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INDUSTRY 4.0:

a Manufacturing Revolution

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Introduction

Since the start of my master degree program, I have been exposed to ideas pertaining the likely changes that the so called fourth industrial revolution, also known as industry 4.0, will bring to the economy and how industries, consumers and governments should react to them. Fascinated by the multitude of scenarios that I was presented, I started to gather up information by myself, exploring news reports, essay books and the announcements of technologies' latest developments.

One of such announcements has particularly struck me during the beginning of this research, and it helped me to set the direction in which my thoughts would later flow. Jessica Rosenkrantz and Jesse Louise-Rosenberg are two fashion designers working in New York. In 2009, they asked themselves a series of fundamental questions on the future of the fashion industry. Would 3D printers represent a new standard for the industry all over the world? What is the current state of such technology? Can we use it to print a dress from scratch, without using any of the traditional manufacturing methodologies we usually adopt for the creation of a new line of clothes? They set on their new task and found out that 3D printed dresses were aesthetically pleasing, but not at all comfortable. Such dresses were made of hard plastic that, even if pretty, would have made the wearer feel as if he/she was stuck in a cage, limiting their movement capabilities to the point that it felt more like an armor than a dress. Other designs would account for hybrid models, in which the parts that needed to be mobile would be made of traditional materials and fabrics, while other elements could be printed, using the best of both worlds.

Rosenkrantz and Louise-Rosenberg felt that this was not the full potential of what a 3D printer could achieve, they believed that a 3D printed dress could be made in a single printing session and could grant the wearer the same mobility and comfort that a traditional dress would ensure. For this reason, they started to work on the creation of a flexible dress that, although made from plastic, could be at the same performance level of its traditional counterpart. The task proved hard. Even if the mobility issue was swiftly resolved by utilizing a series of triangular pieces of various dimensions that could connect with other such pieces on each side, the length of the fabric printed using this technique would not fit inside the printing bed. The key idea that would set the project successfully forward involved the power of computation in the form of a physical simulation.

Transferring the very detailed computer design of the dress to an ad hoc program, the designers were able to simulate the crumpling up of the dress and how each part would react to the movements of the whole. Every single hinge, every single triangle and their mechanical relations were simulated in order to accomplish a computational folding of the dress, so that it could be now easily translated back into a design version and be finally printed within the limited space of the 3D printer's bed[1].

After discovering the feat that these two designers were able to accomplish, I started to wonder how could these machines be utilized and what will be the implications for the economy as a whole. I will explain in this paper how these machines could prove the main protagonists of the industry 4.0, and how, to me, this is really just a manufacturing revolution. Starting from an explanation on how each industrial revolution has contributed to affect societies and economics, I will then explore the foundations of our current revolution, which lie respectively within the technological breakthroughs of computers, 3D printers and robots. The second chapter will deal with such technologies and how their recent innovation could likely shape our world in a very next future, focusing on each, one at the time. At the end of the chapter I will expose the case of how General Electric transformed during the same period of time and how, after the financial crisis, the group decided to redirect its focus from the banking sector to software and 3D printing industry. Finally, with the third chapter I will introduce the results of my initial idea, that is answering the question of who are going to be the most successful players in the wake of the industry 4.0. Introducing the Bowl model, a modification of the smile curve that will be based on an ideal asset, which will derive its main characteristic from the fact that it is not specific to any product or manufacturing process. Subsequently, I will present the Hub firm business model, which will likely arise from the massive utilization of 3D printing machines, and its symbiotic relationship with the small and very lean Meteorite business model. I believe that these three models put together will provide a fair forecast of what we could expect to see optimistically within ten years, and to direct the attention to manufacturing activities, as they will be, in my opinion, what this revolution will modify and change the most.

[1] C. Carmy, "Nervous System Creates Kinematics Dress 3D Printed by Shapeways & Acquired by MoMA", ShapewaysBlog.com, December 9, 2014, https://www.shapeways.com/blog/archives/19275-nervous-system-creates-kinematics-dress-3d-printed-by-shapeways-acquired-by-moma.html, Date of consultation September 30, 2016

Chapter I: The antecedents of Industry 4.0

1.1 The fourth industrial revolution: definition and elements

1.1.1 Mankind seeking innovation

Industry 4.0, or the fourth industrial revolution, is a term that has recently been used with reference to the technology transformations (both current and those forecasted for the upcoming five to ten years) that have been influencing industries and the economy as a whole since the past 10 years. Given that it generates from the third industrial revolution, it uses some of the technologies previously available while also improving them - consider for example the increase in computing power and its miniaturization. However, the fourth IR is different from the previous one because it is characterized by the omnipresence of computing machines, sensors and communication devices, which are nowadays feature of almost any product available on the market.

Furthermore, the fact that these devices are able to communicate among themselves and that they are driven by advancements in the design of artificial intelligence, has given them the ability to interact more and more with their environment.

Before going too deep into analysing the fourth industrial revolution, it would be wise to mention briefly what are the foundations of this revolution, what has happened prior to it and why it is called the fourth one.

Starting from basic definitions, a revolution is a phenomenon that occurs when a brand new concept or idea is applied to our everyday lives, changing them radically from what they used to be before such event. What we call the application of these ideas are disruptive technologies, because they quite literally destroy, or better yet substitute, whatever previous solutions were used to achieve the same mean. Human history is riddled with revolutions of this kind: starting from the mastery of fire some 200,000 years ago, the development of agriculture and the consequent rise of cities and eventually the discovery of metals. Closer to us in time, another agriculture revolution occurred during the eighteenth century and, thanks to the consequent increase in population and thus demand, it laid the starting blocks for the first industrial revolution, which represented a major turning point in our history, because it has substantially changed an economical system that had always been focused on agriculture.

From this moment onwards, human history was characterized by a relatively steady stream of innovations if compared with the previous 2,000 years. Modern history has been characterized by two important industrial revolutions, each of which had different characteristics and scopes.

1.1.2 A shift in key economic sectors: the 1st industrial revolution

The first industrial revolution (1760-1840 ca.) was based on the discovery of steam power and on new ways to exploit power generated from water, also discoveries in metallurgy and the textile industry. Production of goods started to become mechanized following some minor technological advancements occurred in the United Kingdom's textile industry. Initially slow and of little concern for the industry as a whole, these innovations would interest just few steps of the production process, namely spinning and weaving, thanks to the diffusion of machines like the famous spinning jenny, which was patented in 1770 by James Hargreaves. The efficiency gained from such innovations would be lost because of the fact that all other steps of the production would maintain previous operating speeds, creating bottlenecks throughout the process. Spurred by the increased demand for domestic fabrics, each bottleneck would be addressed by a steady stream of innovations, until the speed of the entire industry could efficiently meet the increased demand, creating one of the first mechanized industry.

Incremental innovations in the production of iron, introduced by reverberatory furnaces, together with the utilization of coke as a means for more effective heating, allowed reducing the content of impurities in the final product. Because of this, iron became easier to produce and cheaper.

The introduction of steam engines further aided the quest for speed and increased throughput, at the beginning complementing machineries relying on the flow of water. Example of the first steam engine economically successful where the Savery engine in 1698 and the Newcome one just before 1712, both used in the mining industry to pump water out of tunnels. As the technology improved with changes introduced by Watt and Boulton some fifty years later, it would eventually substitute water based machines also in milling, as it provided a higher flexibility location wise, since it did not require any more the presence of waterways, as well as it generated more power.

Altogether, these innovations caused a shift in the world economy: in fact, for the first time in history, the main driver of growth was to be found in the manufacturing sector, thus moving away from systems that based their wealth on agriculture and the commerce of agrarian products. As a consequence, people started moving away from the countryside while cities experienced a population growth. Furthermore, the first industrial revolution favoured the concentration of different processes in the same physical place, thus bringing together on average more workers than what was previously required. This gave way to an ever-increasing specialization of labor.

Even though greater than previous form of organizations, the size of factories that were introduced during the first industrial revolution were still far from the dimension of the firms that can be found nowadays. This was due to the fact that the cost of transportation was too high and the means to convey goods were still unreliable and heavily influenced by environmental conditions, thus limiting the size of the market that a single factory could potentially service. In short, the first industrial revolution was limited by the existing infrastructures. For such reason innovations from the first industrial revolution were limited to the textile, metal, mining and machine tool industry[2]. However, during the second industrial revolution these issues would be addressed.

1.1.3 Wider markets for wider businesses: the 2nd industrial revolution

The second industrial revolution, which took place between the end of the nineteenth century and the beginning of the twentieth, after a period of relative slowdown in terms of innovation, allowed industries to grow in size, especially in the United States and Germany. Development of new means of transportations and communications, which are mainly found in railroads and telegraphs, effectively tackled the difficulties with which people, ideas and good were able to move around the world. Previously, railroads tracks were made of iron, which was not strong enough to support heavy locomotives, thus

[2] F. Amatori, A. Colli, "Storia d'Impresa. Complessità e Comparazioni", Mondadori Bruno (2011)

limiting the efficiency of early railroads. But with the substitution of iron tracks with steel ones, track of higher resistance and length could be built, which needed little maintenance. This enabled heavier trains and loads to cover longer distances, making trains the favoured means of transportation.

As soon as railroads started to be built, they provided a way of transportation that was reliable and could offer fares at frequencies and speeds never seen before. Once distant markets hard to service were now in reach and at an unprecedented low cost. It now made sense for factories coming out of the first industrial revolution to increase the scale and speed of production in order to meet the ever-growing demand that was unlocked by the lower cost of transportation.

Thus, widely dispersed markets, like those in the United States, benefitted greatly thanks to the rapid and capillary diffusion of railroads throughout its territories, effectively creating one big market. But the railroads did not just provide the means for the economy to scale up, it also provided the model that many would emulate in almost every industry during the course of the second industrial revolution. In fact, especially in the case of the United States, in order to manage the everyday operations of trains travelling such distances and to finance the construction and maintenance of these infrastructures, a new kind of organization appeared, different in both size and scope, which would later be called by business historians as the unitary form. The number of employees and the systematic division of roles required to coordinate and manage transportations efficiently lead to the separation of control from ownership, giving birth to the managerial class[3]. Organized in operating units, managers were paid professionals whose tasks were to control, support and evaluate. They were also divided in two different categories: line managers were responsible of ensuring the flow of operations concerning train fares, while staff managers had supportive roles concerning with bureaucracy and finance.

The experience and knowledge gained by these managers inside railway companies would soon be spread to other industries as well, starting from the steel industry and Carnegie's experience and moving on to the oil industry with Rockefeller and BASF in the German chemical industries. This process would soon spread to

[3] A. D. Chandler, "The Visible Hand: The Managerial Revolution in American Business", Harvard University Press (1977)

almost all those industries that were left untouched by innovations coming out of the second industrial revolution, because now, the growing number of infrastructures were able to support the newly gained dynamicity of markets. During the same period of time, other technologies would be discovered that would keep helping bringing about this second revolution: just to name a few, it is in this time frame that the internal combustion engine was perfected, together with the rise of radio technology and the diffusion of electricity. Furthermore, factories, which were already deeply transformed by these changes –both managerial and technological- where continuously evolving to resemble modern day ones, but it was not until the introduction of scientific management studies, almost immediately followed by Fordism, that the assembly line and standardization rose and the true power of economies of scale was unleashed.

After the second industrial revolution, the world economy was moving at a very different speed with respect to earlier times[4]. Adding to the mix the graduate fall of the communist block and the ever-increasing relaxation on tariffs and import taxes, goods and ideas started to travel significantly more than before, which would eventually lead to the globalization of the economy. However, for the globalization to take place, the world was expecting on yet another revolution, this time influencing how information and computations would be produced, stored and analysed.

1.1.4 The 3rd industrial revolution: introducing computers

The start of the third industrial revolution is placed towards the second half of the twentieth century and it is depicted as a transition period in which computations, information and communications switched from being analogue to digital. To be fair, this was a process that started long before, which origins can be traced all the way back to the first mechanical computer theorized by Babbage and Lovelace almost a century earlier. Furthermore, in between the nineteenth and twentieth century, managing information had seen an enormous improvement in speed and effectiveness thanks to the development of punch card technology, which would help in the 1890 US census. Nonetheless, it was not until the second world war that the digital computer as we know it today was created.

[4] Ibid. footnote 3

Demand for fast and reliable computations during war time was at an all-time high, since armies needed them in order to provide soldiers on the field with tables to aim properly artillery shells, to drop bombs from high altitudes accounting for winds, to hit those bombers from the ground with flak fire, or in order to decipher enemy's communications. These calculations were already being computed by computers, with the only difference that they were human computers, not machines. As a matter of fact, a computer at that time was a professional figure requiring people to literally solve computations. For more complex calculations, a team of such human computer would be organized so that each individual had to focus on just a part of the bigger problem, which would then be reassemble in order to give the final answer to the computation.

However, this was a lengthy and time-consuming process, which could not keep up with wartime demands. It was in response to such bottleneck that the first modern computers were created. Both the United Kingdom and the United States would develop and build these first machines in great secret, thus it is not known with absolute precision which came first, whether the British Colossus, or the American ENIAC. These prototypes where based on vacuum tubes and required an enormous amount of physical space to operate as they were made of several racks each containing many electrical boards. Also, they were providing only the hardware and did not incorporate any kind of integrated software, since they had to rely on external physical memories often provided once again with punch cards. Although extremely advanced for their time, these early machines were programmed using an extensive array of cables, which had to be continuously rewired in different settings for each different task.

The next step would come soon after, when John von Neumann theorized a computer that could store its various programming inside its own memory, thus allowing the machine to switch between its various functionalities based on the task it was presented with. This was possible substituting the bulky punch cards with magnetic tapes, giving birth to the modern computer as we know it.

Further innovations occurred during the cold war and the race for space would focus on the miniaturization of computers, allowed by the development of transistors and subsequently integrated circuits.

Gradually, computers would become almost essential to businesses, but their wide spread use was only halted by their prohibitive costs. The breakthrough came with the development of the microprocessor, which dropped the cost of producing computers and made processing power affordable and compact. Starting from the 70', computers would begin to enter into households. Coupled with the development of the internet, which begun as a simple network of networks connecting researchers in different universities around the United States, it would provide a solid platform for the spread of cheap and potentially massive communications.

To conclude, the third industrial revolution caused the economy to shift from industrialized to service-based, all the while it was providing efficiency gains to every industry, influencing the organization of people and their methodologies[5].

[5] J. Greenwood, "The Third Industrial Revolution: Technology, Productivity, and Income Inequality", Economic Review, Federal Reserve Bank of Cleveland (1992)

Chapter II: The fourth industrial revolution

2.1 Analysing and predicting the 4th industrial revolution

Now, having described which revolutions preceded the current one, a focus on the fourth industrial revolution is due.

Industry 4.0 is difficult to define as it is happening at the time I am writing this paper. Thus, as of yet, there is no clear consensus on when it has started and what its far-reaching consequences will be. However, there is a sort of tacit agreement among scholars that this revolution is a clear cut from the third industrial revolution, and that it has started somewhere after the 2008 financial crisis. The distinction made from the third industrial revolution feels appropriate even though, as it was already mentioned at the beginning of the chapter, this revolution is being built on technologies introduced during the previous one, much like the second industrial revolution was based on technologies coming from the first one, specifically increase in computational power and its miniaturization. Nonetheless, we are now seeing a diffusion and widespread adoption of such computational power that goes beyond the physical computer, as more and more products are integrating capabilities that only fifteen years ago where sole prerogatives of computer machines.

Among the first of these products were record players, which could store hundreds of records using mp3 -digital- format. Mp3 players swiftly replaced disc music players, generating a commercial race to offer the best of such players. Then, the increasing adoption of digital cell phones required mobile companies to compete among one another through diversification strategies, which would soon result in the integration of the mp3 technology along with other features like digital cameras and calculators inside mobile phones, thus requiring greater need to manage digital data, spurring innovation towards the integration of powerful and compact software. A new standard was set for the industry with the presentation of Apple's IPhone in 2007.

Software integration did not stop to music players, video cameras and phones. Refrigerators, ovens, microwaves, washing machines, dishwashers and even cars started to feature software and digital sensors. Sensors, coupled with the capability of computing, are the reason why nowadays almost all products are being preceded by the word smart.

In fact, they are able to collect data they receive from the environment thanks to whatever sensors the machine is provided with and are then able to interpret, analyse and act accordingly to it, thus providing such machines with increased resource efficiency and networking capabilities.

At the same time, developments in artificial intelligence are allowing groups of researchers to build robots that are capable of tasks that only ten years ago where considered impossible for electronic minds to accomplish. Computers are better suited than human minds to deal with computations and to follow clearly defined instructions, but this kind of intelligence alone is far from adequate to ensure a functioning artificial intelligence. In fact, it is almost impossible for a programmer to instruct an artificial intelligence to react in a specific manner to every situation in which it can incur. But since the very idea at the foundation of a robot is of a substitute of humans in everyday activities, it is expected of them to be able to deal with life complexness. Surprising breakthroughs in the ability to codify reality in ways that artificial intelligence can comprehend, together with developments of algorithms capable of reproducing in a crude manner some level of pattern recognition, are allowing substantial improvements and hopes for the future of robotics.

Another exciting development deriving from industry 4.0 is the addictive manufacturing that has been enabled by 3D printers. This is a revolution in itself, as it is the first process that instead of removing parts of material from a block to create the desired object, it adds layer after layer of material. This means that it does not involve cutting or milling, but rather, it uses a high precision laser to solidify layers of powder, which can be composed of various materials such as plastic, metal and porcelain. The printer follows an extremely detailed pattern, which is designed digitally and can thus be as accurate as no previous manufacturing technology could be. It is referred to as 3D printer, but the most accurate depiction of this technology is additive manufacturing, since it simply adds material.

These three technologies, which were briefly mentioned above -3D printers, Artificial Intelligence and computers, are the founding block of the fourth industrial revolution. There is much more that is worth mentioning for each one of them, so in the next three sections I will try to cover the most interesting aspects, analysing these innovations one at the time.

2.2 Simplifying reality: the miracle of computers

As mentioned earlier in this chapter, computers are an innovation from the third industrial revolution. The evolution rate of this technology has been quite constant since its invention, or better, since it was transformed from an analogue technology to a digital one. A digital electronic computer is in fact a machine that uses binary logic as the bedrock for its inner functioning, while also exploiting the flow of electrons to work as opposed to the movement of a lever or gears.

Such conversion enfolded during World War II with prototypes such as the Colossi and ENIAC which were among the first working machine using binary logic, but it was not yet complete, as it occurred only at a hardware level. In fact, in those early days, what we now call software, or the series of rules and commands the computing machine is to follow, was made up of the state in which an extensive array of cables and switches were positioned. This meant that each time those early machines had to tackle a different problem, they would have to be properly reprogrammed.

In a way, the software was still made of human inputs. The idea to integrate the software into a computer's memory so that it could reprogram itself as needed according to the specifics of the task at hand was first theorized by Alan Turing. His vision was a theoretical construction on which later, John Von Neumann would draw inspiration to theorize how, with the technologies of his time, a Turing's architecture could be built. Thus, in 1948, the computer that was able to incorporate its instructions in its own memory ran its first program and the modern computer was born.

During the following years, incremental innovations to both the hardware and the software would make the technology faster and cheaper. Starting from 1955, bulky vacuum tubes were substituted by transistors, which served the same purpose of amplifying or switching electronic signals but they were extremely smaller and did not required as much energy as the vacuum tubes did, thus generating far less heat. After that, integrated circuits were introduced (around in 1959) by both Jack Kilby at Texas Instruments and Robert Noyce at Fairchild Semiconductor, as result of two different and independent researches. Integrated circuits essentially simplified and optimized previous electronic boards, as they quite literally integrated in a small space and without the need of wiring them altogether all of those parts that composed an electronic circuit.

The conversion from analogue to digital had greatly improved the rhythm at which each successive improvement occurred. In fact, only seventeen years after the first modern computer started to crunch numbers, the director of research and development at Fairchild Semiconductors, Gordon Moore, theorized his famous law about the increase in computing power.

2.2.1 Moore's Law

When asked about the future of computers in 1965, Moore answered that they would have doubled their processing power with each passing year. He actually talked about the increase in the complexity for minimum component costs that he had observed in previous years in which he forecasted to keep up for the next ten years. What he meant was that if you were to spend a dollar on computing power, the next year you could spend the same amount and get twice as much computing power. Moore further stated that this would have been a process that would have lasted at least ten years. In retrospect, we can say that he was being a bit too cautious, as his law still holds today.

Granted that the rate at which the doubling happens is not anymore a year but it has settled at about eighteen months, it is still an impressive and remarkable feat, unprecedented for such a long stretch of time. Just think about the examples that are given in the book "The Second Machine Age" by Brynjolfsson and MacAfee, where the authors point out that planes usually do not fly double as high after one year, nor are cars double as fast nor trains able to haul double the goods[6]. Such examples are well suited to make us understand the speed at which computers have and still are evolving.

What really strikes the two authors is the constant betterment of computational power at a factor of two. To them, a constant doubling is unprecedented and, on the long run, it has the potential to lead to a series of innovation that we are just starting to see now, which they call the second machine age. It is important to understand the implications that an exponential growth represents with such a constant doubling.

[6] E. Brynjolfsson, A. McAfee, "The Second Machine Age", W. W. Norton (2014), pg. 22

For the human mind, it is hard to comprehend the numbers involved in an exponential growth, because an increase from one quantity of something to two quantities soon enough turns into numbers that are difficult to grasp for the human brain. The authors further expand this argument by narrating a fable about an emperor, an inventor and a chessboard.

A smart man had already for some time invented the game of chess, and was travelling around what we now know as India during the sixth century BCE. He was promoting his game, and ended up showing his invention to the emperor of those lands, which was so impressed by the complexity and beauty of the game, that he insisted for the inventor to name his reward. Because the emperor liked so much his game, and wanting to show modesty, the inventor only asked for some rice to feed his family, but arranged in a specific manner on the chessboard: starting from on grain of rice on the first square of the chessboard, they would have to put double the amount of rice in the next square. Not seeing how enormous of an amount the constant doubling of one grain of rice for 63 times would have yielded, the emperor agreed to the terms of the inventor.

The number is quite high. In fact, if the emperor were to fill only the first half of the chessboard, it would have given the inventor about four billion grains of rice, which is already much. However, even bigger problems start to ensue after we consider to fill the second half of the chessboard as the numbers start to be inconceivable. More than eighteen quintillion grains of rice would have been needed to fill the chessboard, or as Brynjolfsson and MacAfee put it, probably more rice than it was ever produced in the history of the world. This is why a doubling in computing capacity each eighteen months is quite impressive, especially if one considers that it has been going on since the digitalization of computers in the fifties.

Another example made in "The Second Machine Age" to prove that the speed of innovation is moving fast in the computing world, is that of the ASCI Red computer, a machine built by the US Government in 1996 which was able to process *"one trillion floating point operations per second"*[7] (floating point operation means that the decimal point present in the numbers computed is allowed to "float"). To keep this machine operating, which was almost as big as a tennis court, it would require as much electricity as that needed to power eight hundred homes. In 2006, a computer with almost the same

[7] Ibid. footnote 6, pg. 26

processing power, if not more, than the ASCI Red, was be made available for the general consumer. This machine was used to recreate and depict real time rendered graphics for entertainment purpose and it known as Sony's Play Station 3. Compared to the ASCI Red, which costed 55 millions of dollars to develop, you could buy a Play Station 3 for approximately 500 dollars.

But why does it happen? Why does this phenomenon occur only for computers? Since the digitalization and electrification of this technology, computers are no more constrained by physical limits, at least, not the same physical limits that we are used to see in our everyday lives. Their physical limits are set by how many electrons per second can be carried through a circuit, which is a totally different matter than when considering the flow of fuel inside a car's engine.

However, as in the fable I just summarized, what has happened in recent years makes one wonder whether this wide spread integration of computing power is just the real version of the second half of the chess board: instead of uncountable grains of rice we have many objects that are turning digital and acquiring smart capabilities. The only difference is that the more things turn digital, the more they can enjoy the same blessing that has befall upon computers. In fact, they too would be improving at the same rate as the computing technology, basically jumping on that freight train that is moved by Moore's law and which is going at unprecedented speeds. Thus, while it is not the case for a car to be twice as fast just eighteen months later, we are definitely seeing a digital camera's resolution doubling over the same period of time, or the same could be said about smartphones, download speed or digital communication effectiveness[8].

To put it in simple terms, this trend involves the spread of computing power, integrated thanks to its miniaturization. Then, the object integrating the technology will likewise benefit from the celerity of innovation that is allowed by Moore's law.

[8] M. E. Hellman, "Moore's Law and Communications", Stanford University (2003), https://www-ee.stanford.edu/~hellman/opinion/moore.html, Date of consultation April 3, 2016

2.2.2 Consumers and computations

Computing alone is of mild interest when a consumer is involved. In fact, it is what computing can do for the consumer that fosters the consumer's interest. But in order to effectively help the consumer's experience, computers need inputs, which until recently were manually fed to the machine.

The next step is provided by the diffusion and innovations that are enhancing digital sensors. For example, say that a consumer is interested in losing weight. In order to do so, she/he needs to have an intake of calories that is less than the calories used by her/his body during the day. Given the sex, age, height, starting weight and a constant monitoring of the heart frequencies, a computer can easily calculate how many calories the customer is consuming. The only problem is that, as long as the input is manual, the consumer has to log in the computer its heart rate every time it varies, in order for the calories count to be as accurate as possible. This would have meant logging hundreds of variations throughout the day, an effort that rarely a customer would pay for.

However, thanks to the integration of computing, recent development of wearable technologies and a digital sensor that can read and register heart's pulsation just by being in contact with the wrist's skin, the creation of watches that were able to constantly input those hearts rate was possible. Thus, an accurate computation of calories consumed is achievable, and consumers just need to keep it on their wrist, with all the functionalities of a clock, a step counter and an alarm. Such devices are a commercial success and are selling well[9]. Many organizations are interested in this kind of products and many more were born just to service this emerging market. Fitbit, Moov Now, Garmin, Samsung and Tom Tom are just few of such firms. Here, the difference was made thanks to the addition of a digital sensor, a bridge for the computer to input automatically data collected from our everyday lives.

Heart rate monitoring is just one of such examples. In "The Second Machine Age", the authors talk about the development of another sensor that is exemplary of how important their role is. Once again, this is something that was developed to entertain the general consumer, as it is a device that works alongside Microsoft's Xbox, a gaming platform. The device is called Kinect, and it consists of an array of microphones, a colour sensor

[9] IDC, "The Worldwide Wearables Market Leaps 126.9% in the Fourth Quarter and 171.6% in 2015, According to IDC", February 23, 2016, http://www.idc.com/getdoc.jsp?containerId=prUS41037416, Date of consultation May 15, 2016

(camera), an infrared emitter and an infrared 3D depth sensor. These sensors work together to recognize and capture human movement, they can track up to twenty joints on as many as two players simultaneously. Such sensors, coupled with cleverly designed software, allow gamers to use as a controller not only the usual joypad, but also human movement. People would mimic movements done in games such as tennis, darts and golf, and their digital avatar would perform their same movement.

At release, in 2010, the Kinect has proved to be a huge commercial success. Per se, this would be of minor importance, but many have taken an interest in such a device, since it proved much more powerful than it was needed for mere games.

Almost a year after its release, Kinect's software was made available for download as a development Kit, so that programmers around the world could start tinkering with the device. Only one year after, results of such tinkering have been extremely fruitful, especially for the development of artificial intelligence in the field of Simultaneous Localization and Mapping, or SLAM -which is basically reconstructing a map of any location that the Artificial Intelligence can later use to navigate safely the environment.

Another example of a device that is enabling computers to be efficient at more and more tasks is given by the development of Google's Self Driving Car. To be fair, the car uses a number of devices to navigate safely on the roads: radar, sonar, stereo cameras and LIDAR (a sensor that uses lasers) all work together to ensure the vehicle can move autonomously. Although not yet fully developed at the time I am writing, the success that Google has been having with this project so far is remarkable, and it is bound to improve. In fact, Tesla is already selling cars that have a self-driving mode for highways.

These examples of digital sensors are important to understand how they are giving computers a way to become something else than just a box that crunches numbers. Digital sensors are the gateway for computational power to be applied to our daily lives on the spot, without the manual input that was required for the first sixty years of the history of computers. Moreover, since sensors themselves are digital, we can expect them to show an evolutionary pattern similar to that displayed by computer, to jump all on board the Moore's law train. This brings us back to the fact that devices are increasingly becoming intelligent, or rather smart, by integrating computers and software that are able to react automatically to information they gather from their sensors.

Almost any object you can buy has its "smart" version, which is the same object but supposedly using less resources and anticipating the needs of the consumer. Think about a washing machine, which chooses the right amount of water and soap needed to efficiently clean a load of dirty clothes by just weighting them once they are placed inside the machine. Or a system of crossing lights, that knows how many cars, bikes and pedestrians are present at each side of an intersection thanks to sensors in the concrete and cameras, and is able to calculate priorities such that the total waiting time is reduced, all the while prioritizing buses and ambulances.

Whatever the object, its smart version allows the consumer to use it more efficiently, operating with less resources because the device is able to sense the physical world through its digital "eyes", thus reacting and twicking its resource usage. But it is not over yet. I have purposely omitted another reality that has been brought forth by computers, which, when added to the equation that is being described now, changes quite a bit the yielded result: this is, of course, the ability of computers and devices to communicate among one another, which creates the Internet of things.

2.2.3 Internet of things

While talking about how Moore's Law granted an exponential growth to the digital world, I avoided mentioning how this process did not just occur for computational power and sensors, but it also involved communications technologies, as they too evolved into a digital form.

The history of communications is as long as human history itself, and for most of the time it was based on people physically relaying messages over long distances, or on optical signals, like flags or light coded in such a way that sender and receiver could communicate. However, communications became one of the first recipients of the discovery of electricity, since it was almost immediately understood how fast could electrons move. In fact, the first attempts to create proto-telegraphs took place during the first years of the nineteenth century and the commercialization of this technology started in 1837. From there onwards, communications would travel riding electrons.

Until the third industrial revolution started, internet meant sharing information among desktop computers and communicating from the immovable machine. Later, wireless internet evolved and allowed cell phones and little, portable devices to connect too. Internet became mobile and easily carried around, further increasing its usage. As the adoption of internet expanded to more and more people, becoming a social phenomenon, the amount of information and data shared grew very quickly. The content that, up until recently, internet could provide access to, was mainly information that the users would upload manually to the network. Content generated by people all around the world in the form of text, photos, audios and videos still is today a big part of what the internet is.

However, around 2008 and 2009, according to Cisco[10] things have changed. In fact, during such time frame, there is a date in which the number of devices connected to the internet surpassed the number of people connected. Internet suddenly switched from becoming the internet of, for and from the people to an internet also of things. Actually, an internet which is for the bigger part made of things, since the number of devices connected is estimated to grow to 50 billion within 2020. Once again, this outcome can be directly traced back to the evolution of computers and the integration of its power in smaller devices. This means that all those hand-held devices that I talked about earlier in the previous section are not just capable of crunching numbers and reacting based on what their sensors pick up, but are also able to connect to the internet and share information among themselves. Much like people do, but with a different purpose.

Let us think once again on the meaning of a smart object. A smart object is one that is able to react to certain conditions, which can be determined thanks to sensors that are incorporated in said object, fulfilling its purpose in a most efficient way. Now, if we add to this definition the fact that the object is able to relay the information it has gathered to a network of other smart objects, and that each of these objects can then use that information taken from a multitude of different sensors, then one can state that smart objects can base their reaction on a much larger pool of data, thus potentially increasing the overall efficiency.

[10] D. Evans, "The internet of things, How the Next Evolution of the Internet is Changing Everything", Cisco Internet Business Solutions Group (2014), pg.3

Smart things have the ability to understand through computational power, sense through digital sensors, and finally communicate through the internet. However, even if Cisco claimed that we are already in the midst of internet of things, at the time I am writing this is still in its infancy, with not many real achievements under its belt.

Nonetheless, it is already giving us some minor examples of its capabilities and many people are envisioning how things will change in the near future. The fitness tracker I have at my wrist is monitoring my heart rate and tracking my activities, then it sends the information via Bluetooth to my cell phone, which saves the data and draws charts of my activities of today and the past months. But this communication is not just one-sided. In fact, were I to receive a call on my cell phone and were I unable to know it because of me leaving it in silent mode, the tracker at my wrist would know it and it would vibrate to let me know I am being called, also displaying the name of the caller. Furthermore, if the batteries of my fitness tracker were about to end and I did not realize, I would get an email on my phone noticing me of the fact.

Another example that the internet of things is providing us with is the smart thermostat. This thermostat is able to use its sensors to determine not only the temperature in our houses, but it also keeps track of the habits of its inhabitants, determining which rooms are worth heating more and which would not be used. It also keeps into account local weather as it uses real-time weather forecasts to counterbalance extremes in hot or cold seasons automatically. All of this while it can be remotely accessed via mobile phone in order to know constantly the temperature inside home and empowering the user to modify such temperature from wherever, and once the system reaches the desired temperature it would let the user know with a simple notification.

There are also other examples, but they are all coming from forward-looking people that are trying to give us a sense of what is coming. In a TEDx talk[11] given at Temecula (in California) in 2014, Benson Hougland, vice president of Opto 22, a US manufacturing company which specializes in hardware and software products for industrial automation, remote monitoring and data acquisition, describes his vision of what the internet of things will look like. He uses the same example of the fitness tracker I used but with a twist: it is communicating information on his health directly to his medical provider, so that in case

[11] B. Hougland, "What is the Internet of Things? And why should you care?", TEDx Talks, December 17, 2014, https://www.youtube.com/watch?v=_AlcRoqS65E, Date of consultation May 23, 2016

of a strike, god forbid, an ambulance would be immediately dispatched based on an automatic call made by his wrist tracker.

Others already talk about the possibility to create smart cities, in which the various infrastructures are able to communicate with each other in order to maximize the service they offer in terms of transportation, waste, environment and energy management, all the while ensuring minimal waste of resources.

Remember the smart traffic lights I mentioned in the section before? They too are connected to the network of cities infrastructures, giving real time data on the state of traffic, information that can then be sent to each citizen that he can use to determine the best route and means to get to its destination. Systems that use real time data to inform where parking spots are available throughout the city as well as street lights that only turn on when needed and at the right intensity based on the time of the day and weather conditions.

The number of application are virtually endless, and are bound to increase and involve also the productive economy, the way we relate to producing machines and the way they relate to each other.

2.3 Printing, not building

In 1464 a huge marble statue representing the biblical figure of David was commissioned to be place on top of the Florence cathedral. The very large block of marble required to start the work was taken from a quarry in Carrara, and Agostino di Duccio started the process of removing little by little excess of material to reveal David's final form. But the project would only go so far to start the shaping of legs and the torso, until it was halted. The enormous six meters long block would remain untouched for almost 35 years, yet when in 1501 Michelangelo Buonarroti was commissioned the block, the project was brought back to life. After nearly four years of chiselling out all the unwanted marble from the block, Michelangelo's David was ready: a marble statue 5 meters high carved out of a unique block that required almost 40 years in the making, if we also account for the time the unfinished marble block has waited for Michelangelo to arrive. A true masterpiece of art, which still today amazes those who gaze upon the statue. For this reason, it is emblematic of the subtractive manufacturing process.

Subtractive manufacturing consists of every process that starts from a piece of material bigger in shape than the desired object and then, through the removal of excess parts of material, the final shape is obtained. This manufacturing process together with the formative one, in which the material is given the final shape by applying energy to it, like forging, injection, molding and bending, were until recently the only manufacturing processes available.

Yet things have changed, with the introduction of the additive manufacturing process. Additive manufacturing is a term used to describe the work done by 3D printers, because they add layer over layer of material until the desired object is created with almost no scrap or wasted material. Such printers are the second important element of the fourth industrial revolution and they base their existence, once again, on the power of computation. To understand better why this is, we need to take one step back.

A 3D printer is a machine that operates on two dimensions simultaneously and only after all the work on the plane is completed on a vertical component. It does this working on layers. Almost all of them share the same shape, a squared frame on which the printing part is able to move on the first two dimensions of length and depth, then usually a support lowers the working table over which the printing part is operating, enabling it to operate on different layers and thus achieving the 3rd vertical dimension.

Different printers are able to work with different materials, according to the technology they use they can print with plastics, ceramics and even metals. The list of materials available is growing at a fairly stable pace. The 3D printer was introduced in 1985, when it was patented by Chuck Hull. At that time, only one methodology called SLA or Stereolithography was available: it consisted in printing using beams of light to solidify a special resin in forming a solid polymer. Then in 1989, the SLS (Selective Laser Sintering) process was invented, which consists in a laser sintering powdered material to bind it together and create a solid part. Finally, in 1995 the SLM process, or Selective Laser Melting, allowed metals to be used as printable materials. As of now, 3D printers can work with several types of plastics, like acrylic, rubber, composite polymers; various metals like aluminium, titanium, steel, gold and silver; and several other materials like gypsum, ceramics, concrete, as well as some early prototypes that are able to print using organic materials such as food, paper and biomaterials.

In 2015, during a webinar given by Tyler Reid[12], an employee at GoEngineer stated that the number of materials available for 3D printing is likely to grow, given the interest it is raising especially in these last years.

In their infancy, 3D printers were mainly used for their capacity to print very complex shapes with a fairly good accuracy, they were thus employed especially for the creation of prototypes. Consider that, prior to 3D printers, a prototype would require months of manual work. Depending on the industry and on the project, several prototypes would be required in different materials, to ascertain the various requirements the final piece wold have. This meant having different artisans specialized in each material the prototype was needed of. The automotive industry provides us with an example, where the first translation of a paper drawing to reality is done by modelling clay. In a web article of 2012 on CarbodyDesign.com[13] BMW revealed their prototype process, which can take up to 5 years and involves different stages, in which many different 1:1 clay models of the car's concept, compete against one another. The first draft using the final material is done only after having chosen the winning model, 5 years after the prototypization process begun.

It is easy to see why a 3D printer, which can yield the same prototype in less than a day, would conquer the prototyping process, especially in those industries that make more use of them, such as the car industry, which we just analysed, but also the aerospace and defence industry as well as the medical one.

However, in the last few years, these industries, which have already seen the advantages of 3D printing for prototyping reasons, are beginning to integrate part of their production with these machines. The trend consists in replacing with 3D printers those parts that would otherwise require very complex machining because of their shapes and difficulty in production. This was possible also because during the first years of the 2000s there has been many developments that allowed printing using

[12] T. Reid, "3D Printing - Past, Present, & Future", GoEngineer, July 31, 2015, https://www.youtube.com/watch?v=3ZUQ4QWcmuA, Date of consultation June 27, 2016

[13] CarbodyDesign, "The design process at the BMW Group", March 2, 2012, http://www.carbodydesign.com/2012/03/the-design-process-at-the-bmw-group/, Date of consultation June 28, 2016

new materials, allowing a shift from a process that was only marketed as rapid prototyping to the new and revolutionary concept of additive manufacturing.

On an article published on the Italian newspaper “La Repubblica”[14] it is reported that General Electric is already employing 3D printers to fabricate several aeroplanes parts both because of the complexity of the shapes involved and because of the fact that they allow to use ceramics and titanium as building materials. Previously, turbine blades used behind the main blades of a jet engine were realized soldering 21 pieces of metal. Now the 3D printer does the same job in one take, giving the same result but with a single solid piece, with the added advantage that the purity of the metal is even higher. The newly added Italian division of GE, Avio Aero di Cameri, is even studying the implementation of non-metallic components in the construction of its engines, thanks to their newly added ability to work ceramics materials with the precision granted by a 3D printer. The result is a piece that has exactly the same shape as the one produce with conventional machining processes, but with one fourth of the weight.

But there is more: aside from using better materials, 3D printers are also able to reduce the mass of an object to the bare minimum. This is because it is better suited to recreate complex shapes than conventional machines, allowing the object to be made only of its operating elements and not anymore of those elements that were added for production purposes, like plastic objects that have more mass than necessary, so that the machines can handle each piece. During the course of his webinar, Reid explained this process, calling it topology optimization, a redesigning methodology to reduce a component optimizing it for strength or stiffness given a load. This is possible thanks to software capacity and computational power, the example Reid gives is of a bracket produced once again by GE, which is optimized in such a way to result in a 70% mass reduction.

But why are these machines so revolutionary? The machine itself is just a linear axis machine that does what a computer tells it to do, yet the reality is much more interesting than that. 3D printers are, in fact, another means for the bits to become atoms, a way to transform digital designs in reality in a matter of hours. The additive production process starts at a computer, where thanks to a CAD program (Computer Aided Design) an

[14] P. Griseri, “Stampanti 3D e motori intelligenti così in GE nascono le tecnologie future”, La Repubblica, Affari e Finanza, July 4, 2016, pg. 12

engineer is able to design virtually anything and with a precision which is impossible to obtain in real life, but that for the digital world is just a matter of coordinates in a digital plane. Then, the program will slice the object in layers, so that the printer can begin translating the bits into atoms starting from the bottom layer and working its way up.

But this interface of linear axis is something that goes beyond the mere production of things. In fact, it is a revolutionary concept to allow a computer to do virtually any work inside the square described by the axis of the machine, since the entirety of the space is mapped and translated in the digital format the machine can understand.

Recently, many YouTube videos have been published by a company that introduces its machine, which uses the same principal of the 3D printing, however instead of creating objects, this machine does everything a gardener would[15]. They call it FarmBot. FarmBot is a peculiar machine that once it is placed upon a square or rectangular shaped flowerbed, it will check that the garden grows properly, inserting seeds in the ground, watering them using the right amount of water for each plant so that any waste is reduced, measuring the PH level of the soil and monitoring the general growth of the plant. FarmBot is able to perform all these functions because it comes provided with a series of tools that the machine itself can switch from, because they are placed within the machine reach, inside the linear axis. Thus, allowing the computer that manages the machine to know where the instruments are and plan the movement accordingly, retooling it as needed. It comes equipped with a soils sensor, a weed suppressor, a water hose and a seed injector. From the same computer, the user is able to manage the garden, deciding which crop to grow in each part of the garden thanks to a very friendly user software, and the system lets him know when each crop is ready for harvest. Furthermore, the company is open sourcing the software to run FarmBot, so that anyone interested can customize their experience in a true DIY (do it yourself) style, as they advertise it.

Yet, this technology is not new in itself. Robotic industrial arms with the ability to retool themselves and able to bridge and operate between a digital space and a limited physical space were already used in the automotive industry, performing soldering tasks on car's chassis. However, they were part of an industrial transformation that

[15] FarmBot, https://farmbot.io, Date of consultation July 7, 2016

begun in the late part of third industrial revolution, during the 70s, but that was only available to big manufacturers because of their costs and because of the amount of computer memory that a sophisticated machine like this would require[16].

Machines like these are described as CNC (Computer Numeric Control), and are characterized by the fact that their every movement is guided by a computer, in an automated way. These machines are not part of the newly developed additive manufacturing, but rather of the subtractive manufacturing. In fact, example of these machines are mills, lathes, plasma cutters, the welders used in the automotive industry and so on. Thus, machines like these will remove undesired excessive material from the final product, yet with a precision that previous machines and techniques could not achieve. However, as the computer got better and cheaper at doing its thing, so did these CNC machines, that eventually stemmed into our 3D printers, and the additive manufacturing. As of today, CNC machines are quite popular even among tinkerers and makers: both have recently been the interest of Kickstarter campaigns aimed at founding the production of low cost CNC machines and 3D printers that you can get home for less than three thousand dollars, which are thus no longer just the prerogative of big manufacturers.

Why is it then, that 3D printing is not yet fully implemented in today's economy? Why is it not yet substituting current manufacturing techniques? The answer is quite easy. As of today, 3D printers do not provide all the added benefits that a substitute disruptive technology would need to bring in order for people to switch without a thought. In fact, additive manufacturing is as of yet too young and experimental to attract businesses and make them shift from production processes that are well known and understood.

This is because 3D printers suffer from three main disadvantages: firstly, current production speeds are not able to keep up with a mass demand. Then, it is not easy to use and design with CAD programs. Finally, the availability of materials is still limited. However, there are great expectations for these machines in the near future. In his speech during its webinar, Tyler Reid tries to be cautious, avoiding as much as possible speculations and talking only of those projects he already sees in motion. He says that in the near future we will most likely witness an increase in the technology's throughput and

[16] Modern Machine Shop, P. Zelinski, "Five-Axis Machining For The Masses", October 15, 1999, http://www.mmsonline.com/articles/five-axis-machining-for-the-masses, Date of consultation August 1, 2016

speeds, coming both from improvements in the existing technologies (e.g. adding more print heads or higher power lasers) and the creation of new ones like CLIP (Continuous Liquid Interface Production), that as of now is able to print small parts in minutes against the hours it takes the standard 3D printer[17]. Plus, the steady addition of new materials is likely to keep up, allowing more physical properties to be added to the final printed objects, like conductive materials that would enable to print 3D conductive traces. Lastly, addressing the bottle neck that is represented nowadays by CAD software by simplifying programs and interfaces would provide a greater accessibility to design these parts also to those who do not have a degree in engineering, and if they do, simplifying programs and software is likely to optimize their capabilities in CAD.

Additive manufacturing is already a game changer in many industries, and it is bound to grow in the near future. The chances these machines are potentially able to bring are but one of the marvels we may very soon experience. When mixed with the other two big components of the 4th industrial revolution, computers and robots, makes it a safe bet to state that indeed *"The Times They Are a-Changin'"*[18].

2.4 They, Robots

It would be difficult to trace the origin of the idea of a thinking robot. Allegedly, Leonardo da Vinci tackled with the concept and drew a sketch of an automaton moved by springs and pulleys inside the body of a full renaissances armour, a mechanical knight. Whatever the case, it is no mystery that man has always been fascinated by the concept of an anthropomorphic machine with the ability to perform simple to complex tasks in autonomy.

The definition given when looking up the word robot on the Merriam-Webster online dictionary is *"a machine that looks like a human being and performs various complex acts (as walking or talking) of a human being"* or *"a device that automatically performs complicated often repetitive tasks"*[19].

[17] J. R. Tumbleston et al., "Continuous liquid interface production of 3D objects", Science CCCXLVII (2015), pg. 1
[18] Bob Dylan, "The Times They Are a-Changin'", The Times They Are a-Changin' (1964)
[19] Merriam Webster, http://www.merriam-webster.com/dictionary/robot, Date of consultation August 3, 2016

In the years following World War II, with the birth of computers, robots were depicted as the natural evolution of a computing machine and were used as yet another boogie man by movies directors and sci-fi writers. Popular culture perceived these machines as a threat because of the perception of their far greater intelligence. Needless to say that fear was unnecessary, as still today we have yet to witness a Terminator style scenario, in which machines and robots have forced humanity in hiding and in a last stand guerrilla fight. This is because computers are not as intelligent as we thought they could be. In fact, their intelligence is greater than ours when we consider logic and numbers: computers are exceedingly good at computing and following a seemingly endless set of rules, as I already exposed in the previous section. They can easily outperform the smarter man as they have proven time and time again against chess players (Deep Blue defeating Garry Kasparov in1996), quiz shows (Watson defeating the two best Jeopardy!'s players) and recently another robot, Alpha-Go, has defeated the best human Go player in the world, a much more complex than chess Chinese board game in which the aim is to surround more territory than the opponent.

Nonetheless, they have a great weakness when it comes to abilities that involve spatial reasoning and eye-hand coordination. Moreover, robots lack the ability *"[…] to act on goal oriented instructions, to plan sequences of actions, to learn from their mistakes, or to understand the world around them"*, that are so natural to us human[20]. However, since the end of the second world conflict, researchers and engineers all around the world have steadily advanced the knowledge on the subject, creating various prototypes which are far from the ideal robot we have in mind, but that are increasingly similar to those standards as technologies improve.

I already mentioned in the previous section soldering arms employed in the car manufacturing industry. Even though I used them as an example of a CNC machine, they also provide a good fit when talking about robots, as they were the first to be employed to assist with manufacturing processes. Created by George Devol in 1954, Unimate was the very first industrial robot ever built, and in 1969 Devol and his partner, Joseph Engelberger, signed a contract *"with Kawasaki Heavy Industries (now Kawasaki Robotics) to manufacture and market the Unimate robots for the Asian market"*[21]. This kind of robots

[20] A. F. Blackwell, "Spatial Reasoning for Robots: A Qualitative Approach", Victoria University of Wellington (1988), pg. 9

[21] Robotics, "UNIMATE: The First Industrial Robot", December 1, 2015, http://www.robotics.org/joseph-engelberger/unimate.cfm, Date of consultation August 4, 2016

have been employed in such industry for quite some time, but they hardly resemble the robots one has in mind: they do not roam around, do not speak, see or sense in any way, they just repeat a series of soldering actions on a carefully placed auto chassis.

Recently, studies on robots has benefited greatly from the rise in computational power and the consequent digitalization of sensors. When in 2011 Microsoft made the software that run Kinect open sourced, it was immediately employed by various teams working on robot and artificial intelligence development to solve the seemingly simple problem dubbed SLAM. SLAM stands for Simultaneous Localization and Mapping is the ability to be aware of one's surrounding, localize and identify objects that can represent obstacles and be able to reach your destination avoiding such threats, ability to interact with your environment by opening doors and climbing stairs. These, are all simple tasks that we perform with little to no effort, but they represent a huge challenge for robots and machines.

Oddly enough, Kinect and the development kit Microsoft released began to solve the problem. Thanks to the cheap optical system and the ability to modify the software allowing it to recognize not anymore joints and human limbs for amusement, but chairs, tables and other objects that might get in the robot's way, SLAM had been put on the right tracks. Today, the problem is, if not yet solved, very close to be. One has just to think about Google self-driving car, which to this day is not yet fully developed. Instead, Tesla Motors has already released cars with the ability to drive automatically while cruising on the highway, much like an enhanced cruise control. To do so, it uses cameras, high precision GPS, radars, ultrasonic sensors and a well-written software that can integrate all these sensors to solve the SLAM problematic[22]. The system is capable of maintaining lane, changing it, recognizing and avoiding danger, stop or slow according to surrounding traffic and even park itself.

Another example about how sensor spiked research development is given by Honda's Asimo. Asimo is a robot with legs, arms, hands and a head that is able to solve SLAM problematics and some simple tasks inside the simple layout of an office. The robot is able to roam around an office floor avoiding collision with moving people by giving them right of way, he is capable of recognizing people's face, address them

[22] Autoevolution, S. Toma, "Tesla Autopilot Explained - The Most Advanced Self-Driving Feature on the Market", March 30, 2016, http://www.autoevolution.com/news/tesla-autopilot-explained-the-most-advanced-self-driving-feature-on-the-market-106043.html, Date of consultation April 16, 2016

properly and understand commands both spoken and communicated by gestures and postures. With its hands, Asimo is able to pour you a glass of water, put it on a tray, then pick up the tray and walk up to you to complete your request. Honda's research on the topic begun in 1986 (Technical information pamphlet from honda's website) as a study on two-legged locomotion.

The road to Asimo was long and required more than ten prototypes before it was able to bear fruits. But now, the robot is able to walk, turn, run straight forward, climb stairs and even kick a ball, albeit awkwardly and in what seems an extremely reluctant fashion, given that it takes it some time to find its balance with just one leg on the ground. Still, it is a remarkable feat for Honda's robotic research team to develop such a wonderful machine, but not nearly enough to work in real life conditions. When Japanese people asked why Asimo was not deployed following the Fukushima Daiichi nuclear disaster on the site to help out with the most exposing tasks[23], Honda responded that the robot was not yet capable of moving around in such an unpredictable environment full of debris. In other words, without the comfort of an office's regular surface, Asimo's SLAM solutions were not able to keep up. To be fair, since the tragic events of Fukushima, Honda has been working on the problem in order to be able to address similar crisis in the future.

At the same time, on the other side of the Pacific Ocean, Boston Dynamics has been developing several kinds of robots that took inspiration from how animals move. Since 1992, the research group has been developing quad-legged robots with an amazing and reacting ability to balance themselves in the most difficult environments. Part of the team was already working on the same problematics as early as 1980 in a university research group called LegLab. Nonetheless, in 2009 they released a YouTube video in which they showcased the capability of their quad legged "BigDog" robot to withstand a brutal kick while roaming around, not only did the robot maintain its balance, but it was also able to continue its walk with just a little side slip. Moreover, BigDog was shown while walking on a number of difficult terrain like wet leaves, slopes, gravel, snow and even ice, which for Asimo would have been impossible[24] .

[23] The Japan Times, H. Nakata, "Domestic robots failed to ride to rescue after No. 1 plant blew", January 6, 2012, http://www.japantimes.co.jp/news/2012/01/06/national/domestic-robots-failed-to-ride-to-rescue-after-no-1-plant-blew/#.V6g7n0uLTX4, Date of consultation August 4, 2016

[24] Boston Dynamics, January 27, 2009, https://www.youtube.com/watch?v=3gi6Ohnp9x8, Date of consultation August 5, 2016

Boston Dynamics has been working on various different models of robots, most of them designed with four legs like the "Cheetah", fastest robot in the world reaching 29 mph, the LS3 and the RHex, other were designed to be two legged. In February 2016, they released another YouTube video in which Atlas was unveiled. It is an anthropomorphic robot that is less versatile than Asimo, but it is able to withstand some level of bullying in the form of a researcher pushing him and even to take a fall and get back up on its feet. Although less versatile than Asimo, Atlas is far more capable at solving indoor and outdoor SLAM problematics. In fact, during its unveiling YouTube video, we can appreciate it opening doors, walking in the snow and picking up some crates from the ground to store over shelves.

The robots from Boston Dynamics are able to function thanks to their experience in robotics locomotion on which they have been working since the 80s, and thanks to sensors mounted on top of the robotic frame, among which a gyroscope, a LIDAR and a stereo vision system. However, their robots lack the versatility of an accurate hand system like the one we find on Asimo.

Boston Dynamic's main sponsor, DARPA (Defense Advanced Research Projects Agency, the American bureau for allocation of resources to research projects in the US Army's field of interest), has been trying to overcome this limitation in robotics, which seemed to dictate a trade-off between mobility and reactiveness against versatility. It established the DARPA Robotic Challenge (DRC), a competition opened to researchers all over the world with a final prize of 3.5 million dollars[25]. Such competition was first held in 2012 and consisted of three events, two of which tested the robots during simulations of an emergency-response scenario. The finals took place in California in 2015 and required the robots to accomplish 8 tasks in relative autonomy, meaning that they were to remain operative and perform these tasks even without remote controlling. In particular, they had to drive and get out of a car, walk across rough terrain, remove debris, open doors, climb a series of stairs, cut a hole in a wall, locate and close a valve and connect an industrial wall plug.

The winner of the final prize was Hubo, a South Korean robot that could transition from two-legged locomotion to wheeled locomotion by sitting on its knees, and that

[25] New Atlas, D. Szondy, "South Korea's Team KAIST wins 2015 DARPA Robotics Challenge", June 8, 2015, http://newatlas.com/darpa-drc-finals-2015-results-kaist-win/37914/, Date of consultation August 5, 2016

was able to clear all its tasks in just 44 minutes, beating the only other 2 successful robots of 5 and 10 minutes. The other competing 20 robots failed at least one task. It is a remarkable feat for the South Korean Kaist team, as they demonstrated that we can already achieve working robots that could theoretically substitute men during perilous tasks. However, just considering the time it required them to successfully complete all of the tasks, which would have taken no more than 10 minutes to a human, it is evident that there is still much room for improvements. Especially if robots are to be used in the industry of the future in substitution of men in the most demanding and dangerous work, or simply in order to be employed in those tasks that are too monotonous but for which as of now, human's hand-eye coordination is still required.

Putting boxes upwards on a conveyor belt, combining different items into boxes according to customers' needs, loading and unloading parts and products: performing these tasks is part of the capabilities of Baxter, a robot with no means of locomotion that is however able to work alongside a human and "learn" its task thanks to on the spot training. The company producing it, Rethink Robotics, calls it workforce multiplier. Baxter is an odd machine, in fact, its lower limb is composed of a pedestal that resembles the base of a coat hanger, but on that very base sits a torso with two big arms and a display mounted atop of its head. It cannot move, but once it has been placed at its working station, it can compensate its lack of reach with a great flexibility, and the ability to learn new tasks. As a human co-worker approaches Baxter, the machine head displays a set of eyes that look at the newly arrived, signalling that it knows a man is nearby, thus Baxter knows that it has to carefully watch its every move in order to avoid arming the colleague. The man can now grab one of its arms and guide Baxter in the movement it needs to learn, placing its hand at a specific location within Baxter's reach, the screen will now display a list of actions which Baxter can perform such as grab, release, pick up, etcetera. Then, Baxter can be guided to the next movement it needs to perform, and once its hand arrives to the new destination, a new action can be commanded. While learning, Baxter will assist its co-worker in moving its own arms using a series of sensors to pick up the intended direction of movement, so that the human does not have to bear the weight of the robotic arm and any chance of harm is avoided. Once the job has been rehearsed and its human co-worker has moved at safe distance, Baxter will start its task as long as an object appears, or is moved by means of a conveyer belt, in approximately the same space in which its arm was placed in the first step of its learning [26].

Baxter is already there to substitute lower wage workers in monotonous tasks and, although imperfect and still limited, it is sold at roughly 25 thousand dollars, which is almost the same as the average US production worker's annual salary. Leaving the controversy related to stolen lower salary paid jobs by such robots aside, it is still worth considering that they are already reality, and that the time in which a production manager will have to decide whether to hire a new employee or a new robot is very near. Thus, it is expected that this important component of Industry 4.0 will play a major role in industry developments the close future.

[26] Rethink Robotics, http://www.rethinkrobotics.com/, Date of consultation August 7, 2016

III Chapter: The Bowl model and a new ecosystem of firms

3.1 A machine for all

3.1.1 The value chain

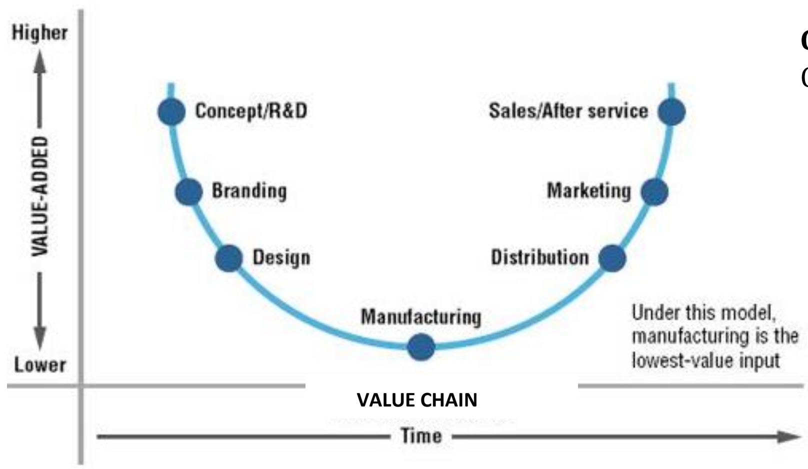
We have seen how each industrial revolution left behind many changes that have impacted enormously technologies, businesses and societies. A topic that I have intentionally left behind is the concept of value chain, and how each revolution affected the way in which value is carried from the ideation of a product, to its creation, and finally its consumption. The theory of the value chain was first developed by Michael Porter in 1985 and it represents one of the most important concepts of business management. It consists in a shift of focus, where a firm has to consider the full range of activities needed to bring a product to the market and the value that each activity adds to said product, rather than arranging the firm in departments or divisions. How the firm manages each step of the value chain, how inputs are transformed into outputs, determines the final value of the product available for the consumer. It is important to note that each value chain revolves around one product or a series of them that are created by the same activities. In his model, Porter divided the activities in two broad groups: primary activities, which collect all those activities that are directly related to the production, maintenance, sale and service of the good or service, and secondary activities, which are the activities needed to support all primary activities, like accounting and human resource management[27].

Based on this theory, in 1992 Acer's founder Stan Shih developed the concept of the smile curve, a graphical representation of the potential that each activity within a value chain has to add value to the final product. The graph is very simple. It depicts on the vertical y-axis the potential to create value, the higher the point on the graph the more value it can add to the final product. On the horizontal x-axis there are all the primary activities that a value chain includes, starting from research, development and design, moving on to manufacturing, assembly and packaging, and finishing with sales and marketing. Looking at the curve the graph describes, one can easily understand why it is

[27] M. Porter, "Competitive Advantage, creating and sustaining superior performance", The Free Press, 1985, p.45

called like this: design, R&D, sale and marketing activities, at both ends of the curve, have very high potential to add value, while manufacturing, assembly and packaging present low potential, thus giving the curve the shape of a smile, which has the productive activities as its lowest points.

In this model, activities related to manufacturing have been placed on the lowest part of the smile curve for every given value chain, be it local or global. If we think of a value chain whose final product are friction matches is easy to see why this is. To simplify things let us imagine that, within such value chain, there is a firm with a research and development team and a design team, the lead firm that then sells the product to customers using its own brand name. They have outsourced production of their matches to a manufacturing firm. The manufacturer produces and then stores the boxes of matches, which are then marketed by yet another firm and finally bought by customers. If the design team or the guys at the research lab discover a new set of chemicals that would make the matches burn brighter and with a different color, they would have increased the value for the final consumer, which would then be willing to pay perhaps a premium price for such matches. Likewise, if a marketer from the third firm has a brilliant idea for an advertisement campaign that goes viral and spreads throughout medias like a wild fire in a forest, then the customer would maybe pay more for such a successful box of matches. On the other side, if a manager in the manufacturing firm has a brilliant idea that enables the company to produce more matches with the same costs, the consumer may experience a reduction for the price of a box of matches, but only if the manufacturing or design firms decide not to increase their margin. The value increased in the case of the manufacturing firm can



Graph 1. Shih’s Smile Curve

only be perceived by the customer in the form of reduced prices, thus the customer can buy more of the good.

3.1.2 Asset specificity

When trying to demonstrate the smile curve empirically inside the electronic industry in the paper "Value Capture in the Global Electronics Industry: Empirical Evidence for the "Smiling Curve" Concept" by Shin, Kraemer and Dedrick, the authors found that the potential for value-added (considered as gross margin in the research), within a value chain, is strictly related with the height of entry barriers and the potential to accumulate capabilities difficult to imitate. In fact, the research, development and design firm has to face very high barriers to entry like patents and proprietary technologies and the acquisition of personnel capable of pushing innovation forward. Also, the marketing firm has to create a name for itself and to build up a brand from scratch, which can take many years and money to sustain. "*On the other hand,* [quoting from the paper] *entry barriers and switching costs are lower for computer assembly because it is relatively easy to build the needed capabilities and therefore subject to rapid imitation and intense competition"*[28]. The argument also holds for any other manufacturing firm: with respect to the obstacles that firms at both ends of the smile curve have to face, manufacturing firms have it quite easy since they just need specialized assets and suppliers of raw materials, which are easily replicable. While competencies, skilled people, years of investments and knowledge are not.

Even if their research is very useful and well argued, it is my opinion that it has overlooked the importance of the role that tangible assets cover within the framework of value-adding activities. To be fair, to them it might have seemed like a fact that is universally taken for granted, but for the sake of this paper it is not. In analyzing the smile curve, it can be observed that the more the tasks involved require tangible assets, the more the value-adding potential decreases. R&D, design, product development, sales, business development and marketing all hinge on assets that are, for the most part, intangible. Intangible are assets that are not physical in nature, like trademarks, patents, brand name and recognition, goodwill, business models, capabilities, knowledge, etc. On

[28] N. Shin, K. Kraemer and J. Dedrick, "Value Capture in the Global Electronics Industry: Empirical Evidence for the "Smiling Curve" Concept", *Industry and Innovation*, XIX (2012), p. 91

the other hand, there are tasks such as manufacturing, assembly, packaging and shipment, which are all heavily relying on tangible assets: land, facilities, building, machines, equipment, vehicles and inventories. Because of their tangible nature, assets of these sort suffer from a huge disadvantage: they are much more specific than their intangible counterparts, limited to a range of tasks that is narrower. In other words, asset specificity plays an important role in the creation of added-value within a value chain.

A would-be-manufacturer of matches has to buy several machines and equipment in order to meet global demand. Specialized machines that can be fed with raw splinters of wood and yield a clean stick, which is then dropped on conveyor belts specifically built to handle matches. The endless stream of sticks is drop into a selector that, through vibrations and holes of just the right size, let only the sticks of the appropriate dimensions and shape pass on to a perforated belt. This ad hoc designed belt will hold the matches in place, with just the tip of it coming out from one side and the rest from the other side. The belt follows a track that makes it dip one end of the sticks inside a chemical bath, now the sticks have become real matches. Then the belt proceeds taking the matches to dry and finally, specialized equipment, built just for the purpose, will box a prearranged quantity of matches and pallet them. Each of this machines can only handle and create matches, they cannot be used to build lighters because they are asset that are specifically built for the purpose of managing little wooden sticks. If demand for matches was to drop and demand for lighters to rise, the would-be-manufacturer would have to sell his machineries and buy new ones, that are built to produce lighters. Since no one is willing to buy matches, his old machines would be of no use to him.

Among the obstacles that have held back manufacturing and lower value-adding activity firm, we must therefore consider asset specificity. The matches manufacturer buys equipment that is specifically built to produce matches and, if he only possesses those productive assets, he will not be able to produce any other product except for matches. In addition, he needs a steady demand to constantly sell his product and to profit from his investment. If the demand drops before he is able to recover his investments he incurs in a loss. Knowing this, the matches manufacturer has to be competitive on the market and sell his products to a price as low as possible. Furthermore, the matches manufacturer cannot just sell its product to any lead firm because of the fact that it is most likely selling to a competitor of the first lead firm, and because it is manufacturing a product that is likely to be covered by some form of intellectual property protection. Thus, even when willing, the matches manufacturer would have a hard time to provide its manufacturing services to another, parallel, value chain. The example has been working for the match industry but it can also be applied to others as well.

When it comes to global value chains, Apple is the poster child, the exemplary firm that has been able to exploit this mechanism so well and to funnel the gains coming from divesting its manufacturing lines into huge profits. This restructuring started in 1996, when Apple sold its largest US manufacturing facility to SCI systems[29]. Now Apple is regarded as having the most successful supply chain management system ever created[30], a system that includes Foxconn as its biggest contract manufacturer. Foxconn is also the supplier of important electronic firms such as Amazon, Cisco and Acer, among others. It is in fact the largest contract manufacturing of electronics in the world, and this position enabled it to be present in many parallel value chains. However, in a famous article by Hal Varian, in which he illustrates the research of Greg Linden and once again Kenneth Kraemer and Jason Dedrick, he points out that the majority of the profit share of a 2007 IPod worth 299 $ is driven away from manufacturing firms. According to the article, the final assembly at Foxconn captures just 1,33 % of the value added, estimating a 4 $ per unit for its manufacturing services[31]. When even the biggest contract manufacturer for the electronic industry sweats to take home just a tiny percentage of the total value created within value chains, for smaller manufacturing firms the struggles to remain competitive and to retain their position within different value chains are possibly even worst, and have contributed to decrease their potential to retain value.

In order to retain a higher share of the profits generated in a value chain, manufacturing firms can try to integrate vertically either upstream, towards research and development in order to create its own innovative products, or downstream, towards a lead firm position, to create a brand name of its own. However, this is not as easy as it

[29] T. Sturgeon, "Modular Production Networks: a new American model of industrial organization", *Industrial and Corporate Change*, XI (2002), p. 456
[30] S. Seth, "10 Major Companies Tied to the Apple Supply Chain (AAPL)", Investopedia, September 3, 2015, http://www.investopedia.com/articles/investing/090315/10-major-companies-tied-apple-supply-chain.asp, Date of consultation September 15, 2016
[31] H. Varian, "An iPod Has Global Value. Ask the (Many) Countries That Make It", NYTimes.com, June 28, 2007, http://www.nytimes.com/2007/06/28/business/worldbusiness/28scene.html, Date of consultation September 15, 2016

sounds, since the manufacturing firm starts with no capabilities whatsoever in either marketing or in R&D, and gaining them requires time and substantial investments. Plus, integrating either way is a clear sign that the manufacturing firm is trying to become a potential competitor of the lead firm[32].

The competition among manufacturing firms to cover the task of producing and assembling a specific product within the value firm is thusly based on services. The one providing the most fitting bundle of services at the most convenient price wins the contract. This is why, again within the electronics value chain, there has been a rise of turn-key suppliers. Turn-key supplier is a term used by Timothy Sturgeon, professor at the Massachusetts Institute of Technology, that defines suppliers that *"provide a full-range of services without a great deal of input by lead firms. Lead firms provide instructions, perhaps, on what to make, but it is almost entirely up the supplier how, and sometimes even where products are made."*[33] Once the product specification and design is passed to the contract manufacturer, every aspect of production is provided by it, in a full range of services that can sometimes provide also shipment and distribution.

Yet, what would happen when asset specificity is out of the picture, or when its presence is reduced? A tangible asset that is less specific would result in a more flexible asset. In the case of the matches manufacturer, if he had bought assets that were of this sort, like machineries and equipment that could also produce say lighters and light bulbs, with no need to retool the machines when shifting the production of one good from another, he could provide his manufacturing services also to other, unrelated, value chains. Differently from when the specificity of his assets forced him to offer his services only to clients within parallel value chain, in this case the matches manufacturer could interact with clients coming from different industries and value chains, without the fear of losing its contract for the original matches value chain since he is not dealing with competitors. At this point, the manufacturer would be freed by the ups and downs of demand of a single industry since, through his machines he would be able to accommodate the production of many different industries. Applying the same logic that was used before, this would lower barriers to entry the

[32] Ibid footnote 28, p. 105

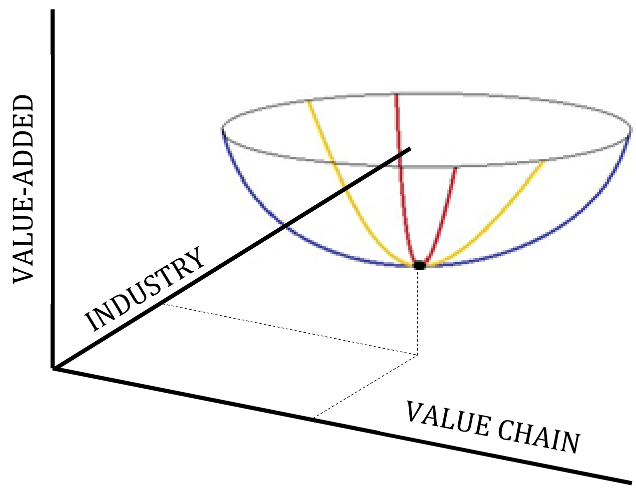
[33] T. Sturgeon, "How Do We Define Value Chains and Production Networks?", Background Paper Prepared for the Bellagio Value Chains Workshop, September 25, 2000, https://www.ids.ac.uk/ids/global/pdfs/vcdefine.pdf, Date of consultation September 18, 2016

manufacturing of as many products as these less specific assets would allow the production of, thus directly influencing the margins of the manufacturer and his ability to add value. But since he is able to produce for every industry its product, demand for its production services is the sum of each individual industry for which his assets can produce, allowing him to generate, ideally, a higher revenue. Therefore, thanks to his machines, there are many different unrelated value chains that are using his manufacturing services.

3.1.3 The Bowl Model

In my opinion, freeing tangible assets from their specificity would allow manufacturers to enlarge the potential demand they could meet, since they can serve customers requiring different goods. I believe that, given such conditions, the smile curve would still be accurate in depicting how value is spread, but when including the multiple value chains that a manufacturer can service, the aggregation of different smile curves could be arranged to form a bowl.

Manufacturing will still be at the lower point of the value chain, probably this less specific asset would further accentuate the smile, making the curve even steeper at both ends. Still, from the lowest point of the graph we could trace another curve, which is equal in every aspect to the first one, except that we will trace this one perpendicularly to the first one. In other words, we would add to the graph a third dimension, in order to accommodate for an equal curve to pass perpendicularly with respect to the first one. This two smile curves would intercept at their lowest point, signifying the fact that the



Graph 2. The Bowld model

manufacturing firm is the only thing each value chain has in common. We could add as many curves as the less specific asset allows production of different products, on as many planes that intersect the first one as we like, being careful to let each curve intersect every other curve in the same lowest point. As the smile curves are added in this 3D graph, a bowl shape would start to appear. Remembering that each smile curve represents a distinct value chain with a different product from the others and that they all pass from the same, lowest, point, we have the representation of a bowl.

In the next section, I will argue that the pillars of the fourth industrial revolution are the means with which the manufacturer can achieve these less specific tangible assets.

3.2 Hub Firms

Of course, the less specific asset described in the previous section does not exist at the moment. At least not to the extent that was provided by the bowl model, since a machine that is able to produce everything has yet to be invented. Given the fact that this technology is out of reach, it follows that becoming the lowest pivoting point of a bowl graph is as of now unachievable.

Even though the empirical analysis drives us to this conclusion, I think that the bowl model is not that far from being achieved. In fact, it is in my opinion that by joining together the advancements in research of technologies such as computers, 3D printers and robots, we are very close to create machines and equipment, or otherwise tangible assets, that can be considered less specific than any previous tangible resource.

3.2.1 Changes in manufacturing process

Throughout this paper I have given examples on how 3D printers work and how they are able to manufacture objects that are different in shape and material, in no small part thanks to the increased computing capacity that Moore’s law has enabled us to funnel towards this kind of machine. Like I already mentioned, 3D printing technology is not ready yet to meet mass market production volumes required to service a global demand. This is caused by the fact that today most of the 3D printing technologies require a lot of time to print even simple little shapes, let alone complex geometries and bigger objects. Furthermore, the fact that there is a limited, albeit growing, number of materials from which to choose when considering whether to use a 3D printer relegates the technology to the limited use of few industrial sectors. Lastly, 3D printing is not an easy technology to handle since it is based on computer aided design programs which are difficult to master, people need extensive training in order to be able to effectively use such complicated software.

Nonetheless, research has been pushed forward at unprecedented speeds starting from the day after the financial crisis of 2008 and, what today seems like a technology that has no use for most of the modern manufacturing world, has actually the potential to turn, in a few years, into a wide spread revolution that can change how we manufacture everything. This is what really the industry 4.0, or 4th industrial revolution, is all about. I have already argued that many believe that it has already started in the form of Internet of things and Industrial Internet of things, and indeed they are right. But I think that those innovations are just the beginning of what has to come in the near future, and that these changes will be mostly targeting manufacturing firms and creating new business models that will revolve around the three pillars of this revolution.

In my view, the manufacturing revolution starts from computing and 3D printing, and will subsequently use also robots in a later moment, in order to create a series of tangible assets that are less specific. I believe it will follow this precise order since, at the time of writing, 3D printers and computers, closely tied together, have already achieved so much, while research in robotics is lagging behind. Granted that, even if a 3D printer can recreate any existing shape, as long as its dimensions can fit within the printing space - thanks to the computational power any computer and software can provide to it - it is limited by the fact that currently a printer that is capable of producing metallic, plastic, ceramics and organic objects at the same time does not exist. This is because each material requires different technologies to be printed. For example, SLA machines print a sheet of molten plastic, then solidify it with lasers and repeat. SLA does not allow for fast production speeds, as the average printing time goes from hours to days, depending on sizes. Digital Light Processing (DLP) also works with photopolymers, but it usually uses a different source of light such as arc lamps, allowing robust results as well as lower costs and less waste because of the need for less material in the case of detail production. Also, the speed of production is way faster, as it requires mere seconds for each layer. For plastics with particular mechanical, thermal and chemical properties, the Fused Deposition Modeling (FDM) technologies allow for a slower printing time with respect to SLS, but with plastics that have better properties and can thus be used directly as end-use parts or final products. The machine heats and extrudes thermoplastic filaments layer on top of layer, but when production is finished, signs of printing remain visible and further work is needed to sand, mill or paint the product. We have already seen the SLS system, a similar technology to SLA and FDM, but that has no need for the machine to also print sustaining structures as the entire production takes place within powder made of the material of choice. SLA and FDM have to also print structures that have the sole purpose of sustaining the final printed part, for this reason these processes can take a lot of time. SLS has no such problem, as the object is printed within a bed of grains made of the material needed. This technology is quite useful as it can print plastic, ceramics, glass, aluminum, steel, silver, etc. Furthermore, since it solidifies only what will later become the resulting product out of the entire bed of sand, the SLS process takes a fraction of the time needed for other printers. SLM is once again similar to all the above technologies, in that it uses high-powered laser beams to melt together metallic powders. Resulting objects can be made out of stainless steel, cobalt chrome, titanium and aluminum. This is the go to technology for the aviation and aerospace industry, as well as finding many practical uses in the medicine orthopedics industry. Electronic Beam Melting (EBM) is the same as SLM, but instead of using a high-powered laser it works with an electron beam controlled through a vacuum chamber. Because of the higher temperatures it can reach, this process is used for the application of fewer but selected metals like pure titanium or nickel-chromium alloys. It presents two major drawbacks, when compared to SLM, which are higher running costs and slower speed. Another printing system is Laminated Object Manufacturing (LOM), which allows to fuse together layers of materials through means of heating and pressure, then cutting each layer in the desired shape once again using a laser. Although technically not a fully additive process, as it creates wastes that need to be reprocessed into layered form for later usage, this technology is one of the most affordable and fastest among the realm of 3D printing. Also, it uses a wide variety of materials, from plastics, to metals and paper. When printing with paper, this machine creates structures that present the same properties of wood, making it possible to print wooden objects[34]. Hp's Multi Jet Fusion (MJF) is a recent system that allows to print in different materials and colors exploiting a vast array of chemical agents and their reaction to different sources of energy. Their proprietary system uses voxels to control the process, which are like pixels but with a volume, allowing them to achieve impressive speeds and precision and to selectively change the physical and chemical properties of each voxel. They claim that in the future they will be able to control the properties of each voxel up to the point that the user can choose their individual color, transparency, elasticity, strength, conductivity, enabling the creation of lenses, integrated circuits, smooth and rough surfaces, etc[35]. Continuous Liquid Interface Production (CLIP) creates plastic parts out of a liquid resin solidified through the use of a UV light projector. This technology is allowing unprecedented speeds, but its limited to polymers materials[36]. Finally, it is important to mention what the future could have in store for us. Harvard materials scientist Jennifer Lewis is leading the research for the creation of microscale 3D printing. Among her biomedical groundbreaking studies on printing organic tissues such as blood vessels, she has also found a way to print lithium-ion rechargeable batteries and simple circuits components the size of a square millimeter. The process only requires pressure and it can be performed at room temperature, giving the possibility to print directly on plastics or other materials, without incurring in surface melting[37] [38].

Altogether, the processes described above grant the creation of objects that are, with each passing day, bigger or smaller, made of different materials, different physical, chemical and conductive properties and continuously improving in the precision with which they are made. Some of these technologies are already enabling the user to print with different materials at the same time and on the same object, giving it flexibility on joint parts and rigidity for cases or outer shells, or directly printing within the object conductive connections and lithium batteries. To be fair, no 3D printer can yet manufacture everything. But a number of them working together can go very close to

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[34] 3DPrintingFromScratch.com, "Types of 3D printers or 3D printing technologies overview", July 15, 2015, http://3dprintingfromscratch.com/common/types-of-3d-printers-or-3d-printing-technologies-overview/#sls, Date of consultation September 18, 2016

[35] HP Graphic Arts, "HP Multi Jet Fusion technology powering the new HP Jet Fusion 3D Printers", YouTube, May 17, 2016, https://www.youtube.com/watch?v=VXntl3ff5tc, Date of consultation September 18, 2016

[36] T. Koslow, "Carbon Finally Unveils First Commercial CLIP 3D Printer", 3DPrintingIndustry.com, April 1, 2016, https://3dprintingindustry.com/news/carbon3d-finally-unveils-first-commercial-clip-3d-printer-75675/, Date of consultation September 19, 2016

[37] M. Orcutt, "Printing Batteries", MITTechnologyReview.com, November 25, 2013, https://www.technologyreview.com/s/521956/printing-batteries/, Date of consultation September 19, 2016

[38] J. Lewis, Publications section, LewisLab, http://lewisgroup.seas.harvard.edu/publications, Date of consultation September 19, 2016

achieving this result. Even admitting that the cost of each 3D printer can be very high, it is still an investment that could be worthwhile. The possibilities are starting to become endless, and for this very reason I conclude that those less specific tangible assets are nearer than what they appear to be, and that within five to seven years' time, we could start to see the rise of what I call Hub firms.

3.2.2 Hub firms, the new actors

I define Hub firms those organizations that are exploiting the potential flexibility that computer power, 3D printers and robots allow them to harness, becoming the production center of not just one kind of value chain, but of many, different and unrelated ones. Much like contract manufacturer already do for the electronics industry, these Hub firms would contract their manufacturing services, however they would not limit their customer pool to just a single industry or value chain. In fact, I have already argued how 3D printers could be deployed in order to achieve this wide variety of production. I chose the term Hub firms because of their relation with the bowl model. Researching the meaning of hub in the English language on the online Cambridge dictionary gives the following two results: *"the central part of a wheel into which the spokes (= bars connecting the central part to the outer edge of the wheel) are fixed"* and *"the central or main part of something where there is most activity"*[39]. The bowl model describes a firm employing tangible less specific assets (still ideal though) as the unique common point through which a bundle of identical smile curves pass. Similarly, the Hub firm would represent that very point, although currently in a less idealistic manner and for a number of smile curves that is lower, and surely not nearly enough to provide the density of lines required to represent a bowl. Still, since the point at the lowest end of the graph represents the center from which curves radiate, and since the firm I have in mind would become the center of the production activity of many different value chains, I conclude that Hub firm describes this business model best.

On account of the fact that I aim to introduce a business model, a description on how Hub firms will be able to generate value for their customers, together with a

[39] Cambridge Dictionary, Hub definition, http://dictionary.cambridge.org/dictionary/english/hub, Date of consultation September 20, 2016

rough idea on its cost structure and some indication of strategies in order to be competitive against other Hub firms have to be provided. I will begin with the first item, the value proposition, and follow with the same order just mentioned.

3.2.3 Investments and resources

The organization willing to become a Hub firm would need to buy many diverse 3D printers, each with distinct technologies, from different producers, requiring the need for a fair amount of initial capital, as the majority of industrial printers are priced above fifty thousand dollars. In few cases, prices can go as high as a million per machine[40]. However, once the investment is done, the Hub firm is in a position to offer an incredible range of customizable production to its clients for a fraction of the cost it would have required using specific assets, especially for products that are currently requiring many hours of manual labor and machining time because of their complexity. The assumption I make is that additive manufacturing is superior to any other sort of manufacturing when considering products and parts that have a complex shape or convoluted internal geometries. This is because of the elements described in the first chapter when talking about 3D printers in general, namely the fact that additive manufacturing uses less material and creates sensibly less waste. Furthermore, with respect to other manufacturing processes, except when casting is involved to a lesser extent, additive manufacturing reduces the number of parts needed to build an object, because of its ability to create small and yet complex parts out of a single monolithic piece. Although casting has the same theoretical advantage, it is just shifting the complexity of production to the creation of casting molds. A good example of this is provided by G.E.'s fuel nozzles. Using 3D printers to manufacture these components for jet engines have reduced its weight by 25%, because it has transformed a component built out of 18 parts in a monolithic piece. Also, because G.E. could print more complex shapes, these fuel injection nozzles are able to provide five time the durability with respect to the same object created with traditional manufacturing techniques[41]. When the production of simpler objects and

[40] A. Wheeler, "How Much Does Every Industrial 3D Printer Cost? Ask the Senvol Database", 3DPrintingIndustry.com, April 9, 2015, https://3dprintingindustry.com/news/how-much-does-every-industrial-3d-printer-cost-ask-the-senvol-database-46265/, Date of consultation September 20, 2016
[41] GE Global Research, "3D Printing Creates New Parts for Aircraft Engines", http://www.geglobalresearch.com/innovation/3d-printing-creates-new-parts-aircraft-engines, Date of consultation September 20, 2016

parts is required, specific assets and traditional manufacturing techniques would still be able to ensure lower production costs and higher speeds, because of their effectiveness in terms of production. Nonetheless, even when simple parts are concerned, it is still worth considering 3D printed product since it offers much more topology optimization potential. Topology optimization is that mathematical process that enables an object to be made of the minimum amount of material for a given set of loads and boundary conditions. This optimization is hard to achieve with traditional manufacturing as it augments the complexity of the part and removes masses that are usually needed for production purposes, so that the machines and equipment can handle the objects being produced. Thus, when the product has to be as light as possible, even if simpler in shape, additive manufacturing becomes more effective than traditional manufacturing. Plus, let us not forget that, because of its flexible nature, additive manufacturing is highly customizable and allows the single customer to potentially ask the creation of many similar items except for some or many details, giving them the ability to mass customize demand. For example, a shoe designer could ask the Hub firm to produce a thousand pair of shoes, and of those a hundred for each size ranging from 35 cm to 45 cm. What the Hub firm requires to meet such demand are as many CAD models as the customer needs. For such reasons, Hub firms would be in a position to meet manufacturing demands from a wide range of customer coming from different industries: medical, aerospace, energy, electronic, automotive, fashion, etc. Because of this, the technical staff and designers of a Hub firm would be used to work on different types of products that have to absolve completely diverse functions. They would be forced to manage and work with an array of different problematics and specifications, enlarging their knowledge regarding various sectors and creating skills and capabilities that can easily be employed across industries and operations. Such a competent human resource potential could add further value to what Hub firm can already offer, because it would be able to provide solutions and experiences that originated in disparate contexts, but that may be also applicable to the client's need. I would regard the work force of a Hub firm, as the catalyst that ensures spillover effects from industry to industry, employing successful strategies and designs coming from different sources wherever they please, within the limitation of the protection of the client's intellectual property. Lastly, due to the fact that a Hub firm is employing the same machines to be the manufacturing activity of many diverse value chains, the potential for economies of scale is huge: the more clients they are able to service, the more effective the economies of scale would be, possibly decreasing prices for all customers, thus providing competitive advantage with respect to traditional manufacturing. This is how Hub firms would manage to bring value to their customers.

3.2.4 Cost structure

The cost structure of such firms would be heavily skewed towards fixed costs. This would be mainly due to two reasons. Firstly, the investment needed to buy many different 3D printers with diverse technologies is substantial. 69% of them have a price that is above fifty thousand dollars, 52% have prices above a hundred thousand, 17% are priced starting from five hundred thousand dollars, and finally just 3% are priced above a million[42]. Depending on the demand the Hub firm is considering to serve, it will buy the minimum number of machines that would ensure the Hub not to incur in any bottle neck. This would be achieved by carefully accounting and planning what each product line requires in terms of how many printers does the product need to be completed (whether it needs two or more printers depending on different materials unachievable on the same one) and the machine hours required. Secondly, at least within the first five to ten years, 3D technology will still be within its early development stages, meaning that there are going to be new developments and discoveries and that machines that are cutting-edge today may be outdated in a very short time. In other words, in order to remain competitive, a Hub firm would need to complement or substitute its machines several times before the technology matures and the rate of innovation stabilizes or drops. As far as variable costs are concerned, they will surely be less significant than fixed costs and of easy traceability. Indeed, except for costs incurred to run the 3D printers, the main expense related to production would be that of raw materials. Plus, Hub firms would be able to spread overhead costs over revenues coming from diverse value chains, since the same machines can be used for the production of multiple kinds of objects. Thus, Hub firms would experience a decrease in their potential dependence to a single customer, industry, or value chain, reducing their exposure to risk since they are differentiating, without really differentiating. In fact, if the client that had them produce shoes was to terminate the contract, the Hub firm could simply shift its production capabilities to a

[42] Ibid footnote 40

different client asking for the production of plastic toy guns, for example. Or, increasing the orders' priority of an existing customer and thus producing more quickly his product, for a premium.

3.2.5 Competition and core activities

If Hub firms prove to be an economical success, or simply a better alternative with respect to traditional mass manufacturing firms, then it is likely that there would be more than one, competing to meet as much demand as possible. I imagine their competition being focused on the tailoring of manufacturing services: the one who offers the most convenient bundle of them and is able to deliver on time while reducing defects of fabrication, would win the majority of the value chains. It is likely to be a competition model based on Sturgeon's Turn-Key suppliers, where clients provide specifications, instructions and a designs, and the rest is of the process is left at the manufacturer's discretion. Services of this kind can be both provided to businesses as well as to the final consumer. When dealing with industrial clients or other businesses, Hub firms could also arrange a service of consultation as far as designs are concerned, or a joint design service, in which the knowledge, knowhow and expertise on how best to print the specific object for the desired need, is shared with the client. This cooperative effort would ensure that the client is able to get exactly what it needs, ranging from the size of its product, to the best material it could be made out of, or to accommodate for the fastest production process only using the quickest 3D printing technologies, or maybe to help the client focus on precision and quality. Especially in the wake of Hub firms, this service would provide clients, whom have little or no knowledge on 3D printing, with the much needed insight on how they could shift their production requirements to an additive-manufacturing process. Plus, it would serve the Hub firm as a critical exercise, where they test whether their assets are able to respond to the client's demand given their existing work schedule and, if they are not able to fulfill the customer's request, whether their need to add more printers that are able to meet more specific requirements. Other services specific for businesses could include on time deliveries of a clearly defined number of parts, components of product, in order to help the client maintain a lean inventory, thus reducing their cost. Eventual changes in their production schedule could be accommodated increasing or decreasing the priority other customers have in the short run, or by adjusting the number of printers the Hub firm has in the long run. Among the services that can be provided both to businesses customer and the general public there is the possibility for the creation of an online platform system that grants the user the ability to upload its computer designed files and to have them printed, giving information such as price, percentage of and expected date of completion, etc. Providing also a worldwide delivery service could complement the online platform system, adding more value to the web experience and providing a service similar to the one Amazon accomplishes. Furthermore, the creation of a successful software tool to design products and component in three dimensions that is fast to learn and easy to use would allow the Hub firm to further expand the demand for their manufacturing services throughout the general public and consumer. In fact, CAD software currently represent a bottleneck in the adoption and usage of 3D printing technologies. Whichever Hub firm is able to reinvent CAD software products and develop a user friendly program easily accessible to anyone would be in a position to become a platform leader and to easily drive demand towards its manufacturing plants. An easy example that comes to mind is a button, within the software, similar to the print button one has when using a writing program, like OpenOffice or Window's Word. This button would directly send the object to the Hub firm's production que, and the user would be notified of its status and consequently asked where it needs to be shipped. Also, I believe that competition among Hub firms will not hinge on the same competitive advantages that have characterized manufacturing services for the last 50 years, that is cheap labor from developing countries. In fact, I argue that the majority of the labor force employed by a Hub firm would be composed of designers and technical engineers, specialized and skilled workers, whose skills and competencies will develop quickly because of the multi-functional environment Hub firm provide. Employees this valuable will be highly regarded because of their potential to know about many different processes and with a good degree of depth. Retaining such valuable work force will be an important priority for Hub firms. Yet, there is also going to be needed manual labor to perform operations that some 3D printing technologies require, such as sanding to smooth out rough surfaces, cleaning the final product from dust particle residues, removing supporting structures, painting, etc. All these services will be performed by specialized technicians and machines. At least, during the first years of existence of Hub firms. In fact, as research in robotics catch up, I imagine Hub firms increasingly utilizing robots to substitute these functions, which are mainly concerned with the transportation of the product or part from one machine to another. In theory, if the two machines are close, the robot Baxter could already be able to perform such task. Still, due to the changing nature of 3D printed products, and to the fact that they can present very different shapes and dimensions, it will still take some time for Baxter to substitute the human input at this stage of production.

3.2.6 Limits and threats to the Hub firm model

Despite how fascinating and profitable Hub firms might be, there are also several threats that could limit their success and potentially stop such business model to take place altogether. Of the many problematics that could rise, I will expose the four I believe are of the most importance, starting from those I deem less severe.

Described in the second chapter, the intellectual property protection that shields each technology and new 3D printing methodology is thick and it has proven efficient in ensuring the dominance of few providers of 3D printing machines. This has effectively limited the competition among such providers, enabling them to keep prices for each machine fairly high. Secondly, and somewhat related to the first threat, together with the fact that each technology is changing very rapidly, a Hub firm will have to dispose of very large amounts of capital in order to keep up with the technology and to buy newest, more effective machines. Yet the problem remains, since also new machines can become outdated very quickly. This could prove extremely problematic especially within the next five to seven years, in which 3D printing technology will still have to mature and its pace of development stabilize. The third threat is represented by the ability of Hub firms to ensure and protect its clients' intellectual properties from being divulged. Although appealing, the choice of outsourcing manufacturing services to Hub firms could be weighed against the hidden cost of losing some degree of control over a proprietary system. Depending on how the legislation of each country will evolve in response to the undeniable spread of 3D printing technologies and to how each Hub firm will shape its own policies, some will be able to grant a more secure environment, thus spelling doom for Hub firms that choose not to relocate and for countries not adapting quickly enough. Finally, the last threat is presented once again by the innovation of 3D printing technologies itself. In fact, if the trend of innovations follows a path towards a cheap machine that is able to print any given object, then it is most likely that many consumers will want to buy such marvelous machine. Although unlikely, or at least improbable as far as the near future is concerned, the introduction of such a machine would drastically reduce the need for Hub firms, as lead firms could simply sell their designs to consumers who are able to print objects for themselves, thanks to their home 3D printer. Each one of these threats is worthy of an accurate and in-depth study on their own; it would be of much interest to see if future business or law academic researchers are able to complement my paper, addressing such issues or founding more, that I was not able to detect.

3.2.7 The future is close

In theory, Hub firms, the business model that I present in this paper, are already a plausible venture as of the end of 2016. Given the examples I have disseminated throughout the dissertation, it is likely that very soon we could start to see Hub firms taking form and rising in the wake of the fourth industrial revolution. In practice, there are already two examples that are worth mentioning, which can be regarded as proto Hub firms. The first example is given by Shapeways, the world's leading marketplace and community for 3D printed objects and creators. Shapeways is a startup company that sells 3D printed objects on its website. Also, it enables users to print their own creation, through the upload of their CAD files or through the use of simple browser design applications that empower anyone to create simple forms, regardless of their skills. Heavily directed towards the consumer market, Shapeways has the potential to very quickly be able to supply businesses' demands[43]. On the other side of the spectrum, we have General Electrics, that has recently opened a plant in India that they call the "Multi-Modal facility". Their plan, following Immelt's strategy of innovating the group and preparing it for the next revolution, consists in configuring this plant in order to produce parts and products to service G.E.'s multiple divisions, including the aviation, oil and gas, transportation and power divisions. Such plant will be filled with 3D printing machines, allowing the group to build economies of scale over each divisions' production that is diverted through the plant. Furthermore, it will enable the technicians working in it to experience problematics and solve solutions coming from different divisions so that they will *"quickly acquire skills across industries and operations, enhancing the value of the jobs*

[43] ShapeWays, http://www.shapeways.com/, Date of consultation September 21, 2016

and their individual skill sets"[44]. Even if aimed at businesses, G.E.'s "Multi-Modal plant" is far from achieving the necessary speed to service any other firm than its own divisions. However, it is still very close to what a Hub firm might look like in the future. These two example are indicative of the direction that the fourth industrial revolution will be taking, and of how additive manufacturing will represent the herald of such changes. I believe that for these reasons Hub firms will be a most present and strong player in the future of manufacturing.

3.3 Meteorite businesses

Depending on the success that may hit the business model of a Hub firm, there are going to be a series of changes that are sure to go beyond manufacturing and to modify other activities within the value chain, such as research and development, design and shipment. These changes will manifest slowly at the beginning, but their pace and diffusion will grow exponentially, especially if additive manufacturing evolves so much that it will be a substitute for other traditional manufacturing methodologies. Changes will likely include a reduction in the number of players and service providers within each value chain, as the manufacturing processes shorten. I believe this will happen because Hub firms will try to provide or arrange as much services as possible, in order to be competitive, ensuring the most appreciated bundle. Designer consultancy, assembly, packaging and shipping will be coordinated and provided by Hub firms. However, because of the nature of their manufacturing capabilities, Hub firms will be able to produce more effectively on-demand, in a situation where supply meets demand in a consumer pull configuration. This means that once the consumer issues an order for one product, only then said product is produced, decreasing inventories costs for every player along the chain. Initially, additive manufacturing will be complementary to traditional means of manufacturing. But, as the technology becomes more versatile and reliable and as it reaches its maturity, I strongly believe that its adoption rate would grow exponentially presenting itself more as a substitute, than as a complement. Within this forecasted setting, I postulate that there will be the potential for another actor to

[44] R. Rao, "How GE is using 3D printing to unleash the biggest revolution in large-scale manufacturing in over a century", TechRepublic.com, http://www.techrepublic.com/article/how-ge-is-using-3d-printing-to-unleash-the-biggest-revolution-in-large-scale-manufacturing/, Date of consultation September 21, 2016

rise and gain in importance, or at the very least, to appear much more often than what it does now but with some different characteristics that will warrant the need to call them differently. We now know them now as startups and crowdfunding projects.

3.3.1 The forerunners

According to the definition given by Steve Blank, a Silicon-Valley serial entrepreneur, a Startup is defined as *"an organization formed to search for a repeatable and scalable business model"*[45]. When the Commissioner for Digital Economy and Society issued the European Startup Monitor in 2015, they were using Blank's definition. Moreover, it was decided that, in a population of firms, start-ups were identified as those being younger than ten years, revolving on (highly) innovative technologies and/or business models, and also having or aiming at a significant employee and/or sales growth[46]. In other words, startups are relatively young firms that present an innovative business model or sell a new technology with the potential to be quickly scaled up to become a global company.

Crowdfunding projects, on the other hand, are small businesses that engage in alternative means in order to raise a starting capital. Such capital is raised by the involvement of a large group of people each giving just a relatively small amount of money. Usually exploiting the internet to showcase their projects and businesses, these small firms have been the result of the recent economic crisis and the consequent difficulty with which bank loans were issued to small and medium firms. Organized on specialized online platforms, donors meet and get to know a vast amount of firms before pledging to a project they deem worthy, guaranteed against scums or fraudulent behaviors by the platform provider. Among the many providers, there have been web sites like Indiegogo, RocketHub, Kickstarter and GoFoundMe.[47] The most successful of them so far is Kickstarter, with 12 million donors, pledging more than two and a half billion dollars to a number of ventures exceeding 112,000 successful projects.[48]

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[45] S. Blank, "What's a Startup? First Principles", SteveBlank.com, January 25, 2010, https://steveblank.com/2010/01/25/whats-a-startup-first-principles/, Date of consultation September 22, 2016

[46] T. Kollmann, C. Stökmann, J. Linstaedt, J. Kensbock, "European Startup Monitor", 2015

[47] T. Prive, "What Is Crowdfunding and How Does It Benefit the Economy", Forbes.com, November 27, 2012, http://www.forbes.com/sites/tanyaprive/2012/11/27/what-is-crowdfunding-and-how-does-it-benefit-the-economy/#1bbf634d4ed4, Date of consultation September 23, 2016

[48] KickStarter, About us Page, https://www.kickstarter.com/about?ref=nav, Date of consultation September 25, 2016

These two types of low cost enterprises have one characteristic in common. The vast majority of them do not provide manufactured objects: in fact, they usually do not set their enterprises around the commercialization of goods intended as physical objects, preferring instead to trade in services and other non-physical goods. Within the European Startup Monitor document there is a categorization of industries done by surveying 2,300 startups and their 31,000 employees. When participants were asked to choose an industry category for their startup, the vast majority responded with the category "software as a service" (16.4%), followed by "IT/software development" (9.1%), "consumer mobile/web applications" (7.6%), "E-commerce" (7.5%), "online marketplace" (6.5%), "media and creative industries" (6.5%), while "industrial technology/production/hardware" was chosen by just 5.8% of the respondents. Expanding the categories and including food and bio-, nano- and medical technology among the manufacturing startups, we reach a percentage of 12,6%, against the service and intangible goods provider represented by the remaining 87.4% out of the entire sample[49]. Likewise, crowdfunding projects share a similar distribution. Kickstarted.com is recording a detailed amount of statistics since its launch in 2009, dividing every project proposed into categories such as art, comics, crafts, dance, design, fashion, film & video, food, games, journalism, music, photography, publishing, technology and theatre. Categories that also include some degree of manufacturing or production of physical goods are crafts, fashion, design, food and technology. Out of every Kickstarter campaign launched from its start, whether successful or not, 29,22% fall within one of the above categories. However, when we look at statistics coming from projects that have reached their founding threshold, thus allowing them to move to the next step towards the creation of a business and to start rolling out their products, the percentage of those categories drops to 20,51%[50]. Keep in mind that this percentage is highly exaggerated as even within these categories there are projects that require any manufacturing activities.

This tendency is to be somewhat expected, in fact both business typologies revolve around being fast to get to the market and to start from minimal founding necessities. When we are considering either of these characteristics alone, it would be enough to exclude, or at least downplay, the appeal of a manufacturing business

[49] Ibid footnote 46
[50] KickStarter, Stats section, KickStarter.com, https://www.kickstarter.com/help/stats, Date of consultation September 26, 2016

model or of introducing products that require some degree of manufacturing. Since crowdfunding projects and startups have to present both characteristics, the figures I have exposed above, and how industry categories that involve manufacturing activities see a reduced presence with respect to services and non-physical goods, come with no surprise. In fact, when production issues are considered, the time to market dramatically increases since the enterprise has to account for the construction of a working prototype, the acquisition of machineries, equipment and a plant, the setting up of a capable workforce and the arrangement of a distribution network and the establishment of retailing contracts, if the need arises. Perhaps more relevant is the fact that, other than presenting a cause for delays and further increasing the time to market of a physical product, with respect to a non-physical or service one, these issues all add up to the capital needs of the newly born enterprise. The bigger the capital requirement, the less likely it is for a crowdfunding project to be backed by the right amount of donors, and the harder it is for a startup to be able to scale its business model and to attract venture capitals. Furthermore, especially for crowdfunding projects, outsourcing these kind of production activities can be hard. If a product is complex or different from similar products, it might prove difficult to find an existing machine or plant, able to manufacture such good, hence requiring the design and construction of a machine able to manufacture said product. Even if such plant does exist it will not provide cheap services. In fact, with the amount of information that donors receive and that the entrepreneurs launching the crowdfunding campaign have to legally disclose, it would send a very bad image if manufacturing services are outsourced to firms which are outside the project's country. The situation worsens further if the project uses manufacturing activities that are cheap thanks to the exploitation of labor force in developing countries. In fact, the majority of projects found on Kickstarter, which include the manufacturing of an object, proud themselves for employing local manpower and services, which do not come at a discount. I argue that it is for these reasons that manufacturing, and on the other side, crowdfunding and startups, do not get along.

3.3.2 Changes in the supply chain

I do believe, however, that when Hub firms are factored inside the equation, among the many changes that they could bring, they are also going to affect the relationship between crowdfunding, startups and manufacturing. So much so, that it is likely to heavily change their modus operandi. Hence, I will explain these changes and why I think they are so extensive that they should warrant for a new name: Meteorite businesses.

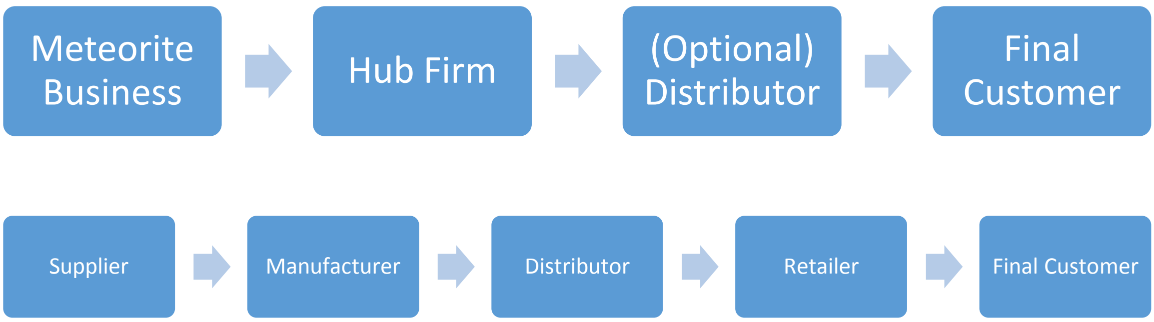
In a market where Hub firms are a successful alternative to the classical set up of manufacturing organizations and additive manufacturing is able to substitute a number of traditional processes, a transformation is likely to happen in both crowdfunding projects and startups. This likeliness will be provided by the ease with which such businesses are able to acquire manufacturing services that accommodate for their different needs. In fact, if Hub firms become reality, not only will they provide the means to produce cheaper functional prototypes, but also a manufacturing plant that is able to scale production based on the enterprise's needs. 3D printing technologies have already proven themselves as a quick and relatively less expensive tool to use when considering building a prototype, with respect to traditional means. In fact, their main use, at the time of the writing, consists primarily as a means to achieve rapid prototyping, as it was shown in the first chapter with BMW's example. Still, since prototyping is a trial and error process in which many combinations are tested before choosing the one the works best, it could prove costly even with 3D printers. Nonetheless, a Hub firm would be able to share the expertise of its designers and engineers through consulting services, even bringing solutions and ideas coming from other industries and ensuring that the customer can get the best out of the manufacturing service. Such service alone would be very appealing, especially to startups, as technical expertise is often what these enterprises lack the most. Indeed, on StatisticBrain, a research institute with the aim of providing free statistics for a number of different subjects, one can find that the first cause for startups' failures is represented by incompetence or lack of knowledge in the field of management and technical subjects.[51] The prototyping process would be dramatically simplified in spite of the cost, as the crowdfunding project or startup would simply need to send their CAD design and issue the production of one unit to the Hub firm. Once a working prototype has been calibrated, the enterprise could simply issue the production of more units, therefore, if successful, scaling up operations would prove a matter of relative ease. With no need for the set-up of a plant holding a vast amount of specific assets for manufacturing purposes, the cost burden on the startup or crowdfunding

[51] StatisticBrain, "Startup Business Failure Rate by Industry", January 24, 2016, StatisticBrain.com, http://www.statisticbrain.com/startup-failure-by-industry/, Date of consultation September 26, 2016

project deciding to produce a physical product would be drastically reduced. The only cost associated with production would be represented by the bill from the Hub firm for each unit manufactured. However, such cost will likely be a fraction of what it would had been otherwise, since the Hub firm is exploiting economies of scale generated from its entire customer base, thus further redimensioning the cost disadvantages crowdfunding projects and startups might experience. Also, these enterprises could have the option to exploit yet another service provided by Hub firms, relying on them for shipment of their products to the final consumer. This way, at least at an initial stage of the enterprise, there would be no need for them to build up a distribution network as they can use at home delivery services, similar to those ensured by Amazon. Setting up dedicated shops or retailing contracts would still be a feasible strategy, in order to provide a different consumer experience or simply to build up on a premium brand image, but the cost incurred to do so might prove to be too much during the enterprise's first steps, as it would make it less lean.

Effectively, adding the Hub firm would reduce the number of minimum players required to set up a supply chain, where the supplier is represented by either a startup or a crowdfunding project issuing the production of a physical product (ergo a Meteorite

Graph 3. Differences between supply chains



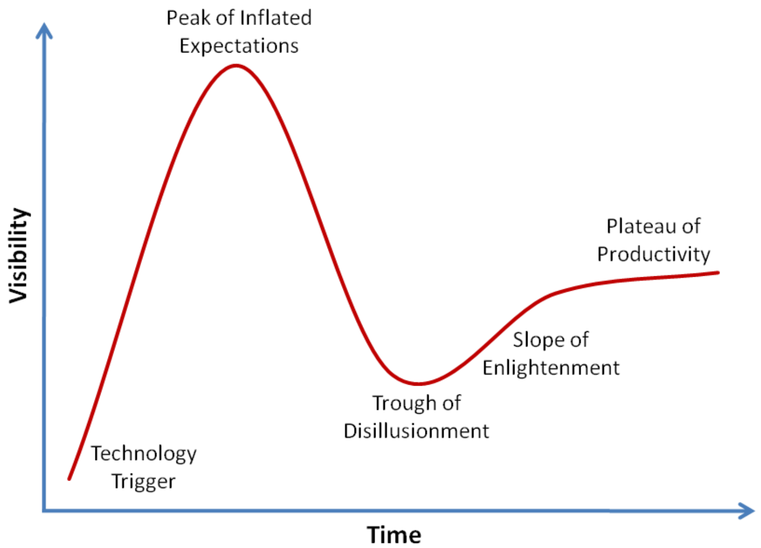
business). The role of the manufacturer, and possibly even the one of the distributor, would be covered by a Hub firm. Finally, since there is no real need for a retailer, the supply chain could end with the consumer as early as this stage, as shown in the graph. Potentially, this would lower the number within a supply chain to two elements, if the Hub firm provides for shipping services and excluding the customer.

3.3.3 Outsourcing manufacturing

I believe that the introduction of manufacturing activities and the new potential to create complex physical products on a scale that can be easily variated guaranteed by Hub firms, will increase the number of startups and crowdfunding projects that choose to integrate such activities in their lean value chain. Yet along with some other crucial differences that will distance them from these kind of enterprises. I call them Meteorite businesses, and their business model will revolve around a very lean structure that will require a small amount of initial capital aimed at producing a successful design, with respect to a firm that has to buy specific physical assets in order to manufacture. In fact, their main asset would be represented by their idea of an object that can be brought to market quickly, probably improving on existing products or creating new ones. Thanks to services given by Hub firms, Meteorite businesses would be able to transfer this idea into physical form at a relatively low cost, by simply creating a CAD file and issuing its production. The main difference that sets these enterprises apart from startups is going to be the ease with which they will be scalable, thus they will not require any particular business plan configured to be scalable, yet retaining their leanness and flexibility. Moreover, Meteorite businesses could use crowdfunding to sustain their initial capital requirements, but it would not be wise to announce their idea publicly before it is either patented or protected by some degree of secretness. However, these enterprises would be heavily relying on the same approach of crowdfunding projects, trying to create a viral marketing campaign that quickly gains them donors and customers alike. The majority of such enterprises will be short lived, because they will hinge for the most part on practical ideas that are able to generate a viral initial interest among consumer, but that quickly fades away. Thus, like meteorites burn quickly into the atmosphere to impact on the ground with their mass so reduced that, although dangerous, they do not represent a threat to human kind, so do these businesses, which will try to transform the initial short lived interest of the majority of consumers into a product built quickly and cheaply. This is done in order to exploit to its maximum the visibility a new product gets and it is based on the Hype Cycle, developed by the research and consultancy firm of information technologies Gartner. Even if developed to be applied to a new technology's life cycle, the graph can also be applied to a product's lifecycle. Much like the well-known product lifecycle graph, the Hype Cycle swaps visibility for profits or adoption[52]. A Meteorite business being able to put on the market a product at the height of its initial visibility is likely to sell many units. The consequent drop due to disillusionment might even be less severe, if the product is able to deliver and to meet expectations. Yet, some ideas are better than others, and just as meteorites have different masses, some have sufficient mass to still be able to produce considerable damages even after the atmosphere has burnt most of it. I hope that these ideas will not be as destructive as a massive meteorite, but there are going to be ideas and Meteorite businesses that will survive the initial fame, because of a product truly successful and with big potential.

3.3.4 Product development and distribution

I believe that Meteorite businesses are going to become a successful business model for those who want to transform an idea into profits as fast as possible and with as little resources as feasible. Meteorite businesses will present themselves as lead firms, retaining activities of the value chain such as research, development, designing and marketing for themselves. Thanks to the internet and the development of information technologies, these activities can be successfully carried out by a relatively small amount of people. The ease with which a small team of marketers is able to communicate effectively a message throughout the world and with just the cost of setting up a YouTube clip favors small enterprises such as Meteorite businesses. Research and development costs could be potentially non existing, as the idea that generates the product can be born



Graph 4. Gartner Hype Cycle

52 Gartner, Gartner Hype Cycle, Gartner.com, http://www.gartner.com/technology/research/methodologies/hype-cycle.jsp#, Date of consultation September 30, 2016

out of technical know-how, on the field experiences, serendipity, university knowledge, open source development, etc. Many of the most successful crowdfunding projects were started by original ideas developed thanks to the founders' experiences. Pebble Time is one of the very first smart watches, whose prototype was developed from scrapped cellphones parts. It raised 20 million dollars. Star Citizen is a space simulator videogame created by the well-known videogame developer Chris Roberts, thanks to its experience and knowhow he was able to raise more than 124 million of dollars. Likewise, the Coolest Cooler was designed by inventor Ryan Grepper and it's a portable food and bevereges cooler design to integrate multiple other functions like bluethoot speakers, bottle opener, device charger, etc. This project raised 13 million dollars[53]. If this is not the case, or the idea needs further refinement through a trial and error process where combinations of different alternatives are tested, costs could rise dramatically depending on the complexity of the overall product. Yet, perhaps it would be in the interest of Hub firms to guarantee a limited prototyping program, where the customer can print for example three different versions of their prototypes at a reduced cost. This could prove a beneficial situation for both parties, if it means increasing the odds of successful Meteorite businesses, which will then consequently require the manufacturing service of the final version of its product. Designing and translating the idea into a CAD file could prove complex and could require technical skills, but this can be provided by either one of the founders of the Meteorite business who has such capabilities, or if insufficient, by the consultant services provided by Hub firms on the matter, or a combination of both. This would prove useful, as Hub firms could introduce within the design insights coming from different experiences from different industries to which, the founders of the Meteorite business, could hardly be exposed to. Their cooperation would also guarantee that the Meteorite business can access the know-how on 3D printing technology that they might lack. Consultant services over what type of printers is best suited for their product, and thus the best materials in which it is feasible to print, could prove vastly beneficial by enabling the joint effort to vary the choice they can make based on whether the product has to be cheap, precise, or to deliver a sense of premium.

[53] Ibid footnote 50

Again, the symbiotic relationship between Hub firms and Meteorite businesses could provide an ideal win-win situation, thus increasing chances for Meteorites in the end would prove beneficial to Hub firms. Such low cost and leanness that Meteorite businesses could potentially achieve along the entire value chain might be determinant for their success and rapidity in bringing to market a new idea. Once the product is ready and sufficiently shielded by some sort of intellectual property protection, the Meteorite business can start a marketing campaign that has to be as viral as possible, possibly financed through crowdfunding or other means. The next step is to time the release of their product at the apex of the media's attention, starting to take orders only after a critical visibility has been reached, in the hopes that by doing so the product would benefit also from world of mouth and first user's experiences, in the form of reviews and positive feedbacks. As in the Hype Cycle depicted previously, the ideal condition would be to release the product as its visibility reaches the apex, to possibly prologue the visibility's growth or, at the very least, to delay its drop. Especially for small businesses the release of a new product is a crucial moment that needs a careful attention to its timing and modality, as it can be the difference between a success or a crushing failure. Unfortunately, there are no models that can effectively provide a precise timing of release. The dangers of early or late release involve losing a chunk of potential customers that would have otherwise bought the product if, in the case of early release, they were given a little more time to know and excite about the product, or, in the case of late release, they had not lost interest due to its lag. However, although hard to release at the precise day in which the apex of visibility is reached, its crucial to act within a brief window of opportunity. After the launch, once the first orders are placed, the Meteorite business would issue its production to the Hub firm, in a market configuration that would see the consumer "pulling" demand for its product and the Meteorite and Hub firm reacting to it, all coordinated thanks to either the Meteorite business' website, the Hub's online services or a combination of the two. The price would include the Hub firm's bill, shipment costs and the Meteorite's markup, defined by the strategy with which they have chosen to market their product, which in my opinion will still be cheaper with respect to traditional business models, thanks to the cost advantages granted by Hub firms and the lean structure Meteorite businesses provide.

The strategy of a Meteorite business should always consider the creation of a brand name from the start. In fact, if a product proves extremely successful and turns in a considerable amount of profits, the Meteorite businesses could consider using the newly gained capital and the success that the brand has acquired to develop a new product, sustaining its competitive advantage introducing new ideas for potential products to it resource pool, or by hiring new employees. As easy as this sounds, I am sure that it will not be as simple as I am describing it here to further develop new ideas with the potential to be successful products. This is the very reason why I believe that the average Meteorite business will be short lived, not necessarily entailing a story of bankruptcy or inability to further innovate, but by fading out of the consumers' attention and by experiencing a drastic contraction of demand.

3.3.5 Cost structure

Their cost structure will mostly present variable costs in the form of manufacturing expenditure from Hub firms and shipment of goods. However, they can be easily integrated within the price the consumer pays, because it will be easy to determine the cost of producing a single unit and its shipment, since the Hub firm and the delivery provider will they themselves ask for a specific price for their services. Variable costs will also depend on the variety of products a Meteorite business is able to offer. At the start of the Meteorite business, the only cost driver will be represented by the demand for their unique idea/product around which the enterprise is born. The more products are added later on, the more variable cost the Meteorite business will incur in.

On the other hand, fixed cost will be represented by the salaries of employees, research and development, design and marketing. Yet, since Meteorite businesses ideally start as a lean firm requiring a minimum amount of people to be run, bringing the competencies needed to create and market the idea, at least at the beginning, the fixed cost that such enterprise will experience are going to be relatively low. This should enable the entrepreneurs engaging in such kind of businesses to recover their investments in a very short time, if the launch window is guessed correctly and close enough to the product's visibility apex. Furthermore, since the capital needed to start these enterprises is relatively low, it will be relatively easy to find donors on a crowdfunding campaign or to ask for commercial bank loans. In fact, the lower the target of a crowdfunding campaign, the less likely it is that the single donor feels that its contribution is worthless or ineffective towards the reaching of the target amount.

3.3.6 Threats

Meteorite businesses will depend heavily on Hub firms. For this very reason, the same threats that endanger the success of Hub firms also apply to Meteorite businesses. Particularly harsh may be the legislation regarding intellectual property and how Hub firm choose to integrate such problematics into their corporate charter. In fact, for a Meteorite business to send their proprietary idea through a CAD file to a third party involves a degree of trust or at least reliability on the institution of patents. If such condition is not met, it is unlikely that the system could work based on trade secrets, in as much as the Meteorite business has to communicate every specification needed for the manufacturing of the product to the Hub firm. Although it would be in the best interest of Hub firms to provide a secure environment in which ideas can be communicated without fear of losing control over it, a strong legal environment ensured by governments, which is able to adapt to the changes that 3D printing technologies will bring to the economy, would provide a best suited foundation for this symbiotic relationship to work. Finally, if the technology allows for advanced 3D printers to become cheap enough that the average consumer can buy one to print product at home, while proving extremely detrimental for Hub firms, it may further ensure the potential success that Meteorite businesses can experience. This is because, by shifting the manufacturing activity to the very customer and removing altogether the need for shipment, the price of the product of a Meteorite business would be even lower than what could have been achieved thanks to Hub firms. In this scenario, Meteorite businesses would be just trading in licenses to use their design. Yet, this implies a different challenge, where CAD files must be able to protect its creator from a user acquiring just one license to be able to print more than one product. Of difficult implementation, this kind of protection would have to revolve around software solutions at different levels, presumably included in both the programs of the 3D printer, which would actively limit the printing of the same file beyond the amount allowed, and in the very CAD file, with some sort of protection like the ones guaranteed by PDF files for written documents.

Much of the challenges presented here are just a hint of the difficulties that both Hub firm and Meteorite businesses will have to face in the future, if they both prove to be successful models. Nonetheless, I believe to have drafted the main characteristics of two potential new players that will help to shape the economy in the aftermath of the fourth industrial revolution, and possibly become the very base of what we will consider to be as future small to medium firms, as long as Meteorite business are concerned, and future big manufacturing firms in the form of Hub firm.

Conclusions

Human history is filled with changes and revolutions. Each of these innovations affected a number of different aspects of our life, societies, economies and even of our environment. Such changes started gradually and required a large time span to develop and spread across civilizations. However, as innovations and ideas started to build up to a critical mass, even their pace began to accelerate. Now, as we witness the start of the fourth industrial revolution and the innovations it brings with it, we can identify the foundations over which we expect the changes to happen. Having described the birth of computers, 3D printers and robots, and how each innovation is likely to grow and shape the future outcome of industry 4.0, we can acknowledge how the fourth industrial revolution already found its roots within the previous one. ENIAC and Colossus, the first two modern computers, were created towards the end of the second world war; some time later, George Devol created Unimate, the first industrial robot ever built; finally, in 1985, Chuck Hull successfully created the first prototype of a SLS 3D printer.

What the future is going to bring and how it will affect our world is impossible to know for sure, nonetheless it is worth to try and forecast what these advancements in technologies can accomplish for us and how will we react to them. Especially as long as manufacturing and the advancement of 3D printers are concerned, I believe that the world's economy will witness a substantial development. Based on the Bowl model, that implies a modification of the smile curve in which manufacturing activities will be able to deploy an ideal asset not specific to any product or manufacturing process, I argued that the main protagonists of future changes will be Hub firms and Meteorite businesses. Hub firms will be characterized by the massive utilization of 3D printers, while Meteorite businesses will heavily rely on their collaboration, in the form of outsourcing production activities, and retaining for them only design and marketing activities. Because of these new businesses, value chains will likely get shorter and populated by less players. Manufacturing will still be at the bottom of the smile curve, being the less value adding activity. However, the freedom that it will gain from the technological innovation brought about by the industry 4.0 will be the main driver of changes around which the fourth industrial revolution will take shape.

Unfortunately, this research of mine lacks any empirical evidence other than what is represented by G.E.'s experience and its "Multimodal Plant" in Pune, India. But even such experience is not fully how a Hub firm should look like. Although G.E. is planning to produce many different parts for a variety of divisions, in order to exploit economies of scale at a greater level than each division could do on its own, the plant will not produce for any other customers, and will be servicing only G.E.'s divisions, in other words its own confined internal market. In the model I described, Hub firms would be ideally able to service a great many customers. I believe that Hub firms will grow outside the boundaries that the Pune plant faces today, which are represented by the internal market tailored for the many divisions G.E. has.

Also, in some lesser form, even Shapeways can represent an example of what a Hub firm could look like at its early stage. Shapeways provides its production services mainly for consumers or small businesses, but it is often unable to print its customer's designs because of its limited access to different techniques of 3D printing.

Empirical evidences of the business models I depicted in chapter three are hard to obtain. Creating such models to test my hypothesis requires a lot of capital to invest in 3D printing technologies, as well as a reliable and solid knowledge of the design of a wide array of products. Because of the constraints that nowadays the 4^{th} industrial revolution still faces, as for example the legal protection of new technologies through patents, it was not possible for me to find a company willing to approach the business model I described in order to serve as a "test" or "case study". Hence, my forecasts of what the future of the manufacturing industry will be are based on my educated guess and the knowledge I gained throughout my research on the topic. As one can notice by reading my paper, I made a detailed analysis of the current state of both technology and the industry in order to come to my conclusions, so that every hypothesis was supported with appropriate sources.

Even if at the time of my writing Hub firms and Meteorite businesses seem models that are rather difficult to achieve or to recreate, I believe that in a matter of five to seven years, one or more technological obstacles will be overcome. Further innovation in any of the three pillars of industry 4.0 will likely produce the foundations on top of which Hub firms and Meteorite businesses can prosper and allow the revolution of manufacturing.

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