



UNIVERSITE CATHOLIQUE DE LOUVAIN
LOUVAIN SCHOOL OF MANAGEMENT

**The Place of Additive Manufacturing in Libraries:
Case Study at the UCL and Sustainability Considerations**

Supervisors:
Paul Belleflamme
Christophe Lejeune

Research Master Thesis submitted by
Jan Zaniowski

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Abstract

Additive Manufacturing (AM) technologies are progressively making their way in the modern society as a new method to create objects layer by layer from digital data. Even though Charles Hull developed the technology in 1984, the mass adoption of 3D printing only started recently with the disruptive innovation of desktop 3D printers. The arrival of cheaper entry-level personal fabrication machines on the market emphasized rapid prototyping practices and accentuated the development of Do-It-Yourself movements like Fablabs and Makerspaces. A larger public now starts using desktop 3D printers as their performance continuously improves and their prices decrease. Educational institutions and libraries in Anglo-Saxon and Nordic countries have also demonstrated a keen interest for 3D printing projects in the last years.

The purpose of this thesis is to understand how Belgian libraries, which tend to be followers rather than early adopters of the trend, are concerned by AM technologies. More precisely, how academic libraries of the Université Catholique de Louvain (UCL) should react to this new disruptive technology. Sustainability in AM is also considered, as the topic starts to concern universities who could perhaps play a role in defining missing sustainability guidelines.

Firstly, the author reviews the literature about AM in libraries and sustainability in AM. Secondly, he examines the potential implementation of 3D printers in libraries with a qualitative case study at the UCL.

The design of 3D printing services in libraries speaks to many people's imagination. However, making the best use of 3D printers requires more than just putting a machine in a room. Understanding user needs, developing relations with local Fablabs and sharing experiences with libraries abroad is necessary to offer tailored services to library patrons. Education and research institutions also have a great role to play in defining future AM sustainability practices.

This case study makes an original contribution to a nascent topic of the AM literature. It provides clear answers and recommendations to UCL librarians while setting up a good ground for further research and more general theories about the dynamics of personal fabrication technologies in academic libraries.

Keywords: Additive Manufacturing, 3D Printing, Library Services, Fablab, AM Sustainability, UCL,

IV.

Acknowledgments

Over the last two years, I have been passionate about Additive Manufacturing and the groundbreaking applications this technology makes possible. This interest for the topic started during an innovation course at the Louvain School of Management, in the first year of my master in International Business. During those two years, I carefully followed the 3D printing industry news and did a 7-months internship at Materialise in Malaysia.

As a final step to obtain my degree, I was happy to use my knowledge and passion to conduct this research and clarify how this technology applies to my home university. However, this project wouldn't have been possible without the precious help of some key contributors who supported me in this work.

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1. Introduction

“They are both called “printers”, but it does not mean they are the same thing”

- Régis Lomba, 2015 –

The introduction of this thesis firstly defines two key words of the thesis: Additive Manufacturing and libraries. Then, it explains the motivations that led the author to conduct a research in this field.

1.1 Definitions

A definition of the key words building the title of this thesis is important to understand it. Therefore, those terms are defined in the following section.

1.1.1 Additive manufacturing

The Wohlers Report (2015), main reference report of the Additive Manufacturing (AM) industry’s report, defines AM according to the ASTM International Committee F42 on Additive Manufacturing Technologies as *“the process of joining materials to make objects from 3D model data, usually layer upon layer, as opposed to subtractive manufacturing methods. Synonyms include additive fabrication, additive processes, additive techniques, additive layer manufacturing, and freeform fabrication”*. The term 3D Printing (3DP) is usually associated with a specific type of AM machines’ technology, officially defined by the ASTM F42 committee as *“the fabrication of objects through the deposition of a material using a print head, nozzle, or other printer technology”*. Yet, the terms of 3D Printing and Additive Manufacturing are interchangeably used as synonyms in the literature (Wohlers, 2015).

AM is used for different purposes such as building physical models, prototypes, patterns, tooling components, and production parts. Different technologies enable to print in plastic, metal, ceramic, glass, wood, conductive and other composite materials. The most common raw materials are filaments, pastes, liquids, powders, pellets, and sheets. As an input, AM systems read and reproduce slices from 3D

models created by computer-aided design (CAD) software, 3D scanning systems, medical scanners, and video games. There are different methods of manufacturing layer-by-layer such as extruding, jetting, photo-curing, laminating, or fusing materials. Organizations most commonly use AM parts for products in the consumer, industrial, medical and military markets. Amongst others, AM is useful for the design and production of cameras, mobile phones, engine parts, interior trim for automobiles, parts and assemblies for aircraft, power tools, and medical implants. Those are just the beginning of a long list of products benefiting from AM technologies. Companies of all sizes now rely on AM as a tool for rapid product development, reducing time to market, costs and improving product quality. The use of AM for the mass manufacturing of final complex products is also becoming possible thanks to the latest progress in the industry (Ready et al., 2013; Wohlers, 2015).

1.1.2 Libraries

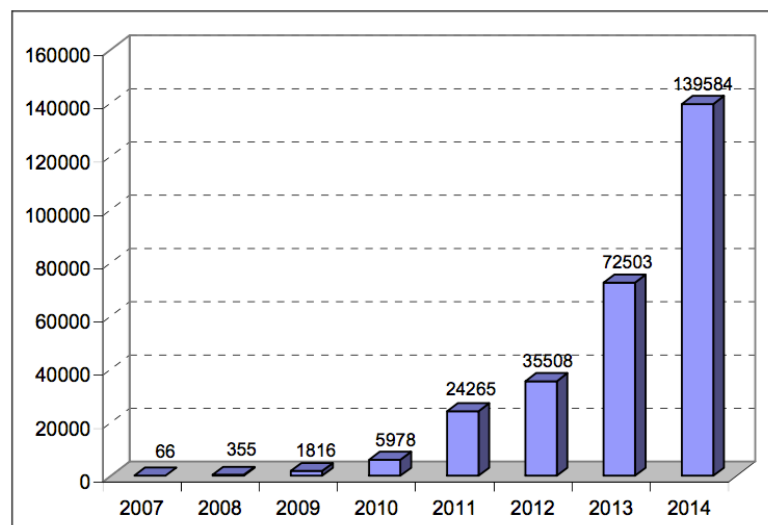
As defined by Dalby (2015), director of the International Librarians Network, there are four main types of libraries in the world: public, university, school and special libraries. Public and community based libraries are the most common type of libraries that people think of, are open to the public and range from huge national libraries to small community libraries, including mobile libraries that travel to their patrons. University, academic or college libraries vary depending on the institution they serve, may have different branches across several campuses and may sometimes offer primarily digital services. School libraries serve a defined group of people for a particular period of their life, generally from kindergarten to grade 12; their spaces and services can be very different from other libraries. Finally, special library is an umbrella term usually referring to libraries or information services present in government, corporate and non-for-profit environments (Dalby, 2015).

In this thesis, 3D printing initiatives in libraries of all types were researched. However, the case study developed further in this paper focuses on academic libraries of the UCL. Therefore, academic libraries are the most important type of library explored in this work.

1.2 Why focusing on library and sustainability topics

According to the Wohlers report, the sales of a specific category of AM systems known as “desktop printers” are growing at a high rate since 2011. Desktop 3D printers are defined by Wohlers Associates as “*AM systems that sell for less than \$5,000*”. In 2014, the estimated number of those systems sold per year grew at an exponential rate of 92% compared to 2013 as represented on the Figure 1.

Figure 1 – Estimated number of desktop 3D printers sold per year



Source: Wohlers Associates, Inc. (2015)

Many members of the 3D printing industry agree that those AM systems do not equal higher end machines in terms of output quality. Yet, the capabilities of desktop 3D printers are quickly improving and those systems appear to be slowly transitioning to the professional market space. Wohlers Associates believe that a significant percentage of desktop printers total sales are sold to small businesses and corporate customers for early concept design amongst other activities. The majority of those affordable AM systems is however sold to hobbyists, do-it-yourselfers, engineering students and many educational institutions purchasing this type of equipment for hands-on learning (Wohlers, 2015).

Towards the end of the 2000s, the use of digital fabrication in education started with a multiplication of initiatives such as the FabLab@School project (coinciding with the development of the FabLab concept by Neil Gershefeld at MIT) or the DARPA-

funded MakerSpace project. In 2011 and 2012, countless schools, museums, community centres and libraries announced plans to build digital fabrication and making facilities, popularising the trend which became mainstream (Blikstein, 2013). The development of the making culture in education going along with the development of the desktop 3D printing market, low-cost AM systems became a hype in educational institutions. A few years later, according to Bull et al. (2014), 3D printers and related systems such as 3D scanners are considered as offering “*an entry point for advancing children’s engineering as well as connecting to other STEM subjects*” (Bull, Chiu, Berry, Lipson, & Xie, 2014).

As Blikstein (2013) remarks, many libraries have announced plans to build digital fabrication and making facilities. Many articles and blog posts share the experience of the implementation within their institutions, which raises the interest of the entire community about the topic (Pryor, 2014). Concrete examples of academic and public libraries having incorporated Makerspaces in their settings can be found online. Pioneering libraries in this field are mainly located in the USA, where the Fablab movement was first initiated (Ginsberg, 2015). In Belgium, such initiatives are far from being mainstream yet, and there seems to be a gap in Belgian libraries’ technological practices with what is happening overseas. This idea is supported by a publication from the UCL’s BSPO, an academic library, which was discovering the “making in libraries” trend only in July 2015 (BSPO, 2015).

In the past, libraries of all types, including public and academic ones, have demonstrated a willingness to diversify their services to remain attractive as public spaces. Concrete examples of this adaptation have been demonstrated with the extensive use of informatics in libraries for information management purposes. MacWhinnie (2003) says, “*The future of the academic library will continue to be moulded by user demands and driven by technological advances. Librarians will continue to organize information, provide research assistance, and to teach users the best ways to access, evaluate and select the best information (for) their specific needs, but by using new methods in an evolving physical setting*”. To continue their mission, libraries will have to provide their users with the resources and amenities they need such as research assistance, latest technologies or appropriate study spaces. MacWhinnie further defends the idea that future libraries “*will be more a learning*

and information centre than a collection of bookshelves and study spaces” (MacWhinnie, 2003).

The question of the maker movement in academic and public libraries, previously noticed overseas, and the possible application of this trend in Belgian libraries is therefore an interesting research topic. To prepare the ground for this research, this literature review focuses on AM in libraries and develops the key elements to the implementation of such projects in libraries.

Additionally AM process sustainability has become a subject of high interest because of growing environmental concerns in the manufacturing industry (Mani, Lyons, & Gupta, 2014). This high interest paid off as researchers identified AM *“to cost-effectively lower manufacturing inputs and outputs in markets with low volume, customized and high-value production chains”* (Gebler, Uiterkamp, & Visser, 2014). The technology has therefore a positive effect throughout the entire product life cycle on a sustainable and ecological point of view (Gebler et al., 2014). Nowadays, not only the industry but also private users are adopting the technology (Wohlers, 2015). However, those practitioners do not always address environmental implications and there seems to be a lack of sustainability guidelines for private users (Kohtala & Hyysalo, 2015).

As the making culture expands in the society and starts to concern universities and academic libraries, those could perhaps play a role in defining those missing sustainability guidelines for the use of AM, as Kohtala (2015) says. Reviewing the literature about the implementation of AM in libraries together with the literature about sustainability in AM is therefore appropriate to support the sustainable use of desktop 3D printing. In that regard, this literature review also includes sustainability in AM, to prepare the ground for further research *“standing on the shoulders of giants”*.

Part I

Theoretical Part

2. Literature review

2.1 State of the Literature about 3D Printing

The literature of AM is not limited to the topics of sustainability or libraries. Many colleges, universities and institutions run research & development projects to make advancements in AM technologies. The Wohlers report lists over one hundred of those institutions and their area of focus. They run basic and applied research projects about AM topics like design for AM, rapid product development, metal casting, high-performance tooling, medical modelling, tissue engineering, architectural modelling, and 3D scanning (Wohlers, 2015).

Also, the topic of AM becomes more and more exploited by academics from every field. Indeed, the technology affects many industries and economies, and therefore practitioners from very different backgrounds address the topic of AM. The result is that the literature about AM is very diverse and abundant. It is therefore interesting to draw the structure of the existing literature topics and approaches to have a clear view on what type of articles have been written about AM. Although AM literature reviews can be found in the literature, they tend to focus on a specific domain and do not provide a clear understanding of the AM literature structure.

The following section is an attempt to draw the general structure of AM literature in order to highlight where this thesis adds knowledge.

2.1.1 *Technical publications: Engineering*

Technical publications are a dominating topic in the AM literature (Jensen, Tanev, & Hahn, 2014). As Ratto & Ree develop, a majority of current scholarship on AM relates to engineering or scientific approaches of the topic (Ratto & Ree, 2012). According to the articles cited by Ratto & Ree, the engineering literature can be structured in the following categories:

- *Industrial design and modelling processes*: The design, modelling and file preparation steps take place before the actual printing process and require engineering knowledge developed by researchers. Examples of this literature

include Burton, (2005); Brackett, Ashcroft, & Hague, (2011); Chu, Graf, & Rosen, (2008).

- *Materials and printing processes:* AM production is a complex engineering process involving a combination of software, hardware and materials. Researchers constantly push the limits of engineering with projects about the AM process itself. Examples include Sells & Bowyer, (2006); Ivanova, Williams, & Campbell, (2013); Kruth, Mercelis, Vaerenbergh, Froyen, & Rombouts, (2005); Murr et al., (2012).
- *General literature:* Some specialised books, papers and industry reports present extensive summaries of AM technology and explore many subjects. Those are good introductions to the technology and are used for teaching purposes. Examples include Ian Gibson, Rosen, & Stucker, (2010); Hopkinson, Hague, & Dickens, (2006); Balci & Campbell, (2004).

Grey literature such as blogs or industry-specific news websites regularly reports about the newest findings of research in AM, amongst other news. 3D Printing Industry, 3ders.org, 3dprint.com and inside3dprinting.com are some examples of information sources where industry watchers report about the newest trends in AM.

2.1.2 Technical publications: Medical

The medical industry can be considered as a niche market for the AM industry according to Ratto and Ree (2012). It has already adopted the technology for a series of applications such as surgery models, orthopaedic implants or cutting and drill guides, as explained in the Wohlers report 2015. The dental industry is also evolving developing digital dentistry thanks to technological advances (Wohlers, 2015).

- *Medical literature:* There is a whole set of medical papers and case studies reporting the use of AM process in surgery and other medical fields. Examples include Liacouras, Garnes, Roman, Petrich, & Grant, (2011) and I. Gibson et al., (2006).
- *Engineering research for medical modelling and production:* Those papers are more from an engineering background but develop specific solutions for medical use. Examples include Salmi, Paloheimo, Tuomi, Wolff, & Mäkitie,

(2013); Gebhardt, Schmidt, Hötter, Sokalla, & Sokalla, (2010) and Vandenbroucke & Kruth, (2007).

- *Bio printing*: As Laysaght et al. and Melchels et al. present in their respective papers, the junction between sectors of tissue engineering, regenerative medicine and stem cell therapeutics coupled with AM processes for the production of bio-compatible scaffolds have grown significantly since 2002 to form the field known today as “bio-printing” (Lysaght, Jaklenec, & Deweerd, 2008; Melchels et al., 2012). Amongst others, Khalil et al. also produced widely cited research papers about multi nozzle deposition systems that create bio-compatible 3D scaffolds (Khalil, Nam, & Sun, 2005).

2.1.3 Cross-disciplinary works

Besides technical publications with an engineering or medical background, there is plenty of what Ratto and Ree (2012) call “cross disciplinary works”. Those papers can be sorted in two main categories of a broader or narrower scope.

Broader Scope

The broader scope literature mixes topics about the AM industry business, additive technologies, engineering, computing, and other knowledge together, usually as an introduction for practitioners with no technical background (Ratto & Ree, 2012). Also, it appears that consultancy reports and reviews dominate the literature and are like a disease for it. They “lack the methodological depth and the predictive power of serious research studies” (Jensen et al., 2014).

According to the literature review that was conducted to write this paper, we can confirm a large coverage of the topic by consultancy firms such as PwC, McKinsey, Deloitte, BCG or CSC. This kind of reports is not only made for AM technology; similar papers are conducted for other technologies considered as disruptive. (Bassan & Srinivasan, 2012; Deutscher, Schuurin, & Ritter, 2013; Earls & Baya, 2014; Grymol, 2014; Manyika et al., 2013; Sulavik, Portnoy, Waller, McNelly, & Carrick, 2014). Those reports top up the industry-standard report published by Wohlers associates.

On the other hand, conference proceedings and academic papers also offer good introductions to the AM market and technology. An example of such an article would be the MARS Market Insights report *Layer-by-Layer: opportunities in 3D Printing* (2013). After going through a classic introduction or primer to the technology, this type of reports goes through a series of topics such as the impact of the technology on various sectors, the financing of AM initiatives, potential market opportunities or business models. Legal and environmental issues are also often addressed (Munoz, Kim, & Armstrong, 2013; Pierrakakis, Kandias, Gritzali, & Gritzalis, 2014). Those papers give a good introduction to AM but do not go through every topic thoroughly.

Narrower scope

Papers with a narrower scope offering a more complete approach are often linked to a specific topic. Those papers generally start with a primer to AM and explore one or two specific topics in depth. The main topics developed in this type of AM literature are listed below:

- *Legal & Intellectual Property (IP) issues*: AM technology and the exchange of 3D files over the internet have the potential to copy products protected IP rights and therefore create new legal issues that are widely discussed in the literature (Andersen, 2014).
- *Business, entrepreneurship and innovation*: AM technology has an impact on business model including those on the e-commerce point of view (Eyers & Potter, 2015; Hämmäläinen, 2014; Hasan, Rennie, & Hasan, 2013). Some academic papers explore entrepreneurial implications of the disruptive innovation that AM represents to try to predict its impact (Cicchetti, 2015; Hahn, Jensen, & Tanev, 2014; Sauramo, 2014). Still business related, the Gartner hype cycle provides an overview of the relative maturity of a specific technology. It also applies to 3D printing which is analysed regularly according to this framework (Gartner, 2012).
- *Societal impact of AM, social sciences*: According to Ratto and Ree, there was still little social science scholarship referring to AM in 2012. Huang et al. observed one year after in 2013 that issues relating to the social impact of AM have been discussed but that the information was “scattered in various publications with different technical focuses” (Huang, Liu, Mokasdar, & Hou, 2013). Recent papers like *Direct digital manufacturing: definition, evolution*

and sustainability implications (Chen et al., 2015) deliberately choose to adopt a societal approach to digital manufacturing instead of the classic manufacturing viewpoint and contribute to develop this area of the literature.

- *Economies and supply chain impact*: Some academic papers and journal articles study the implications of AM from an economical point of view by analysing the impact of the technology on innovation and market structures (Baldwin & von Hippel, 2011; Weller, Kleer, & Piller, 2015). Papers about supply chain or geographical implications of AM can also be cited in this category as they analyse topics with economical implications (Gress & Kalafsky, 2015; Khajavi, Partanen, & Holmström, 2014).
- *Education*: The interest about 3D printing in Education has significantly increased in the last years. However, the integration of AM technology within education practices faces some challenges that are discussed in the literature (Eisenberg, 2013). Researchers believe that AM can offer an entry point to teach STEM (science, technology, engineering, and mathematics) topics (Bull et al., 2014). Therefore, papers exploring curriculum development projects, workshops and experiments for open source 3D printing bring empirical findings to the literature (Barlex, Givens, & Steeg, 2013; Kostakis, Niaros, & Giotitsas, 2015; Schelly, Anzalone, Wijnen, & Pearce, 2015).
- *Sustainability*: Because of growing concerns about environmental issues in manufacturing, AM sustainability is a topic of increasing importance (Mani et al., 2014). Nevertheless, the literature reviewing sustainability and distributed production together is still limited (Kohtala, 2014), even if researchers have been developing this topic in the latest years. One can find in the literature papers relating to how practitioners of AM assess the environmental sustainability (Kohtala & Hyysalo, 2015; Troxler, 2010). There are also scientific assessments of AM sustainability on global, life cycle, social, economical or ecological points of view (Chen et al., 2015; Gebler et al., 2014; Kreiger & Pearce, 2013). On a less AM focused viewpoint, the literature about corporate sustainability practices can also provide food for thought in the sustainability analysis (Amini & Bienstock, 2014; Maletič, Maletič, Dahlgaard, Dahlgaard-Park, & Gomišček, 2014). For further details, the literature about sustainability in AM is reviewed thoroughly in the literature review of this thesis.

- *Other topics (food printing, software development, libraries)*: Besides the main topics described above, many other approaches are possible depending on the industry affected by AM. To name a few, the journal Trends in Food & Science Technology published a paper about AM for the food industry describing the situation in the particular niche of food printing (Lipton, Cutler, Nigl, Cohen, & Lipson, 2015). Software engineers also research topics related to the development of AM specific softwares, including for the booming consumer market (Acher, Baudry, Barais, & Jézéquel, 2014). Last but not least, information professionals have an increased interest for AM and study the suitability for its use in libraries (Marcoux & Bonin, 2012; Massis, 2013).

2.2 Sequence and scope of the literature review

A clear structure of the existing AM literature is drawn in the previous section. Within this structure, the literature review of this thesis about sustainability in AM and the implementation of the technology in libraries finds its place in the section of cross-disciplinary works with a narrower scope.

Precisely, the next section develops the subjects of AM in libraries and sustainability in AM.

Most libraries share their experience of implementing AM on non-academic supports online. The non-academic literature on the topic is used as reference to some cases, but is not as thoroughly reviewed as the academic literature about AM in libraries. Furthermore, studies of sustainability in manufacturing are numerous and many go beyond the scope of this thesis, which focuses solely on AM. Since the focus is on the additive methods of manufacturing, studies of sustainability in general manufacturing will not be reviewed in detail and will only be referred to as appropriate, depending on the manufacturing method.

2.3 AM implementation in libraries

2.3.1 AM in libraries: Why and How?

AM usually enters the library through the implementation of 3D printers within the premises of the building. However, the hardware itself does not come alone, it is a tool that participates to a greater project of creating a lab within the library. (Blanpain, 2014)

Types of labs

As Blanpain (2014) explains in her thesis about the utility of labs in libraries, a lab is a physical co-building space - virtual or relational, temporary or permanent, punctual or recurrent – allowing the creation of a diverse community through experimentation around innovative projects participating to an open and evolving ecosystem. This definition voluntarily avoids the location and technology terms. Those two are essential but they limit the representation of labs while new forms of labs are still to be invented (Blanpain, 2014).

There exist several forms of labs that can take different names, the main ones being Makerspaces, FabLabs, Hackerspaces and Techshops.

Makerspaces usually include 3D printers, electronic equipment and other traditional arts and crafts equipment such as metal or woodworking. According to Kroski (2014), *“Makerspaces are creative, DIY spaces where people can gather to create, invent and learn”* (Kroski, 2014). Educause (2013) in the paper “7 things you should know about Makerspaces” define them as *“a physical location where people gather to share resources and knowledge, work on projects, network, and build”* (Educause, 2013).

Fablabs are a type of Makerspaces created at MIT by Prof. Dr. Neil Gershenfeld. They started with the aim to provide access to modern means of invention to makers so that they can realize their projects (Kroski, 2014). However, the meaning of a Fablab is nowadays not only technological but also strongly centred around the community of makers and collaboration (Blanpain, 2014). According to the Fablab foundation, there are three main requirements to create an enabling environment that can be called a Fablab. If the criteria are met, the space can use the Fablab logo for

fundraising efforts and the centre can be listed amongst other Fablabs in a network. Those requirements are the following:

- Public access must be guaranteed for the Fablab: It is essential to open the space to the public at least part of the time, as the mission of Fablabs is to democratize access to tools for personal expression and invention.
- A common set of tools and processes is necessary for all Fablabs around the world: Every prototyping facility must be equipped with a same base of tools and machines so projects shared in the Fablab network can be realised in all facilities, all around the globe. *“If I walk into a Fab Lab in Russia, I should be able to do the same things that I can do in Nairobi, Cape Town, Delhi, Amsterdam or Boston Fablabs”* says the Fablab foundation. The list of critical machines and materials is available on the foundation’s website.
- Participation in the global Fablab network and community is a third requirement: The spaces can connect through public videoconferences, the Fab Academy, attendance to the annual Fablab meeting or collaborations and partnerships with other labs on projects and workshops (Fab-Foundation, 2015b).

“The plethora of constructionist toolkits created and deployed in the 2000s [...] coincided with the development of the FabLab concept by Neil Gershefeld at MIT and the popularity of the Maker Faire - the perfect storm was in place” writes Blikstein (2013). After conducting many robotics and invention workshops in schools, Blikstein was disappointed by the fact students had no particular space for engineering and invention as music rooms or basketball courts are spaces for music and sports activities. If schools had robotics or science labs, those spaces were judged as highly gender-biased and not disruptive anymore. In 2008, the professor started working to establish digital fabrication labs in schools around the world; the FabLab@School project was born. Digital fabrication labs since then proved to be a disruptive, inviting and gender-neutral place in educational institutions (Blikstein, 2013).

Why libraries?

AM will become a mainstream technology for the society by different ways, and one of them may be through the development of the making culture in libraries. This

development will probably not happen only with 3D printers, but along with other digital and non digital fabrication technologies, by the launch of digital fabrication labs that include 3D printers in their tools (Educause, 2013).

About academic libraries, Colegrove (2014) notes that the need for 3D printing services might extend to more than one university department. He therefore suggests that offering 3D printing services and other technologies as a library service might be a cost-efficient move that makes sense for a university. He says *“Libraries have always provisioned community access to rare and sometimes expensive technology for the common good”* (Colegrove, 2014). Bodycomb (2014) further defends that *“3D printing service at an academic library benefits the whole university campus by allowing universal access to a new technology suitable for rapid prototyping for the whole campus, thereby benefiting even those institutions that already have some 3D printing facilities in specific schools or laboratories”*. As AM technologies become more widely adopted by industries, students may also have a tangible benefit on the job market with knowledge of 3D modelling and 3D printing. That equipment can also provide a support to students for independent studies, research and course projects (Bodycomb, Brown, Kim, & Pinho, 2014).

In a recent blog article, Rogers (2015) wrote about her vision of “What if we redefined making in libraries”. She claims that traditionally, the information world is based on print publications and that academic making is restricted to writing academic works. However, schools and universities have fields where making (other than writing papers) is part of the learning process in arts, sciences and even business. Rogers therefore imagines libraries as a good place to centralise computer and making centres for such making activities, which could even go beyond the limits of academic coursework (Rogers, 2015). For Massis (2013), AM technology has reached affordable prices for libraries, which are well positioned to be a hub of transformation and technological adoption (Massis, 2013). The possibility for cross-disciplinary projects also encourages to set up Makerspaces in areas open to students from different fields, like libraries (Educause, 2013). According to Colegrove’s (2014) experiences, the need for ready access 3D printing has proven to be substantial and broad-based across different disciplines (Colegrove, 2014).

During interviews for her thesis, Blanpain (2014) noticed that labs induce librarian’s curiosity. Some see them as a temporary hype that will be over in two years; others

make easy connections between labs and libraries as they both have similarities as both are spaces of learning and empowerment with an access to digital technologies. However, having similarities is not enough to justify an integration of both concepts into each other according to Blanpain. How this integration can be realised raises a lot of questions that can be answered mostly by project-driven experimentations. Makerspaces and other concepts, which some are yet to be invented, seem to fit with possible library evolution models (Blanpain, 2014). Multi-technological and multi-purpose projects such as Makerspaces in libraries allow a large range of possibilities that has already proved to be a powerful learning force in the non-academic community. As education assessment evolves, projects realised in Makerspaces may soon become accepted and reviewed for course credits instead of conventional coursework (Educause, 2013). Makerspaces, 3D printers, and similar technologies can be low on cost, create technological interaction opportunities and allow students to become makers, potentially solving real-life problems (Fisher, 2012).

How many libraries with AM around the world?

In 2013, Gallant wrote a report about the number of libraries who have adopted a 3D printer worldwide. In 2011, the Fayetteville Public Library (New York state, USA) was amongst the first institutions to receive a large media attention for its hackerspace. Since then, other libraries followed the trend. Gallant's research shows that, as of June 2013, 51 libraries reported having a 3D printer within their facilities, 25 actively using them for a public use. Most of them were in the USA and public libraries have adopted 3D printers at over three times the rate of academic libraries in this listing. Gallant also noticed a possible geographic trend as public libraries followed academic ones in the installation of 3D printers in more than one state (Gallant, 2013). Gallant forecasted that adoption rates should continue to grow as the popularity amongst the general public was strongly growing. It would be difficult to report exactly how many libraries effectively made the adoption but influencing factors such as the average machine price and the popularity of 3D printing have continued to evolve in the good direction for an increased adoption (Bodycomb et al., 2014). Looking at the literature that was published since his research, a large number of libraries have followed the movement and reported the learning experience of implementing 3D printers in a library, often on non-academic online supports such as blogs, webpages or social media.

Makerspaces in academic libraries vs. local Makerspaces

In the “Makerspace Task Force Report” of Bodycomb et al. (2014), an analysis of the differences between Makerspaces in academic libraries and local Makerspaces is proposed. Thirteen libraries including Makerspaces are reviewed, mostly in the US, while the local Makerspaces were analysed in the Baltimore area as it is a growing hub for Makerspaces due to a large number of universities and a wealth of technology and arts programs (Bodycomb et al., 2014). Even though this study is a snapshot of the US situation, it provides a good understanding of how Makerspaces in libraries and local Makerspaces compare with each other. In the Table 1 below is a summary of this section of the report, highlighting main differences or similarities between both types of Makerspaces.

Table 1 - Comparison between Makerspaces in academic libraries and local Makerspaces

	Makerspaces in academic libraries	Local Makerspaces
Vision	No information on Makerspace background, alignment with library’s mission or purpose for patrons; maybe because the project is a small scale experimental project.	Promotion of science, creativity and future innovative discoveries. Desire for individual freedom to create without limitations
Role	Allow access to rapid prototyping new technologies to the whole university. Enable students and researchers in their projects, enable teaching faculty staff to create equipment and instructional models, enable students with 3D modelling/printing knowledge.	Allow members to prototype ideas and manufacture items using various manufacturing equipment not available at home. Fun space to engage in creative activities. Provide access and education to specific domains (biotechnology, design)
Staffing	Hiring of students familiar with 3D printing, allocating part of the work time of existing librarians and staff to the operation of the 3D printing service. Usually more staff than in local Makerspaces.	Part time staff during set hours, based on the membership fees. Environment encouraging to collaboration and help between members
Service	Most universities offer a mediated service: only library staff handles 3D printing equipment. Cases of open access spaces are limited.	Equipment is made available to members. Regular workshops, talks and events are organised.

Workshops and activities	Libraries usually provide a list of helpful resources and tools for learning 3D modelling and setting parameters for the print, but only a few provide in-depth workshops or consulting, despite a need for demonstrations and instructional seminars.	Workshops are necessary to bridge the knowledge gap between new and experienced users, but also to allow members to use the equipment safely. 3D modelling, programming, innovation and creativity inspiring activities stand out as a very important factor in developing and sustaining a successful Makerspace.
Space	Not much information is provided, as the equipment is usually not made available to patrons in a mediated service. Computers with relevant 3D modelling software would be what patrons interact with.	Local Makerspaces vary in size, generally between 140 and 325 m ² and are often broken in different work areas, keeping the different available machines separately and separating the computer workstations from the fabrication machines.
Equipment	3D printing is the major focus in academic libraries, rarely offering other machines.	Wide ranges of equipment are available in local Makerspaces. Labs associated with arts or digital media institutions usually had larger and higher end devices.
Operation policies	Costs policies of 3D printing and FAQs are usually provided, as well as some online video tutorials and self tests.	Most spaces require safety training for members. Online tutorials such as Lynda.com also provide self-directed learning related to the Makerspace equipment. When in-person training is not possible due to insufficient staff, members are encouraged to help one another when using the space.
Cost recovery	Academic libraries usually charge their users to recover the cost for the material used for printing.	When it comes to 3D printing supplies and sometimes other machines, Makerspaces usually charge for the raw materials. Membership fees participate in maintaining the regular operations of the centre.
Usage pattern	Demand is relatively small with a high rate of repeat users, due to the fact that only a few members of the university have the knowledge or the software to use the equipment.	Local Makerspaces have good attendances due to the variety of services they offer. An active maker community is even more crucial than expensive high-end equipment for the success of a local Makerspace.

Source: Bodycomb et al. (2014)

2.3.2 Key considerations for AM implementation in libraries

Some librarians spend months planning the implementation of a Makerspace in their library while others start only after they get confirmation of a grant and a 3D printer coming. In any case, a certain time is needed for planning the new library service (H. M. Moorefield-Lang, 2014). The following section reviews some key points to consider during this planning period.

Need for policies

Labs and Makerspaces are reasonably cheap to experiment with, but librarians who want to implement them in their libraries should consider some key points. The maker culture is very open and experimental but when implemented in a library, there should be a set of rules, agreements and policies defining what patrons are allowed to do in the space (H. M. Moorefield-Lang, 2014).

There are two main possible models for AM services offered by libraries. The first one is a mediated service where only the library personnel are allowed to handle the 3D printing equipment. Patrons submit their 3D files and pick up finished products 2-3 working days later depending on the backlog. The second one is an open access model closer to the idea of a Makerspace. Introduction workshops and individual consultations are usually required to let patrons use the equipment autonomously (Bodycomb et al., 2014). To encourage participation to those initial trainings, some libraries state in their policies guidelines on being fined if damages are incurred during a misuse of available equipment (Crumpton, 2015).

Gallant (2013) strongly recommends libraries to have policies in place for the internal use of 3D printing when making the technology permanently available to patrons (Gallant, 2013). Those technologies are not intuitive and there is a learning curve to be able to use the technology safely and efficiently. Therefore, training and policies are important to ensure a good functioning of those initiatives along with other library activities (H. M. Moorefield-Lang, 2014). Some policies for the good conduct of patrons could also be borrowed from existing library policies (Gallant, 2013). None of the 51 libraries from Gallant's research had clearly visible policies on their websites but rather 3D printing information on a webpage or sometimes subject guides. Getting correct policies and procedures is one of the main challenges for libraries: in some

cases it took more than a full year to define them by experience and those are still far from being perfect (H. M. Moorefield-Lang, 2014).

Bodycomb et al. (2014) recommend that the policies should convey the spirit of core librarian values, fostering learning opportunities and promoting the engagement of knowledge. Interactive tutorials on YouTube, FAQs about 3D printing at the library and online self-trainings are examples of existing practices developed by other universities that go in that direction (Bodycomb et al., 2014).

Access should be open to students, faculty members and researchers. Policies should not represent a barrier for curious patrons to come into the Makerspace, but should include introductory and safety trainings before granting a full access to the space. The Task Force Report led by Bodycomb et al. (2014) proposes open hours where a staff member introduces the Makerspace to curious students of the University of Maryland in Baltimore (UMB). They also recommend the use of card readers to grant trained patrons access to the Makerspace when no staff member is present. The report proposes three types of hours: staffed open-hours for walk-in visitors, unstaffed open-access hours for trained patrons and consultation hours by appointment for a one-on-one assistance from a staff member (Bodycomb et al., 2014).

Staffing and librarians training

Staffing can be challenging in libraries, and Makerspaces are additional services putting an extra charge on staff members. Therefore, it is common for patrons to be independent, with typically one staff member helping around. On top of allocating some time of existing staff members to the Makerspace, some academic libraries decided to hire trained students familiar with the equipment to work at the library Makerspace. In case of a high variability in demand, those students can support library staff as work-study students. This method can help in maintaining a fully staffed Makerspace, save in salaries and pairing with library staff can be used to create tutorials and handouts. (Bodycomb et al., 2014; H. Moorefield-Lang, 2015).

Knowledge for librarians to learn how to run a Makerspace is spread across many platforms and there is actually a lack of solid training in this field. Until today, librarians usually learn through their personal network of peers in the field, YouTube, Twitter or other online resources, student assistants and community volunteers. Visiting museums, Fablabs or other schools using 3D printers is also a good source of

learning. In general, experimentation, trial and error, patience and a lot of time are necessary in the learning process of Makerspaces management. Above all, it is important to have a space for discussions and information exchange to answer questions (Bodycomb et al., 2014; H. Moorefield-Lang, 2015).

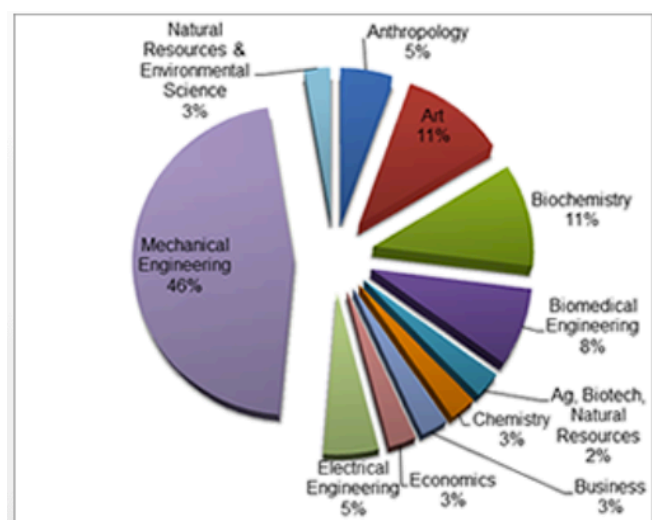
Having an adventurous spirit of investigation, willingness to try new things and little fear of failure are key elements for the creation of a Makerspace in a library (Bodycomb et al., 2014; Crumpton, 2015; H. Moorefield-Lang, 2015). Koh and Abbas (2015) have recently conducted a research about the key competencies that information professionals should have in the Makerspaces context. They identify the ability to learn, adapt to changing situations, collaborate, advocate (i.e. represent the Makerspace as an entity) and serve diverse people as key competencies important in the innovation process (Koh & Abbas, 2015). Those personal attributes can later transition into the technical knowledge necessary to staff's performance and user satisfaction (Crumpton, 2015).

The minimal technical knowledge of Makerspaces staff should be to know how to process an ".stl" file through the 3D printer settings and send it to the printer. The staff should also be capable of performing a basic troubleshooting on the machines and fixing regular bugs. Some staff members should also be knowledgeable in 3D modelling software to be able to provide help to patrons as many errors can occur because of the original 3D file. A period of at least two months should be planned for staff training before the launch of the Makerspace according to the Task Force report (Bodycomb et al., 2014).

Patron education

Makerspaces are especially popular amongst science, engineering and arts students and can be mostly found in libraries serving those students (Bodycomb et al., 2014). However, those departments are not the only ones interested: students and faculty staff from environmental science, economics and business also show interest in the resources of Makerspaces, as shown in Figure 2 (Colegrove, 2014).

Figure 2 – Distribution of 3D print jobs by self-identified discipline of customers



Source: Colegrove (2014)

Younger patrons coming to Makerspaces tend to be fearless and have a willingness to experiment, play, break and build, which Makerspaces encourages. However some education on how to properly use the tools is needed. Educating on good modelling techniques, requirements of models for a successful printing and the printing process itself is also a great challenge in patron education. Common training methods are done face-to-face in classes, lectures or workshops but some institutions are also offering online tutorials, videos and webinars. Those services would usually be free of charge to avoid discouraging curious potential patrons (H. M. Moorefield-Lang, 2014).

Colegrove (2014) notes that many 3D print failures are usually linked to errors in the original .stl file, and that many files presented to print have common errors such as inverted normals, bad edges, holes, multiple shells or too thin wall thickness. To reduce waste of time and material during the printing process, Colegrove suggests introducing a file screening and repairing process before starting the print job. Those operations can be accomplished by software such as Meshmixer or online services such as Netfabb online repair or Materialise 3D Print Cloud (Colegrove, 2014; Materialise, 2015; Nelli, 2014).

Equipment / Tools

3D printing is usually the main focus of Makerspaces in academic libraries, as the projects usually start small without investing in too much equipment. However, some

libraries such as NCSU library in North Carolina, the university of Michigan library and DeLaMare Science and Engineering library in Nevada report having invested additional machines such as laser cutters or other equipment very present in local Makerspaces (Bodycomb et al., 2014). Colegrove (2014) recommends to start the pilot implementation of a Makerspace by investing in two 3D printers as first equipment: one higher end machine capable of better results and a cheaper one that can be moved to external events. A 3D scanner system is also a recommended investment as it enables to convert real world objects into digital models to rework them digitally. Later on, additional investments in new equipment can always be considered (Colegrove, 2014).

Funding

Full or partial funding of library Makerspaces with grants seems to be a common practice to launch such a project. Other funds can be provided through school budgets, foundational funding and friends of the library groups (H. M. Moorefield-Lang, 2014). Initial funding can focus on equipment and supplies as overhead and facilities costs are usually absorbed within the larger budget of the library (Crompton, 2015).

In his research, Colegrove (2014) noted that the academic departments of users with mechanical engineering or arts backgrounds sometimes already had a 3D printing capacity purchased with a one-time funding. However, a lack of on-going financial and staff resources limited the access to the equipment and reduced the potential to catalyse innovation (Colegrove, 2014). To avoid such issues, future funding must be considered to keep the space running (H. M. Moorefield-Lang, 2014). The Task Force recommends seeking enough funds to allow the Makerspace operating for one year free of charge. This period would encourage patrons to try out and experiment with the technologies without cost barriers (Bodycomb et al., 2014). A sustainable revenue model offsetting operating costs must be put in place at the end of the initial funding period to ensure the continuity of the project, like a start-up would prepare a business plan for its operations (Crompton, 2015).

Fees

During the implementation of a mediated 3D printing service at the DeLaMare Science and Engineering library of the university of Nevada in Reno, Colegrove

(2014) reports that an initial free-of-charge policy quickly created a big backlog in orders due to an excessive use of the free service. However, this backlog also discouraged less motivated patrons hence filtering them according to their motivation. After the free trial period, existing library policies enabled the library to only recover operating costs of the prints.

The services were thus implemented on a strict cost recovery basis to minimise the financial impact on patrons while enduring a maximal adoption rate without adding financial costs to the library (Colegrove, 2014). Usage fees are generally considered as necessary for economical sustainability reasons but they are not the only solution to raise funds for the Makerspace. Fairs, fundraising campaigns, company sponsorships or maker clubs can represent alternative sources of revenues to sustain or expand Makerspace activities (Garcia-Lopez, 2013). Crumpton (2015) notes two beneficial points of charging fees to patrons using Makerspaces. First, fees can narrow the pool of users down to the most serious ones. Second, fees allowing investments in higher quality tools offer more benefits than a free service but with poor equipment (Crumpton, 2015).

2.3.3 Bottom line to AM in libraries

As Blanpain (2014) says, it is difficult to conclude precisely what a lab in a library is useful for, as new applications will be discovered and added to the existing list of possible utilizations. The challenge for libraries is to use this window for bottom up innovation and to experiment with local initiatives. Blanpain (2014) recommends to not only test existing applications but to also participate in the development of new technology utilizations as a community. She proposes to follow an open, sharing and knowledge productive model on a horizontal and participative basis in order to foster innovation. Labs proved they could be developed according to many different models and methods, the most common ones being Makerspaces, FabLabs, Hackerspaces and Techshops. The number of labs is growing and they form networks such as the Fablab network, which libraries are not, or only partially a part of. A library willing to develop a lab project must persist and show its qualities for experimental innovation within the local sphere (Blanpain, 2014). Moreover, networks of other university libraries having similar initiatives could support this convincing effort.

2.4 Sustainability in AM

In the next section about sustainability in AM, the term “sustainability” is defined at first and some key sustainability indicators are presented. Then, a review of the existing literature about sustainability in AM is proposed, followed by the main sustainability implications of AM compared to mass manufacturing and other conventional fabrication methods.

2.4.1 Definition of sustainability

In 1987, the World Commission on Environment and Development (WECD) defined sustainability as *“development that meets the needs of the present without compromising the ability of future generations to meet their own needs”* (Brundtland, 1987). Chen et al. (2015) support the idea that this is the most common definition of sustainability from a society perspective. However, Haapala et al. (2013) add that although the wide acceptance of this definition, it is not operational for business and engineering decision makers in manufacturing (Haapala et al., 2013). In 2003, Milheic et al. proposed a definition of sustainability that is more appropriate for an engineering context *“as the design of human and industrial systems to ensure that humankind’s use of natural resources and cycles do not lead to diminished quality of life due either to losses in future economic opportunities or to adverse impacts on social conditions, human health and the environment”* (Mihelcic et al., 2003). Chen et al. confirm that there are many aspects of sustainability generally gathered into three main groups, which are social, economic and environmental dimensions (Chen et al., 2015). Other authors have suggested considering those three dimensions equally and simultaneously instead of traditionally following the economic aspect in decision making only (Salonitis & Ball, 2013; Seliger, 2007). All those reports build on the work of Elkington (1998) who presented the approach of the triple bottom line in the book titled *“Cannibals with forks: The triple bottom line of sustainability”* (Elkington, 1998).

When it comes to manufacturing, the definition of sustainability also refers to the triple bottom line approach. Indeed, the U.S. Department of Commerce defines sustainable manufacturing as *“the creation of manufactured products that use processes that minimize negative environmental impacts, conserve energy and natural*

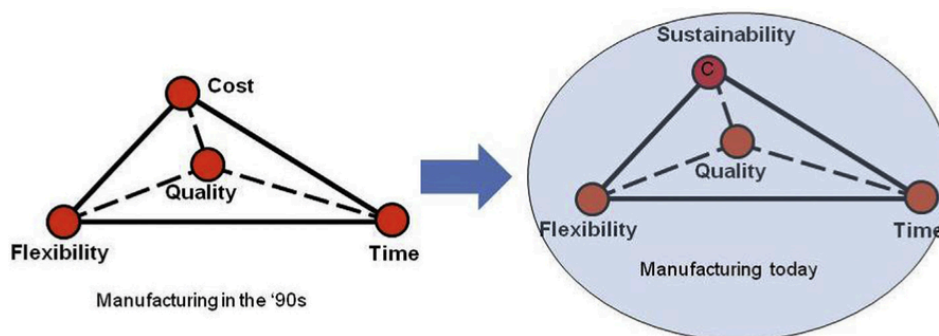
resources, are safe for employees, communities, and consumers and are economically sound.” (DOC, 2015). Nevertheless, according to Haapala et al. this definition neglects the concept of strictly discussing sustainability in the context of a closed system. Many definitions of sustainable manufacturing have been proposed but a broadly accepted definition is still not available as of today. However, even though one general definition is not accepted, it is clear that the triple bottom line approach is widely integrated into the definitions of sustainability. As Haapala sums up, *“Manufacturing subsystems coexist alongside human, ecological, and natural subsystems. Therefore, sustainable manufacturing is a philosophy that cannot be considered independent of broader environmental and socioeconomic systems”* (Haapala et al., 2013).

Mani et al. (2014) further develop that a sustainability assessment should be done through the entire life cycle of a product (Mani et al., 2014). The different phases of a product are design, manufacturing, use and disposal. Sustainability perspectives and indicators are different for those different phases (Chen et al., 2015).

Diegel et al. (2010) also refer to the triple bottom-line approach when it comes to sustainable product design, the first step of the product life cycle according to Chen (2015). However, the meaning of a sustainable product can be confusing as there are many definitions that sometimes contradict each other. This leads to the use of the word sustainability as a “marketing buzz-word” that designers should move beyond to engage in design activities with a stronger level of integrity (Diegel, Reay, Singamneni, & Withell, 2010).

A main challenge of AM is the lack of developed standards to increase market acceptance and adoption of the technology (Clemon et al., 2013). To make of sustainability more than a buzz-word, the ASTM International standards organisation created a subcommittee on sustainable manufacturing working on facilitating the development and use of sustainable manufacturing by defining standards for the manufacturing industry. The ASTM Committee F42 is specifically working on AM to promote the knowledge, research and encourage the implementation of the technology. (ASTM, 2015; Mani et al., 2014). Manufacturing performance is traditionally assessed by the following attributes: cost, time, quality and flexibility. On Figure 3, it is clear that sustainability evolved since the nineties to become a key manufacturing attribute that incorporates the cost factor (Chen et al., 2015).

Figure 3 – Manufacturing decision making attributes in 1990s and in 2013



Source: Chen et al. (2015)

Besides Elkington's triple bottom line approach, Amini & Bienstock (2014) consider the zero-waste approach amongst the most significant and constructive approaches. This "cradle-to-cradle" approach developed by McDonough and Braungart (2002) goes beyond the triple bottom line by suggesting that at the end of the life cycle, the product provides superior raw materials for new products. It is a sophisticated, circular and preventive approach to sustainability (Amini & Bienstock, 2014; McDonough & Braungart, 2002).

Corporate Sustainability

Lots of research has been conducted on Corporate Sustainability (CS) as well. CS is described by many various terms in the management literature but there is an overall similarity among those terms which all rely on the vision of a company that considers all the contexts in which it is embedded. Those contexts are usually similar to those of the triple bottom line approach: economic, social and environmental (Amini & Bienstock, 2014). Lozano (2008) proposes in an extension to the triple bottom line approach a new way of visualising sustainability by incorporating the temporal dimension. His new model called Two Tired Sustainable Equilibria (TTSE) takes in account short and long-term sustainability perspectives which are important for a company to build a sustainability strategy (Lozano, 2008).

Amini & Bienstock (2014) propose a multidimensional definition of sustainability in a framework, represented on Figure 4, incorporating five dimensions and how strongly those are implemented in an organisation. The dimensions of this framework include how much sustainability is integrated in the company's strategy and how it is communicated; how sustainability is integrated in the supply chain; how much

innovation is oriented towards sustainability; how strongly the triple bottom line is embraced by the company; and finally how much the company complies with the existing sustainability rules and laws it is subject to. This framework can help a company to evaluate its sustainability level and serve as a guide to increase the sustainability level of a company (Amini & Bienstock, 2014).

Figure 4 – Multidimensional definition of sustainability (Bigger copy in appendix 7)

Dimensions of Sustainability	Business Level Application & Communication	<i>Ill defined sustainability initiatives within organization; no external communication with respect to CS activities</i>	<i>Tactical level sustainability activities; few external communications with respect to CS activities</i>	<i>Strategic level sustainability activities; some quantification & external communication of CS performance</i>	<i>Intrinsically sustainable zero-waste oriented organization; public disclosure of highly granulated sustainability performance data</i>
	Scope of Organizational Focus	<i>No supply chain interaction</i>	<i>Limited interaction with supply chain</i>	<i>Some information/resource sharing within supply chain</i>	<i>Significant information, resource sharing & optimization efforts across supply chain</i>
	Sustainability Oriented Innovation	<i>Innovation activities are not sustainability related</i>	<i>Some awareness of relationship between innovation and sustainability</i>	<i>Innovation activities begin to involve multiple stakeholders</i>	<i>Zero-waste approach involving significant sustainability oriented innovation (SOI) efforts that involve multiple stakeholders</i>
	Economic/ Ecology-Environmental/ Equity-Social Emphasis	<i>Emphasis solely on economic sustainability</i>	<i>Primary emphasis on economic sustainability; tentative efforts toward ecological-environmental sustainability</i>	<i>Triple bottom line approach, economic, ecological-environmental, equity-social sustainability</i>	<i>Organization embraces a "triple top line" sustainability approach</i>
	Compliance Stance	<i>Sustainability activities limited to minimal efforts at regulatory compliance</i>	<i>Sustainability activities increase beyond minimal regulatory compliance, but are not systematically related to organizational strategy</i>	<i>Incorporation of regulatory compliance within organizational strategy; participation in development & evolution of sustainability regulation</i>	<i>Recognized industry thought leader that embraces and encourages zero-waste approach to sustainability regulation; recognition of importance of public-private partnerships</i>
		I	II	III	IV

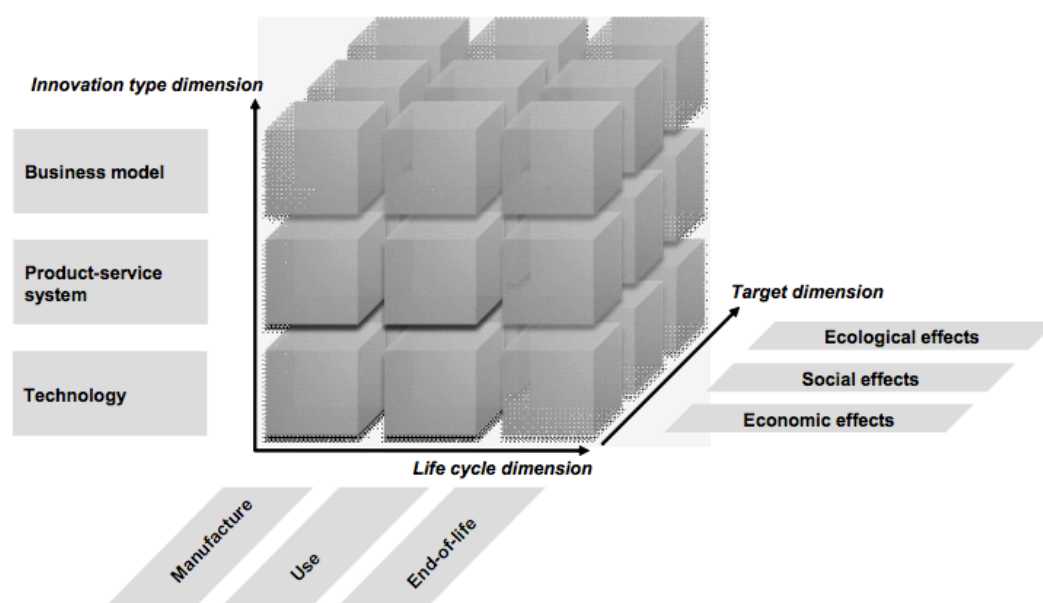
Level of Sophistication (I = least sophisticated; IV = most sophisticated)

Source: Amini & Bienstock (2014)

Maletic et al. (2014) studied corporate sustainability and its impact on performance. The concepts of sustainability exploitation and exploration are two key concepts of this framework and both represent ways to innovate with a sustainability objective in mind. Exploitation involves the ability to manage existing assets and capabilities such as knowledge, skills and processes while exploration involves the development of new capabilities and is closer from radical innovations with a focus on new customers and markets (Molina-Castillo, Jimenez-Jimenez, & Munuera-Aleman, 2011). Maletic et al. research showed that the impact of sustainability practices on organisational

performance depends on multiple factors including environmental uncertainty, competitiveness, long-term orientation and institutional approaches. Organisational performance dimensions can also vary between countries and the impact of sustainability on performance is also different depending on the country. Managers may want to exploit trade-offs between exploration and exploitation for a better short-term impact but the pursuit of both sustainability development methods is preferred in the long term (Maletič et al., 2014).

Figure 5 – The sustainability innovation cube



Source: Hansen et al. (2009)

Amini & Bienstock (2014) have put together conclusions from previous research about the impact of sustainable innovation on performance. The bottom line of this literature review is that sustainability initiatives usually lead to a form of sustainable innovation that is generally positive for the company performance (Amini & Bienstock, 2014). On this topic, Hansen et al. (2009) developed a “sustainability innovation cube”, represented on Figure 5, to visually bring together the triple bottom line, the life cycle and different innovation types (Hansen, Grosse-Dunker, & Reichwald, 2009).

Sustainability indicators

Metrics and indicators of sustainability are necessary when optimising processes and systems and have an objective of improving decision-making (Jawahir et al., 2006). There are many assessment tools to evaluate sustainability, but not all of them integrate every dimension of the triple bottom line. The Dow Jones Sustainability Index, GM metrics for sustainable manufacturing and GRI Reporting Framework are tools for manufacturing, factories and the whole company but mostly related to the economical part of sustainability (Chen et al., 2015). To measure the society perspective of sustainability, the United Nations Commission for Sustainable Development (UNSCD) offers a structure with 14 themes, 44 subthemes and 96 sustainability indicators (United-Nations, 2007). In previous works, Chen et al. showed that this UN framework could be adapted to a factory level and be useful to evaluating social sustainability. Therefore, for their review of sustainability in AM, Chen et al. summarised important sustainability subthemes and indicators from previous research and the UNSCD framework according to the triple bottom line structure. A simplified version of this table is represented in Table 2. Many other metrics systems have been developed by researchers (Haapala et al., 2013), however, the one presented by Chen et al. is one of the most recent ones and is adapted to AM. Therefore, this metrics system can be considered for the case of this paper.

Table 2 - Examples of the sustainability subthemes and indicators for manufacturing phase

Dimension	Subtheme	Indicator
Economic dimension	Energy use	Energy consumption [Tonnes of oil equivalent]
	Material consumption	Material consumption per manufactured product [ton or kg]
	Waste management	Generation of waste [kg/category]
	Profitability	Profitability per product
	Manufacturing costs	Manufacturing cost per article/product:
Social Dimension	Working condition	Number of work injury or fatalities [U] per year in a factory

	Work's impact on worker's long term health	Number of long term injury [U] per year in a factory
	Employee turnover	The rate [%] at which the factory gains and losses employees
	Proportion of permanent employees	The proportion [%] of permanent to non-subcontract employees at the factory
	Employee empowerment	The number [U] of vocational education and training seminars the factory offers to improve the employee qualification for their work.
Environmental dimension	Impact on climate change	Emission of carbon dioxide equivalent [tonnes]
	Source of energy	The proportion [%] of energy the factory utilises of renewable energy
	Impact on water quality through radiation heat transfer	Emission of waste process heat [W] to process water
	Impact on water quality through solid waste	Amounts of solids (dissolved and un-dissolved) [kg] passing as process waste to adjacent water source(s).
	Impact on water and soil through acidification	Amount of acidifying compounds carried through process water [kg]

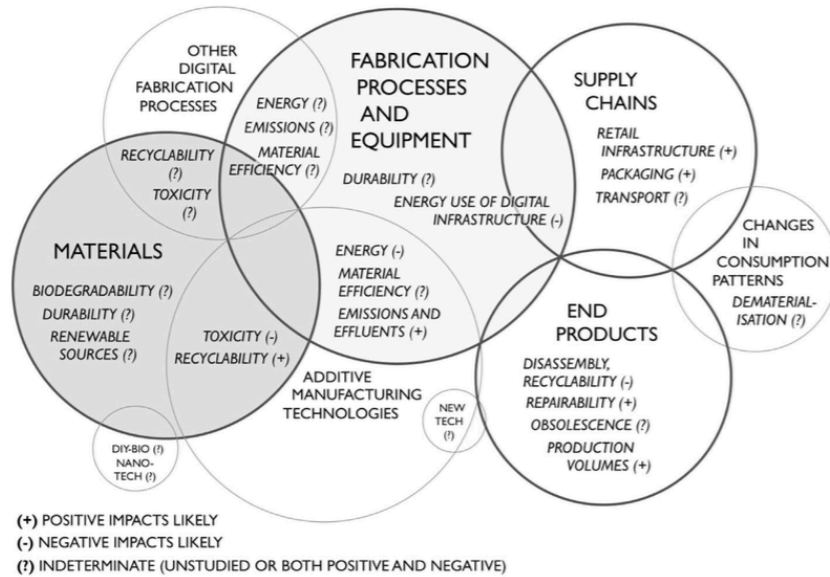
Source: Chen et al. (2015)

2.4.2 State of sustainability research in AM

Because of growing concerns about environmental issues in manufacturing, AM sustainability is a topic of increasing importance. Furthermore, being able to compare AM sustainability with other manufacturing techniques will close gaps for comparisons between those technologies and help to get over the challenges for AM wider acceptance (Mani et al., 2014). In the integrated literature review made by Kohtala (2014), one of the remarks was the limited quantity of papers reviewing distributed production and sustainability together (Kohtala, 2014). Reports on the sustainability of personal fabrication are emerging with the adoption of AM technology often as grey literature. Common subjects for empirical studies are energy consumption and life cycle analyses (Kohtala & Hyysalo, 2015). An overview of

existing environmental issues studied in the literature is proposed by Kohtala & Hyysalo (2015) and can be found in the Figure 6.

Figure 6 – Overview of environmental issues in personal fabrication and Makerspaces



Source: Kohtala & Hyysalo (2015)

AM advantages for sustainability

Mani et al. (2014) list a series of AM advantages for sustainable manufacturing that is regularly mentioned through the literature and that can be found in Figure 7.

Figure 7 – Key AM advantages relevant to sustainable manufacturing

- Less waste because of the nature of the additive process, unlike parts that are stamped or sculpted out of a larger piece of material
- No specialized tooling or fixtures required for AM
- Ability to build functionally light weight parts, while maintaining strength
- Reduces the need for large amounts of raw material within the supply chain and transportation
- Largely material efficient when compared with traditional machining and casting
- Ability to produce optimized geometries with near-perfect (compared with wrought material) strength-to-weight ratios
- Less impact of the part over its life cycle, resulting in a lower carbon footprint, less embodied energy, and better economic model
- Ability to create on-demand spare parts, reducing or eliminating inventory

Source: Mani et al. (2014)

Grunbaum (2012) confirms some elements of Mani's list by presenting three environmental selling points of AM. Respectively the material efficiency of AM, the ability to build many products with one machine without requiring additional tools or machinery and the on-site production that simplifies supply chains by removing the shipping from the factory stage (Grunbaum, 2012).

Nevertheless, AM is not a universal solution and positive sustainable impacts are not verified in every situation. Indeed, an AM process for parts with low material requirements and complex geometries would be a good idea to improve sustainability while an AM process for parts with high material needs and a simple geometry would not be consistent with sustainability objectives. The environmental benefits of AM compared to traditional manufacturing methods significantly depend on electricity sources, machine efficiency, raw material sources and how much material is needed to build the object (Haapala et al., 2013).

Sustainable development through AM

Appropriate Technology (AT) is a method of sustainable development that enables impoverished populations to pull themselves out of poverty. The Internet has brought the open source movement, which rose AT to the level of "Open Source Appropriate Technology" (OSAT). However, beyond a specific level of complexity, it is too difficult to physically produce OSATs. Nowadays, open source 3D printers enable the production of those technologies (Pearce et al., 2010). Pearce et al. (2010) have critically studied how open source 3D printers enable the fabrication of OSAT. At the time of their research, open source 3D printing was still at a "hacker" stage and was not ready to be rolled out in developing countries. However, they conclude their study by stating that there is an enormous potential for open source 3D printers to assist in driving sustainable development, given appropriate resources.

In a more recent study, Basmer et al. (2015) support that new manufacturing technologies such as AM represent a great chance to foster social sustainability. The examples observed in the study show that a shift towards collaboration-oriented industrialisation is already happening. Studying the phenomenon will help to increase sustainability in production strategies and cycles. Yet, the few existing studies did not generate enough data to enable further scientific research on the long-term effects of

AM for the production of OSATs. Further evaluation studies are still required in this field (Basmer et al., 2015).

The maker movement is often promoted as being more environmentally sustainable than mass manufacturing. Studying how makers organise their activities may provide a reference in making practices to set up sustainable good practices for the future. However, Kohtala's study showed that 25% of the issues foreseen by makers in maker spaces had environmental implications but that there was a big gap in the answers of different maker sub-cultures. Environmental sustainability does not appear to be a main aspect of the issues identified by all makers while discussing future trends in making. However, finding implications for environmental sustainability seems easier when practitioners discuss solutions to issues and not only future trends. Therefore, the paper suggests enhancing dialogue between pro-environmental and new-technology-oriented maker sub-cultures through shared spaces, workshops and conferences (Kohtala & Hyysalo, 2015).

Basmer et al. (2015) recommend following the FabLab movement in particular when studying sustainability in AM as they fully participate to the maker movement's expansion (Basmer et al., 2015). Bertling et al. (2012) describe FabLabs as open high tech workshops where makers can develop and produce tailored products that cannot be made by conventional industrial scale technologies. Fablabs are built on the idea of collaboration, decentralisation, participation and democratisation and are highly connected to social web activities (Bertling, Blömer, Rechberger, & Schreiner, 2012).

Troxler (2010) has put together the results of three different researches he conducted about Fablabs. His work looked at explaining the business model of Fablabs and creating a map of fabbing activities; understanding the pain and pride of a Fablab and reviewing a series of case studies explaining innovation activities in Fablabs. The topic of a hybrid innovation in commons-based peer-production is addressed in the literature but not often in the Fablab environment. The research in this paper shows that there is a desire and intention for a hybrid innovation technology. However, there is no replication of existing good practices from other industries in this regard yet (Troxler, 2010).

Bertling et al. (2012) studied sustainability aspects of the FabLab movement as an example of a paradigm shift in the consumer-producer relationship. The paper

suggests that the whole system of production and consumption must be innovated in order to decisively reduce the ecological footprint of consumption. An increase in everybody's responsibility in the production process, as proposed in the maker movement, seems to be a good basis to increase sustainability (Bertling et al., 2012; Mani et al., 2014).

Design sustainability in AM

Mani et al. (2014) mentioned that when assessing sustainability in manufacturing, for AM as well as for any other process, one should consider the entire life cycle of the product (Mani et al., 2014). Furthermore, design is considered being the first part of the product life cycle and has an increased importance in AM due to the simplification of the production stage (Chen et al., 2015).

One design philosophy that could be part of a solution for an increased sustainability is to design products that become lasting objects of desire for which the user has a deep attachment. Such products usually have an increased longevity and are less harmful for the environment. It appears that AM has the potential to create such objects (Diegel et al., 2010).

Diegel et al. (2010) have studied how aspects of AM are useful for the sustainable design of consumer products. From their research, they recommend to adapt tools such as life cycle analysis or cradle to cradle to fit the AM paradigm. They think that revising some of those frameworks by applying them earlier in the design process may better reflect the possibilities of AM technologies. Furthermore, the field of product design will have to evolve to keep up with sustainable design trends as long as new multiple material technologies enabling the creation of complex multi-material assemblies are developed (Diegel et al., 2010).

2.4.3 Sustainability implications of AM

AM has the potential to outperform mass production on some sustainability metrics in terms of material, waste and energy use and improve some supply chain structures (Kohtala & Hyysalo, 2015). However, Grunbaum said in 2012 that there was still not much data on how AM compares to mass manufactured products for the environmental impact over the life cycle (Grunbaum, 2012). In the years following

his paper, research brought stronger empirical results about the environmental sustainability of AM. Those are developed in the next section of this thesis along with recent findings in social and economical sustainability, according to the triple bottom line structure and through a product life-cycle point of view.

Economical sustainability implications of AM

Traditionally, AM process is considered as more cost effective for markets with high value, low volume, and customized products. AM will greatly impact some key markets such as consumer products, aerospace, automotive and medical tools by 2025 (Manyika et al., 2013). To define when it is interesting to use AM over other manufacturing methods, the break-even point is usually used. It is “*a central measure to describe the maximum size of production volumes below which AM is the most effective manufacturing process*” (Hopkinson et al., 2006). However, a life cycle based approach has to be taken as the costs of AM builds are not the only ones that should be considered (Lindemann, Jahnke, Moi, & Koch, 2012). Lindemann et al. (2012) further develop their paper on the cost structure of AM manufacturing and note that the shares of machinery costs are higher for AM compared to other manufacturing techniques.

Chen et al. (2015) consider energy and material flows as a base for economic and environmental assessments. They support the idea that economic and environmental dimensions are strongly connected and summarise their analysis in the Figure 8. The figure indicates if the aspects of AM are: beneficial (+); unfavourable (-); or whether it cannot clearly be assessed for the general case (+/-) (Chen et al., 2015).

Figure 8 – Overview for the implications of DDM on the sustainability dimensions

Economic	Environmental
■ Higher material utilisation (+) ■ Simpler, more efficient supply chains with less transportation efforts (+) ■ Less material and energy losses due to less inventory (+) ■ Less waste and better waste management through possibility of direct recycling (+) ■ User oriented manufacturing, less over-production in stocks (+) ■ No moulds etc. necessary (+) ■ Higher specific energy demand (–) ■ Quality issues are not finally solved, thus risk of bad parts and rework (–) ■ Potentially higher profit due to customer specific solutions (+) ■ Profitability could be proved in selected cases (+/–) ■ Longer manufacturing time (–)	■ Ambivalent studies in terms of an environmental impact or eco-efficiency, (+/–)
Social	
■ equal possibilities to all participants in markets and societies (+) ■ bridge technological, educational and cultural gaps between developing and developed countries (+) ■ user oriented products, more customer satisfaction (+) ■ potential benefits on human/worker health (+) ■ unclear impact on an employment situation of industry (+/–)	

Source: Chen et al. (2015)

As Faludi et al. (2015) partially confirm, AM has a potential to reduce waste as the process uses raw materials more efficiently notably by making hollow parts. The total cost of a product through the entire life cycle can be lowered through lightweight designs and improved geometries, which can lead to significant economies, especially in the aerospace industry. However, a higher energy use during the manufacturing process can overwhelm savings in material (Faludi, Bayley, Bhogal, & Iribarne, 2015). Therefore, it is very important to calculate precisely the benefits of a product created with AM over its entire life cycle to determine its sustainability impact. Haapala et al. (2013) add that most of the energy consumption is not often due to the production stage but rather during the use of a product. The opportunities to reduce energy consumption at all stakes should therefore be balanced against environmental and social aspects of sustainability in order to maximise the total sustainability balance (Haapala et al., 2013).

AM also has potential to reduce waste by producing on demand close to the consumer: this results in less packaging and transport which reduces the total energy impact of the product (Campbell, Williams, Ivanova, & Garrett, 2011).

Clemon et al. (2013) developed energy and quality assessment methods applicable to AM to educate users about the energy consumption of their 3D print jobs. The paper concludes that the power consumption in AM follows distinct phases made of standby, warm up, printing and idle phases. The energy demanded in AM depends mostly on individual characteristics of the machine, the part size and build time (Clemon et al., 2013).

Campbell et al. (2011) studied supply chain implications of AM and announced a possible shift in the global economy due to AM. This scenario is relying on the assumption of a widespread adoption of AM and is going beyond the scope of this thesis. However, the information in Campbell's paper is very much worth the reading and is highly recommended to imagine future trends of AM (Campbell et al., 2011).

Environmental implications of AM

Environmental implications of AM are similar to economical ones in some points as the cost-related factors of energy and waste also have direct environmental implications. As energy demands over the entire life cycle can be lowered through AM, related CO₂ emissions are also reduced. This impact is very significant in the aerospace industry where CO₂ emissions can be lowered by 75% thanks to lightweight designs. For some complex aerospace parts high buy-to-fly ratios of 20:1, relating how much raw material is necessary to produce a final product, are very common. AM has a potential to reduce this ratio to almost 1:1. Some case studies show that up to 40% of waste can be reduced while 95% of unused raw material can be reused for powder systems (Gebler et al., 2014; Petrovic et al., 2011; Reeves, 2013). AM can also reduce the carbon footprint of some products by reducing the distance and therefore transport between the production site and the customer (Chen et al., 2015). Distributed recycling is also possible through products such as RecycleBots. However, those systems are limited to plastics and therefore to FDM (Fused Deposition Modelling) machines, and may be dangerous due to toxic fumes occurring during the melting of the material. The purity of the produced raw material is also another issue to those systems. (Kreiger & Pearce, 2013).

Diegel says that economic sustainability is easier to measure compared to social and environmental sustainability. The difficulty of measuring environmental sustainability has led to the development of a variety of quantifying methods such as cradle-to-

grave, cradle-to-cradle, and Life-Cycle Analysis (Diegel et al., 2010). Life Cycle Analysis (LCA) is the most common method to evaluate the actual and potential environmental impact of manufacturing goods over the product life cycle. This analysis can be conducted from the raw material acquisition through production (cradle to gate) until the disposal of the product (cradle to gate) or its recycling into new raw materials (cradle to cradle) (Haapala et al., 2013).

Comparing environmental impacts of additive manufacturing with traditional machining via life-cycle assessment

Faludi et al. (2015) conducted a comparative LCA comparing the sustainability of AM FDM (Fused Deposition Modelling) machines to CNC (Computer Numerical Control) milling machines. The conclusions are mixed, as the authors cannot conclude clearly which system is more environmentally friendly. However, the FDM machine had the lowest impact in the most scenarios and could therefore have an advantage over traditional manufacturing. According to Faludi, the best strategy is to share tools and have a few machines operating at maximum efficiency. AM centres with a diversified portfolio of machines would thus have an economic advantage but also an environmental one (Faludi et al., 2015).

Krieger & Pearce (2013) also made a comparison research for the energy consumption of AM systems (RepRap) against conventional large scale production in low labour cost countries with shipping, this time coupling the AM systems with solar photovoltaic power. The results indicate significantly lower energy consumption with open source 3D printers using <25% fill and polylactic acid (PLA) as a raw material. The results were less significant with acrylonitrile butadiene styrene (ABS) as it demands higher temperatures for the print bed and extruder. In general, distributed manufacturing using AM systems has possibly a lower environmental impact than conventional manufacturing, and even more when coupled to solar energy. However, the instability of photovoltaic power supply increases the risk of a print failure. Further reducing the energy consumption of such machines is possible with a smart control of the system's temperature, as proved by some initial experiments (Kreiger & Pearce, 2013).

Social sustainability implications of AM

The overview presented in the Figure 8 by Chen et al. (2015) gives a good insight of important social sustainability implications of AM.

Social sustainability is not commonly operationalized and research in social metrics is still in early stages (Basmer et al., 2015; Haapala et al., 2013). Different authors have proposed series of indicators; those proposed by Chen et al. (2015) specifically for manufacturing are: working condition, work impact on worker's long term health, employee turnover, proportion of permanent employees and employee empowerment (Chen et al., 2015). Nevertheless, social sustainability is still a topic harder to measure than environmental sustainability as many factors are subjective and intangible. Methodologies to measure social impact are clearly not as detailed environmental ones (Faludi et al., 2015). There are many ways social sustainability can be impacted: employees' physical and mental health, public perception and customer loyalty are some examples (Diegel et al., 2010; Haapala et al., 2013).

Labour pattern shift

AM induces a shift in labour patterns for workers using this technology as the manufacturing stage now requires less workforce during the production itself, and more skilled workers in pre- and post-processing (Gebler et al., 2014; Lindemann et al., 2012; Petrovic et al., 2011). This change in needed labour induced by AM creates *“a paradigm shift in design thinking as well as the need to increase training and education in digital manufacturing”* (Gebler et al., 2014). As democratised production provides equal chances to all participants of the society, it is possible that entry barriers to needed skills can be reduced through the democratisation of AM (Chen et al., 2015).

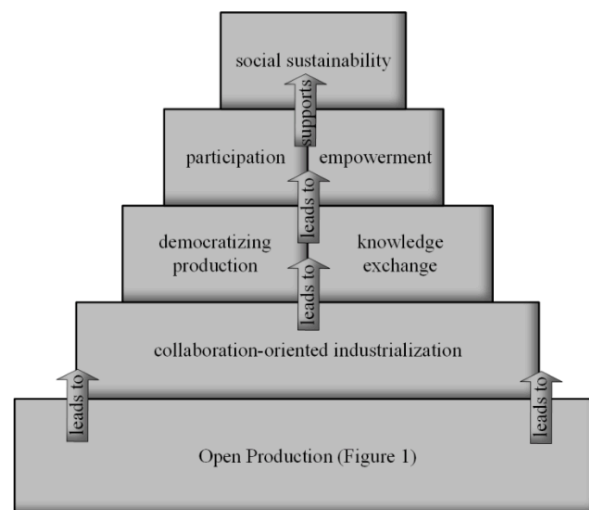
Open source development of people

Open source AM has the potential to contribute to sustainable development in rural areas with low economic profiles as it can be considered as an Open Source Appropriate Technology (OSAT) (Pearce et al., 2010). Indeed, open source hardware is able to reduce technological and educational gaps between developing and developed countries (Chen et al., 2015).

Basmer et al. (2015) present how open production leads to social sustainability in a pyramidal scheme represented in Figure 9. New patterns of value creation such as

open production, based on the new manufacturing technologies such as AM, give individuals an opportunity to increase their customer power thanks to the potential of producing their own goods with their own infrastructure. Open production brings a potential democratisation of production. The second positive sustainable impact is that this democratisation occurs for less developed countries as well (Basmer et al., 2015).

Figure 9 – Criteria of social sustainability fostered by Open Production



Source: Basmer et al. (2015)

Social acceptance of AM

The social acceptance of AM depends on the social entity. Governments have an interest in the technology as it serves their sustainability objectives, fosters innovation and participates to the development of new markets. Markets are favourable to the technology as it creates new opportunities in many industries. However, community acceptance is mixed: 3D printer sales are booming but recurring debates about security threats caused by the manufacturing of homemade guns and the regulation of such weaponry continues working against the free use of AM (Gebler et al., 2014).

2.5 Literature review conclusion

The literature review presented in this thesis sheds some light on the essential theoretical foundations necessary to conduct a research about AM in libraries. By reviewing the academic literature about 3D printers, the making movement and their use in the library setting, the researcher is able to make links between practical findings and theoretical knowledge. This literature review is therefore a highly valuable base to a practical research on the field.

Kohtala (2015) notices that clear sustainability guidelines for the personal (non-industrial) use of AM are missing. This thesis does not provide clear sustainability guidelines, but makes a first step by reflecting on the sustainability implications of AM and providing those considerations to librarians in a single body of work about sustainability and AM in libraries.

Part II

Practical Part

3. UCL Case Study Research

3.1 Research question

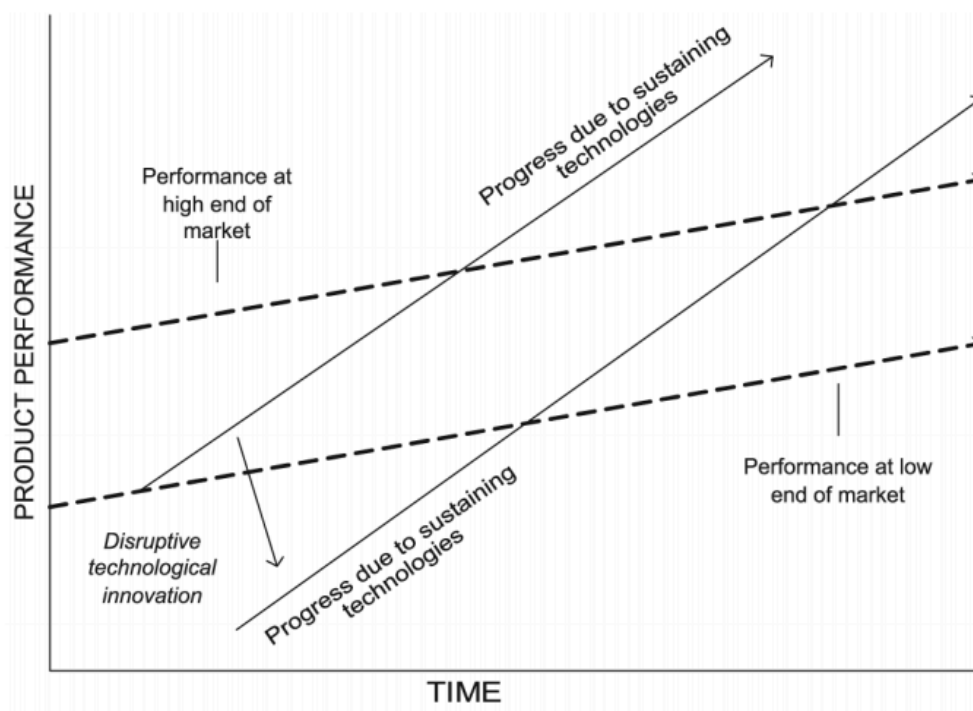
The technology of Additive Manufacturing has picked up the interest of researchers in various fields of practice such as engineering, medicine, research & development and arts, becoming increasingly important in the society. Broader adoption of AM also has sustainability implications, as seen in the literature review. This production process impacts more than one industry when it comes to product and process innovation. Knowledge about AM production and AM innovation therefore becomes a valuable asset for innovative companies or individuals for who the use of this technology becomes a regular practice.

For graduates leaving university, having a basic knowledge of AM becomes growingly more valuable depending on the industry they are entering. And as many industries are impacted, this topic becomes relevant to more students as well. Bodycomb (2014) supports this theory by stating that as AM technologies become more widely adopted by industries, students may have a tangible benefit on the job market with knowledge of 3D modelling and 3D printing (Bodycomb et al., 2014). Universities themselves are directly impacted as international research and teaching standards now start to use AM as a new technology in their processes. Furthermore in the case of UCL it is particularly relevant to consider the topic, as pedagogical innovation is one of the core university missions (UCL, 2013). Additionally, the making movement, which includes AM technologies amongst other digital fabrication methods, proved to bring an added value to lower and higher education (Blikstein, 2013; Bull et al., 2014).

Based on the perspectives presented above, a better access to AM technologies and the making culture for a larger number of students appears as an interesting topic for the academic world. As of today, digital fabrication technologies might be present in laboratories of some faculties, but are mainly kept behind closed doors and available only to researchers and a few students. A parallel can be drawn between this situation and the one of mainframe computers before the arrival of personal computers.

Back in 1997, Clayton Christensen proposed the theory of disruptive technologies in his book *"The Innovator's Dilemma: when new technologies cause great firms to fail"* (C. Christensen, 1997). Christensen often uses as an example how personal computers disrupted mainframe computers by starting as simple machines at the bottom of the market and then relentlessly moving up this market, improving the product and eventually displacing higher end competitors (C. Christensen, 2015). Disruptive innovation theory is also relevant to academic libraries and higher education; academic libraries may become irrelevant with the arrival of new information technologies (Lafferty & Edwards, 2004). Christensen himself joined education experts to explain how the best practices of disruptive innovation could apply to the school education system. He specifically examined how a more creative use of IT could deliver an education adapted to the needs of different students (C. M. Christensen, Horn, & Johnson, 2008). Sauramo (2014) propounds that personal 3D printers are meeting the general criteria for a new market disruptive innovation. New products and new entrants have no doubt disrupted the total 3D printing market, which will lead to a significant market expansion (Sauramo, 2014).

Figure 10 - The Impact of Sustaining and Disruptive Technological Change



Source: Christensen (1997)

Research about AM in libraries is justified, as 3D printers are another disruptive technology, which is expected to impact libraries as personal computers did in the past. This topic is particularly relevant to the UCL and its libraries as part of its official mission is to answer the needs of research and teaching, developing services for their public (UCL, 2012). The literature shows that university libraries can play a key role in providing advanced technologies to a community of students and staff. It also shows that some academic libraries outside of Belgium (mainly in the USA) have already started initiatives to democratize AM and the making movement, with successful results.

- Would an AM, a digital fabrication or a making project in academic libraries be as popular in Belgium as abroad?
- Are academic libraries the best players to handle initiatives supporting the making culture at UCL, taking in account existing actors such as Fablabs nearby the university campus?
- How to support and ensure that making, digital fabrication and AM projects at the UCL are sustainable?

The list of questions above will be answered in the practical part of this thesis. It can be summarised by the following global research question:

“If Belgian academic libraries are interested in Additive Manufacturing and digital fabrication, are they the best place for implementing such initiatives at the Université Catholique de Louvain, and how to take into account sustainability in AM projects at the UCL?”

3.2 Methodology

The objective of the next section is to describe and discuss the research method and methodology applied for this thesis. A definition of the case study's scope is proposed along with remarks about the methodology and a discussion about the reliability and validity in qualitative research.

3.2.1 Research strategy and scope

In order to answer the research question stated above, it is necessary to set up and design a research strategy with the relevant tools and methods.

The research strategy for this thesis began by an analysis of the literature about AM in libraries and the sustainability implications of AM. Results of this theoretical research are presented in the theoretical part above.

It was then necessary to limit the scope of the case study to an environment that could be analysed by one student in a master's thesis. The decision was made to limit the research to university libraries at UCL for two main reasons. First, the BSPO (Bibliothèque des sciences économiques, sociales, politiques et de communication de UCL), library of economic, social, politic and communication sciences of UCL, had publicly shown an interest to 3D printing and Makerspaces in libraries through the publication of a blog article listing a series of articles about this topic in July 2015 (BSPO, 2015). The second reason for extending and keeping the research to all the academic libraries of the UCL is that gathering the insights of librarians servicing different fields of practice allows a triangulation of the data and an understanding of the local phenomenon of AM in libraries as a whole, based on the particular case of UCL.

Literature about AM sustainability is large and its theories are used in drawing recommendations and answering a part of the research question. Literature about AM in libraries is still nascent, but it is growing. Some international cases presented in the literature review are used as secondary data but is not sufficient to analyse the case of UCL. Generation of primary data is therefore necessary to answer the research question in its scope.

The primary data generated through empirical research in this case study seeks to understand the local situation of the UCL. It does so by gathering local data on essential aspects for the implementation of AM in a library, aspects that were previously identified in the international literature and case studies.

3.2.2 Research method

Two paradigms of data collections are most often used in research: qualitative and quantitative methods.

As Gloafshani (2003) defines it with multiple definitions from the literature, the concept of quantitative research is a positivist or scientific paradigm, leading researchers to observing a concept as made up of observable and measured facts (Glesne & Peshkin, 1992), often looking at information in the form of quantified and summarized numbers (Charles, 1998), employing experimental methods and quantitative measures to test hypothetical generalizations (Hoepfl, 1997) and expressing final results in statistical terminologies (Charles, 1998).

The other paradigm of qualitative research is a naturalistic approach that, broadly defined, is any type of research that produces findings not through statistical procedures or any means of quantification but where findings are revealed from real-world settings where the "phenomenon of interest unfold naturally" (Patton, 2002; Strauss & Corbin, 1990). Unlike for quantitative research, qualitative researchers seek understanding and extrapolation to other situations (Golafshani, 2003; Hoepfl, 1997).

With the objective of generating primary data about AM in libraries at UCL, it appears clearly that a qualitative research method answers best the research needs. Indeed, only a few people are involved in the management of libraries at UCL, existing academic data about AM at UCL libraries is inexistent as the topic is very new. A qualitative research was therefore conducted to gather the needed data.

3.2.3 Data collection and analysis method

In this thesis, both primary and secondary data were used. Primary data had to be generated with a qualitative research method to answer the research question. There are different approaches to qualitative interviewing, the most common being unstructured and semi-structured interviews.

The research was performed under the form of semi-structured in-depth interviews. The reason for choosing this technique is essentially to provide the interviewees with enough control over the interview, encouraging them to freely express their own opinion as their knowledge and situation is at the centre of the research. However,

following an interview guide with well defined main topics ensured consistency between the different interviews while allowing the interviewer to adjust questions according to the specificities of the interviewee's situation.

Five interviews were conducted in total between November and December 2015. Four separate interviews were conducted with different directors of UCL libraries serving different faculties and one common interview was made with two key advocates of the making movement in Louvain-la-Neuve: the "OpenHub" and the "Makilab" Fablab. The OpenHub was already organising projects related to AM technologies and the maker movement on the campus at the time of the research. A potential for collaboration between UCL libraries and OpenHub was highlighted in preliminary research and discussions. Further information about the respondents is available in the analysis and results section.

Main topics for the interviews with librarians went from a background check of the technological situation in libraries to discussions about the potential of AM for students or researchers at UCL. How the library could participate in opening the access to new technologies for students was also an important topic discussed during interviews. A detailed interview guide, used for the interviews with library directors is available in the appendix n°1 for further details about interviews. The interview with the OpenHub and the Makilab followed a less structured pattern and focused on answering the research question directly.

Despite the interview guide, room was given to discussion about the specificities of the different libraries and the different visions on the potential of AM in the academic context for the different members of the university community. The research is therefore purely qualitative, but looks at the topic from different perspectives to understand a general trend.

The data gathered during interviews was recorded and transcribed on paper to provide as much details as possible for the analysis of the data (transcripts are available in the appendix n°2 to 6).

The analysis method is based on two steps. The first step was to summarise the different points of views expressed in the interviews as primary qualitative data. In a second time, it has been necessary to link practical findings with elements from the literature review to prepare the discussion of recommendations.

3.2.4 Remarks and limitations of the methodology

There are two main theories about the relationship between data and theory: deductive and inductive theories. In the inductive approach, data is collected from observations to build theories and hypotheses. In the deductive approach, a theory is considered at first and data is collected to test hypotheses based on the theory (Bryman & Bell, 2015). The inductive approach is often quickly linked with qualitative research and the deductive approach linked with quantitative research. However, this quick link is not always true as most research can combine both inductive and deductive elements (Winch, Todd, Baker, Blain, & Smith, 2015).

In this thesis, both approaches are used. First an inductive approach is taken by analysing the literature and international case studies to understand the theory of AM and the making movement in libraries. Then, a deductive field research is conducted to understand the local situation in Belgium, through the case study of the UCL. Finally, a discussion about the results is made between the theory and practical findings, combining inductive and deductive approaches.

It is important to note that the recommendations made for the UCL case cannot be generalised to all universities because of the nature of case studies research design. Indeed, the research design of case studies has some limitations to the generalisation of the findings. The external validity is often questioned when using this method as one or a few cases can hardly represent a general situation. As case studies focus on one particular reality, generalisation of the findings to other cases or larger populations may not always be accurate (Bryman & Bell, 2015). In the case of this thesis, this limitation is important as it directly affects the way results of the paper can be used later on. The literature about AM in libraries is mainly based on case studies; drawing general lessons from those is therefore difficult, especially when situational and cultural differences are present. Although recommendations made at the end of this thesis may not be fully applicable to every other situation, they can help other researchers to refine their research questions or to exploit better the qualitative results that they could get from other interviews. Further research in other universities could hence benefit from the results of this thesis.

3.2.5 Reliability and validity in qualitative research

To understand the meaning of reliability and validity in the conditions of qualitative research, Golafshani (2003) presents multiple definitions given by qualitative researchers from different perspectives. The following definitions are based on Golafshani's findings (Golafshani, 2003).

Seale (1999) says "*trustworthiness of a research report lies at the heart of issues conventionally discussed as validity and reliability*". To ensure reliability in qualitative research, an examination of trustworthiness is therefore crucial. The trustworthiness is understood in regards with the researcher's ability and skill in the qualitative research (Seale, 1999). In qualitative research, reliability is also a consequence of the validity in the study (Patton, 2002). Ensuring the validity of the study would also ensure its reliability.

The concept of validity is described by a wide range of terms in qualitative studies and many researchers have developed and adopted their own concepts with terms considered as more appropriate such as quality, rigor and trustworthiness (Golafshani, 2003). Like a bias in quantitative research, subjectivity, reflexivity and the social interaction of interviewing can be taken as threats to validity in qualitative research (Davies & Dodd, 2002). Limiting those aspects would therefore ensure research validity. Patton (2002) advocates the use of triangulation to increase validity as it "strengthens a study by combining methods" (Patton, 2002). Using triangulation of several data sources may pinpoint exceptions which, in quantitative research, would lead to disconfirmation of the hypothesis while exceptions in qualitative research would be fruitful and used to modify theories (Golafshani, 2003).

To increase the reliability and validity of this research, the interviewer took a special care to create a context of casual conversation, asking for true and honest opinions to limit the social bias of the interview. Furthermore, the triangulation of primary data collected through multiple interviews and secondary data from the literature also increases the reliability and validity of the research.

3.3 Analysis and results

The next section presents results and analysis of the practical part. The interviewees are first introduced and a summary of their thoughts about technology in libraries is proposed. The research questions are then answered subsequently, linking theory findings from the literature with practical findings from field interviews.

3.3.1 Interviewees presentation

Five semi-structured interviews were conducted in this research. Six different interviewees can be distinguished in two categories: academic library directors on one hand, innovation and making organisations on the other hand.

Academic library directors

Frédéric Brodtkom – BST

Since 2002, Frédéric Brodtkom is the director of the BST (Bibliothèque des Sciences et de Technologie), library of Sciences and Technology of the UCL. He was a university assistant in geology until 1997 and did a complementary master in management at the IAG, actual Louvain School of Management. Mr Brodtkom worked in the mining industry during eight years, also working with the European Union to draft a guide for good environmental practices in the mining industry. In 2002 the UCL needed a scientific person with management skills to lead the BST; answering this need, Mr Brodtkom came back to work for the university. In 2014, the BST moved to new facilities and became a library and learning centre, hence extending its missions. There are 12 people employed at the library (9,2 FTE – full time employees), which serves 4 different faculties as a sectorial library.

Fabrizio Tinti – BSPO

Since 2004, Fabrizio Tinti is working at the BSPO (Bibliothèque des Sciences Economiques, Sociales, Politiques et de Communication), library of Economical, Social, Politic and Communication Sciences of the UCL. He became director in September 2015, after working for 11 years for the library's public services (welcoming, trainings and others) and social media presence. 7 librarians are employed at the BSPO and have classical librarian skills in front and back office positions. In 2016, the library will hire a person specifically dedicated to study the

needs of patrons and bring detailed information for future improvements of the library services.

Ghislaine Declève – BSS

Since 1997, Ghislaine Declève is the head librarian of the BSS (Bibliothèque des Sciences de la Santé), Library of the Health Sciences of the UCL, on the campus of Woluwe in Brussels. She was a French language teacher, worked as a research assistant then for the medicine library's head librarian at the ULB (Université Libre de Bruxelles). 9 people are employed at the BSS (7,5 FTE), which is just enough to run all the library services. The physical visitors are only students coming to study in the premises, while researchers and professors access digital articles remotely and are extremely demanding about the quality of service. The number of researchers using library services is particularly big, counting hundreds of practitioners from many different research institutes.

Geneviève Bricoult – BTEC

Since 1990, Geneviève Bricoult is working in UCL libraries and became in 2010 director of the BTEC (Bibliothèque de Théologie) Theology Library of the UCL. Besides her responsibilities of director, she has multiple roles as a trainer for library trainers and co-teacher for religious science courses in multiple faculties. The library employs four people including its director (3FTE), which are helped by student workers at times. The particularity of the BTEC is that it shares a common reception desk with the neighbouring library of the Arts and Letters, merging together some complementary library services. Also, the library's public is specific as it welcomes particular users from the field of humanities, which still have a big need for an access to the paper literature, as a lot of useful resources are not digitalized yet.

Innovation and making organisations

Quentin D'Aspremont - OpenHub

Since 2014, Quentin D'Aspremont represents the OpenHub, one of the 7 creative hubs of Wallonia, initiated by the Walloon region's programme "Creative Wallonia". He is very active in the organisation, managing the collaboration with the Makilab (LLN's FabLab) as well as the physical expansion project of the OpenHub to turn it into a real "garage for innovators". In 2014/2015, the OpenHub conducted many pilot projects to create innovation-generating programs in the Brabant Wallon province.

This creative hub puts prototyping in the centre of its programs, which distinguishes the OpenHub from other creative hubs in the region. The OpenHub is collaborating with the UCL as well as other organisations of entrepreneurial companies and technological industries such as the CEI and AGORIA. The OpenHub is serving different groups of users: students, researchers and professors of the university but also companies of the private sector. Another function of the initiative is centralise technological equipment and offer it to different groups of users, hence creating lucky encounters.

Régis Lomba – Makilab

Régis Lomba is the co-founder of the Makilab, the Fablab of Louvain-la-Neuve created in June 2014, which is like an embryo of the future OpenHub. It focuses on the core activity of prototyping and deals with all the technical aspects of the project. The Makilab integrates very well in the OpenHub project, supporting many of the programs on the technical side. However, it also keeps its original and personal objectives of making rapid prototyping machines available to all publics, while promoting a “Do It Yourself” culture. Besides the OpenHub-related projects, the Makilab also holds trainings on Fablab-specific subjects such as 3D drawing, which are available for OpenHub patrons but also external people. This Fablab respects the conditions of the Fablab network to be called as such, and is hence a member of the international Fablab networks.

3.3.2 Technology in UCL libraries

To set the stage and understand the actual position libraries hold towards technology, questions about the place of technology in libraries were asked to the directors of those institutions. Different answers were gathered about how libraries adapt to modern information technology solutions. However, UCL libraries identify their missions and objectives according to the same guidelines and demonstrate a strong unity in their organisation.

Different libraries with the same missions

In December 2015, there are two sectorial libraries and seven faculty libraries at the UCL. Despite many different locations and different publics, UCL libraries’

organisation is very centralised and works with a lot of cooperation between the entities. Library directors regularly meet in a council to discuss and decide of UCL's library management with Mr Nyns, chief librarian, heading the council and managing the team of the libraries central service. Besides the main directors council, many specific workgroups are also researching and proposing initiatives in fields common to every library such as marketing, learning centres or access to people with disabilities.

Libraries at the UCL focus their efforts on four main missions: (1) Acquire, manage and make available on every support sources of information which are requested for research and teaching; (2) Develop services for the profit of their public; (3) Welcome, inform and train this public to the optimal use of those resources; (4) Organise and manage library spaces. There are also secondary missions of resources conservation. The mission of every UCL library follows this exact scheme and applies it to the patrons it serves in a specific field, for a faculty or a whole academic sector.

Every library commonly uses a series of technologies, definitely putting them at the centre of librarian regular operations. However, there are differences amongst entities regarding advanced new technologies, libraries do not always conduct the same technological initiatives, as the needs of their patrons differ.

Basic information technologies

Some core technologies such as computers linked to the Internet, copiers or scanners have been implemented in libraries a very long time ago, since their early days. Libraries were often pioneering in the use of those technologies for information management and documents conservation.

From the experience of interviewed directors, information and communication technologies have always been a core element of their profession. Recent technologies making documents available online and connecting users to resource databases are definitely used by UCL librarians, who are at the edge of librarian techniques and technologies. It is important to remain at the edge of modern techniques in their field, as they are essential for them to achieve the library missions.

Advanced new technologies

All the librarians agree on the importance of information and communication technologies in their field, and strive to excel at the use of those technologies to

achieve their first mission (mission (1) above). However, interests differ amongst libraries when it comes to the development of additional services for library patrons (mission (2)) or the organisation of library spaces (mission (4)).

Some librarians, but not all of them, mentioned original topics such as MOOCs (Massive Open Online Courses), LCD screens for information sharing or group works, the introduction of modular and thematic seminar spaces or even technological support for disabled people as a topic of investigation to enhance the library services and space management. The directors showed a lot of enthusiasm regarding different possibilities but there was not much consistency between the interviews to draw a specific pattern in needs that would be common to every library.

Nevertheless, one philosophy mentioned by every library director was the need to redefine library spaces into something broader, according to the concept of the learning centre.

As defined by the UCL libraries workgroup on learning centres, *“A learning centre is a venue presenting a reception, spaces, resources and diversified integrated services, that answer expressed needs. The dynamic of the centre facilitates student learning and research activities. It is also a living place, offering convivial and cultural spaces - UCL/BIUL GT Learning Center nov15” (Brodkom, 2015).*

One of the workgroups investigating initiatives of UCL libraries is thus dedicated to learning centres. The BSS considers this type of initiatives to enlarge its range of services, but didn't apply any concrete measures in that way yet. The BSPO decided to hire an additional person to conduct research about patron needs, to gather a micro perspective and establish an action plan for the improvement of library services, perhaps following the model of a learning centre if it fits users' needs. Mr Tinti thinks that it is now time for planning and action, and therefore made this first step towards new services. The most advanced UCL library in terms of learning centre is definitely the BST, which while moving to new premises in 2014 redefined itself as a library and learning centre, offering large spaces facilitating student learning and research activities.

Librarians do not hesitate to share their ambitions but they are still looking for understanding the needs of their patrons to set up concrete action plans and finally offer learning centre spaces, resources and services in their libraries.

Libraries position towards future technologies

Every library director that was interviewed in this study reported the needs of students, professors and researchers at the centre of their attention. The interviewees recommended conducting needs assessments with their patrons to ensure projects would answer a demand. In this regard, the directors believe that in union there is strength, and decided to conduct a common macro study named “Libqual” in all UCL libraries. Although bringing good quantitative macro data, this study will not provide the qualitative micro details, which are also necessary in defining the needs of patrons precisely. Another use of the unity between libraries is that an innovative project can be tested out in a specific library on a smaller scale while keeping other departments informed of the concept progress. If the project is a success, it can be expanded to other libraries with less risk. The idea of one person can therefore lead to a joint solution. This collaboration also gives the opportunity to test out several projects at the same time.

Libraries are very keen on investigating their users’ needs to upgrade their offering and perform better on their missions. It is in this environment of open and considerate libraries that the research was conducted.

3.3.3 Interest for digital fabrication and making at UCL

In this section, the interest for digital fabrication and making at UCL is analysed with a macro approach based on the global Fablab movement and with a micro approach based on interview results. The objective is to conclude whether or not digital fabrication, making and 3D printing projects meet a similar interest in Belgian academic libraries, as it is the case in some foreign countries.

International Fablab and making movement

As seen in the literature review, there are several theoretical reasons to the implementation of Fablabs in libraries. All types of libraries are concerned and the theory finds a confirmation in the real world. As noted in the theoretical part of this thesis, Gallant (2013) and Bodycomb (2014) say that it is difficult to estimate the exact number of academic libraries developing making projects (Bodycomb et al., 2014; Gallant, 2013).

Figure 11 – Fablabs in public and academic libraries, USA, December 2015



Source: Google Map by Sharona Ginsberg (2015)

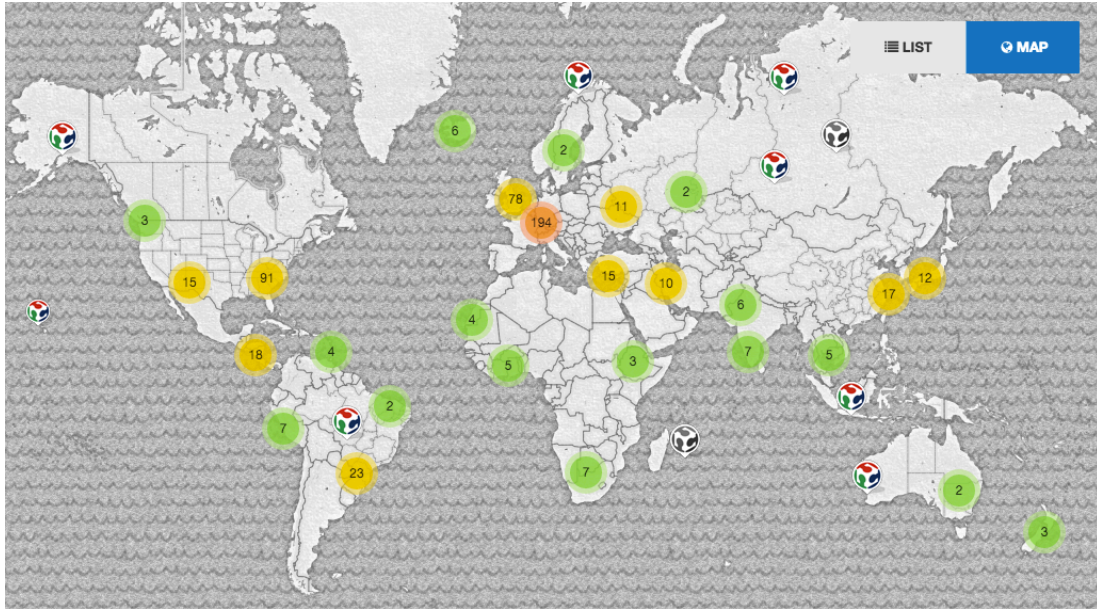
However, it is possible to find public and academic libraries in the USA which include Fablabs thanks to an initiative of Sharona Ginsberg (Ginsberg, 2015). This index is also reported on a map (See Figure 10) listing 20 academic libraries and 71 public libraries in December 2015, including the University of Texas at Arlington Fab Lab. Unfortunately, this initiative has not been conducted for other countries yet.

Besides traditional academic literature and Ginsberg's list, another way to find about Fablab initiatives in the academic world is to research Fablabs on the Fab Foundation database with keywords linked to higher education (Fab-Foundation, 2015a). In December 2015, 13 Fablabs were listed with the keyword "University", which is far below the real number of Fablabs having an impact on universities, due to the creative names often given to such centres and the fact that Fablabs are not always a direct initiative of Universities while still servicing academic users.

The interest for Fablabs and the making culture is tangible, as the Fablab Foundation lists 589 labs globally in December 2015 (see Figure 11). Regions of the world with the highest concentration of Fablabs are Europe and the USA, according to the Fab Foundation listing (Fab-Foundation, 2015a). It is unclear how the topic catches the attention of universities and academics on a global scale, but examples of academic

libraries developing such projects in the USA suggests a similar trend in other parts of the world as well.

Figure 12 – Map of Fablabs listed in the Fab Foundation, December 2015



Source: Fab Foundation

Local interest for digital fabrication and making

If the global interest for making and Fablabs is real, Belgian academic libraries should be concerned as well. As a first sign of confirmation, Mr Tinti (director of the BSPO) conducted some passive research and gathered information about other cases of 3D printing in libraries (BSPO, 2015). However, other UCL library directors may not be as much interested as Mr Tinti due to cultural differences in education systems. Therefore, specific questions were asked to ensure UCL librarians are also interested in 3D printing and Fablabs. The interview with the OpenHub and the Makilab also allowed understanding what a Fablab could bring to the UCL. The results of this section are therefore issued directly from the interviews conducted for this thesis. The discussions have been transcribed and are available in appendix 2 to 6 in French, language of the interviews. The answers of the interviewees were grouped according to the research questions and summarised in the next sections.

The interviewees liked referring to the three main missions of the UCL when answering questions about the usefulness of 3D printing at the university: teaching, researching and serving the society. The most important element of answer brought by every interviewee was the need to perform a needs analysis and understand clearly what patrons require before undertaking any realization of ideas. The 3D printing technology being more and more present in the news and in the society, librarians acknowledge the need of being up-to-date with the latest technologies and offering an appropriate access to them if those are identified as needs of library users.

It was found that the concept of learning centre as defined by UCL libraries fits particularly well with 3D printing and making technologies. The concept of a Fablab space is very complimentary with such library spaces, idea confirmed by the OpenHub and the Makilab who are already examining possible partnerships with the learning centre of the BST for some of their activities. However, some difficulties related to the nature of the technology arise when it comes to giving access to the machines and when users finally have to use them without too much guidance.

The interviewees shared concrete remarks about the development of 3D printing activities at the university for the core mission of teaching. For instance, it is believed that leaving the university in 5 years without having had the chance to work with 3D printers would be completely unthinkable in some fields of study such as engineering, medicine, architecture or arts. It is therefore important to give the opportunity to students to develop skills in using personal fabrication technologies, but this shouldn't hinder the learning of basic office software tools. In medicine as in other fields where students would be less curious and entrepreneurial towards personal fabrication technologies (basically everyone except science and engineering students), the initiative of installing 3D printing machines should be supported by a set of teachers, which would incorporate the use of the machines into their courses. If there is not enough academic incentives for using the technology, the machines would be mostly used for non-academic purpose and for leisure, which is not part of the libraries mission.

The second core mission of the university is research, and the interviewees also shared valuable insights regarding this mission. It is agreed that rapid prototyping technologies such as 3D printing can benefit in many ways to researchers at universities. Researchers can innovate by themselves without much training, which

makes them very good users of rapid prototyping technologies for innovation. Laboratories in many different fields would have an interest in this technology to support their research activities but according to most interviewees, the laboratories would have equipped themselves with their own budgets with solutions fitting their needs perfectly. In medicine, fields of dentistry and surgery would definitely be already using 3D printers in their labs without asking anything to libraries. The centralisation of some machines in an expertise centre servicing multiple laboratories and research institutes was proposed as a good idea. Indeed, researchers sometimes decide to put expensive resources together in a fabrication centre. For instance, a mechanical fabrication lab already exists next to the Makilab; this centre was created and used by researchers in mechanical engineering. However, for the development of similar facilities including other technologies and for different purpose, a needs analysis is still essential to ensure the university does the right investments. In other academic fields such as economical sciences, social sciences, communication, or arts and letters, it did not seem that researchers were using 3D printers, according to the interviewees. A needs analysis would be particularly necessary in those fields where the use of personal fabrication is not common today. On a side note, some public amongst researchers and university staff might be very demanding regarding schedules and the quality of the outputs, putting an additional pressure on a potential centralised fabrication lab to reach excellence in service.

Regarding the third mission of the university, which is service to society, interviewers again agreed that a centre with centralised technological equipment could also be useful for users external to the university. However, if those investments had to come from the university or the libraries themselves, the service should not be free of charge for external users. If the service is implemented by the university entities it should serve the users who are part of the university with more care and a financial advantage.

Additionally to the main missions of libraries and more within the mindset of a learning centre, the idea of making libraries technological discovery centres was proposed. As it is sometimes done in the USA, libraries can be the first entities to showcase new technologies to their users, as it was the cases with virtual reality where libraries were amongst the first places where people could try out and experiment the technology. It is a great additional idea but doesn't represent a

sufficient condition to rolling out a technology in a library noted Fabrizio Tinti. Furthermore, there are many other technologies than 3D printing in which users could be interested, so libraries should explore the benefits of multiple technologies on their institutions, not only Additive Manufacturing said Régis Lomba from the Makilab. Another interesting use of 3D printers if they were implemented at the university would be to adopt them for production of replacement parts, introducing the administrative staff responsible of material maintenance to the possibilities of latest technologies in personal fabrication.

Some librarians shared their preference for keeping a “wait-and-see” approach while supporting other libraries to experiment with projects, as they couldn’t think of relevant needs of their users that could be answered by this technology. The most entrepreneurial library that was the most advanced in discussions with the OpenHub and the Makilab is definitely the BST. Then, the BSPO demonstrated a lot of interest as well by conducting research, supporting this thesis and recruiting a special person to get a better understanding of the users’ needs.

The position of the OpenHub, which is very active in promoting innovation and making at the UCL and companies of the region, is that it is essential to re-learn how to create self-made stuff at university. In that regard, the OpenHub definitely sees a value in the interest of libraries towards 3D printing and recommends investigating how the making philosophy could eventually add value to libraries. For the case of the BST learning centre the added value can be understood quickly, but it is more difficult for the other libraries. Quentin d’Aspremont adds that it would be very interesting for libraries to connect with fellow academic librarians who successfully implemented a Fablab in their libraries to exchange on the best practices and share experiences in this field. Some cases might be very surprising, like the one of the Aalto media institute that implemented a Fablab inside their institute for the sole reason that both spaces typically attract users with the same profile of “early adopters”. This criterion of the patrons apparently was a sufficient one to implement successfully a Fablab in another existing space, extending the services and tools available in that place.

Last but not least, Frédéric Brodtkom and Ghislaine Declève mentioned concerns about different perceptions of academic libraries in Belgium and Anglo-Saxon or Nordic countries. They believe those differences might have an influence on the

development of AM services in Belgium. Specifically, the Anglo-Saxon and Nordic cultures place librarians at a very important and appreciated place in the society while in Belgium the sector is not as much popular or valued. This difference means that it is much harder to gather external support for any project initiated by a library in Belgium, compared to other countries. Also, in North America, the situation in libraries is better in terms of financing, staff and rules of staff employment. There are usually much more librarians per user and bigger budgets in the USA compared to Belgium, which helps providing many quality services and sets positive conditions to the implementation of 3D printers.

Confirmation of an interest for 3D printing and making

The results presented above are directly issued from the interviews with library directors and with the OpenHub and Makilab. The interviews were conducted in French, native language of the interviewees, and so are the transcripts in appendix 2 to 6. Interviewees' answers relative to the first part of the research question are presented above along with a geographic analysis of Fablabs.

While two interviewees shared concerns about cultural differences with other countries when it comes to perception of libraries, all study's interviewees showed a lot of enthusiasm regarding 3D printing and the making culture, thinking of many good impacts this culture and technology could bring to the UCL. Therefore, the first research question finds a positive answer, confirming an interest for 3D Printing and the making movement at the UCL and amongst the directors of its libraries. As we have noted the enthusiasm of UCL library directors regarding AM, the hypothesis of UCL libraries as a good place to set up an AM project is therefore issued and will be tested in the next section. This question will also take into account other existing actors such as Fablabs that operate nearby the university main campus. It is important to include them in the research, as every Fablab must offer at least one 3D printer to users according to the Fab Foundation criteria defining Fablabs.

The results presented in the two next sections are also a summary of interviewees' answers, now about the second and third elements of the research question.

3.3.4 Best place for AM projects at UCL

The qualitative research of this thesis started on the topic of AM in education and in libraries. The themes further developed from the literature are the place of AM in universities (most precisely in their libraries) and the sustainability of AM. The tentative hypothesis developed in the previous section proposes academic libraries as the place to offer 3D printing and other personal fabrication services. This section will test that hypothesis on the UCL field of study according to the results of the interviews, balancing the pros and cons of setting up a Fablab in a library. The goal is to determine whether or not UCL libraries should create a Fablab in their premises. As Quentin d'Aspremont mentioned: *"If the UCL was to involve its libraries as gateway to a specific technology such as 3D printing, it is important to ensure libraries will be able to provide appropriate access to this technology"*.

AM in libraries: the pros

Libraries and learning centres offer a secured space to university members

Many library directors present libraries as a safe space for displaying expensive technological tools and offering a secured and controlled access to university members during a large time window. Staff members are present to welcome users and can answer technical questions if needed. It is also possible to organise classes and book rooms in a learning centre for learning or research activities. The advantages of libraries compared to IT rooms are the controlled access and the availability of the staff to provide basic support to users.

Libraries have the willingness to claim themselves more as centres providing services. The process is well underway at the BST with the new learning centre recently created while the BSS has deep considerations for similar projects but no concrete actions yet. 3D Printing, personal fabrication and Fablabs perfectly fit in the concept of learning centre and might therefore be a great opportunity to go further on this path.

Libraries know the specific profiles of their users and can offer tailored services

Because personal fabrication involves a physical connection between the user and the object, the service must be thought locally for every UCL campus (Louvain-la-Neuve, Woluwe, Mons, Tournai, Anderlecht), answering the potential needs locally to offer a

complete service on the university scale. There are libraries on every campus, which could facilitate the spreading of the service for the entire university. Sharing experiences on the implementation and the operating rules would be possible as libraries work together on some topics within the specific workgroups.

Every field of study does not have the same requirements; the local presence of libraries and their knowledge of the field place them in a strong position for offering an adapted service. Their privileged contact with faculties and research departments is definitely an advantage to offer a service tailored to the local situation.

Libraries can offer services to a large population having similar needs

If the access to 3D printing and personal fabrication technologies is requested by a large number of users, the OpenHub and the Makilab could reach a critical mass and a saturation of their services. In that case, an open administrative service such as academic libraries would be a great partner to offer 3D printing services to a large population as they already offer services to many students, professors and researchers as explained Quentin and Régis. Libraries can also be a technological discovery place for larger publics that would not proactively think of using fabrication technologies said Fabrizio Tinti.

Libraries have a willingness to experiment upon user needs

Library directors are generally positive to experiment with 3D printers in libraries where the need for such technologies is expressed. Therefore, to identify the right place for offering new services, some libraries such as the BSPO are already conducting qualitative and quantitative surveys to understand the potential needs of their patrons and act upon them. Other libraries seriously consider investing time in deeper qualitative needs analysis to develop their services. To support those initiatives and share information, the board of directors could set up a specific workgroup related to that cause. Once the needs are known, libraries could also profit from the help of their IT teams to set up the relevant bundle of hardware and software in their premises.

Fablabs in libraries: the cons

Lack of qualified staff members to assist with the technology

A regular issue in libraries is the number of staff libraries can employ, which is often just enough to operate the core services of the library and a few additional services. Also, library employees are not always very comfortable with technological tools as many library directors admitted. Those employees should be trained to the use and basic maintenance of any new equipment. Trainings for the patrons themselves as well as bigger maintenance operations would better be subcontracted to experienced people from the making world, because of librarian's non-familiarity with personal fabrication technologies.

During interviews, it was noted that library directors had very little knowledge of the technical side of 3D printers, often underestimating the complexity of use of the machines and the file preparation process. People less familiar with using personal fabrication technologies also often underestimate the time investment beyond every print; it can easily take up to 15 minutes to simply understand someone's project and how to design and execute it. Then setting up print parameters is not always simple and often requires a trial error process that induces longer times for fabrication. Maintenance is also a heavy time consuming part of the job and it can easily take hours to solve a minor issue on a 3D printer. Those technical difficulties deepen the gap between required time and skills necessary to operate 3D printers with the time and skills librarians would have if 3D printing services were offered in a library. It takes a lot of time and passion to maintain a 3D printing service, which might not be easily found in today's librarian staffs.

Library trainers' skillset is broad, but making technologies and practices might go well beyond information technologies in which librarians are specialised. Régis Lomba confirms that personal fabrication technologies are a completely different world than information technologies: *"It is not because classic printers and 3D printers are called "printers" that they belong to the same set of technology"*.

Researchers already use rapid prototyping technologies in laboratories

Researchers knowingly use 3D printing as a rapid prototyping technology in their laboratories. Indeed, the polytechnic school of the UCL has invested in this type of equipment, enabling researchers and students to experiment with those technologies.

Offering the same machines outside of laboratories might not be very beneficial to researchers, reducing the benefits of 3D printers to the learning support mission of libraries. Furthermore, some professors and researchers in medicine at the BSS have demonstrated dissatisfaction because of libraries' strict access control policies, not willing to follow them. Putting resources together for researchers from different research institutes might be interesting, but this initiative should rather come from the researchers themselves if they feel it could help them access better equipment. However, putting resources in common strengthens the output quality requirements and the pressure lying on the shoulders of fabrication centres. Expert technicians in such a centre would be an absolute necessity. Libraries start from scratch in this field, which means the path for an up and running quality printing service might be long.

Focusing only on academic activities might be difficult for libraries

As in Belgium the role of libraries and librarians is perceived as less prestigious compared to Anglo-Saxon and Nordic countries, librarians tend to struggle more to get support for their projects, according to Ghislaine Declève. Therefore, in order to implement AM projects, academic libraries should seek direct support of professors who would include the use of AM technology in the curriculum. These projects would be highly dependant on teachers and their willingness to adapt the curriculum.

Furthermore, students come to the library mainly to study according to the director of the BSS. In some libraries, few practical works take place but the majority of patrons come to find a calm space to self-study. Noisy and messy activities generated by a Fablab may therefore disturb these users. The library must therefore carefully choose the space selected to hold a Fablab if it decides to set up this service.

Also, personal fabrication technologies have a lot of recreational applications, which might interfere with a sole focus on academic activities; the limit between leisure and academic use might sometimes be blurry. If external people used the 3D printing service for leisure purpose, Frédéric Brodtkom recommends making this service chargeable for those people, as the service should benefit academic activities in priority. A special charging system for non-academics would bring another layer of complexity in the implementation process. External users might also distract librarians for their primary mission of serving students and researchers, which is not valuable for libraries. The wide range of recreational activities enabled by personal

fabrication technologies might partially explain their popularity in public libraries so far according to Régis Lomba from the Makilab.

Libraries can only offer a part of personal fabrication possibilities

According to the practical experience of Régis Lomba, founder of a Fablab, it is important to remember that 3D printers are machine tools, part of a broader set of personal fabrication and prototyping tools. There is a high risk, according to him, of falling in the trap of the hype around 3D printing. People realise quickly that the machines are not that special, and that other tools like CNC milling machines using subtractive manufacturing are sometimes needed to get to the end of a meaningful project. Showing only 3D printers would even be discriminating towards other tools; people might miss a part of the personal fabrication spectrum and miss discovering other interesting tools and techniques if they are only introduced to 3D printers.

Libraries only developing a new 3D printing service besides their existing library services would be doing an incremental innovation to their regular activities. Instead, it would be possible to innovate disruptively by giving access to a full range of personal fabrication tools and methods to a much bigger group of users. According to Quentin d'Aspremont, it would be wiser for the UCL to think about a complete disruptive solution rather than simply put machines in some facilities. Furthermore, it would be interesting to investigate other technologies, as some might be even more adapted to the library setting. For instance, virtual reality glasses might perhaps be a good incremental service to the existing offer made by libraries.

In the last interview, Fabrizio Tinti confirmed what the other librarians previously mentioned about the fact libraries do not have much means nor spaces, and that modular spaces should be favoured to offer more than just a fabrication space, allowing other activities to happen as well. He concluded telling it is not useful to create a duplicate space on the same campus if the OpenHub and the Makilab could handle the demands of library users.

A synthetic table of the main ideas described in this section to answer the second research question is presented below.

Table 3 – Data summary table for the second research topic

AM in academic libraries: the pros	AM in academic libraries: the cons
Staff to welcome users	Lack of qualified staff with the relevant experience to maintain and operate a 3D printing service
Safe space with controlled access	Underestimation of the complexity and time investment for 3D printing services
3D printing fits in the learning centre concept	Fabrication technologies are totally different from information technologies
Multiple spaces offering services to the whole academic community	Researchers already use 3D printers in their laboratories
Local presence to adapt the service to user needs	High dependency to teacher willingness to adapt the curriculum
Willingness to experiment solutions upon expressed user needs	Many recreational applications may distract from academic focus
	Libraries can only offer a part of all personal fabrication technologies (AM)
	Limited means and spaces

An external Fablab filling university AM needs

As we understand from the summary of discussions held with library directors and personal fabrication experts, libraries have strong arguments justifying the placement of 3D printers in their spaces: namely security and the access to the whole academic community, a localised service answering the needs of respective patrons and great willingness to experiment.

On the other hand, they face several reasons playing against them: providing the appropriate staff with the relevant experience to maintain and operate a 3D printing service would be an issue; the researchers community has already found its ways to use rapid prototyping technologies; offering a complete range of personal fabrication

tools and techniques would be rather complicated; and it would be difficult to ensure a total focus on academic applications.

Furthermore, as Fabrizio Tinti mentioned, creating a duplicate and more limited service to what the OpenHub already offers in libraries would not be necessary as far as student needs can be answered through the OpenHub initiative. Indeed, the OpenHub already sustains a series of programmes for university members and for companies. “Innofaster” and “Fastmaker Corporate” programmes encourage companies to innovate by prototyping their ideas. Additionally, the “Fastmaker” programme, the “Art-Sciences” laboratory and “Innovation Classes” instil the innovator’s spirit to university students and external users. The extensive experience acquired by the OpenHub and the Makilab via conducting those programmes comes from both the industry and the university spheres, which places them both in a prominent position to answer the needs of early adopters of the UCL.

To conclude on this research question, results of the above analysis lead us to reject the hypothesis that university libraries are the best place to develop Additive Manufacturing solutions for academic users in the case of the UCL at the end of 2015. Indeed, the many uncertainties about academic library patrons’ needs consequently require more in-depth understanding before putting 3D printers in libraries. Until those are not clearly identified, librarians must consider the needs of the UCL in terms of personal fabrication and 3D printing as general and coming from a small community of early adopters. To answer such general needs, the OpenHub and the Makilab are better equipped in terms of experience and tools to answer those general needs. Those organisations are already actively working with the UCL, and appear in a better position comparatively to academic libraries to offer AM services on the UCL main campus of Louvain-la-Neuve as of December 2015.

In the discussion section below, the next steps and recommendations to act upon this conclusion are presented and discussed.

3.3.5 Supporting and ensuring sustainability of AM projects at the UCL

Before moving to conclusions, we will address the third element of the research question: how to support and ensure that making, digital fabrication and AM projects at the UCL are sustainable

As discussed at the beginning of this thesis, AM technologies have three types of sustainability implications according to the triple bottom line approach: economic, social and environmental. As a manufacturing method, AM is known for lowering inputs and outputs in the manufacturing process of low volume, customized and high value products. AM is also known for its impact on the entire product life-cycle and supply chain dynamics by bringing the possibility of producing locally (Gebler et al., 2014). Unlike in the AM industry, there seems to be a lack of sustainability guidelines for private users of AM technologies. Academic institutions could therefore play a role in defining missing sustainability guidelines and educating the new private users of AM technologies (Kohtala & Hyysalo, 2015). Hence, it is important for the UCL (or any other university) to support and ensure sustainability topics are developed in academic AM projects.

UCL library directors confirmed the value of sustainability for local projects. As Ghislaine Declève mentioned: a non-sustainable project would be demotivating and would break links between the library and its users but also within the library team itself. This section will thus develop economical, social and environmental sustainability implications in the UCL case study. Further recommendations from the literature about potential action points to improve sustainability are presented in the discussion.

AM Economic, Social and Environmental implications at the UCL

Economic implications

People interviewed in this study had a rather limited view on the economic implications, focusing on short-term issues. For instance, to maintain an AM project financially viable, Frédéric Brodtkom recommended to subcontract trainings to expert companies and to lease the equipment instead of buying it. The service should also be chargeable to non-members of the UCL. Ghislaine Declève added that the project should serve a given need during at least 1 to 3 years to justify the investments and not just be a temporary hype. In the long run, it would be important to not compete on prices against external services but keep a specialised service with a strong added value to university members.

In the literature, much broader and long-term economic implications are found. Universities could consider educating users and encouraging research about topics

such as the patent dynamics of local production, its impact on supply chains, the economic implications of additively manufactured products over their life cycles or the point below which AM is the most efficient process.

Social implications

The social dimension of sustainability was of smaller interest to library directors although the project had to inspire people and bring pride to project members. However, the social aspect was well present in the discussion with Régis Lomba, founder of a Fablab. His initiative invites people to experiment with new technologies, the interactions of different groups of people foster unexpected encounters and the personal fabrication philosophy offers alternatives to mass consumption models in a broader sustainability ground.

There would be much room for sociological research around AM, as the literature is still nascent. The analysis of labour pattern shifts or the development of people through open source technologies are examples of interesting issues bringing sociological and manufacturing topics together.

Environmental implications

The interviewees of this research could well understand the importance of the first-degree environmental implications such as the use of environmental-friendly and biodegradable materials or the amount of waste generated during the fabrication process. From his experience at the Makilab, Régis Lomba could develop further on environmental sustainability: he shared advices about the choice of materials and told examples of recycling projects that were prototyped in his Fablab.

However, AM has much larger implications on the environmental aspect. Significant economies of energy, and therefore reduction of the carbon footprint, can be achieved through unique lightweight designs created with additive manufacturing. Life cycle analysis is a common method to evaluate the ecological footprint of products and the awareness of such topics could be increased within the academic community.

By educating and researching on this type of topics, the UCL would participate actively in the development of new manufacturing standards. The university would play a greater role in the creation of a more sustainable society, which is in the end one of the greatest humanity's challenges nowadays.

3.4 Discussion

Academic libraries of the UCL have not developed any Fablab in their spaces yet unlike some university libraries abroad. However, the UCL is not particularly lagging at the local level, as other Belgian academic libraries have not developed Fablabs neither. Proactively starting research on the topic already places UCL libraries in a good position.

International case studies have so far reported on libraries implementing a small-size Fablab. In the UCL case, we do not recommend following the same model because a bigger project is possible thanks to external partners. Indeed, looking at the university from a helicopter view, an independent Fablab (the Makilab) is already operating on the main campus of Louvain-la-Neuve and the OpenHub is actively developing links between the Fablab and the UCL, creating diverse programs in making and innovation. Those external partners have a lot of technical experience, which gives the UCL a good starting base. The university should continue preparing for a plausible larger adoption of 3D printers in the society.

We have seen through this thesis that academic libraries at the UCL were not the best place to develop AM projects at the end of 2015 because the user needs and demands for personal fabrication technologies are very low and unclear to librarians. However, the situation is meant to change with the high adoption of those technologies in K-12 schools and with the growing use of additive technologies in many industries. The fundamental difference between information technologies (which are a speciality of libraries) and fabrication technologies is another element making libraries not the best place for developing AM projects, especially when taking in consideration the trainings and experience required to operate those tools. However, personal 3D printing is evolving fast and the technology might be adapted for a library use in a few years. A series of recommendations for the UCL libraries is therefore proposed below as librarians should stay informed on those technologies and explore how fabrication technologies could involve them in the future.

3.4.1 Recommendations for the UCL case study

The very first and most important action UCL libraries should take in the short term is to perform a deep qualitative needs analysis with their users (as the BSPO decided to do by hiring a specific employee dedicated to this type of research) putting a

particular accent on personal fabrication technologies. This needs evaluation would complement the “Libqual” quantitative macro study conducted at the end of 2015, offering a complete overview of library services and user needs. Informed decision-making for library services improvements would then be possible.

The second recommendation of this thesis is that UCL libraries should create a connection with their local Fablab, the Makilab, and with the OpenHub. Such relations are being developed by the BST but would also benefit other libraries. Some other actors such as the new UCL museum or the Point Culture also have initiatives regarding personal fabrication technologies. Connecting with those groups of people is also interesting for libraries to have an idea on the complete range of possible activities and practices.

Third, an international connection with academic libraries that have implemented personal fabrication technologies is highly recommended. For instance, UCL libraries could exchange experience with The University of Texas at Arlington Fab Lab, which is upgrading its making facility to reopen in 2016. The example of the Aalto Fablab, located within the Aalto media institute is another great partner to understand the dynamics between libraries and Fablabs. Connecting with those libraries can provide powerful insights to UCL librarians to improve their services if they face similar user needs as their colleagues abroad.

Those three recommendations for short-term actions will equip UCL librarians with the knowledge necessary to eventually set up supporting activities regarding innovation and the making culture at the university. In line with the needs expressed by their users, in collaboration with the OpenHub and the Makilab, depending on the experience shared with international universities, UCL libraries could organise events, conferences or expositions for researchers, professors and students of the university. Staying aware of the latest trends in the promotion of innovation will enable libraries to adapt to an always-changing environment and remain attractive meaningful places within universities.

This research also leads to making recommendations for professors and researchers at the UCL. Indeed, those members of the academic community could participate in teaching and research activities related to sustainability topics in AM, adding knowledge to this field. Some examples of possible topics are developed in the

theoretical part of this thesis. Sharpening research and learning activities on such topics would strengthen the UCL as a creator of a more sustainable society, supporting one of its main missions.

3.4.2 Critical evaluation and limitations

Qualitative studies generally have small sample sizes, allowing the researcher to have extensive interactions with the participants. In the case of this research, the sample of interviewees was indeed limited to 6 people in 5 interviews. The perspectives of all UCL library directors could not be gathered which might add some bias in the results. However, the diversity in the library profiles was large enough to have a general idea on the field reality. The interviews have been recorded and then transcribed in interview transcripts, which are available in appendixes 2 to 6. The research question has been addressed step by step according to its successive 3 elements; answers to those questions, scattered through the transcripts, have been grouped and translated from French to English in the summary presented in sections 3.3.3 to 3.3.5. This process of data processing and data structuration is also subject to the bias of the researcher. The results expressed in a narrative format are then describing a situation at a precise time point, which might be relevant in 2016 but not in five years time.

Also due to the nature of the research, a strong limitation of this case study research is its generalization to other universities. The practical part of this thesis focused on the UCL case might be applicable for other universities in Belgium, but cultural differences in the perception of the library within the society could make this case irrelevant in some other situations, as explained by Ghislaine Declève. However, the researcher has investigated the topic of AM in libraries thoroughly, interpreted the outcomes based on participants' (and not researcher's) perspectives and created a holistic picture of the situation. This complete outlook on the subject should be an interesting resource for UCL academic libraries to discuss further action points related to AM and personal fabrication technologies in their institutions.

3.4.3 Contribution and future research opportunities

This thesis adds knowledge to the existing literature about AM in libraries and to the topic of AM sustainability. Indeed, the literature review develops both topics thoroughly, giving to the reader a good overview about the existing knowledge on

those topics. Although the empirical part has brought less information about AM sustainability than about AM in libraries, the base knowledge necessary to conduct a research on the two combined topics is presented in the literature review; it is a good support to develop the case study research and could perhaps be of a similar use for further research in the same fields.

The existing literature in AM is very diverse and one can be confused by the abundance and diversity of papers about this technology. The first part of this thesis proposes a schematic cartography of the existing literature about AM and clarifies to any reader how to classify papers about AM. This allows to research related articles more easily but also helps to focus on a specific topic. It also helps to realise the breadth of AM impact across multiple and diverse industries. For this thesis, the cartography exercise helped in structuring the literature articles collected in the exploration phase to focus on a specific topic of the literature. Bringing the two very new topics of AM in libraries and AM sustainability together in a single body of work is also a unique approach that adds originality to this thesis.

Additionally to the contributions of the literature review, the practical part of the thesis generates a unique knowledge about AM in UCL libraries. The research question developed in this thesis is contemporaneous as it builds on the very recent trend and new applications of AM in education and in libraries, which appeared first in the USA. The research takes also an original approach to Christensen's disruptive innovation theory. It proposes to analyse the adoption process of a disruptive technology (desktop 3D printers) in a field of study (academic libraries) where another disruptive technology (personal computers) have significantly impacted the field. The result of the practical part is a clear answer to the research question and a discussion on the consequences of those answers. The outcome of the practical part is very relevant to the stakeholders of the case study. The international generalization of the study's results must be done carefully but it remains a good base reference for other academic libraries facing the same questions.

Future research could definitely build on this case study. A good example of future research would be the reapplication of the UCL case study with other libraries. Would it be an academic or a public library, in Belgium or abroad, in 2016 or in a couple of years once the market of personal 3D printing will have further evolved; any additional research providing new data on the topic of AM in libraries and the

sustainable implementation of similar projects will be an added value. Today, information is too scarce and literature on the topic is not sufficient to draw any general conclusion or pattern about the use of 3D printing in libraries.

The results on the sustainability point of view have underlined the important role universities can play in developing new AM sustainability standards. By educating students and sensitizing them to the stakes of personal fabrication and innovation, the university could also play a great role in the education of responsible citizens, knowing how to use personal fabrication technologies sustainably. Additional research about the dynamics and the impact of education practices on the use of AM technologies would help academics to improve their programmes.

Last but not least, research about the “new needs for university services”, which come with the development of AM, would definitely help universities to understand the recently appeared demands of students and researchers regarding personal fabrication. It was recommended to perform this type of research on the UCL campus, but a more general approach could perhaps identify trends in modern education and help universities to plan their future investments in technological tools.

4. Conclusion

Going back to the title of this thesis, its main objective is to have a better understanding of the place and role Additive Manufacturing could have in academic libraries, especially in the case of the UCL. The motivations for undertaking this research can be summed up in two points.

First, it appears from the literature and the media that, thanks to the disruptive innovation of desktop 3D printers, personal fabrication technologies are increasingly used in education and libraries. Understanding the history and the dynamics of this 3D trend, as well as implications of this new technology on higher education is therefore necessary for academic institutions that want to use the latest AM technologies in their field.

In the case of AM services at the UCL, what is needed is precise understanding of potential user needs and the associated added value that could be generated from AM projects. Informed reflections about technological investments will be made possible with a better understanding of AM local application. Therefore, this research aims at giving recommendations to UCL librarians so the topic of AM in libraries can move forward at the UCL.

Sustainability in AM is also a very new and important research topic developed in this thesis because of its importance for the future of manufacturing and the impact universities can have on supporting research in this field.

A literature review of AM in libraries and sustainability in AM was performed as a preliminary to qualitative research on the field. This theoretical work allowed the researcher to precisely frame the research question and prepare the approach for gathering relevant data. The research question of this thesis has three phases.

The first part of the research question studies if AM, digital fabrication or making projects are as popular in Belgian libraries as abroad. The answer to this first question is positive. All interviewees displayed a lot of enthusiasm regarding AM technologies and their possible applications in the academic setting while staying cautious not to just go after a hype but really answer user needs. The interest of UCL library directors for 3D printing and the making movement is confirmed in this study.

Therefore, the hypothesis of UCL libraries as a best place to develop AM academic projects is tested in a second phase. This hypothesis is rejected, as the needs for AM services in libraries are too low or too unclear for academic libraries. Furthermore, the existing Fablab of Louvain-la-Neuve and the OpenHub organisation appeared in a better position to make AM technologies available on the campus in the short term. Future cooperation between those organisations and academic libraries is recommended to exploit as much synergies as possible on the long run and offer quality services to students and researchers with the latest technologies in personal fabrication.

Last but not least, the sustainability considerations reported during interviews were very simple and oriented on the short term. The actual sustainability implications of AM seem to be much more developed. This observation leads to conclude that education has a role to play in raising awareness about AM and its sustainability implications.

The contribution of this thesis to the literature is to answer some key questions asked by UCL academic librarians with the advent of new disruptive technologies such as 3D printers.

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