases like you say in the supply chain aspect as well this can be used as well to make us more competitive. (8:21)

M: it keeps popping up the particular geography of SA : you are developing technology very far away from where other technological advances is happening. And when come to think of these supply chain opportunities that maybe we could circumvent getting stuff through customs..

W: yes but I believe at the moment and in the future, as we all know getting things done via the internet is instantaneous and if you want to have files you get it quickly, and if you then need AM to do the physical manufacturing it can happen almost anywhere and anytime and for us in SA it is also quite relevant because our large industrial areas are fairly remote from us like Gauteng and the Eastern cape. So this kind of approach is relevant for us as well. We can say we are physically removed from you but we can do the design, the models and prototypes and we can courier it back to you. (10:12) type of new models way of thinking that I think are very relevant for us going forward

M: how it helps even within the borders of SA and of course across the borders.

W: yea cause stuff is so expensive to get things from customs.

M: do you think this is something that Airbus or boeing is thinking about/ or make them interesting in SA. Or differently – why are they interested in SA in relation to other players in the industry from other countries?

W: so there are two players here there are existing relationships with them and also our own local aviation industry are buying from them over the years but other players like embreya are also relevant, they are just not that prominent at this point in time. I think strong part of this interest from Boeing and Airbus is particularity from SA producing titanium (11:35) and if we are successful with our current technology in terms of hardware, and in terms of producing our powder directly the potential is there to get to solid material and components at much better cost than what we currently have for titanium. As you may know in the aerospace industry the Titanium usage is growing particularly due to the use of carbon fibers in a larger extent even in large commercial aircrafts and even there titanium is a better metal to use in conjunction with the graphite fibers than for instance aluminum (12:30)

M: when talking to Dawie van vuuren, he says its more in the longer term, so he still thinks that it is a bit too far in the future to say something in terms of the opportunities. I mean he can see them theoretically but his focus is on making the metal powder full stop and then we'll see in terms of downstream activities if it will be to AM or other areas. He sees 5-10 years from now in terms of commercialization. (13:15)

W: I think that's correct in the sense of the technology upscaling because this type of getting to a commercial plant eventually is not a short term thing. But he also attended the conference in San Diego with me and also a number of AM presentations there and what is becoming clear is that there is a growing confidence amongst the different players that titanium AM can really meet the specifications of conventional current materials and manufacturing processes. But there is another important aspect that I got confirmation of (14:10) which is that if you have the pure titanium powder, one can blend in powders like aluminium to give you an alloy even with AM which is something that I wasn't sure of but got

confirmed from players who had done experiments that tended to work. So we will look at this further in the future. Now from a SA point of view – yes it will be a few years before we can talk of numbers of titanium powder kg available but its definitively there in the future. (15:19)

M: So I talked to Höganäs, Swedish metal powder manufacturing. And they weren't keen on saying where they got their powder from and they did say as well that they hadn't gotten their eyes on SA.

W: it's probably not too unexpected because if we look at this historically, up to around 2007 there hasn't been a strong drive in SA do to more with the titanium bearing resource even today we are still really only producing the titanium dioxide sludge which we export. And that needs to be further beneficiated overseas, we don't produce any metal. So it's really only recently that this is becoming potential and I think as Dawie shared, it will still take us a number of years to get to a stage where we can produce real commercial quantities that could be sold. On the other hand we are keen on making some of this powder available who just want to experiment with this powder.

M: to start engaging in the dialogue already now?

W: yes (17:24)

M: so we talked about the opportunities, what are the risks? What are you going to work with the next couple of years to make your vision happen and who is important to get onboard?

W: I think one of the challenges is to make sure that the expectations are not totally unrealistic in this field. People often talk of freedom of design that you have. Now that is true to a large extent but if you do not design appropriately and do not keep setting the design rules in mind you may find that you cannot actually produce exactly what you want to produce with AM. So there is a challenge with design for AM and to get the more conventional designers to also understand how to get the most of this technology. (18:45) now in the field of product development it remains an important tool that you can use and then it is also important to promote the concept of the green technology: we are not wasting any material as

we are only adding material. And as you know (19:11) this is becoming more and more important. What we also need for this to go forward is ongoing support from government, from our funders and also from the players in the industry. There are examples even from recent history that points to things we want to avoid for instance a decade or half ago there were very high expectations around using this for tooling for manufacturing and not all of these were met. And I think people were expecting this too early so we want to avoid unrealistic expectations that cannot be met and rather be realistic in how we move forward. (20:24) and then the other important aspect which is related to this is that one should make sure to really understand the process right and also the material that you use. If you have a part that is full of pores that you do not expect then it will probably not have the strength that you want from it in the end.

M: and this require the necessary education and skill set?

W: yes and that for as an educational institution (21:12) is a very important challenge cause we have to make sure that we introduce courses of AM so students are familiarized early on in their graduate years.

M: a bit off the script here on a question, how many machines do you think are installed in SA? What is your guess and what kind of machines? E.g. what kind of machines are you working with at the center?

W: all the machines that we are working with here are produced overseas and we import them but in the technology roadmap, Deon de Beer has been keeping track of the number of machines where this graph indicates the growth of these machines and at that point in 2014 we were looking at 2375 machines and of these the majority are personal 3DP < USD 5000. The high end machines ie > USD 5000, those are only 375. These machines as I understand it are all imported machines that were bought overseas. We don't really develop on a commercial scale (24:00)

M: that's also my impression that the industrial side is still very proprietary.

W: so in our center we have 8 machines for our work. The majority from EOS, we've got 3D systems Objet as well. 3 machines for metal and 5 for polymers.

M: still impressive!

W: I think in the country and even broader than that probably the most diverse set of machines!

M: think its better than the center in Denmark too! what is your relation to EOS?

W: we have essentially one 3D systems that we use regularly so I can't say too mauch about that. With EOS most of our machines are from them and here we have ongoing contact with them.

M: always good to get an idea of the contact with the foreign actors.

W: the Vaal University have Stratasys and 3D systems but Deon de Beer will be able to give you more details

M: It's been very informative, you touched upon all my questions one way or another so its been great!

W: Just further recommendation [namedropping] Garth Williams is the key government players in this field at this time, directing the funding in R&D.

M: I'd be happy to take his information!

W: I can just from my own experience say that I have been involved in this technology just from the start when this technology got going in the country and even if I look back 5 to 10 years many of the aspects of the technological developments have exceeded my expectations. For instance I didn't at the time think we would be able to do titanium alloys but today we are there! So it's really progressing very strongly (30:07). [...] The strong point of the technology is that it empowers people to operate really their own imagination, if they understand how to use the technology and how to design for it I think we're going to see very interesting things in the future (31:00).

- Closing -

Interview: Public Official (PO), Department of Science and Technology, Additive Manufacturing

Introduction:

- Introduction of interviewer: current position, affiliation and duration
- Introduction of interviewee: current position, affiliation and duration

PO: I was working in the aeronautical industry and at the time there was a company called adept aeromotives which was involved with VAL where Deon de Beer was employed at the time, he subsequently moved, they had printed a metal manifold part. Instead of using the traditional cast or forming technology they had used 3DP and I think what got me hooked was the tool technology that I got excited about and I became aware of the industry association the RAPDASA and then became involved. What happened was that a couple of years ago we requested that the RAPDASA community to develop a technology roadmap on AM which essentially drove our investment drive, development and innovation for the next decade or so. And that led to a funded R&D program. And we are now in the 2nd year. I've been aware of 3DP personally, and I was fairly new to the public sector at the time (5:00) it was really serendipitous that I saw that demonstration by Deon de Beer.

The fund that you mention through the DST, is that the M137 R that I've read about?

PO: You're partially correct, it's about 130M dedicated to 3DP R&D and about a 106M dedicated to the Aeroswift project phase 1 & 2 (6:00). And then 31M to the more collaborative projects.

And what do you define as collaborative?

PO: CPAM (Collaborative Program AM) and Aeroswift are managed by the national laser center (incl, Hardus and Marius) and CPAM came about as a consequence to the technology roadmap developed and was based on historical developments and also industry connections into the global supply chain. In the program there is the titanium program, for medical and aerospace industry. In terms of competitiveness we got now aerostructures and Denel dynamics who

joined the supply chain of airbus and also there is a leading tier 1 supplier – Aerosud – Aerosud training etc. they have links to into Denel, and they have links into airbus and Boeing. The focus on titanium specifically is actually in addition to the program that involves polymers manufacturing and on the metal AM the focus is mostly in the aerospace alloy which links back to our titanium centre of competence.

M: Where Dawie is?

PO: (9:16) correct. And the titanium Centre of competence, that is where the proof of concept and principles for Aeroswift as well as certain elements on the CPAM and AM and would be beneficial to the titanium powder industry as well as the Aeroswift project. In isolation sure there would be successes but there is now one OEM of the aerospace industry, I'm not going to tell who it is, but that decided to be part in both the hardware and the powder project. Then we've got something interesting – the titanium powder and the machine that could print with commercially available powder for the aeroswift, then put those together and it does present a real argument for this company to participate (11:03). The people that we are engaged with need to sell South Africa with their principles within these aerospace OEM and sometimes there is a perception like 'why do you wanna bother with South Africa, there is nothing there' and so there really needs to be a strong value proposition for anyone to partner with us and so if we can string these two together then I think we would have a real winning situation. (11:42)

M: and the success criteria for you is job creation? And the assumption being that partnering with these OEMs is a way to do so?

PO: We probably are removed from that kind of impact, we would use fairly traditional indicators like IP portfolio, knowledge generation, journal publication and human capital development. But the umbrella approach that we would work at with the specific programs is about industry development and so more about technology focus, technology development focus or relevance to society whether that is economic or social. Unlike other initiative or our colleague for example this radio telescope project. 70% is done in SA and 30% in Australia and New Zealand and these guys want to look at fundamental, you know the origin of universe and etc. this is a big science projects also, like CERN, the Manhattan Project, those

are big science projects whereas our approach is more R&D and technology development relevant for society. We are interested in opportunities that do lead to enterprise creation or job creation (14:29), or addressing inequality... our management developed a framework where you have baskets of indicators where you include say addressing geographic... because of our apartheid past there are areas that are really underdeveloped and so because of the more social interventions address that. We have more an impact on for eg. Helping companies to become more competitive using existing technologies or technology upgrading or emerging technologies that have a real promise to an industry. So for ex. The titanium powder – if you develop a successful process that develops titanium powder 4 times cheaper than the current, you get to unlock an entire new market. Titanium is expensive not because it is rare but because the process and technology is long laborious and intensive – so if you make it cheaper you can open up for new markets where titanium can be used where previously it was too expensive (16:01) or opportunities within the CPAM there is a focus on using existing polymer additive manufacturing tech to help industries and companies become more competitive with Rapid prototyping, Rapid tooling esthetics or conventional prototypes which then helps time to market and shorten product development and so increases competition. (16:43) Now we make it more within our mandate which is about human capital development but we also have a key eye on the socio-economic impact of our programs.

Which could be hard to measure? Also drawing from the bottoms up approach, the open source space and maker movement.... What is your take on this movement? You are investing in aeroswift and CPAM but what is your take on this bottoms up movement?

PO: If you are talking of fablabs and the maker movement we've been involved in fablabs and actually extended that involvement for some time. While it's an exciting space to be in, it is difficult to I guess support that initiative with one entity. Like the fablabs we were funding several cross country and ultimately it didn't fit our strategic objective and you also have dependency created. You would have this entrepreneur that would come in and become cosy and then wouldn't leave. And then some using more science commercial activities. There was some success but the way it was run was not sustainable in terms of what it would deliver for us. So most of the fablabs have actually been absorbed by the hosts

which actually are the universities or they have transformed into something that is slightly different based on geographical location or local vendors. So getting back to top down versus bottom up I think the technology roadmap we did for AM in fact catered for both, it look at existing (19:59) equipment R&D projects, skills competencies, R&D outputs as well.

(part 2/3 recording)

PO: So that is really the bottom up approach but we also looked at the top down in the sense the political environment the requirements for adding value to mineral reserve, links to OEMs etc. so I don't say there was some preference more of a technology push than a market pull. My preference is to have market pull cause then you have buy in from industry. But what I see from AM is still emerging and native and has its niche like the GE nozzle, but it's not mainstream in manufacturing. So we had to accept that it would have to be technology push though I would say that there are some industry partners like airbus is a good example and sometimes we have been too fast in saying we only want industry partner but the matter of the fact is that they do provide a good link to GVCs. They also have their corporate culture is very supportive of innovation and R&D. you know mainstream of manufacturing is very reactive when it comes to innovation and would sometimes only innovate when they have to and even then it may be too late, so we prefer working with associations where we have a sector or a broad perspective that we are not only furthering individual company interests (3:00). The polymer perspective has a broader aim.

Such as RP? Product development?

PO: Yes to shorten time to market and so on

For local firms?

PO: Yes mainly. Both airbus and Boeing have partnerships but they don't have presence, so it would mainly be local firms because not a lot of foreign players have presence here. (4:08)

And I understand these partnership have signed LOI, MoM and so on so its clear that this industry and that SA is embedded in GVCs. And you use AM to ensure that you maintain relevant. Not only relevant but maybe even competitive darwing from the scenario you presented earlier on titanium powder AND hardware. (4:53)

PO: Yes and that is why DST is funding the Aeroswift project because there are two revenue generating projects one is the machine becoming a single large IP and deriving revenue from that and then secondly companies that have aeroswift manufacture, service bureau on an industrial scale. And then there would be on R&D maintaining the technology developed by Aerowsift and commercialization of the technology.

And for other industries? What do you think are the opportunities?

PO: Aerospace is strong contend ant, second medical sector on customized devices implants and so on, and then.... Have you seen the roadmap btw? (explaining the roadmap) (6:50). Then within materials not only titanium but also stainless stell and other materials. Again I would refer you to the roadmap

Fantastic! I'll look at that for sure.. so to round off a bit... you'r talking of general technological capabilities, technological upgrading which is central to my research and so considering the manufacturing that is in decline, what are the improvement areas institutionally and structurally? What are the biggest risks?

PO: On the government side what is needed is sharper industrial policy. If you look at our current industrial policy, essentially it identifies many sectors for intervention and the relevant officials said that they need to be sharper. Two things 1) the right sectors and screen the technologies to invest in.. here you should look at McKinsey's global Industries overview where they look at sectors and 5 game-changing trends for advanced manufacturing. (explaining the McKinsey: and then particularly within the contexts of re-shoring, re industrializing regaining competitive advantage like what is happening in the US, UK and even China wanting to become a high value adding manufacturing country) (13:39). Going back to the risks we have the matter of integrating industrial policy with science and technology work. Senior support like they have

public officials in the US that come from senior people in the industry. We don't have something similar here. And I'm not saying that is the solution but we have manufacturing as a sector that contributes disproportionately to jobs in the economy relative to high value adding activities in the value chain and now advanced manufacturing is changing manufacturing (14:59). So that is on the government side now on the private side, if you look at the traditional manufacturing sector despite that we contribute to exports, our geographic location just makes transport impossible and that kind of burdens us – the inability to deliver despite being cheaper.. and another is access to finance you know one of the Denel executive told me that in one of their foreign competitive companies they had access to finance at really favorable rates and so Denel's prices really need to be competitive (16:42) and quality on top. Generally we were a low cost producer and costs have risen for conventional manufacturing but productivity and it is the traditional manufacturing processes that are seeing a lot of distress, basic manufacturing processes like assembly and basic processing those are the sectors that are under pressure

For you advanced manufacturing is a totally different sector?

PO: For me, advanced manufacturing is not a new sector is a new philosophy (17:54). There is confusion in interchangeability for ex. High tech manufacturing was referred to the manufacturing of goods for trade purposes like electronics. There is confusion that a high tech product like electronics needing high technology to produce it, and the other way around for e.g the clothing industry. (explaining the Zara concept) High value adding manufacturing is probably more descriptive where (20:09) because of the depth of value added to much more value per labor component. If you have a supply chain in the country you probably gather more from spillover effects...

So back to the categorization issue.... Telling the Maersk story to talk about location becoming a competitive advantage.

Part 3/3 recording

PO: The roadmap was developed in parts, here we are focused in direct economic impact but we have had interaction with colleagues more on the social impact side that have an interest in assistive devices e.g prosthetics or other specialized assistive devices. Here we created a family of assistive devices that could be printed out fairly easy in multiple locations in onsite lab to print out artificial limbs. Together with universities, now we have 23 prosthetics to the poor section that only have access to the public healthcare (4:45) which is not great. They will have different genital defects we have facial cancer that is being removed but not reconstructed or you have where the patient doesn't have the funds for reconstructive surgery and their quality of life is affected either through personal stigmatization or through actual consumption function like they literally can't chew or swallow or etc. and so the CUT has done work with implants companies such as southern implants, with clinicians and with 3D design companies to custom implants whether they are in titanium or polymer based and so that is an additional layer of implementation of the roadmap that we are into (5:28). Ultimately you can save X number of lives and livelihoods influenced or impacted but ultimately you also need to boil it down to the financial measure. Example if you operate using conventional techniques the operation might take 12 hours, the preparing time might be a week and you will a secondary infection being clean. And that is a quantifiable financial impact of that if you use 3DP, you do your 3D modeling you can create a custom implant on CAD, you print it out, surgeons can visually plan their surgery using 3D modeling etc. you can cut your surgery time from 12 hours to 4 or 5 hours. Your recovery time is then and chance for secondary infection is reduced so you can also quantify that sort of impact which is being communicated to us. So there is that interest, and the reason I am telling you is that even with 3DP, it is a process of implementation and influencing our colleagues to investing in this road map, let alone other government departments. We are frequently in relations with Department of Trade and Industry but we struggle to find a common ground. They say a certain industry, but we can't support that we can support clusters, or machinery upgrading. And then there is the economic development department (7:43) who has the industrial development cooperation under the air and IDC is a development finance organization so they will also get involved in new enterprises and commercialization of new technologies but it still fairly new process and everyone is under fiscal constraint so there is the fiscal intersect between mandates between interests and departments and we see that national, regional and local and operators are

sometimes separate governments and firm requirements who ensure alignment as suggestion to consult but often that is not done. So if you are talking about a project as complex as distributed manufacturing and free trade that is something that will take quite a lot of time and effort to put the right players together to get something on the table (09:03)

M: and to define it so that everybody can have a common denominators

PO: well you know then you need to maybe define it into areas of mandate or interest. So the IDC would be interested in growing exports and import replacement, the DTI would be interested in a different set of measures and the DST would be interested in another. We have a fairly interventionist government so for their money they want to see what are the output what is the impact. What I have seen in the American manufacturing innovation, they are fairly loose with regards to the effects they want out. As long as it's good governance and is involving different industry partners and maybe a bit of enterprise development with their training and my understanding is that they are not measuring the numbers whereas we are not (10:26).

M: it's a bit more short term oriented?

PO: I would say maybe we focus on the short-medium term. Our budget cycles is a running three years although we do approach our implementing partners beyond that. So with maybe a decade effective. But we can't really go beyond three years in terms of financial commitment. And then there is also the political sphere, local government selections coming up next year, and then national election and so there is a bit of reluctance to invest in medium to long term initiatives. If you talk about DST, the time horizon is not something that makes politicians happy. Its not like service delivery such as sanitation and health etc. where we can see immediate benefits. (12:00)

M: I think that's an excellent point. It's valuable that you 'chop' everything down for me the entire interview has really been valuable...

Closing

