13 “Enhancing Smart Cities: 3D Printing for Higher Education Research and Innovation”

Diriba HABTUAMU
Grischa FRAUMANN
Jon MAES
Master Students of the Master Program "Research and Innovation in Higher Education" (Joint Degree Danube University Krems/Austria, University Tampere/Finland, Pedagogic University Beijing/China)

13.1 ABSTRACT:

Smart cities and 3D printing technologies are attracting unprecedented attention with signs that they will be key drivers of societal and economic change. Yet, the connection in how 3D printing can enhance smart cities remains understudied. To this end, this paper argues that 3D printing has widespread applications across higher education and smart city settings through the opening and democratizing of innovation. Accordingly, several examples of recent 3D printing developments and smart city advancements are presented. However, higher education institutions (HEIs) must also be mindful of the social, ethical, and legal challenges involved with 3D printing research, integration, and democratization. Reflecting on the Triple Helix Model of university-industry-government relationships, this paper concludes that HEIs should take the lead for 3D printing and smart city collaborations. It is only through this leadership that 3D printing’s positive uses will prevail over the potential pitfalls that this disruptive technology is capable of.

13.2 Introduction

13.2.1 Smart Cities Basics: The What?, Why?, and Why Now?

Discussions about smart cities are gaining momentum around the world. Integral aspects and/or parallels of smart cities such as sustainability, integration, and resilience are now taking center stage in public policy discourse and agenda (Moir, 2014). Accordingly, grand research projects are carried out to tackle the challenges of future cities (e.g. the City of the Future Initiative, 2015). Against the background of such developments, this part briefly discusses the different conceptualizations of a smart city along with an explanation of why it is receiving unprecedented attention from a widening group of stakeholders.

Based on a study conducted by Moir (2014) that surveyed various communities of interest (e.g. citizens, government, and academic institutions) to describe their ideal future city, the most recurrent depiction given was ‘smart city’. However, when it comes to what this term entails, there is no consensus among the respondents. Correspondingly, there also is no agreement among scholars with some narrowly equating it to the extensive use of information and communication technology (ICT), while others expand the definition to incorporate additional characteristics like sustainable socioeconomic development (Gamero, 2012; European Union, 2014). Moreover, the fact that several terms ('Intelligent City', 'Knowledge City' 'Sustainable City', 'Talented City', 'Wired City', 'Digital City', 'Eco-City') are employed by different scholars to refer to smart cities also adds to the confusion surrounding the concept (European Union, 2014, p. 21). Considering these complexities, and in the absence of an internationally accepted definition, this paper follows the European Commission's (2015) characterization of smart cities because of its comprehensiveness:

A smart city is a place where the traditional networks and services are made more efficient with the use of digital and telecommunication technologies, for the benefit of its inhabitants and businesses. It means smarter urban transport networks, upgraded water supply and waste disposal facilities, more efficient ways to light and heat buildings, more interactive and responsive city administration and safer public space.

Hence, the term smart city encapsulates Smart People, Smart Living, Smart Governance, Smart Mobility, Smart Economy and Smart Environment (European Union, 2014; Komninos, 2014, p. 29).

Cities have been absolutely pivotal to human civilization for numerous reasons of practical importance. In addition to being places where sizable populations of people and most business organizations reside, cities are the building blocks of a country and the engines of socioeconomic development (Gamero, 2012; Moir, 2014). What is more, cities account for 80% of global energy consumption (The Guardian, 2012). Nonetheless, considering that the above mentioned facts have been true for centuries, it makes one wonder, why are more energies being focused on urban planning now compared to the past?

A series of interrelated developments could be cited in this regard. First is the rapid advancement of ICT and its impact on the balance of power. In particular, the unprecedented growth in data, (often called "big data") and, more importantly, efforts to make it accessible to the community at large (often called "open data") has increasingly empowered various stakeholders (Gurin, 2013). Nowadays, citizens are more conscious about city initiatives and demand greater transparency and accountability (Institute for Technology, 2015). The media is also more powerful than ever before and philanthropic organization can make their voices heard by mobilizing greater support for their causes through various channels including the internet. Such developments are piling more pressure on governing bodies.

Second is the accelerating pace of urbanization. According to an estimate by World Health Organization (WHO), in approximately three decades more than half of the world's population will reside in cities (as cited in The Guardian, 2012). This has its own economic, demographic, social, and environmental implications. Third is the advent of indexes that evaluate different qualities of cities. As noted by Vienna University (2007), for more than two decades city rankings have become an appealing indicator to a wider audience (e.g. the Quality of Living

Worldwide City Rankings – Mercer Study) (Mercer, 2015). This has also added to the internal and external demands being placed on government officials to improve local conditions. Fourthly, the growing awareness of important issues that are plaguing overcrowded cities such as air pollution caused by escalating emissions and traffic congestion from more cars on the road. Moir (2014) contends that many urban challenges are the products of decisions made several years ago. In the same fashion, decisions made now will shape the composition of cities in the years to come. This line of argument is described in economic and social science circles as ‘path-dependency’. It is based on the logic that governing bodies, feeling the impact of their predecessors’ actions, become more cautious about the sustainability of their own decisions, to avoid the so-called negative lock-in. This has also given impetus to the smart cities discourse.

To sum up, all the aforementioned developments point in the direction that smart cities will continue to be at the center of national and international public policy discussions for the foreseeable future.

13.3 3D Printing: An Overview

We live in the Knowledge Age where a nation’s wealth and prosperity is contingent on the stock of knowledge at their disposal. This is particularly intertwined with the issue of technological innovation that is frequently transforming human life as we know it. Thus, today’s economic developments are rooted in the creativity of citizens and their ability to convert their inventive ideas into reality (Rosenberg, 2004; Divining Reality, 2014; Organization of Economic, 2012; Cohen, 2011).

Although as apparent as it might seem, it took economists a while to identify the innovation-economic development nexus. Particularly, Russian scholar Kondratieff first identified the role of a disruptive innovation for the revival of the economy. He justified his argument by providing several 19th and 20th century examples from the steam engine, railways and electrical engineering to petrochemicals, the automobile and information technology with each innovation reviving the global economy at different points in time (van Lambalgen, 2014). The Austrian scholar, Joseph Schumpeter, building upon the work of Kondratieff also reaffirmed the importance of innovation, which he framed as “creative destruction.” (Divining Reality, 2014). In light of this, various stakeholders are making a concerted effort globally towards fostering innovation.

Among these innovative endeavors, 3D printing is one that has caught the attentions of business practitioners, academics and technology enthusiasts. 3D printing, or additive manufacturing as it is professionally called, involves “the process of creating an object using a machine that puts down material layer by layer in three dimensions until the desired object is formed” (EDUCAUSE, 2012, p. 1). Several file formats using computer-aided designs can now be 3D printed. (Z Corporation, 2009). With respect to raw materials, different inputs can also be utilized to create three dimensional objects. However, the most common techniques include plastic filament extruded through a nozzle (Fused Deposition Modeling), liquid resin hardened by a laser beam (stereolithography), or powder sintered by a laser (Selective Laser Sintering) (Sauramo, 2014).

Additive manufacturing began surfacing in the 1980s. American engineering physicist Charles Hill is attributed with making the first 3D printer in 1983 (Wohlers & Gornet, 2012). Since then, 3D printing has gone through several changes. A notable breakthrough is Massachusetts Institute of Technology (MIT) advanced 3D printer that they named “Darwin”. It is considered a landmark in the 3D printing field as the first machine that was capable of fabricating its own replacement parts (McLellan, 2014). Similarly, the industrial reach of 3D printing has seen significant improvement. According to a research and consulting firm Canalys (2015), the market of 3D printing is now estimated to be over 3 billion USD with this figure expected to grow fivefold in the next half decade.

Despite 3D printing’s achievements, a number of scholars are still skeptical about whether or not additive manufacturing will transform the global economy. This is understandable with the vast majority of technological innovations being unable to survive in the marketplace even for a short while, let alone bring about significant economic development. In response, there are advocates like the Computer Science Corporation ([CSC], 2012) who defend that 3D printing will live up to the hype. Referencing the conceptual framework developed by Dr. Clayton Christensen at Harvard Business School in 1997, CSC contends that 3D printing satisfies the criteria of a disruptive innovation. More specifically, they point to the fact that this emergent technology is getting simpler, cheaper, and more convenient when compared to the conventional manufacturing methods (Sauramo, 2014).

From the literature, other research also reinforces pro 3D printing claims such as those made by CSC. Additional supporting arguments include: (1) the remarkable technological improvements 3D printing has undergone; (2) the drastic decline in the cost of production; (3) the rapid expansion of the technology to different industries and; (4) increased attention and commitment from various governmental and intergovernmental entities (see Diriba, Fraumann, & Maes, 2014).

To recapitulate, the main premise of this subsection is that 3D printing is here to stay. This begs the next question. How can 3D printing, through higher education research and innovation, support the enhancement of smart cities?

13.4 3D Printing for Smarter Cities

There are two frontiers in particular where 3D printing is showing potential for playing a significant role in the growth of smarter cities. They are open innovation and democratization of innovation. Open innovation is a concept popularized by Henry Chesbrough, adjunct professor at University of California Berkeley’s Haas School of Business. In his pioneering book, Open Innovation: Researching a New Paradigm he defines the theory as “the use of purposive inflows and outflows of knowledge to accelerate internal innovation, and expand the markets for external use of innovation, respectively” (Chesbrough, 2006, p. 2). This is in contrast to closed innovation models where firms maintain strict control over their intellectual property from the research and development phase to production, marketing, distribution, and after-service. In addition, special care is taken in closed innovation systems for security of a firm's intellectual property rights against violations of use without permission and/or compensation. Meanwhile, open innovation allows for the free flow of ideas to externalities outside the firm including consumers, but also academic institutions, government agencies, and even rival companies.

Similarly, Eric von Hippel, professor at the MIT Sloan School of Management, is renowned for his contributions to the democratization of innovation. This perspective promotes users and consumers as the innovators of new products as opposed to the long held view that focuses on companies and suppliers (von Hippel, 2006). As Björgvinsson (2010) states "innovation has been democratized through easy access to production tools and lead-users as the new experts driving innovation" (p. 1). The effect is a more inclusive approach to innovation that empowers individuals as pioneers of their own original ideas, designs, and services without having to rely solely on manufacturers as the source of all breakthroughs.

3D printing, by its very nature, is a testament to open and democratized innovation. It is "the fabrication of almost anything by anyone, anywhere in the world" (Leblanc, 2014). This is to say that additive manufacturing puts the power of creation in the hands of lead-users to construct the products that they themselves have envisioned. MacDonald (2012) describes this movement as grass-roots manufacturing with some experts even heralding that a digital fabrication revolution is on the horizon (Bass 2014; Federal Ministry, et al., 2013, p. 10 & 85; Universität Liechtenstein, 2014; University of Cambridge, 2014; Ranaldi, 2014, p. 1).

All in all, 3D printing's major contributions to smart cities is not simply the products that this technology is capable of fabricating. Even more profound is the environment that additive manufacturing creates for giving everyday users greater opportunities to actively engage in the innovation process. As the examples in the next section will show, it is this form of democratization and opening of the knowledge-based society that will make cities even smarter.

13.5 Examples of Research and Innovation for 3D Printing and Smart Cities

Current research and innovation is developing both 3D printing technologies and the growth of smarter cities in various ways. Considering the above mentioned concept of user-based approaches to additive manufacturing, some HEIs are making 3D printing facilities more available to the campus community. Academic libraries are one example where 3D printers are being installed for people to experiment with outside of laboratories (Nicholls, 2014). Tod Colegrove (2014), Director of the DeLaMare Science and Engineering Library, states that 3D printers are fundamentally changing the common understanding of libraries from purely knowledge archives to places taking part in knowledge production and innovation (also cited in Murphy & Leigh, 2014, p. 3).

Another example is the establishment of so-called "Fab Labs" i.e. Fabrication Laboratories (The International Fab, 2014). These Fab Labs are open to the public and offer production space, equipment, and volunteer staff for helping people to bring their innovations to life. Universities also initiate comparable initiatives such as MOVEFAB at the University of La Laguna, Tenerife, Spain. The MOVEFAB project encourages students to engage in the innovation process by providing the necessary background in digital fabrication as well as the 3D printing equipment (Fundación General, 2015).Cooperative efforts such as these go far beyond the original expectations that Tenerife had for 3D printing when the technology was first introduced to the island (Trujillo, 2014).

Similar to Fab Labs is the field of cloud-based design and manufacturing (CBDM). CBDM is a collective means of managing ICT where several users work together online to design, and in the end manufacture a product (Leblanc 2014, p. 3). For 3D printing specifically, FabHub (2015) is a global online network where anyone can locate a qualified fabricator, submit their design, and collaborate for creating a distributable commodity. There are also open source 3D blueprint websites with Thingiverse (www.thingiverse.com) by MakerBot Industries being one of the largest communities of this kind. HEIs have also joined the open source cause for 3D printing with a notable example being Michigan Technology University who have made their schematics for building a 3D printer from commercially available parts (McLeod, 2013).

3D printing is showing potential to create a zero waste society. This may seem like a utopian view, but organizations like the Zero Waste Advocacy ([ZWA], 2015) group argue that this future is attainable. As the leading consultancy organization for zero waste community plans in the United States, ZWA is building on their concept of resource recovery parks to incorporate additive manufacturing that fabricates with the salvaged materials brought to these facilities. ZWA also promotes giving access to the waste streams and 3D printing technology not just for industrial use, but for community members and local businesses as well. If this sustainability strategy spreads, it will have a tremendous impact on the smartening of cities.

On the topic of sustainability, HEIs are also connecting additive manufacturing to green technologies. Returning again to the University of La Laguna, scientists are exploring methods for 3D printing advanced fuel cells for sustainable energy uses (Hernández-Rodríguez et al. 2014, p. 1-2). There is also LuminoCity, an interactive map from MIT's (2015) that fabricate 3D replicas of geographic locations as a means of visually highlighting trouble spots in need of improvement like areas of heavy air pollution or traffic congestion mentioned in section 1.

To a greater extent, there are even the emergence of sustainable and smart campuses. For instance, the International Sustainable Campus Network (2015), an association made up of several universities around the world, hosts an annual conference where topics are discussed on how smart campuses can be achieved and managed. An individual example is the Harvard Office for Sustainability whose function is to aid in the university's teaching and research mission by connecting initiatives and facilitating campus-wide collaboration for sustainability (Harvard University, 2015). There are even HEIs like Universidad Carlos III de Madrid (http://www.uc3m.es) and Universitat Jaume I (http://ujiapps.uji.es/) that have made grand efforts to reach the status of being a smart campus.

Collectively, these examples emphasize how not only higher education research and innovation, but HEIs themselves can serve as a model for smart cities, which is a topic that will be explained further in section 3.

13.6 The Future of 3D Printing, Higher Education, and Smart Cities

In Fabricated: The New World of 3D Printing, Lipson and Kurman (2013) provide a glimpse into the next chapter of additive manufacturing technology. By tracing the history of 3D printing developments to cutting-edge research being conducted today, the authors map what they call “the three episodes of 3D printing” (2013, p. 265). Presently, the first and second episode involve mastering command over physical matter and manipulating its internal structures. This has led to the expansion of available materials that can be used for printed in going beyond plastics to incorporate heavy metals and glass, even food and living cells. 3D printing machines are also now experimenting with blending multiple materials at the nanoscale to create new microcomposites that have extraordinary properties. For instance, scientists at the Karlsruhe Institute of Technology (KIT) have created a ceramic-based material that “has a higher strength-to-weight ratio than the toughest known engineering materials and boasts a density lower than that of water” (Halterman, 2014).

For the third episode, Lipson and Kurman envision that 3D printing will soon control the behavior of fabricated objects. In other words, humans will have the ability to program how products function on their own after they are manufactured. One example they give is automobile bumpers made of compounds that absorb and redirect energy upon impact while then remolding to the original shape with no signs of damage (Lipson & Kurman, 2006). Others include running shoes that use synthetic biological materials called Protocells that self-repair themselves like new overnight (Curtis, 2013). There is also what has been hailed as “reactive blueprints” that adjust to the environment in real time, which allows for variations that could not be anticipated during the initial printing (Lipson & Kurman, 2013, p. 257). This includes post-design adjustments based on the specific circumstances surrounding the print job. To illustrate, “a house that needs to adapt to a yet unknown terrain, a bridge that needs to adapt to wind conditions, or a lampshade that needs to compensate for particular ambient lighting conditions” (2013, p. 258).

Combined with other disruptive technologies like robotics and artificial intelligence, the future of additive manufacturing is boundless. Some experts predict that 3D printers will eventually be encoded with competencies that not only sense malformations before they develop, but that can interact with the human operator to assist in brainstorming solutions. Also, that society is not too far from having machines that design, print, repair and recycle other machines in addition to their own ability to self-replicate. As advancements in 3D printing of multimaterial integrated systems improve, it is only a matter of time before internally wired electronic parts will literally “stroll out of the printer” (Lipson & Kurman, 2013, p. 266).

After all, the range of prospects for 3D printing and its contribution to the enhancement of smart cities is only limited by humans' ability to express their imaginations. Greater possibilities are unlocked with every new lead-user that additive manufacturing technologies reach. Engineers and researchers are also hard at work to develop enhanced design tools and machine interfaces that are more intuitive and responsive for printing complex designs with better precision, which will inspire generations of products that have not even been thought of yet.

13.6.1 Challenges to 3D Printing Research and Innovation

The transition from mass manufacturing to mass customization is not without potential drawbacks. There are ethical, legal, and feasibility issues that must be considered. It is especially imperative in regards to the adverse consequences that additive manufacturing could cause if left unchecked. This section will look at some of the main arguments against 3D printing.

Ethics. Government and the media are raising concerns about 3D printing on the grounds of dual-use dilemma. This perspective emphasizes that scientific discoveries are capable of not only making positive impacts, but also causing severe harm. Much like atomic energy, jet propulsion, and other disruptive technologies, additive manufacturing can also be detrimental to society. A particular concern is the printing of plastic guns and other non-metallic weapons that can go concealed through metal detectors. Firearms that are 3D printed by individual consumers also have no serial numbers so they exist outside of national tracking systems.

There is also the highly controversial topic involving living cells also known as bioprinting. The technology is now capable of not only building prosthetic limbs, but customized anatomical organs and tissues. This medical accomplishment is praised as lifesaving by some, but condemned by others that fear it will be taken to the God-like extreme of designing humans. It is also resurfacing other ethical debates on subjects such as genetic engineering, the use of embryonic stem cells, and animal testing.

Legalities. At the moment, laws and regulations governing additive manufacturing are almost nonexistent on national and international levels. This situation is compounded by the fact that the future impact of the 3D printing is also difficult to predict accurately. However, there are two legal realms that will inevitably be involved. The first is tort law in determining liability for 3D printed products that inflict personal injury or property damage. To explain this point, imagine a consumer printing a mechanical part for their automobile from a free blueprint online. The mechanical part malfunctions causing the automobile to get into an accident. Who is to blame? The consumer, the blueprint designer, or the automobile company? There is a case that could be made for either of the three parties based on more detailed investigation of the circumstances. In this regard, liability issues such as these are of particular importance for public safety.

Then, there is the matter again of intellectual property. For 3D printing, this legal realm can actually have a bidirectional effect. Companies defend their intellectual property citing their right to receive payment for the 3D printed products that they created, which also risks protectionism and price fixing. On the other hand, small businesses and individual inventors could have their ideas taken by large corporations, modified just enough, and then sold for cheaper. Either way, additive manufacturing inevitably involves discussions about copyrights, trademarks, and patents when consumers have the ability to print anything from the privacy of their own home.

Feasibility. Even considering positive speculations from reputable sources such as Gartner's 2014 Hype Cycle Chart and New Media Consortium's annual Horizon Report, 3D printing is still an emerging technology in its early stages of development. Currently, enterprise-class 3D printers still costing around USD $2000 or more with high-end models priced between USD $100,000 and $1 million (Gartner, 2013; Mearian, 2014). This begs the question, is 3D printing practical outside of experimental labs? Financial consideration are important for HEIs when making decisions about budget allocations and system changes, especially in countries like the UK and the US that are experiencing reductions in public funds while operating costs continue to increase. In these conditions, why should colleges or universities invest in 3D printing technologies when resources are already strained as it is?

Ultimately, there is no question that these ethical, legal, and feasibility concerns must be taken seriously. However, they also should not be reasons to impede the positive applications of additive manufacturing. To an even greater degree, the potentially harmful impacts of 3D printing are justification for why HEIs must be proactive in steering the positive use of this technology for the enhancement of smart cities and the public good. The next section will elaborate on these points.

13.6.2 The Role of 3D Printing Research and Innovation in Higher Education for Enhancing Smart Cities

A number of experts have offered explanations and recommendations for how to organize innovation systems. One of the first theories in this field is Sabato's Triangle, which defends that countries should adopt top-down, government-led approaches for coordinating science and technology developments (Sabato & Botana, 1968). There are also Lundvall (1992), and Nelson (1993) who propose national frameworks for harmonizing complex sets of actors across higher education, private enterprise, and government sectors. Even more recently is the work of Swanson and Leitner (2014) that extends considerations of innovation engagements to the regional level.

Perhaps the most influential theory for describing innovation systems in the past decade is Etzkowitz's (2003) Triple Helix model. Specifically, Etzkowitz recognizes that HEIs do not merely hold supporting positions within innovation systems, but they hold a central place. Namely, as "natural incubators" for innovation with greater "flow-through" of fresh knowledge and young talent than public research institutes or corporate laboratories (2003, p. 324-325). Other benefits from universities that business and government agencies rely on include student laborers, consultations from faculty, and access to physical resources.

This is the principal function that HEIs must play as an integral partner in university-industry-government relations.

Additionally, Torres-López et al. (2014) make the observation that HEIs are suitable test beds for the adoption of innovations to cities by and large. In fact, there are HEIs that can be considered cities, in and of themselves, because of their sheer size and vast network of campuses (e.g. the University of California and California State University systems). As mentioned in section 2, there are already smart campuses providing models that cities can follow such as the Universidad Carlos III de Madrid and Universitat Jaume I. There is also the International Sustainable Campus Network and universities like Harvard that offer sound practices. These vanguards are yet another reason why HEIs are pivotal in being an example of 3D printing innovation for other institutions, organizations, and entire cities.

Furthermore, HEIs as a cornerstone of knowledge economies can enhance smart cities via 3D printing research and innovation through their social engagement missions. For one, continuing education and lifelong learning programs could find creative ways to bring aspects of 3D printing into their courses or even offer standalone 3D printing courses. As shown in section two, establishing Fab Labs and setting up 3D printer stations in libraries are also effective methods for offering 3D printing to the community towards democratizing the base of lead-users. Meanwhile, HEIs must find ways to make 3D printing research and innovation more open. This could be accomplished in various ways like contributing to open-source 3D printing blueprint databases or "educate to innovate" projects that give 3D printing expertise and resources to local primary and secondary schools (The White House, 2015).

On the topic of 3D printing's destructive uses, this is an area that HEIs are vital in providing scholarship and policy advisement. Philosophers, political scientists, medical doctors and even engineers can help in expanding the knowledge-base about the ethical and legal complications of additive manufacturing. In the end, like smart cities, 3D printing technology is here to stay. Therefore, it is imperative that HEIs expand awareness about 3D printing through lectures, publications, conferences, workshops, and other academic avenues.

Questions also persist about the practicality and feasibility of 3D printing for higher education and smart city settings. First, additive manufacturing technologies are still commonly viewed as a luxury, especially in terms of their cost and the extent of their capabilities. However, research firms like Gartner (2014) predict that 3D printing for consumer use is on its way to the plateau of productivity within the next decade and even sooner for enterprise-class 3D printers. Referring again to history, disruptive technologies only get exponentially cheaper and more functional with time. Consequently, concerns revolving around 3D printing's practicality and feasibility will eventually wane with early adopters placing themselves in an advantageous position (Gartner, 2013). As the global higher education landscape continues pressuring universities to become more entrepreneurial, it may not be optimistic to say that more funding for 3D printing research and innovation will become available.

Lastly, there is the issue of implementation. How should HEIs approach 3D printing research and innovation for the enhancement of smart cities? There are no simple answers to this question nor are there one-size-fits-all solutions. Every HEI and city should consider good practices and good models, although they must devise their own course of action for integrating 3D printing into their infrastructures. At the same time, HEIs would be wise to follow strategic planning and strategic management guided by institutional research before embarking on any major, system-wide changes (Dooris, M. & Rackoff, 2012). That being said, a case can be made regarding comprehensive efforts for utilizing 3D printing at all corners of the campus. This is a bold suggestion that requires instilling and sustaining a culture of innovation for motivating buy-in from all stakeholders including students, the professoriate, administrators, governing boards, and external partners. Otherwise 3D printing will remain locked away in science and engineering laboratories to be used only in isolated instances.

13.7 Conclusion

Beginning with an overview of the underlying principles behind smart cities and the progress that additive manufacturing has made since it's invention in the 1980s, this paper showed how 3D printing and smart cities are connected by the paradigms of open innovation and democratization of innovation. Second, examples of recent 3D printing research and development were given to emphasize that this industry is thriving and already having an impact on society. This is especially true in the areas of self-sustainable communities and increasing lead-user participation in the innovation process. Third, this paper concluded that higher education should play a central role in 3D printing research and innovation for the enhancement of smart cities. Specifically, foresight predications about additive manufacturing's disruptive nature emphasize that HEIs are essential to the acceleration of 3D printing's positive contributions while serving as guide for the prevention of harmful applications. Lastly, there are research limitations that are important of noting. As mentioned previously, 3D printing and smart cities are emerging areas of study that are gaining scholarly interest. However, more research is needed about the various manners that additive manufacturing can contribute to smart cities and vice versa. If the scenarios presented in this paper serve as any indication, one could audaciously say that the future depends on it.

13.8 References

Bass, C. (2014, May 28). An Insider's View of the Myths and Truths of the 3-D Printing 'Phenomenon'. Wired. Retrieved from http://www.wired.com/2013/05/an-insiders-view-of-the-hype-and-realities-of-3-d-printing/

Björgvinsson, E., et al. (2010, November). Participatory Design and Democratizing Innovation. Proceedings of the 11th Biennial Participatory Design Conference (pp. 41-50). ACM.

Canalys. (2015, April 2). 3D Printing Market Surpasses US$3.3 Billion Worldwide in 2014. Canalys Newsroom. Retrieved from http://www.canalys.com/newsroom/3d-printing-market-surpasses-us33-billion-worldwide-2014

Computer Science Corporation. (2012, Fall). 3D Printing and the Future of Manufacturing. CSCLeading Edge Forum, Technology Program, Fall 2012.

Chesbrough, H. (2006). Introduction. In: H. Chesbrough, W. Vanhaverbeke, & J. West (Eds). Open Innovation: Researching a New Paradigm (pp. 1-14). Oxford University Press: Oxford, UK.

City of the Future Initiative (Morgenstadt) (2015). Research Fields. Retrieved from http://www.morgenstadt.de/en/research-fields.html

Cohen, A. J. (2011). Innovation and Economic Growth. Private Wealth Forum. Retrieved from http://www.goldmansachs.com/our-thinking/archive/archive-pdfs/gsr.pdf

Colegrove, P. (2014, October 27). Making It Real: 3D Printing as a Library Service. EDUCAUSE Review. Retrieved from http://www.educause.edu/ero/article/making-it-real-3d-printing-library-service

Curtis, L. (2013, December 13). 3D-printed Regenerative Shoes Developed by British Designer. Retrieved from http://www.telegraph.co.uk

Diriba, H., Fraumann, G., & Maes, J. (2014). The Role of Higher Education in 3D Printing Research and Innovation (Unpublished paper). Danube University Krems, Krems

Divining Reality from the Hype. (2014, August 27). The Economist, Retrieved from http://www.economist.com/blogs/babbage/2014/08/difference-engine-2

Dooris, M. & Rackoff, J. (2012). Institutional planning and resource management. In R. Howard, G. McLaughlin, W. Knight (eds.). The Handbook of Institutional Research. Jossey-Bass: San Francisco. 183-202.

EDUCAUSE. (2012). Things You Should Know about 3D Printing. EDUCASE, Learning Initiative. Retrieved from http://net.educause.edu/ir/library/pdf/eli7086.pdf

Etzkowitz, H. (2003, September). Innovation in innovation: the Triple Helix of university-industry-government relations. Social Science Information. 42(3), 294-337.

European Commission. (2015). Smart Cities. Digital Agenda for Europe. A Europe 2020 Initiative, Retrieved from https://ec.europa.eu/digital-agenda/en/smart-cities

European Union. (2014). Mapping Smart Cities in the EU. Retrieved from http://www.smartcities.at/assets/Publikationen/Weitere-Publikationen-zum-Thema/mappingsmartcities.pdf

FabHub. (2015). FabHub. Retrieved from https://www.fabhub.io/
Federal Ministry of Science and Research, et al. (2013). Austrian Research and Technology Report 2013. Retrieved from http://www.bmvit.gv.at/en/service/publications/downloads /downloads_ftb/ftb_2013_en.pdf

Fundación General, Universidad de La Laguna (2015). MOVEFAB: Programa piloto de fomento de la creatividad y el talento a través de la fabricación digital. Retrieved from http://www.fg.ull.es/es/proyecto/movefab_programa_piloto_de_fomento_de_la_creatividad_y_el_talento_a_traves_de_la_fabricacion_digital/68/

Gamero, R. (2012). Why Do We Need Smart Cities? Retrieved from http://www.publicpolicy.telefonica.com/blogs/blog/2012/11/12/why-do-we-need-smart-cities/

Gartner. (2013, March 26). Gartner Says Early Adopters of 3D Printing Technology Could Gain an Innovation Advantage Over Rivals. Gartner Newsroom. Retrieved from http://www.gartner.com/newsroom/id/2388415

Gartner. (2014, August 11). Gartner's 2014 Hype Cycle for Emerging Technologies Maps the Journey to Digital Business. Gartner Newsroom. Retrieved from http://www.gartner.com/newsroom/id/2819918

The Guardian. (2012, November 16). Why Smart Cities will Help Save the World. The Guardian. Retrieved from http://www.theguardian.com/sustainable-business/blog/ smart-cities-energy-consumption

Gurin, J. (2013). Big Data vs Open Data - Mapping it Out. Retrieved from http://www.opendatanow.com/2013/11/new-big-data-vs-open-data-mapping-it-out/#.VSkGf8Kqqkp

Halterman, T. (2014, February 11). Stronger than Steel, Lighter than Water – 3D Printed Micro Trusses. 3D Printer World. Retrieved from http://www.3dprinterworld.com/

Harvard University. (2015). Sustainability. Retrieved from http://green.harvard.edu/

Hernández-Rodríguez, E. M. et al. (2014, September-October). Prospective use of the 3D printing technology for the microstructural engineering of Solid Oxide Fuel Cell components. Boletín de la Sociedad Española de Cerámica y Vidrio, 53(5), 213-216

Institute for Technology Assessment and Systems Analysis (ITAS) (2015). Assessing Big Data (ABIDA). Retrieved from http://www.itas.kit.edu/english/projects_grun15_abida.php

The International Fab Lab Association. (2014). Where Does it Come From. Retrieved from http://goo.gl/XZsnYn
The International Sustainable Campus Network. (2015). Purpose. Retrieved from http://www.international-sustainable-campus-network.org/about/purpose.htmlKomninos, N. (2014). The Age of Intelligent Cities: Smart Environments and Innovation-for-all Strategies. Routledge: Oxfordshire.

Leblanc, F. (2014). “Anything, Anyone, Anywhere. Toward a Cloud-Based 3D Printing Fabrication in Architecture.” In: N. Gu, et al. (eds.). Rethinking Comprehensive Design: Speculative Counterculture, Proceedings of the 19th International Conference of the Association of Computer-Aided Architectural Design Research in Asia CAADRIA 2014 (pp. 1-10). Kyoto, Japan

Lundvall, B.-A. (ed.) (1992). National Systems of Innovation: Towards a Theory of Innovation and Interactive Learning, London: Pinter.

MacDonald, C. (2012). 3D Printing and the Ethics of Value Creation. Retrieved from http://businessethicsblog.com/2012/12/01/3d-printing-and-the-ethics-of-value-creation/
Massachusetts Institute of Technology, Lincoln Laboratory. (2015). Gauging Hazards in the Air. Retrieved from https://www.ll.mit.edu/news/2014CEEcoursementors.html

McLeod, M. (2013, December 11). Scientists Release Plans for Open-Source 3D Metal Printer. Design Engineering. Retrieved from http://www.design-engineering.com/cad-cam/scientists-release-plans-for-open-source-3d-metal-printer-design-eng-127164/

Mearian, L. (2014). HP's New 3D Printer is Aimed at Manufacturing, Not Consumers. Computer World. Retrieved from http://www.computerworld.com/article/2844936/hps-new-3d-printer-is-aimed-at-manufacturing-not-consumers.html

Mercer (2015). Quality of Living Worldwide City Rankings – Mercer Study. Retrieved from http://www.mercer.com/content/mercer/global/all/en/newsroom/2014-quality-of-living-survey.html

Moir, E., Moonen,T., Clark, G. (2014). What are Future Cities? Origins, Meanings and Uses. Retrieved from https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/337549/14-820-what-are-future-cities.pdf

Murphy, H. & Leigh, M. (2014). Breaking the Third Dimension: Bringing 3d Printing to the Library. In: Academic & Special Libraries. Section of Library Association of Ireland.

Retrieved from http://www.aslibraries.com/#!about2/c1f2

Nelson, R. R. (ed.) (1993). National Innovation Systems: A Comparative Analysis. New York: Oxford University Press.

Nicholls, D. (2014). The Future of Higher Education: Reshaping Universities through 3D Printing. Retrieved from http://3dprintingsystems.com/the-future-of-higher-education-reshaping-universities-through-3d-printing/

Organisation for Economic Co-operation and Development. (2012). Innovation for Economic Development, A Discussion of the Issues and an Overview of Work. Paris: OECD

Ranaldi, R. (2014). Medical 3D Printing: Printing a New Face for the Future. Retrieved from http://mms.ecs.soton.ac.uk/2014/papers/9.pdf

Rosenberg, N. (2004). Innovation and Economic Growth (Unpublished working paper) (pp. 1-6). Paris: OECD

Sabato, J. & Botana, N. (1968). La ciencia y la tecnología en el desarrollo futuro de América. Revista de la Integración. 3, 15-36.

Sauramo, H. (2014). The Proliferation of a New-Market Disruptive Innovation: Case Personal 3D Printers (Unpublished master's thesis). Aalto University, Helsinki. Retrieved from http://epub.lib.aalto.fi/en/ethesis/pdf/13730/hse_ethesis_13730.pdf

Swanson, A., Leitner, K-H. (2014): How do Prevailing National and Regional Innovation Systems Affect University Contribution, and Transformation towards Building an Entrepreneurial University? Insights from a Study of the Life Sciences Area in Stockholm and Vienna. Helice, 3(11).

Torres-López, L. et al. (2014). Mobility Analysis Using MapReduce to Enhance Services Improvement for an University Smart Campus. In H. R. Arabnia, et al. (Eds). Internet Computing and Big Data: The 2013 WorldComp International Conference Proceedings. Paper presented at Internet Computing and Big Data: The 2013 WorldComp International Conference Proceedings (USA), Las Vegas, Nevada (pp. 27-36). Duxbury, MA: Mercury Learning & Information.

Trujillo, D. (2014). Impresoras 3D en el ámbito educativo (Master's thesis). University of La Laguna, Tenerife. Retrieved from http://www.academia.edu/8254010/TFM_Impresoras_3D_en_el_%C3%A1mbito_Educativo

Universidad Carlos III de Madrid (2015). AULA 2015. http://www.uc3m.es/ss/Satellite/UC3MInstitucional/en/TextoMixta/1371211265109/

Universität Liechtenstein. (2014). 3D-Druck - Technische, Wirtschaftliche & Rechtliche Herausforderungen der Additiven Fertigung. Retrieved from http://goo.gl/p32uHS

University of Cambridge. (2014). Innovation, Intellectual Property and Sustainability Research. Retrieved from http://www.franktietze.de/?cat=48

van Lambalgen, R. (2014). Strategies for Economic Development in the Knowledge based Economy. Utrecht: University of Applied Sciences Utrecht
Vienna University of Technology, Centre of Regional Science. (2007). Smart Cities – Ranking of European Medium-Sized Cities. Retrieved from http://www.smartcities.eu/download/smart_cities_final_report.pdf
von Hippel, E. (2005). Democratizing Innovation. Cambridge: MIT Press
Z Corporation. (2009). How 3D Printing Works: The Vision, Innovation and Technologies Behind Inkjet 3D Printing. Retrieved from http://www.arctron.de/uploads/media/Zcorporation-3DPrinting-Info.pdf
The White House (2015). Educate to Innovate. Retrieved from https://www.whitehouse.gov/issues/education/k-12/educate-innovate
Zero Waste Advocacy. (2014). How Smart Cities Will Use 3D Printers to Achieve Zero Waste. Retrieved from http://zerowasteadvocacy.com/how-smart-cities-will-use-3d-printers-to-achieve-zero-waste/