10-023
September 2017

Udi Aharoni
Alon Epstein
Erez Cohn
Shira Lifshiz

Nano Dimension—Printing Disruption

Printing—A Disruptive Force

Few technologies can be said to have disrupted the very fabric of humanity, revolutionizing economies, mindsets, and deposing formidable forces once deemed eternal. In the mid-15th century, Johannes Gutenberg, a German goldsmith developed a technique to efficiently produce books—the printing press was invented. At the time, this revolution was so significant that it ushered in the Renaissance, laying the ground for modern science and the enlightenment of humanity. Today, in the age of information, most societies pursue values of knowledge dissemination and democratization of thought. Thanks to the internet, people are granted unmediated access to information, views, facts (and their alternatives), regardless of wealth, social class, and geography.

Could the printing press really be regarded as a disruptive innovation? Up until its invention, two techniques were used to reproduce books. One was hand copying of written materials, mostly by the church, thus preserving the dominance of the clergy over human thought and literacy. The other option was reproducing words or pictures by printing blocks. Invented in China, the printing blocks were certainly a rigid and non-efficient way to print, but at least they allowed a more efficient form of production.

When Clayton Christensen coined the term disruptive innovation, he stated that it does not have to be a radically new technology, and the printing press was not. It simply borrowed techniques from other industries, introducing them into a new market. It did however introduce a potentially different level of performance, despite not being highly valued by existing rivals and consumers.

Udi Aharoni from the Eli Hurvitz Institute for Strategic Management at the Coller School of Management, Tel Aviv University, prepared this case with the assistance of Alon Epstein, Erez Cohn, and Shira Lifshiz as the basis for a case competition. The case does not intend to illustrate effective or ineffective handling of business processes or decisions.

The Gutenberg bible was printed only 200 times, hardly signifying the mass production of books, but performance attributes improved so rapidly that mainstream clients were unable to stay indifferent to the disruptive revolution. Only a few decades after the invention of the printing press, approximately 2,500 European cities had acquired presses—marking the centralization of the role of the printing press throughout the known world.

During the 20th century, the printing industry went through several disruptive phases. One was when personal computers rendered the typewriter obsolete. At first computers were expensive, cumbersome and word processors were not ubiquitous enough. But after a few years and technological breakthroughs, all typewriters, mechanical or electric were a thing of the past. Actually, it was IBM, the leading manufacturer of typewriters that used the "creative destruction" model by introducing the first PCs, rendering its once leading products obsolete.

Xerox, which became a synonym for printing and photocopying, lagged behind when it came to servicing small businesses and institutions, and other low end users. The introduction of the personal copier in the 1970s created a new market altogether. Gradually, new entrants to the office printing industry moved upwards, obtaining growing market shares from Xerox's core clientele. Research shows that most market leaders keep ahead of other rivals in developing both incremental and radical innovation, just as long as those improvements address the future requirements of their existing mainstream client base. But it is the non-customers, the smaller niches and overlooked segments that foresee the entrance of disruptive technologies, eventually penetrating mainstream markets and overthrowing previous hegemonies. This happened with the printing press and the diminishing of church dominance; it happened when Xerox neglected to consider companies such as HP, GE, or Brother when they introduced cheap and accessible table-top printers.

More recently, a disruption process has started to revolutionize the short-term and vacation rental industry. Hilton, Marriot and other hotel chain companies neglected to see Airbnb as a threat to their core business—without a single piece of real estate or revolutionary technology, Airbnb has become the largest vacation rental provider world-wide. Airbnb moved from the fringes of holiday travelers and short-term renters, seeking an authentic and perhaps cheaper way to travel, to the very center of the short-term property rental industry.

Most disruptive technologies studied never surpassed the capability of classical technologies. Christensen found that the trajectory of the disruptive technology compared with that of the market is the significant factor.

Printing in the 21st Century—The 3D Revolution

3D printing, or additive manufacturing, is the process in which a solid three-dimensional item is manufactured through adding layers of one or more raw materials, following a digital 3D model. The basic technology has been around for more than three decades, but only since 2010 has it emerged from behind the veils of university laboratories and research centers, reaching the awareness of the general public. Predominantly, 3D printing uses polymers, powders (plaster or resins), and metals; raw materials are either solid or liquid before being applied and layered into a 3D object.

Many companies develop disruptive solutions which compete in various markets, industries and products through 3D printing, and they vary greatly in terms of attributes, regulation, sensitivity to precision, level of maturity and size. Nevertheless, 3D printing has yet to completely overtake existing solutions and dominate market incumbents.

Nano Dimension (NNDM), an Israeli publicly traded company, has developed a printer and proprietary inks that produce multi-layered rigid printed circuit boards (PCB)—one of the most basic and essential building blocks in electronic devices. NNDM was conceptualized as an industry disrupting company. Targeting the rigid PCB prototyping segment, NNDM invented the DragonFly 2020, and has already deployed beta devices in client sites, while additional machines are to be sold in the second quarter of 2017. It possesses two major advantages compared to the current solution. The first, as in all cases of 3D printing, is flexibility and time efficiency. Traditionally, if an electronics device developer wishes to prototype its PCBs, it sends the digital file to a PCB fabrication plant. The manufacturer needs to prioritize and streamline the manufacturing of the single prototypes between mass production series, a process that might take one to three weeks. Using NNDM's solution, the prototype can be manufactured in a matter of hours, ready to be tested the following working day. The second advantage lies in the protection of intellectual property; not having to share information with third-party entities, and keeping any proprietary designs in-house has immense appeal to defense companies, innovative device designers, and anyone who is reluctant to send their prototyping information outside of their systems.

NNDM presents a classic case of potential disruption, introducing an advanced technological solution, targeting a niche within a very large market. Currently, the technology is not cheap and fast enough to provide a solution for large-scale manufacturing, but when it comes to prototyping, it provides a unique solution.

Counter Disruptive

Everybody relishes a good Cinderella story, in which a small innovative and shrewd company disrupts a traditional market, or, better yet, creates a market of its own, rendering rival markets obsolete. But it is not only an availability bias that causes us to recall the stories of success, Christensen's findings showed that incumbents outperformed entrants in a sustaining innovation context but underperformed in a disruptive innovation context.

Nevertheless, in many cases of potentially disruptive companies, the disruption journey ends badly.

One such example is Better Place, an Israeli company which until May 2013 was believed to be a notable rival and rising star in the transportation industry. The technology was not necessarily groundbreaking, but the value proposition was at the time entirely different than any concept in modern transportation. Essentially, customers would buy the entire car, all but its core—the electric battery. They would pay monthly fees for driving distance, as well as infrastructure, and recharging services. In return, Better Place promised to provide an abundance of recharging spots, but the hallmark was the battery swapping depots that enabled drivers to be on their way with a newly charged battery in a matter of five minutes. Better Place chose Israel as its beta site, built 21 swapping depots and erected around 1,000 recharging poles, servicing less than 1,000 of the specifically designed Renault Fluence Z.E vehicles (a quarter of its original goal), before going bankrupt and shutting down their entire global operations.

Better Place's value proposition was aimed at a segment of users who drove short distances along regular routes and had generally predictable driving habits. The solution presented a highly innovative business model, augmented by values of sustainability and environmental conservation. Better Place drew positive sentiment wherever they were present, receiving endorsements from business as well as political sources of influence. This made their colossal downfall even more painful. Why did disruption fail in this case? A number of factors were at play, and probably it was the combination of a few that left Better Place little chance to disrupt the highly consolidated transportation market.

Many other examples exist, some known, others that have faded away into disruptive anonymity. But the lesson should be learned—when attempting to disrupt existing, mature, and highly financed markets, entrants need to be modest—making realistic estimates of their capabilities and aiming for achievable goals, rather than sweeping in and attempting to revolutionize reality overnight. Flukes do happen, but not when a conservative market needs to be reeducated, and very costly and complex infrastructure investments are involved.

Will 3D printing disrupt the market and force incumbents to adapt or die? And if so, when? Christensen understood that the success of disruption depends on the trajectory of improvement of potentially disruptive technologies and their intersection with the needs of the mainstream manufacturers, realizing that the steepness of any disruptive trajectory is a function of how quickly the enabling technology improves.

Nano Dimensions—Giant Potentials

NNDM's story started in 2012, when four friends were sitting on a beach in Israel, thinking how they could revolutionize a market. They still did not know which market or how they would do it, but with enough combined accumulated experience, funds, and heaps of audacity, they were certain they would be able succeed. The four entrepreneurs aspired to found a corporation, not just a start-up company. From the start, they were thinking in global terms and market disruption. They knew that in order for their aspirations to materialize, they would need to raise a large amount of cash, and at least for the time being, were unable to print it.

Only one year after conceptualization, NNDM raised the initial sum from a reverse merger—taking over a stock market skeleton company. Just two years later, two printers were already leased out—a groundbreaking achievement in hardware market terms. By the end of 2016 six printers were operational at beta sites—a world leading defense company, a consumer goods manufacturer, and additional markets. By the end of Q12017, an additional six units would be deployed to customer sites.

The DragonFly 2020 (DF), NNDM's 3D printer, is essentially a "factory in a box"—able to produce a ready to use PCB in a matter of hours. The printer uses a combination of two proprietary inks to produce the PCB—a conductive silver nanoparticle ink and a dielectric nano-polymer ink, to create the structure of the PCB. The DF is designed to produce multilayered rigid PCBs with conductive traces down to 90 microns in width and a board size of 20cmx20cm (the DF is also able to print flexible PCBs, but this development is more advanced, and is considered a growth engine for the company). This allows a robust solution for multiple markets and purposes, but cannot provide a solution for smartphone manufacturers for example, who require 50 micron traces in their latest PCBs.

Currently, NNDM employs over 100 people; most are R&D personnel, while some are in operations, procurement and management. All development is performed in-house, while there are two major verticals that enable NNDM's products—mechanical and electrical engineering honing the printers, and chemical engineering and chemistry to develop the proprietary inks. NNDM developed their own unique software, labeled "Switch", which is installed in the system, enabling seamless communication between user, printer, and the deposition of ink. The three components together create a turnkey solution for the manufacturing of multilayered rigid PCB prototypes. The system is compatible with industry standard ECAD or electronic design software file types such as Gerber files.

Value Proposition & Strategy

In its value chain, NNDM is aiming at the designers and developers of electronic devices, focusing only on prototyping requirements, gradually aspiring to develop small volume production capabilities.

In the next four years or so, thousands of printers will be able to be manufactured through a strategic contract between NNDM and Flextronics.

NNDM's revenue comes from selling printers, priced at around $200K for each unit and from reselling their proprietary inks, at substantially higher profit margins—a classic razor-razorblade strategy. Management understands that any electrical device, such as their 3D printers, can be eventually reverse engineered, redesigned and manufactured by competitors. However, the precise combination between hardware, proprietary nanoparticle inks, and tailored software creates a solution that is extremely difficult to imitate. Eventually, once competition enters the market, the price of the printers will inevitably drop, but it is the unique inks and the full combination of the package that will potentially provide NNDM with the sustainable competitive advantage it seeks.

A Prototyping Market

As of today, prototyping is performed through the conventional manufacturers of PCBs, and players who are well equipped to mass produce thousands or millions of items. There are milling machines that enable some level of in-house PCB manufacturing, but these are seen as cumbersome and not well suited to the complexity of today's circuitry. However, no tailored 3D solution exists for prototyping requirements of multilayered PCBs. There is no distinct market for prototyping PCBs as it is often bundled into larger manufacturing contracts and its valuation has been reached through estimations and extrapolations of probabilities. The entire PCB manufacturing market has been valued at around $61.5bn as of 2015, with an estimated CAGR of 5.3% from 2016 to 2021; demand is driven mostly by consumer electronics, medical devices, and the automotive industry. Analysts estimate that prototyping activity constitutes around 5% of the global PCB market, and if only 20% of prototyping is brought in-house, mostly through 3D printing solutions, that will leave an estimated $836m for 3D printing solutions for prototyping.

As the market seems limited at this point, incumbents cater mainly for the core needs of their large customers—that is, production units within the client companies, somewhat yielding the niche customers of developers and designers in those same organizations. The major manufacturers of PCBs are in China, but the potential competition is of higher relevance. Companies such as HP, Xerox, Brother, and GE, all venture towards 3D printing solutions, not necessarily in the PCB arena, but if deemed relevant, they would certainly attempt to capture a foothold in this large market.

As insightfully stated by Christensen and his colleagues, "..small, hungry organizations are good at placing economical bets, rolling with the punches, and agilely changing product and market strategies in response to feedback from initial forays into the market". The large players would rather see how the small entrants do in the market, assess its potential through more accurate estimations, and only then decide on their strategy.

NNDM has a chance to be the first player in this blue-ocean market, but will it prove to be a lucrative one, serving as a foothold into the general PCB market and others in the future?

For a complete and comprehensive analysis of NNDM's technology and value proposition, see Edison's full report.

From Niche to Robust—NNDM's main dilemma

NNDM has honed a technology of disruptive potential, positioning it at the forefront of the rigid PCB prototyping market, a market that at the moment has only one occupant. It is the company's ability to move from the position of a single player in a niche market to that of a dominant rival in a broad and mature market that will determine the fulfillment of its disruptive potential. However, the company's 3D printing platform encompasses a multitude of applications.

Just as with computers, regardless of the computing power, it is the software that determines the utilization of the potential, so it is with 3D printing. The hardware infrastructure is an enabler of endless possibilities, and the inks, their attributes, qualities and potential utilizations determine the array of end products to be created. What does NNDM need to do in order to position itself as a formidable player in the additive manufacturing arena, entering new domains and disrupting not only the PCB manufacturing market, but the entire electronics industry?

Undoubtedly, the transition from a niche market to a market of hundreds of billions of dollars, encompasses immense prospects, but with equivalent risks. Therefore, it is up to management to choose a path that will maximize its potential for the next three years.

Currently, NNDM's business model stipulates that the company is a one-stop-shop, honing everything from hardware, to software, to inks. But this is not the sole alternative. NNDM could partner with other ink material manufacturing companies (companies that produce the raw materials for 3D printing), becoming a hub for additive manufacturing, thus broadening its product portfolio.

What are the actions that NNDM needs to take in order to position itself as a dominant global player, fulfilling its disruptive potential for the next three years? The following aspects should be analyzed:

- Which industry possesses a high potential for disruption through the application of NNDM's advanced technology: the electronics manufacturing industry (alternative 1), or other industries (alternative 2)? Which of the two is the preferable solution, and why?
- Strategic partnerships—in which fields, with whom, and what should be the form of collaboration and go-to-market strategies?
- What is the business potential, and what would the company's expected value be?
- What would be the optimal business model to achieve the objectives, and how should the company implement it?
- What are the foreseen risks, and how should the company attempt to confront them?
- What are the expected financial resources needed to achieve the chosen solutions?

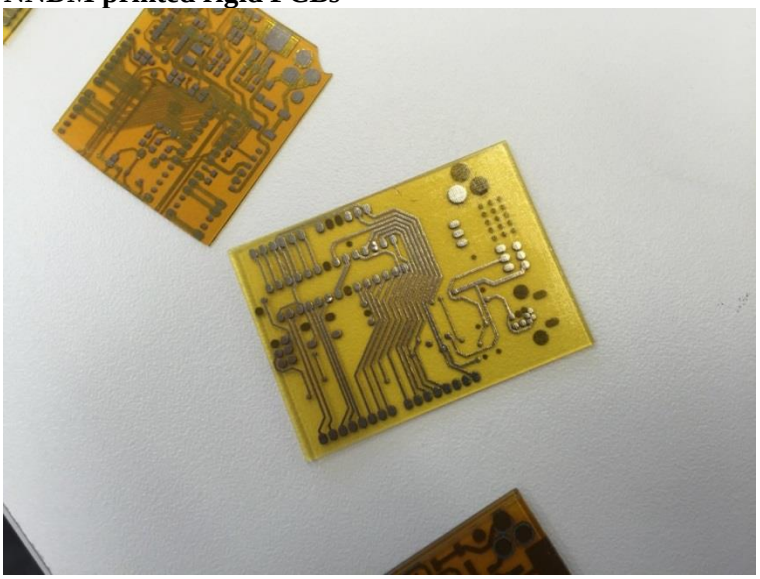
Appendixes

Exhibit 1: Samples of 3D printers

Exhibit 2: NNDM's products

Dragonfly 2020 3D PCB printer-

NNDM printed rigid PCBs



Conductive Ink—A uniquely formulated nano-conductive ink for use in NNDM 3D printers. Using advanced nanotechnology, NNDM developed a liquid ink that contains nanoparticles of conductive materials such as silver and copper. Nanoparticles are particles between 1 and 100 nanometers in size. By employing this technology, NNDM is able to create a liquid ink that maintains its transport properties and electric conductivity. The liquid properties of the nano-conductive ink allow taking advantage of inkjet printing technology for fast and efficient 3D printing of PCBs.

Dielectric Ink—NNDM proprietary dielectric ink is a unique ink that contains materials that are not electrically conductive. The use of non-conductive ink is crucial in the production of multi-layer circuit boards, as the conducting layers that are placed on top of each other must be separated by dielectric layers. NNDM's internally developed, proprietary dielectric ink is a unique one-part-epoxy material. The dielectric ink can withstand high temperatures (e.g. five hundred degrees Fahrenheit and more) without distorting its shape, which is a necessary requirement for professional PCBs.

Source: NNDM Annual Report, 2016

Exhibit 3: NNDM consolidated statement of income, in thousands of $US (convenience translation from NIS)

	31.12.2014	**31.12.2015**	**31.12.2016**
Revenues	**-**	**-**	**46**
Cost of revenues	-	-	19
Cost of revenues—amortization of intangibles	-	-	174
Gross loss	**-**	**-**	**147**
Research and development, net	858	2,858	4,059
General and administrative expenses	367	2,878	4,797
Other income	16	1	-
Operating loss	1,209	5,735	9,003
Listing expenses	2,406	-	-
Financial expense (income), net	30	(355)	(38)
Total comprehensive loss	3,645	5,380	8,965
Loss attribute to holders of Ordinary Shares	3,645	5,380	8,965

Source: NNDM Annual Report, 2016

Exhibit 4: NNDM balance sheets, in thousands of $US (convenience translation from NIS)

	31.12.2015	31.12.2016
Assets		
Cash	8,793	12,379
Restricted deposits	130	130
Trade receivables		39
Other receivables	268	775
Total current assets	**9,191**	**13,323**
Restricted deposits	111	110
Property plant and equipment, net	1,148	2,006
Intangible assets	2,953	6,787
Total non-current assets	**4,212**	**8,903**
Total assets	**13,404**	**22,226**
Liabilities		
Trade payables	449	679
Other payables	472	1,289
Total current liabilities	**921**	**1,968**
Liability in respect of government grants	258	629
Other long-term liabilities		327
Total non-current liabilities	**258**	**956**
Total liabilities	**1,179**	**2,924**
Equity		
Share capital	1,005	1,417
Share premium	16,339	30,902
Treasury shares	(1,368)	(1,368)
Warrants	1,803	1,138
Capital reserve from transitions with controlling shareholders	485	485
Capital reserve for share-based payments	3,298	5,091
Accumulated loss	(9,398)	(18,363)
Total equity	12,225	**19,302**
Total liabilities and equity	13,404	**22,226**

Source: NNDM Annual Report, 2016