THE CENTER FOR CLIMATE AND SECURITY

The 3D Printing Revolution, Climate Change and National Security: An Opportunity for U.S. Leadership

Caitlin E. Werrell and Francesco Femia

05 December 2012

The 3D Printing Revolution, Climate Change and National Security: An Opportunity for U.S. Leadership

Introduction

Humanity has lived through many ages and transformations, usually without knowing that it was doing so. Hunters and gatherers reigned for hundreds of thousands of years until the agricultural revolution slowly changed the way we managed our environment, leading to denser populations, and eventually, sprawling empires. In Western Europe, the age of empires reluctantly but swiftly gave way to the plodding age of feudalism, followed by the energetic burst of the Enlightenment and on to the manufacturing juggernaut of the industrial age, which took us from steamships on the Mississippi to robots on Mars in less than two hundred years. We are now furiously typing and tweeting our way through the computer, or "virtual" age, with an unprecedented population, resource and climate crisis as an anxious backdrop. But as we stare at our screens, a new age is sneaking up on us, quite unexpectedly - one that combines the solidity, durability and strength of the industrial age, with the nimbleness, flexibility and adaptability of the virtual age. This mix will be necessary to address the complex challenges of a rapidly changing and uncertain world – not the least of which are the associated security risks of climate change. It is an age that has the potential to be built not with hammers, but with printers. 3D printers, to be precise. And the United States of America is in a perfect position to lead the way.

What is 3D Printing?

3D printing, also known as "additive manufacturing" is the printing of physical 3D objects directly from a digital plan, and encompasses a range of new technologies. As the name suggests, unlike traditional manufacturing processes that "subtract materials from a form," additive manufacturing builds an object by printing it out layer by layer from the bottom up. Some may be familiar with 3D printing because of its use in producing props for movies, such as in the Hobbit films.[1] But its potential reaches far beyond the world of fantasy. Additive manufacturing allows designers to create intricate structures that in some instances would be impossible to construct otherwise (see here).[2] Printing an object can be

[1] *Weta Workshop uses 3D printers to make props for Lord of The Rings and The Hobbit*. July 20, 2012. http://www.3ders.org/articles/20120720-weta-workshop-uses-3d-printers-to-make-props-for-lord-of-the-rings-and-the-hobbit.html

[2] *Lisa Harouni: Kennismaking met 3D-printen*. TedSalon London Spring 2011. http://www.ted.com/talks/lang/nl/lisa_harouni_a_primer_on_3d_printing.html

as simple as downloading product design data for the object and hitting print, or making a 3D scan of an existing object, and then printing out a physical copy of that scan. The materials (or "ink") used to physically create the object range from plastics to metals to food.[3] Currently, there is a limited range of objects that can be printed because of the limited materials available and the size of the printers. Nonetheless, to date, cars, bikes, houses, and prosthetic limbs have all been printed.[4] There are even 3D printers that can print other 3D printers![5]

For the foreseeable future, additive manufacturing will not replace the economies of scale associated with mass production. However, it has a number of distinct advantages that collectively have the capacity to change the entire manufacturing paradigm, that, in turn, could help human civilization - and the Unites States - tackle some of the most intractable security challenges of the 21st century.

Current National Security Benefits of 3D Printing

The national security benefits of 3D printing are not just future projections – they already are being recognized and acted upon, even if on a limited scale. As with the development of numerous other cutting-edge technologies in the past, from digital photography to the computer, the U.S. military already is trailblazing the way forward with 3D printing. Why? Because it is a technology that can enhance the security and operational effectiveness of the armed forces.

One of the most notable uses of 3D printing technology by the military is its new Expeditionary Lab - Mobile.[6] The Expeditionary Lab currently is in use in Afghanistan, and as the name implies, it is a mobile unit that brings engineers, 3D printing technology, and a wireless support network of experts, to troops, to give them quick, on-the-ground solutions to equipment problems.

---

[3] *Watch and Learn: There's More Than One Way to Additively Manufacture a Metal*. Core77. Aug. 22, 2012. http://www.core77.com/blog/digital_fabrication/watch_and_learn_theres_more_than_one_way_to_additively_manufacture_a_metal_23236.asp ; Purvis, Andrew. *Will 3D printers make food sustainable?* The Guardian. May 18, 2012. http://www.guardian.co.uk/environment/2012/may/18/3d-printers-food-sustainable

[4] Davies, Alex. *This 3D Printed EV Will Change The Future of Cars*. Business Insider. Aug. 28, 2012. http://www.businessinsider.com/this-3d-printed-ev-will-change-the-future-of-cars-2012-8; *Printing a bicycle with a 3Dprinter*. BBC clip on YouTube. Uploaded March 8, 2011. http://www.youtube.com/watch?v=hmxjLpu2BvY; Kraft, Amy. *A giant 3D printer builds a livable house*. Smartplanet. Aug. 11, 2012. http://www.smartplanet.com/blog/smart-takes/a-giant-3d-printer-builds-a-livable-house/28301; *Personal Prosthetics: 3D Printed Custom Prosthetic Limbs.* Gajitz. Accessed Dec. 5, 2012. http://gajitz.com/personal-prosthetics-3d-printed-custom-prosthetic-limbs/

[5] RepRap. RepRapWiki. Accessed Dec. 5, 2012. http://www.reprap.org/wiki/Main_Page

[6] Cox, Matthew. *Mobile Labs Build On-the-Spot Combat Solutions*. Military.com. Aug. 17, 2012. http://www.military.com/daily-news/2012/08/17/mobile-labs-build-on-the-spot-combat-solutions.html

One notable example of the effectiveness of the expeditionary lab was the rapid prototyping of a new battery charger, so that troops could carry a single battery charger rather than multiple (and heavier) back-up batteries.[7] Since the mobile lab was located in Afghanistan, it could establish a direct link between troops using the charger and the engineer designing the prototype. It took about a month to produce the charger and distribute it to the troops as opposed to the six-plus months it would normally take to do so. These mobile units can be utilized not just for combat missions, but also for critical disaster relief operations.[8] Other current uses of 3D printing in the military include the printing of parts for the Boeing F-18, the cockpits of helicopters, and complete drones.[9]

At this point it is estimated that 3-D printing is, however, only operating at about 1-2% of its potential.[10] But like many technologies first created for the defense industry, including GPS and the internet, the applicability of 3D technology has potential civilian applications to help address the broader and more complex security challenges of the 21st century.

Future National Security Benefits of 3D Printing

The 21st century is characterized by an increasingly complex global security landscape, and increasingly complex transnational crises. The top national security risks facing states today have moved beyond the traditional state-based threats associated with the Cold War and now include transnational threats from non-state actors such as international terrorists, non-state weapons proliferation (and the proliferation of materials needed to make and launch those weapons), cyber-security, organized crime, natural resource degradation, and climate change. The United States must develop new ways of addressing these problems. Good governance coupled with innovative technology can go a long way towards doing so, and 3D printing offers a potentially critical component of achieving both[11]. And it has the potential to be especially useful in addressing the security implications of a changing climate.[12]

---

[7] Ruiz, Rebecca. *3-D Printers Now Solving Problems on the Front Lines*. Txchnologist. Sept. 10, 2012. http://txchnologist.com/post/31269995564/3-d-printers-now-solving-problems-on-the-front-lines

[8] Hoffman, Mike. *Deploying MacGyver to Afghanistan*. Defense Tech. Aug. 17, 2012. http://defensetech.org/2012/08/17/deploying-macgyver-to-afghanistan/

[9] *Additive Manufacturing. Solid Print*. The Economist. April 21, 2012. http://www.economist.com/node/21552892; Gordon, Leslie. *World's first "3D-printed" UAV*. Machine Design. Sept. 8, 2011. http://machinedesign.com/article/world-s-first-3d-printed-uav-0908

[10] Ruiz, Rebecca. *3-D Printers Now Solving Problems on the Front Lines*. Txchnologist. Sept. 10, 2012. http://txchnologist.com/post/31269995564/3-d-printers-now-solving-problems-on-the-front-lines

[11] Connor M. McNulty, Neyla Arnas, and Thomas A. Campbell. *Toward the Printed World: Additive Manufacturing and Implications for National Security*. Defense Horizons. National Defense University. September 2012. http://www.ndu.edu/CTNSP/docUploaded/Defense%20Horizons%2073.pdf

[12] National Research Council. *Climate and Social Stress: Implications for Security Analysis*. Washington, DC: The National Academies Press, 2012. http://www.nap.edu/catalog.php?record_id=14682

Addressing Climate Change with 3D Printing

Hurricane Sandy created havoc along the north-eastern coast of the United States, claiming lives, disrupting electrical supply, devastating houses and businesses, and overwhelming sewage treatment systems.[13] Increasing the climate resilience of communities along this coast should therefore be a high priority for policy-makers. But at least for the foreseeable future, the north-eastern United States is not likely to be politically and economically destabilized in the wake of a major storm.

But in a place like Pakistan, which is wracked with extreme poverty, ethnic conflict, terrorism, government fragility, water-stress and the proliferation of loose nuclear materials, the capacity to adapt to and recover from climate-related disasters like floods or prolonged droughts, could play a crucial role in maintaining stability.[14]

In either case, additive manufacturing at a larger scale can both contribute to enhancing resilience to the implications of climate change, and, as a by-product of the manufacturing process, reduce greenhouse gas emissions and waste.

Climate Resilience Potential

Additive manufacturing has five key attributes that could help places as different as north-eastern United States and Pakistan enhance their climate-resilience, and ultimately, their security.

- *Reducing the cost of tailor-made solutions.* According to Chris Anderson, additive manufacturing is revolutionary because it "takes the expensive parts of traditional manufacturing, and makes them cheap."[15] He adds:

> "In mass production, the more complicated a product is and the more changes you make, the more it costs. But with digital fabrication, it's the reverse: The traits that are expensive in traditional manufacturing become free. Variety is free: It costs no more to make every product different than to make them all the same. Complexity is free: A minutely detailed product, with many fiddly little components, can be 3-D printed as cheaply as a plain block of plastic. Flexibility is free: Changing a product after production has started means just changing the instruction code."

[13] Schwirtz, Michael. *Sewage Flows After Hurricane Sandy Exposing Flaws in System*. New York Times. Nov. 29, 2012. http://www.nytimes.com/2012/11/30/nyregion/sewage-flows-after-hurricane-sandy-exposing-flaws-in-system.html
[14] Kugelman, Michael. *Pakistan's climate change challenge*. The AfPak Channel. Foreign Policy. May 9, 2012. http://www.nytimes.com/2012/11/30/nyregion/sewage-flows-after-hurricane-sandy-exposing-flaws-in-system.html
[15] Anderson, Chris. *The New MakerBot Replicator Might Just Change Your World*. Wired. Sept. 19, 2012. http://www.wired.com/design/2012/09/how-makerbots-replicator2-will-launch-era-of-desktop-manufacturing/3/

These qualities could dramatically increase the ability of communities to quickly and cheaply develop locally appropriate solutions for enhancing resilience to climate change.

- *Enabling rapid prototyping where existing solutions are inadequate.* The afore-mentioned Expeditionary Labs in use by the U.S. military in Afghanistan have used rapid-prototyping to quickly develop the design for rechargeable batteries for troops. This concept could be just as effective in responding to climate uncertainties and risks. In fragile countries that are particularly vulnerable to the impacts of climate change, a quick response could help avert a humanitarian disaster or a broader breakdown in security.

- *De-globalizing hazards.* When a tsunami in 2011 flooded factories in Japan that were the only ones in the world manufacturing specific car parts, it meant that Honda factories in the United States screeched to a halt.[16] With additive manufacturing, the ability to cheaply and easily download and print the missing parts could buffer downline manufacturers from unexpected breaks in the supply chain. Essentially, additive manufacturing could de-globalize climate-related hazards, and enhance the resiliency of global and local markets to climate shocks.[17]

- *Introducing open innovation to the manufacturing process.* To paraphrase MIT's Neri Oxman, additive manufacturing could democratize production and design, which would increase the resilience of those communities and nations that use it.[18] Additive manufacturing offers the opportunity to provide "open innovation" methodologies, expertise and design solutions to any place in the world with internet access, and a 3D printer. With open innovation, a community anticipating or experiencing climate threats could present their concerns to an online global platform, where experts could quickly offer a solution or transfer "ready-to-print" technological ideas.[19] Mobile labs also could be deployed to "print" location specific parts, to fix a broken water pump handle, print a climate-resilient emergency shelter or meet other infrastructure needs when parts or specialized engineers are not locally available.

---

[16] Pollack, Andrew. *Honda in Japan Resumes Tenuous Car Production*. New York Times. April 18, 2012. http://www.nytimes.com/2011/04/19/business/global/19honda.html; Gearino, Dan. *Honda plants in Ohio affected by Japan earthquake, tsunami*. The Columbus Dispatch. March 26, 2012. http://www.nytimes.com/2011/04/19/business/global/19honda.html

[17] Chen, Baizhu. *Yes, We Can Make iPhones in America*. Forbes. Sept. 7, 2012. http://www.forbes.com/sites/baizhuchen/2012/09/07/yes-we-canmake-iphones-in-america/

[18] *MIT's Neri Oxman on 3D printing in art and design*. 3DPrinter.net. May 4, 2012. http://www.3dprinter.net/mit-neri-oxman-3d-printing-in-art-and-design

[19] Hoyle, William and Evan O'Neil. *3D Printing Can Unlock Development Potential*. Policy Innovations. Nov. 1, 2012. http://www.policyinnovations.org/ideas/innovations/data/000225

- Increasing Accessibility. Additive manufacturing could be particularly effective for disaster risk reduction or post-disaster assistance in inaccessible areas, such as in some of the world's most fragile and conflict-ridden states. For example, additive manufacturing would allow places isolated from the international community to print a shelter built to withstand location-specific environmental stresses.[20] In places that are particularly vulnerable, this capability could provide an important lifeline.

Climate Mitigation Potential

Additive manufacturing is also inherently energy efficient. Indeed, according to the U.S. Department of Energy, additive manufacturing on average uses 50% less energy and saves up to 90% on materials costs compared to traditional manufacturing.[21] Because 3D printing is additive rather than subtractive, the printer prints out only the desired product and minimal support structures, greatly reducing the amount of materials used, and significantly reducing the energy required to manufacture the product.[22] Second, since additive manufacturing involves sending data around the world via the internet, rather than sending physical materials around the world on trucks, ships and planes, shipping, packaging and storage is reduced to almost nil, which dramatically reduces energy use. Lastly, the ability to cheaply print complex designs leads to more efficient designs and products, which reduces the "footprint" throughout its production and lifespan, often strengthening the object in the process (see for example this formula one race car).[23] Should additive manufacturing spread beyond its current limited niche, the ability to print replacement parts (with recycled materials) rather than buy new products could contribute to a dramatic reduction in waste and greenhouse gas emissions.

An Opportunity for U.S. leadership

As evidenced by experimental successes in 3D Printing technology by the military, the United States appears to be well-positioned to lead the way in scaling-up additive manufacturing technology to address a number of broader challenges and opportunities.

---

[20] *The Man Who Prints Houses*. 3DPrinter.net. Oct. 29, 2011. http://www.3dprinter.net/man-who-prints-houses

[21] Chu, John. *Building an American Economy to Last: American Competiveness in Manufacturing*. Department of Energy. Aug. 16, 2012. http://energy.gov/articles/building-american-economy-last-american-competiveness-manufacturing

[22] *Additive Manufacturing. Solid Print*. The Economist. April 21, 2012. http://www.economist.com/node/21552892

[23] *New System auto-detects & corrects structure problem of your model for 3D printing*. 3ders.org. Aug. 22, 2012. http://www.3ders.org/articles/20120822-new-system-auto-detects-corrects-structure-problem-of-your-model-for-3-printing.html; Wrenn, Eddie. *From dot matrix to the starting grid: Racing car designed purely by 3D printing can go from 0-60mph just seconds*. Aug. 28, 2012. http://www.dailymail.co.uk/sciencetech/article-2194626/From-dot-matrix-starting-grid-Racing-car-designed-purely-3D-printing-0-60mph-just-seconds.html

Domestically, additive manufacturing offers the possibility of building an entirely new manufacturing paradigm, with new markets, new jobs, and communities that are more resilient to environmental and climatic changes.[24] This, in turn, can collectively help spur economic growth, build national strength and resilience, and give the United States a new technological mission for the 21st century.

Internationally, the United States could both lead by example, and make strategic investments in additive manufacturing solutions – potentially spurring nations around the world to "leap-frog" over traditional manufacturing, much as some communities in poor countries have eschewed landline-based telephone infrastructures for cell phones. Such forward-thinking investments in additive manufacturing can also give the United States a leg up in competing with China, and other emerging economies, in the global market-place.

The United States can also play an international leadership role by channelling these investments for addressing new security risks, including those presented by climate change. This could fill a key gap in strategically significant parts of the world, such as the Asia-Pacific and the Middle East, where the security risks of climate change are projected to be quite acute, or in some of the most vulnerable nations in Africa.

U.S. investments in innovative solutions to addressing security risks, including climate change, will also complement and enhance U.S. relationships with current and prospective international partners. As such, there may be significant diplomatic and alliance-building benefits to investing in additive manufacturing capacities around the world.

Creating Rules of the Road

Though additive manufacturing presents many new opportunities, it also creates some new risks that are worth addressing at the outset. For example, it is already possible to print a drone, or parts for a gun.[25] Unchecked, the nature of the technology could lead to significant security risks, such as the ability of a non-state actor to print components for such weapons (or worse), and use them for disruptive purposes. However, as in other fields such as cyber-security, these risks also provide an opportunity for the United States to lead the world in developing the international norms and governing principles necessary for mitigating its abuse. Given the revolutionary nature of the technology, it will be important for the United States to ensure that the extraordinary opportunities of additive manufacturing outweigh the risks.

[24] For a forward-thinking discussion of how domestic innovation can bolster U.S. strength and resilience both nationally and internationally, see Mr. Y, *A National Strategic Narrative*, 2011. http://www.wilsoncenter.org/sites/default/files/A%20National%20Strategic%20Narrative.pdf

[25] *World's first "3D-printed" UAV*. Machine Design. Sept. 8, 2011. http://machinedesign.com/article/world-s-first-3d-printed-uav-0908; Anthony, Sebastian. *The world's first 3D-printed gun*. ExtremeTech. July 26, 2012. http://www.extremetech.com/extreme/133514-the-worlds-first-3d-printed-gun

No Need to Start From Scratch

The good news is that the United States does not need to start from scratch. Policies are already in place to advance these technologies, even if on a limited scale.

For example, the afore-mentioned Expeditionary Lab is a product of a $9.7 million contract between the U.S. Army and Exponent Inc., an engineering company, initiated in 2011.[26] In addition to this initial partnership, the Obama Administration has recently invested $30 million dollars in a new additive manufacturing center called The National Additive Manufacturing Innovation Institute, which will focus on 3-D printing technology.[27] According to the White House, a "consortium of manufacturing firms, universities, community colleges, and non-profit organizations" will match that $30 million with $40 million more.[28] The Administration also recently released a report on enhancing US manufacturing, which highlights 3D printing as an important element of its advanced manufacturing plans.[29] The Department Of Energy has also noted the role of additive manufacturing for energy efficiency.[30]

Lastly, the U.S. humanitarian assistance and disaster relief community is also starting to explore the benefits of additive manufacturing. According to an NDU paper on the subject, the Center for National Security Policy (CTNSP) at National Defense University (NDU) has proposed a project that will "examine the uses of additive manufacturing for humanitarian assistance and disaster relief (HA/DR) operations."[31]

These are all good starts, but the full potential of this technology has not yet been tapped. Scaling-up is the next step.

---

[26] Cox, Matthew. *Mobile Labs Build On-the-Spot Combat Solutions*. Military.com. Aug. 17, 2012. http://www.military.com/daily-news/2012/08/17/mobile-labs-build-on-the-spot-combat-solutions.html

[27] McKendrick, Joe. *US government invests $30 million in new 3D printing center*. Aug. 17, 2012. http://m.smartplanet.com/blog/business-brains/us-government-invests-30-million-in-new-3d-printing-center/25817; Coren, Michael. *A New 3-D Printing Center Aims to Recreate U.S. Manufacturing*. Co.Exist. 2012. http://www.fastcoexist.com/1680425/a-new-3-d-printing-center-aims-to-recreate-us-manufacturing; National Center for Defense Manufacturing and Machining. *NCDMM is Chosen to Manage National Additive Manufacturing Innovation Institute (NAMII)*. Aug. 16, 2012. http://ncdmm.org/2012/08/14/namii-press-release/; Compton, Matt. *Boosting Innovation in the Rust Belt*. The White House Blog. Aug. 16, 2012. http://www.whitehouse.gov/blog/2012/08/16/boosting-innovation-rust-belt

[28] The White House. Office of the Press Secretary. *We Can't Wait: Obama Administration Announces New Public-Private Partnership to Support*. Aug. 16, 2012. http://www.whitehouse.gov/the-press-office/2012/08/16/we-can-t-wait-obama-administration-announces-new-public-private-partners

[29] McNaull, Aline. *White House Releases Report on Advanced Manufacturing*. Aug. 16, 2012. http://www.aip.org/fyi/2012/109.html

[30] Chu, John. *Building an American Economy to Last: American Competiveness in Manufacturing*. Department of Energy. Aug. 16, 2012. http://energy.gov/articles/building-american-economy-last-american-competiveness-manufacturing

[31] Connor M. McNulty, Neyla Arnas, and Thomas A. Campbell. *Toward the Printed World: Additive Manufacturing and Implications for National Security*. Defense Horizons. National Defense University. September 2012. http://www.ndu.edu/CTNSP/docUploaded/Defense%20Horizons%2073.pdf

Scaling-up 3D Printing to Address Risk

One of the major catalysts to ratifying the Montreal Protocol agreement to limit damage to the ozone layer was that the technology needed to meet international requirements was already available, and ready to be scaled-up.[32] While additive manufacturing technologies are available, they need to be scaled-up, become more affordable, and increase their range of functionality.

Namely, there is a strong need to develop 3D printing technology that can be easily and cheaply implemented regardless of location. The primary aim should be to ensure that no matter where the user is, he or she can easily access a design, print a needed product, and do so without importing material inputs from thousands of miles away. This is, in essence, the degree of resiliency necessary for coping with uncertainty and risk (think of how cell phone technology is able to operate almost independently of geographic location, allowing users in the developing world access that was previously impossible). Such a capability could be crucial in addressing all kinds of security risks, including climate-related disasters. Scaling-up will therefore require significant investments in increased internet access around the world, as well as flexible 3D printers that can utilize a wide range of material inputs from an equally wide range of locations.[33]

Conclusion

Though most of us don't know it yet, additive manufacturing has the potential to be one of the most transformative technologies since the advent of the personal computer. This technology could revolutionize the way we live in the present, and adapt to the future. It could help us address the unique and existential risks of the 21st century, such as climate change, and to usher in a new era of resilience. It offers the promise of completely decentralized manufacturing, with the potential to transform the global marketplace, turning the entire notion of a supply chain on its head. Need a crucial part for a wind turbine or water pump?[34] No need to wait for it to be delivered from a warehouse thousands of miles away. Just print it. And if you don't have enough printers, print some more printers. And as a side benefit, if additive manufacturing is robustly supported and promoted by policy-makers and private industry, it may well provide a convenient and timely leadership opportunity for the United States. If the 21st century is to be another American century, additive manufacturing could very well be at the center of it all.

---

[32] Femia, Francesco & Caitlin Werrell. *Unintended Consequences: Thomas Midgley and the Geo-engineering Treadmill*. The Center for Climate and Security. Oct. 3, 2012. http://climateandsecurity.org/2011/10/03/unintended-consequences-thomas-midgley-and-the-geo-engineering-treadmill/

[33] Markus Kayser built the Solar Sinter which 3D prints glass converted to sand via solar power. This is a good example of how scaling-up could be sustainable. http://www.markuskayser.com/work/solar-sinter/

[34] *Design & Print Wind Turbine Blades*. Instructables. http://www.instructables.com/id/Design-Print-Wind-Turbine-Blades/

THE CENTER FOR CLIMATE AND SECURITY