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Additive manufacturing social impacts: a conceptual model

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"Não ter já mais nada para dizer e continuar a escrever é um crime.
Porque não tem o direito de continuar a escrever se não tem nada para dizer."
José Saramago, Prémio Nobel da literatura 1998

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Resumo

A tecnologia aditiva, também conhecida como impressão em 3D, está a ganhar popularidade entre o público em geral, os serviços de informação, e as indústrias. Acredita-se que seja uma tecnologia disruptiva, e, por isso, a avaliação dos seus impactos sociais é muito importante. Até ao presente momento, poucos trabalhos são encontrados nesta área. Os impactos sociais desta tecnologia ainda não foram identificados. Por esse motivo, o primeiro objetivo desta dissertação foi identificar os possíveis impactos sociais causados pela implementação desta tecnologia em grande escala. Foram encontradas onze vertentes sociais impactadas com a tecnologia aditiva. Essas vertentes encontradas foram: educacional; comercial; propriedade intelectual; emprego e trabalho; acesso à tecnologia; económica; ambiente e energia; cadeia de abastecimento; riscos de saúde e ocupacionais; cuidados de saúde e segurança; e abordagem governamental. Houve um total de vinte e seis impactos sociais entre estas componentes sociais. O segundo objetivo da dissertação foi determinar quem são as partes interessadas a quem esses impactos sociais afetam diretamente. Para isso, analisámos as categorias existentes de stakeholders numa perspetiva de avaliação do ciclo de vida do produto. De seguida, combinámos os impactos sociais com as categorias dos stakeholders, criando uma tipologia para os impactos sociais da tecnologia aditiva. A dissertação também considera, entre todas as categorias dos stakeholders, uma subcategoria onde se entende o tipo de impacto em cada um dos stakeholders. O terceiro, e último objetivo, cumprido por esta dissertação foi propor indicadores sociais para os impactos da tecnologia aditiva identificados. Uma lista de indicadores propostos é encontrada na dissertação. Esta dissertação resulta num modelo conceptual para analisar os impactos sociais de fabricação aditiva.

Palavras-chave: Tecnologia aditiva; impressão 3D; Impactos sociais; Análise do ciclo de vida; Indicadores sociais

Abstract

The additive manufacturing technology, also known as 3D printing, is gaining popularity amongst the general public, the media, and in the industries. It is believed to be a disruptive technology, and so the assessment of social impacts is very important. There are still very few works in this area and social impacts are yet to be identified. The first objective of this dissertation was to identify the possible social impacts caused by the implementation of this technology. There were found eleven social strands that were impacted with the additive manufacturing technology. These strands were: educational; commercial; intellectual property; employment and labour; access to the technology; economic; environment and energy; supply chain; health and occupational hazards; healthcare and safety; and governmental approach. There were found twenty-six social impacts amongst these social components. The second objective was to determine who are the stakeholders by those social impacts. For this we analyze the categories of stakeholders in a product life cycle assessment perspective, and matched the social impacts to the stakeholders' categories, creating a typology for the additive manufacturing social impacts. Amongst every stakeholder category, a set of sub-categories is proposed for each stakeholder too. The third, and last, objective, fulfilled by this dissertation, was to propose social indicators for the additive manufacturing impacts identified. A list of proposed indicators is found in the dissertation. This dissertation results in a conceptual model to analyze the additive manufacturing social impacts.

Keywords: Additive manufacturing; 3D printing; Social impacts; Life cycle assessment; Social indicators

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Chapter 1. Introduction

The first chapter serves to clarify the focus of this dissertation. The background, objectives, research design and structure of the study are explained in the next section.

1.1 Background

The additive manufacturing (AM) technology, also known as 3D printing, is gaining popularity amongst the general public, the media, and in the industries. This process unlike the traditional manufacturing technologies such as machining that produce the parts using a subtractive method (material removal) from a large raw material piece, creates the final part, from nothing, by printing successive layers of material (Khajavi *et al.*, 2014).

The relevance of the technology amongst the organizations has raised significantly in the past years since it can be used in many areas from medicine to airplanes. The applications of this technology are vast, and many are not explored yet. This interest of the organizations is easily justified since the AM can produce complex parts using an extensive diversity of materials, that is not possible with the conventional methods of production. With this, there is also a cost reduction for the companies, since permits to optimize the design for a lean production, through waste reduction (Chen *et al*., 2015; Ford & Despeisse, 2016; Tuck & Hague, 2006; Tuck *et al.*, 2007). This decrease is noticeable on the amount of energy, fuel, and natural resources used (Serres *et al*., 2011).

The technology offers an innovative set of opportunities for developing original ways to generate and capture value (Piller *et al*., 2015). Furthermore, the technology can be applied in the different life cycle of the product, and it is possible with this technology to extend the product life (Despeisse *et al*., 2017). Because of these advantages, large, small, and medium size enterprises that are inserted in various manufacturing sectors, are adopting the AM technology in their manufacturing processes (Petrovic *et al*., 2011). The AM technology represents major difficulties to the enterprises business model since it is an innovative approach to the standard business models, generating new value propositions regarding the cost structure (e.g. enables the production of small batches and uses economies of scales) and the value chain setup (e.g. local production or distributed production).

The sustainable manufacturing is the capability to use the natural resources for manufacturing in a conscious way, by developing products and services (with the aid of the new technologies, governmental measures and conscientious social behaviors) are capable to fulfill economic, environmental and social objectives, while preserving the environment, as the quality of human life is also improved (Garetti & Taisch, 2012). AM technology has the potential to be a manufacturing process with sustainability values (Despeisse *et al.*, 2017). However, there is still no clear understating in the impacts on industrial systems.

The AM technology is believed to be a disruptive technology, such as social networking, internet, e-mail, smartphones, etc. (Weller *et al.*, 2015). When observing the reaction between the society and these technologies, there is evidence that this interaction brought some notorious negative impacts on the society. Some examples of these negative impacts are companies using child labour workforce in the production of smartphones, a large number of legal battles because of copyright infringement with the globalization of the internet, governments are lacking regulations and laws in the question of privacy on the web. Knowing about these examples it is important to be ahead of the curve and prepared, by applying control methodologies and legislation to protect the best interest of the society and companies. This alteration can only be implemented if there is a broad understanding of the possible impacts of the technology.

There are a large number of companies that are already using the AM technology, and there are still very few developments in understanding the social sustainability of this technology (Ford & Despeisse, 2016). And so, when doing research, the shortage of documents in this area is apparent, and the existent literature provides few pieces of evidences that clarify this issue. This lack of understanding leaves a research gap. And that gap is what this dissertation aims to fulfill: the understanding of the social impacts of AM technology.

When the social impacts of the technologies are identified, there is a need to measure them. The social life cycle assessment (S-LCA) had been used to measures social impacts of some technologies. Di Cesare et al (2016) affirm that the main function of the S-LCA is to aid in the process of decision making. They affirm that in a S-LCA the positive impacts are favored over the negatives ones, since the positive impacts are the foundation of any social-related policy and intervention. When conducting a S-LCA the social impacts of a scenario in which the technology is implemented and a scenario in which is not are compared (Jørgensen, Finkbeiner, Jørgensen, & Hauschild, 2010). However, the scenario where the technology is not implemented is very difficult to assess (van Haaster *et al.*, 2017). The S-LCA is a recognized measurement methodology by Di Cesare et al (2016), they identify thirty-six case studies using S-LCA and thirty-seven that analyze theoretical frameworks on S-LCA.

For S-LCA to be relevant in policy support, there is the need to develop relevant indicators that can assess both positive and negative impacts (Di Cesare *et al.*, 2016). There are some references when doing an S-LCA, being one of them, the “Guidelines for Social Life Cycle Assessment of Products” from UNEP (2009). This guideline, provides a map, a plan, and flashlight for the stakeholders’ engagement in the assessment of social and socio-economic impacts of the products life cycle. This guideline is a reference for this dissertation since it provides a solid ground on understanding how the stakeholders should arrange the social impacts.

The relevance and importance of this study occur from the need to understand the social impact of the AM technology since the technology is contemporary, and there are still few studies and analysis on this subject. There is also a proposal for performance indicators to analyze these social impacts.

1.2 Objectives

This dissertation is aimed to propose a conceptual model for the social impacts of the AM technology. To accomplish this, this work focuses on three points:

- Identify the social impacts for the AM technology;
- Propose a typology of the AM social impacts;
- Propose performance indicators to measure the AM social impacts.

This study responds to the research gap previous identified and can be a contribution for future research in this area.

1.3 Research design

According to Meredith (1993) the use of conceptual research methods based on descriptive, experimental search results on an increase in the peripheral validity of operation management research outcomes and therefore they represent relevance to the managers. A conceptual model portrays, reflects, or duplicates a real episode, object, or process but does not explain it totally. Moreover, according to Meredith (1993) a conceptual model can take two forms: taxonomy or typology. Taxonomy are listing of items along a permanent scale. The typology, is a taxonomy model with two dimensions or more, where one dimension is not satisfactory to correctly classify an item, and the other one, or more, dimensions are to complement with measures needed. The typology does not explain the relationships but simply describes the event with more accuracy than other descriptions.

In this dissertation, a conceptual model will be proposed. The model pretends to represent the social impacts of the AM providing a basic representation or concept from reality. The model pretends to be a typology to classify and identify AM social impacts.

1.4 Structure of the dissertation

This dissertation will be structured in 4 chapters, being the first the present introduction.

The second chapter will focus on the theoretical background when there is a literature review on the definition of AM technology, and there is an identification of the social impacts of the technology.

Then, in the third chapter, a typology will be proposed, connecting the social impacts to the stakeholders involved in the product (produced with AM technology) life cycle. There is also a proposal for performance indicators to measure the social impacts identified.

For last, the fourth chapter will be the final conclusions for the work, identify the difficulties and limitations encountered, and advise themes for future development.

1.5 Summary

This chapter provides an overview of the dissertation. The aim, the objectives, and the justification of the research topic are reviewed. The dissertation is an exploration of the AM technology, more specifically, the social impacts of the technology. Although the limitations, since the scientific papers in this area are scarce, the dissertation investigates the past literature to understand the social impacts of a disruptive technology, in this case, AM technology. After this identification, the work will correlate the social impacts to stakeholders that are involved in the processes of this technology. After this identification, there is a pitch for performance indicators to measure these social impacts. The next four chapters will present in detail the objectives referred here.

Chapter 2. Theoretical Background

This chapter reviews the relevant literature about the compromising between additive manufacturing (AM) and social impacts. The chapter starts by explaining the process used in the literature review. This analysis is followed by a brief definition of AM technology and their processes. Following, the building capabilities of the AM technology are identified. Succeeding, there is an explanation on the relation between AM technology and sustainability. The chapter ends with the recognition of the social impacts of the AM technology.

2.1 State of the art

2.1.1 Review methodology

To achieve the dissertation objectives the research process started with a critical review of the literature. According to Grant & Booth (2009) critical review goes beyond mere description of literature and includes a degree of analysis, typically results in a model comprising the most significant items in the field. They describe the critical review as a demonstration that the writer has lengthily investigated the literature and critically evaluated its quality. A critical review usually results in a hypothesis or a model.

2.1.2 Literature review search

The literature review starts with choosing the most relevant keywords. This selection means that the keywords have to represent the theme, or subject, wanted. Considering this, two research strings were chosen: "Additive Manufacturing" and "Social Impacts"; "3D Printing" and "Social Impacts". This search was focused on the title and abstract of the paper, and not the full document. In a subsequent step, it is necessary to decide in which databases the search advances. The databases chosen were the "Web of Science" and "Scopus". The searches only brought papers until May 2017, since that was the date of the search. After doing the keyword search, the results were scarce. For the search with the keywords "Additive Manufacturing" and "Social Impacts", only three papers appeared. As the first search, the second one, with the keywords "3D Printing" and "Social Impacts", brought few results with only one paper. Table 2-1 provides the results of the research string search.

Since the structured search was not achieved, a non-structured search was the method used. This search was conducted by searching referred subjects from other authors within the papers mentioned in table 2-1, and then investigate the cited article. The search was for authors that combined the AM technology with some social approach, that could be governmental, medical, workforce-oriented or any other. This process was repeated various times throughout the papers found. In short, the search consisted of analyzing crossed references, to find relevant documents within the papers. This cross-reference analysis was the process to write the state of the art research in the thesis. The objective of the state of the art is to answer two questions:

- What is the AM?
- What are the social impacts of AM technology?

Table 2-1. Results from the search strings.

KEYWORDS	RESULTS
"Additive manufacturing" and "Social Impacts"	1. Chen et al (2015), "Direct digital manufacturing: Definition, evolution, and sustainability implications", Journal of Cleaner Production; 2. Gatto et al (2015), "Multi-disciplinary approach in engineering education: learning with additive manufacturing and reverse engineering", Rapid Prototyping Journal; 3. Minetola et al (2015), "Impact of additive manufacturing on engineering education – evidence from Italy", Rapid Prototyping Journal
"3D printing" and "Social Impacts"	1. Lau & Leung (2015), "Opportunities and impacts of additive manufacturing: A literature review", Proceedings of the International Conference on Electronic Business.

2.2 Additive manufacturing

2.2.1 Additive manufacturing characterization

The AM technologies are shifting the paradigm of designing and manufacturing products (Comotti *et al.*, 2016). AM, usually referred as three-dimensional (3D) printing, is a production process characterized by disposing materials layer-by-layer (Conner *et al.*, 2014). Khajavi et al (2014) refers to the AM as a digital technology since enables the manufacture of a tangible object from a 3D computer-aided design (CAD) file throughout three phases: (1) Generating a 3D CAD model of the object; (2) The CAD file is sliced into very thin two-dimensions (2D) layers; and (3) These 2D layers are then sent to the 3D printing machine one layer at a time. The 3D printing machines produce the object by printing each layer on top of the previous one, applying diverse solidification approaches of raw materials in its production chamber, until the last tier (Kruth *et al.*, 1998). This steps show the difference between AM and the conventional processes, such as subtractive processes, formative processes, and joining processes (Conner *et al.*, 2014).

The AM technology, firstly introduced as a rapid prototyping (RP) and 3D printing, was developed during the 1980s as a technique for producing rough prototypes of final products (Khajavi *et al.*, 2014). Since then, and according to Bourell (2009), this technology has been evolving continuously. Thanks to this evolution, progressively more parts are being produced with the appropriate precision and quality required to be used as final function components for specific applications (Gideon *et al.*, 2003).

Holmström et al (2010) consider that with the AM technology is possible for the customer, or user, to produce virtually any shape objects, without the typical limitations. At last, Holmström et al (2010) identify the following benefits of the AM technology when compared to other processes:

- The tooling phase is removed, reducing production ramp-up times and costs;
- Minor productions are still viable and cost-effective;
- The design can be changed rapidly;
- The object can be produced for a particular function, optimizing the manufactured product;
- Batches of one are possible (economic custom products);
- Possibility of waste reduction;
- Simples supply chains can be achieved; better lead times; and lower inventories.

However, the AM technology has its limitations. Weller et al (2015), classify the limitations in two categories: technological and economical The technical limitations can be: space is limited to the printable materials; quality issues of the objects produced; the finishing on the surface still requires some effort; AM still lacks tools and guidelines to take the full advantage of the technology; small production throughput time; and requires skills and intense experience. The economic limitation can be: the marginal cost of production is too high; there are no economies of scale; there are no quality standards; the products offering controlled by technical viability; requires skill and strong experience; limitations due to intellectual property rights and warranties; and requires significant training efforts.

Gao et al (2015) clarify the AM technology by making a relation between the categories, technologies, the “ink” used to print, the power source, and strengths/downsides of each one. This relation is found in table 2-2.

2.2.2 Building capabilities of Additive Manufacturing

The capacity of AM technologies to selectively place (multi) materials in space affords unique design and capabilities opportunities that are not possible with another production method (Gao *et al.*, 2015). The AM technology allows the production of multifunctional products, through the integration of various materials, creating functional assemblies, and parts with integrated circuits and sensors, clarified in table 2-3.

Table 2-2. Additive manufacturing processes characterization.
Adapted from Gao *et al.* (2015)

CATEGORIES	TECHNOLOGIES	PRINTED "INK"	POWER SOURCE	STRENGTHS / DOWNSIDES
Material Extrusion	Fused Deposition Modeling Contour Crafting	Thermoplastics Ceramic slurries Metal pastes	Thermal Energy	• Inexpensive extrusion machine • Multi-material printing • Limited part resolution • Poor surface finish
Powder Bed Fusion	Selective Laser Sintering	Polyamides / Polymer	High-powered Laser Beam	• High accuracy and details • Fully dense parts • High specific strength & stiffness • Powder handling & recycling • Support and anchor structure • Fully dense parts • High specific strength and stiffness
	Direct Metal Laser Sintering	Atomized metal powder (17-4 PH* stainless steel, cobalt chromium, titanium ti6Al-4V) Ceramic powder		
	Selective Laser Melting			
	Electron Beam Melting		Electron Beam	
Vat Photopolymerization	Stereolithography	Photopolymer Ceramics (alumina, zirconia, PZT)	Ultraviolet Laser	• High building speed • Good part resolution • Overcuring scanned line shape • High cost for supplies and materials
Material Jetting	Polyjet / Inkjet Printing	Photopolymer Wax	Thermal Energy / Photocuring	• Multi-material printing • High surface finish • Low-strength material
Binder Jetting	Indirect Inkjet Printing (Blinder 3DP)	Polymer powder (plaster, resin) Ceramic powder Metal powder	Thermal Energy	• Full-colour objects printing • Require infiltration during post-processing • Wide material selection • High porosities on finished parts
Sheet Lamination	Laminated Object Manufacturing	Plastic film Metallic sheet Ceramic tape	Laser Beam	• High surface finish • Low material, machine, process cost • Decubing issues
Directed Energy Deposition	Laser Negineered Net Shaping Electronic Beam Welding	Molten metal powder	Laser Beam	• Repair of damaged / worn parts • Functionally graded material printing • Require post-processing machine
Notes: * - It contains approximately 15-17.5% (17) chromium and 3-5% (4) nickel, as well as 3-5% copper; + - alpha-beta titanium alloy featuring high strength, low weight ratio and excellent corrosion resistance				

2.2.3 Additive manufacturing and sustainability

Manufacturing is comprehended by converting raw material inputs into products or services (Ford & Despeisse, 2016). The AM technology has the potential to deliver several sustainability advantages, such as higher material use; less material and energy loss due to lower levels of inventory; less waste and better waste management; and user-oriented products amongst others (Chen *et al.*, 2015).

A recent study in the field investigated and examined at which level are these potential advantages being realized (Ford & Despeisse, 2016). From the study, it is not possible to affirm whether AM has the least environmental impact compared with the other manufacturing technologies since the life cycle assessment of parts produced with AM technology is highly correlated with the machine operation (Faludi *et al.*, 2015). The AM technologies allow machine and tools sharing, which is a key feature on reducing environmental impact (Ford & Despeisse, 2016).

Table 2-3. Additive manufacturing capabilities.
Adapted from Gao et al (2015)

CAPABILITIES	FEATURES	APPLICATIONS
Multi-material printing	• The designer can specify materials properties (hardness, flexibility, adhesive properties, etc.)	• Produce pieces of art • Creating flexible joints while maintaining the stiffness of the members
Printed assemblies	• The components have gaps in the region of the hundredths of a millimeter, such that the parts can produce the intended motion correctly	• Physical working models • Complaint mechanisms • Articulated models • Locomotive robots • Prosthetics.
Embedding foreign components	• Offers the opportunity to add different components (circuits, sensors, etc.), while the part is printed • Provides the capability for the fulfillment of applications such as actuated robot limbs, keen assemblies with built-in sensors, and energy gathering devices with piezoelectric parts	• Shape deposition manufacturing • Stereolithography • CNC accumulation • Ultrasonic consolidation • Material jetting • Extrusion
Printing circuits, sensors, and batteries	• Direct Writing can be used to create patterns of conductive materials, by enabling the selective deposition and patterning of material	• Signal Routing • 3D antennas • Conformal electronics • Strain gauge sensors • Force and magnetic sensors

Chen et al (2015) indicate that the connection between the economic and ecological performance of manufacturing systems in AM technologies is very powerful. Ford & Despeisse (2016), claims that producing small and medium batches of metal parts using the AM technology is economically opportune and can compete with the standard methods. Ford & Despeisse (2016) also pointed out that the prices of the machines and materials to build parts using AM are currently high, but these prices will tend to go down as AM develops in the most used production method.

Atzeni & Salmi (2012) conclude that AM can reduce time and costs from the design phase to manufacturing, claiming that the economic gain, the growth of efficiency and the improvements on the project's processes, analyses, assessments, and production are greater than that from only avoidance of investment in tools. The measured outcomes of the sustainability impacts of AM regarding costs, energy, and CO_2, display that the entire life cycle of 3D printed parts has sustainability potential. Gebler et al (2014) claim the cost reduction to be in the region of 170 - 593 billion US $, and the avoidance of CO_2 emissions in the 130.5 - 525.5 Mt region by 2025.

AM materials are not unavoidably more environmentally friendly than materials used in the common techniques for production, despite the potential recycling rate (Ford & Despeisse, 2016). "*It cannot be categorically stated that 3D printing is more environmentally friendly than machining or vice-versa*" (Faludi *et al.*, 2015, p. 25). The environmental impact of AM depends on the machine utilization. A low usage (one part per week), results in a small contribution to the overall environmental impact if the devices are switched off when not in use (Faludi *et al.*, 2015).

There are few studies in the field of knowing the social sustainability of AM technology (Ford & Despeisse, 2016). Huang et al (2013, p. 1200) identified the positive impacts of AM:

- *Customized healthcare products to improve population health and quality of life;*
- *Reduced environmental impact for manufacturing sustainability;*
- *Simplified supply chain to increase efficiency and responsiveness in demand fulfilment.*

The AM technology may have health benefits when compared to the conventional industrial processes since the workers avoid extended periods of exposure to potential hazards surroundings (Ford & Despeisse, 2016). Nonetheless, Huang et al (2013) affirms that the operators in the AM machines need to be well-informed in the handling and disposal of the materials used for the build, as well as the processing of high-intensity laser beams. The same authors defend that slow and continually, the AM technology is becoming safer for the operators as new safety features are being developed and applied in AM machines.

2.3 Social impacts

Di Cesare et al (2016) defines social impacts as the consequences of positive and negative pressures on social areas of protection. Sutherland et al (2016) refers that a social impact is thought of as the direct or indirect effects on humans observed by stakeholders, that are the people involved in the life cycle of the product. An immediate impact is often clearly recognizable, quantifiable, and restricted spatially, and can be easily correlated to business, while the indirect impacts need not be in close proximity to an enterprise. In the same article, is stated that these impacts can be positive (e.g. increasing literacy or facilitating gender equity), extremely negative, (e.g. promoting slavery or allowing discrimination), or something in the middle, (e.g. child labour or encouraging extra working hours that surpass the country-allowed maximum).

To identify a social impact, it is important to define what constitutes a concern for the social well-being. van Haaster et al (2017) define four main areas for the concert of social well-being:

- *Autonomy.* It is defined as an individual being in control of himself and his resources, and it can be negatively impacted when activities disable this control. For example, child labour or slavery;
- *Safety, security, and tranquility.* This area of concern combines freedom from threats to human health and property. This area still concerns in the positive impacts connected of employment, that can go past monetary compensation but also comprise the satisfaction of an individual due to self-realization;
- *Equality.* It is defined by the level of inequality amongst countries and regions. This level of inequality can be negatively impacted when the income distribution is not equal;
- *Participation and influence.* Defined as the capacity of an individual to take part or share in something that affects the development of the event. It is the ability for an individual to participate in a decision-making process.

van Haaster et al (2017) affirm that when doing a life cycle assessment, the concept of “social utility” must be present. The “social utility” is defined by the potential positive social impacts. This is the benefit a product can accomplish that surpass the quantified function.

2.4 Additive manufacturing social impacts

Since the AM technology is a relatively new technology becoming global, the social effects of the technology are yet to be fully understood and identified. Because of this, an early awareness of possible social consequences of AM technology is a requirement.

No available literature clarifies in detail the social impacts of the AM technology. The literature review supports the collection of several pieces of evidence that identify eleven categories of social impacts. Each social impact is discussed in the next sub-sections.

2.4.1 Educational perspective

Because of the high rate of AM production technologies adoption, it is necessary to educate the workforce on how to employ AM (Gao *et al.*, 2015). Minetola et al (2015) assess that affordable AM devices and basic techniques can be an important tool in the formation of successful engineers, that can acquire hands-on experience and skills both on engineer design and AM technologies. The author claims that AM technology as the third industrial revolution. In universities, the usage of AM equipment is often justified as part of research efforts or training students on methodologies of 3D printing machines (Gatto *et al.*, 2015). According to Campbell et al (2012) "hybrid" designers that are capable of taking their concepts from nature and then convert them into product forms that will also perform efficiently and ergonomically. People with design and modeling skills will fabricate self-designed spare parts at home (Minetola *et al.*, 2015). This will extend the products' life-cycle and durability. Minetola et al (2015) defend that this potential to change the product life-cycle motivates the education on educating people about the use of AM technologies.

2.4.2 Commercial view

As referred early, the AM technology can extend the life cycle of a product. The manufacturers around the world are exploring this AM capability (Gao *et al.*, 2015). Namely in aerospace, defense, power generation, and medical device manufacturing industries. The AM technology allows the production of single parts (Tuck & Hague, 2006), and, the economic output of low and medium size batches. The AM production can be very flexible and can introduce technologies and products that were not possible to obtain, or very difficult, with traditional technologies. This flexibility and technology availability creates opportunities for reducing cost in production, through waste reduction, labour, stock holding and can deal with changeable demand patterns. Tuck & Hague (2006) also claim the cost reduction to be capable of changing manufacturing environment on a global scale, returning the foreign production to the country again, as the labour costs are now smaller or non-existent. Atzeni & Salmi (2012) referred that when considering time, the AM also takes an advantage that the production of the part can begin as soon as the CAD file is released, reducing delays and eliminating processes such as tooling.. As referred early, the AM technology can be used to produce customized parts to suit the specific needs of a consumer. Tuck & Hague (2006), consider that the development of AM technology and full customization still have unclear answers on how to implement. Regarding, they still believe that the manufacturing environment will be drastically changed, what will, subsequently, change the economic environment.

2.4.3 Intellectual property

With the knowledge of how other technologies evolved, the growth of 3D printing, as the potential popularity becomes mainstream success, can be easily anticipated that some legal battles for intellectual property (IP) are being developed (Hornick & Roland, 2013). IP owners will face some difficulties: almost everyone will be able to reconstruct the existing product design, change, and produce the product, or part, to their specific requirements, and use or distribute it. The IP has three primary protections: copyright, patent and trademark (Susson, 2013). With the number of 3D printers at home raising, printing complex structures, as electric devices, becomes very common, and this can be worrying for the utility patent holders, in the same way that the Internet, file sharing networks and piracy stressed the music industry and the copyright system (Hornick & Roland, 2013).The authors affirm that even if the patent holders are cognizant of the transgression, the process of sue every part involved (at-home manufacturers) in the offence would not be very cost effective, since that the number of people transgressing should be abundant. Vis-à-vis copyrights, there are various products that are not copyrightable, leaving this group of products more vulnerable to be 3D printed at home, where the process will be effectively unnoticeable (Hornick & Roland, 2013).

With this it is possible to understand that the legislation is not beside the 3D printing evolution and this will be more serious, the more mainstream 3D printing becomes. Kurfess & Cass (2014, p. 38) assert: "*the digital manufacturing revolution has accelerated user capabilities well beyond the capacity of traditional legal structures to provide intellectual property protection*".

2.4.4 Employment and labour structures

With the AM growing inside the industry, the paradigm of the labour structure tends to change (Gebler *et al.*, 2014). These changes, according to Campbell et al (2011), can benefit the developed world, amongst the aging societies, since it may reduce the need for labour and imported products as production. The technology will allow companies to regain productivity in these societies, which would otherwise fell as the ratio of people unemployed grows. This growth will result in an increasing demand of qualified workforce, and so 3D printing will create new jobs and industries (Garrett, 2014). Pearce et al (2010) mention that an example of this will be the open source printers that will be a reason for people to have CAD and design skill. The same authors affirm that this will *encourage training and provide meaningful sustainable employment* in which the skilled workforce could contribute back to their community, becoming product designers of technical support experts on the 3D printing community. West (2015) on the other hand, affirms that with the exponential expand of the market of 3D printed objects, the easiness and capabilities of this technology will increase. Therefore fewer design people and factory workers are required. This can have a negative impact on the community around 3D printing factories.

So, the AM technology can, in one hand, increase the job demand for specialized people, but, on the other hand, decrease the number of workers in some industries.

2.4.5 Access to the technology

The price of open source 3D printers are in a range that are accessible to the majority college students, that will allow the share of engineering drawings to open access, resulting in a sustainable development (Pearce *et al.*, 2010). The home 3D printers, regarding sustainable development, will allow to produce low cost parts with open source designs custom-made to local needs (Pearce *et al.*, 2010). Since these designs are from open source, they can be produced and modified freely and locally using a computer. That local prediction can be scaled globally and used by other communities to satisfy their needs (Mikhak *et al.*, 2002). This explains the expansion of 3D printers, and, subsequently, the AM technology to the public.

2.4.6 Economic

Garrett (2014) supports that the globalization of the AM technology can change the paradigm of the actual economy's global structure because the production and distribution would be de-globalized with the manufacturing of the parts closer to the local communities. The author affirms that this location of the production could potentially as the countries with large export volumes lose their export significance, which will change the import and export economy amongst all countries. This is referred as an *import substitution*.

2.4.7 Environment and energy consumption

The manufacturing of goods requires energy and raw materials. Huang et al (2013) state that one-third of the energy consumed USA is used for industry. The same authors affirm that one-third of the energy consumed in USA is used for industry two reasons:

- Energy efficiency improvements (Huang *et al.*, 2013);
- Structural changes: mainly in the product and off-shoring the production of high energy consumption products (The National Association of Manufacturers, 2005);

Although the consumption of energy has reduced, a study conducted by Gutowski et al (2009) revealed that the energy consumption per unity of material has increased dramatically over the past decades. In the study is mentioned that the new manufacturing techniques can deliver benefits to the society and environment, because it is possible to produce in finer dimensions and minor scales at lower rates, which resulted in a very large specific electrical work requirements. In the study, it is stated that *the seemingly extravagant use of materials and energy resources by many newer manufacturing processes is alarming and needs to be addressed alongside claims of improved sustainability from products manufactured by these means*. With this is necessary to understand the environmental impact of the AM technology.

When considering an environmental impact assessment off AM processes, the opinion is that AM environmental friendly (Luo *et al.*, 1999). When a product is made using AM technology, it means that only the needed amount of material was used, whereas in the established subtractive production technique, a lot of waste is generated, resulting in more mass and energy consumed than in AM processes (Huang *et al.*, 2013). Luo et al (1999) point that the AM technology does not require any cutting fluids, that are the main cause of hazards and contamination in manufacturing waste. Huang et al (2013) refer that AM technology can have a lesser impact in the pollution of terrestrial, aquatic, and atmospheric systems.

In a study conducted by Serres et al (2011), an AM technology process is compared to the conventional machining process, by implementing an extended life cycle assessment. The experimental result revealed that the AM technology is much more environmental friendly, with a reduction of the environmental impact of 70%. However, when compared to other manufacturing techniques, AM technology has unique features in the systems complexity and operating style (Huang *et al.*, 2013). In the ATKINS project (Hague & Tuck, 2007), is conducted a comparison – in terms of energy usage, water usage, landfill usage, and virgin materials usage – between AM and other manufacturing processes (namely casting, flexline machining, and clean machining). In this study, it is shown that the AM technology does not consume less energy than the common production techniques. From the study, it is possible to conclude that the AM technology:

- Consumes more energy that the other processes;
- Has 0 kg of water usage per component;
- Has 0 kg of landfill waste;
- Just uses more virgin materials than clean machining;
- Produces 0 kg per component of hazardous waste.

One possible reason for why the AM technology's energy consumption are greater, could be due the measure used (Huang *et al.*, 2013). The same authors affirm that the AM building alone is not a heavy energy consumer. But when considering the whole process, the AM may not have an advantage on the other processes, regarding energy consumption.

2.4.8 Supply chain

Mentzer et al (2001, p. 4) define the supply chain as *a set of three or more entities (organizations or individuals) directly involved in the upstream and downstream flows of products, services, finances, and/or information from a source to a customer*. Choon Tan (2001) defines that this group of companies includes raw material suppliers, component suppliers, final product manufacturers, wholesalers/distributors, logistics service providers, and retailers. The materials flow from suppliers to the customer, through various steps, while the information flows backward.

Tuck et al (2007) sustain that the AM technology has the potential to improve the standard supply chain:

- AM can improve the efficiency on a lean supply chain with just-in-time (JIT), through waste elimination;
- AM can also improve the responsiveness of an agile supply chain.

This is justified, firstly because the AM reduces the number of processes and steps in manufacturing. Secondly, the technology also allows the implementation of a build-to-order structure to ensure that stakeouts never occur.

Studies made by Hasan & Rennie (2007) and Walter et al (2004), investigate the AM technology in the spare parts industry. Both authors study the aircraft industry, that faces a constant race against the time to provide maintenance and repair as fast as possible. A large number of parts are combined to assemble a commercial airplane. Huang et al (2013) affirm that the supply chain in the aircraft industry is represented by a large safety stock with part's substitutes. With the AM technology, it is possible to solve this problem, although with some limitations because AM technology is still in development, preventing the economical production of all the parts.

Hasan & Rennie (2007) proposed a business model that rests on the importance of an e-business to integrate the AM technology in the supply chain. This model is a symbiosis between design environment, process/material selection environment, and trade environment. This idea ensures a total coverage from end-to-end, from design until the distribution (Ariadi *et al.,* 2008). In their model, Hasan & Rennie (2007) propose the potential services:

- Sourcing or discovery: Facilitate the access between buyers and suppliers, saving time and giving better prices to the customers, raising the competition amongst suppliers:
- Demand identification: Suppliers identify the customers' needs, in a free market economy;
- Content: The existence of an e-catalog with a vast number of products, allowing the customer to obtain the product needed;
- Transaction: Actual exchange of procurement information, between customer and supplier;
- Promotion: Advertisement through the platform.

Holmström et al (2010) propose two other concepts to involve AM in the supply chain. The first model is bycentralized rapid manufacturing to replace holding. This model consists in centralizing AM machines, in printing centers to produce slow-moving parts on demand. The advantage of this model is to aggregate demand from the regional service locations to improve the availability of spare parts and reduce the inventory holding costs. The disadvantage is that centralized inventory increases the response time. In the second model, they propose that distributed rapid manufacturing can be used to replace inventory holding and conventional distribution. This model is suitable when the demand of the parts is too high, justifying the capacity investment. With this model, the response time is reduced, and so the transportations costs. Holmström et al (2010) conclude affirming that further research needs to be developed to understand the integration of AM in the supply chain.

2.4.9 Health and occupational hazards

Huang et al (2013) pointed that conventional processes, such as casting, forging, and machining can leak gases, liquid, noise, and wasted powders that are a potential health and occupational hazards. They identified the main health risk generated in the conventional production processes is the oil mist in the fluid for metalworking. This oil mist, when in long-term exposure, can increase the probability to various types of cancer (Huang *et al.*, 2013). Noise is also a risk source, being the most common work-related injury in the USA, disturbing 22 million workers (NIOSH, 2017). Huang et al (2013) allege that these problems may be avoided with AM technology. However, they affirm that this technology can trigger other health problems.

Having this information, it is important to investigate the AM technology to understand the toxicological and environmental risks when using the AM technology.

It was found that when the operator becomes in contact with chemicals present in the AM process, skin reactions, eye irritation, and allergies can occur by inhalation or direct contact (Huang *et al.*, 2013). Long exposure to these chemicals can lead to chronic allergies.

In a research done by Drizo & Pegna (2006) it was identified that gases with noxious environmental impacts, such as carbon monoxide (CO), carbon dioxide (CO_2), and oxides of nitrogen (NO_x) are produced in AM processes. Hui et al (2002), identified that halocarbons (CFCs, HCFCs, CCl_4), trichloroethane (CCH_3CCl_3), lead and nickel compounds are also generated in AM operations.

The need for the standardization of the materials used in AM processes, the potential toxicity, environmental hazards is an urgent, and, still an unattended, topic according to Drizo & Pegna (2006).

To Huang et al (2013) safety equipment, education and formation are a must when handling any AM machine. Despite all the concerns, they argue the AM technology will be safer in the future with the time.

2.4.10 Healthcare and safety

Dobriansky et al (2007) stress that the global population is aging in a fast pace: in 2006, roughly 500 million people were 65 and older, by 2030 this number will increase to 1 billion people 65 and older. This is a very worrying scenario, and so, technology needs to be developed to properly assist in the solving of this problem, or, at least, in lessening it.

Regarding this, the technology must be focused in aiding the global majority of the global population. Since the population is aging in a fast pace, the technology developed must be appropriated to assist the elderly. When using the AM technology, it is possible to produce parts custom-made to the patient needs. In the study made by Melchels et al (2012), is shown the potential of AM technology to produce organs and tissues. The AM processes can evolve into a technology platform allowing suppliers to produce tissue-engineered constructs with economic of scales in the years to come.

The AM technology is being used in the production of surgical implants. One example is a study conducted by Singare et al (2004), where AM technologies were used to develop a mandible to be integrated in the skull of an individual But more works have already been developed for other body parts: knee joint (He *et al.*, 2006); elbow (Truscott *et al.*, 2007); and hip joint (Popov & Onuh, 2009).

Another application for AM technology, is the production of personal protective equipment (PPE). Since the equipment is custom made, when using the AM technology, it provides the safety features as well as comfort for the user (Huang *et al.*, 2013).

Giannatsis & Dedoussis (2009) affirm that when looking at the benefits of the AM technology in the health area, the initial investment is justified. However, affirm the same authors, there is still a large amount of research to be done in the development of reliable manufacturing of systems and materials.

2.4.11 Governmental approach

As seen, the manufacturing of spare parts using AM technology is very likely to happen and become more mainstream. These spare parts, as seen, can be produced and altered at home, if open-sourced. Regrettably, some of these open-source platforms can be used to produce parts that are security threats (Gebler *et al.*, 2014). Open source CAD files of weapons, now banned from the internet, allows the users to produce the parts necessary to assemble a firearm at home, violating the International Traffic in Arms Regulations (Simon, 2013).

The governmental acceptance of this technology is usually high since the government can view the benefits of the AM processes, like the reduction of resource-intensified manufacturing, and the development of the new markets (Campbell *et al.*, 2011).

2.5 Summary

In this chapter, it can be found overview how the AM technology is characterized and its respective processes. The social impacts regarding the usage of AM technology were also displayed in the chapter.

There are eleven categories of social impacts, resulting in twenty-six impacts gathered between the social impacts. These categories, as their social impacts are presented in figure 2-1.

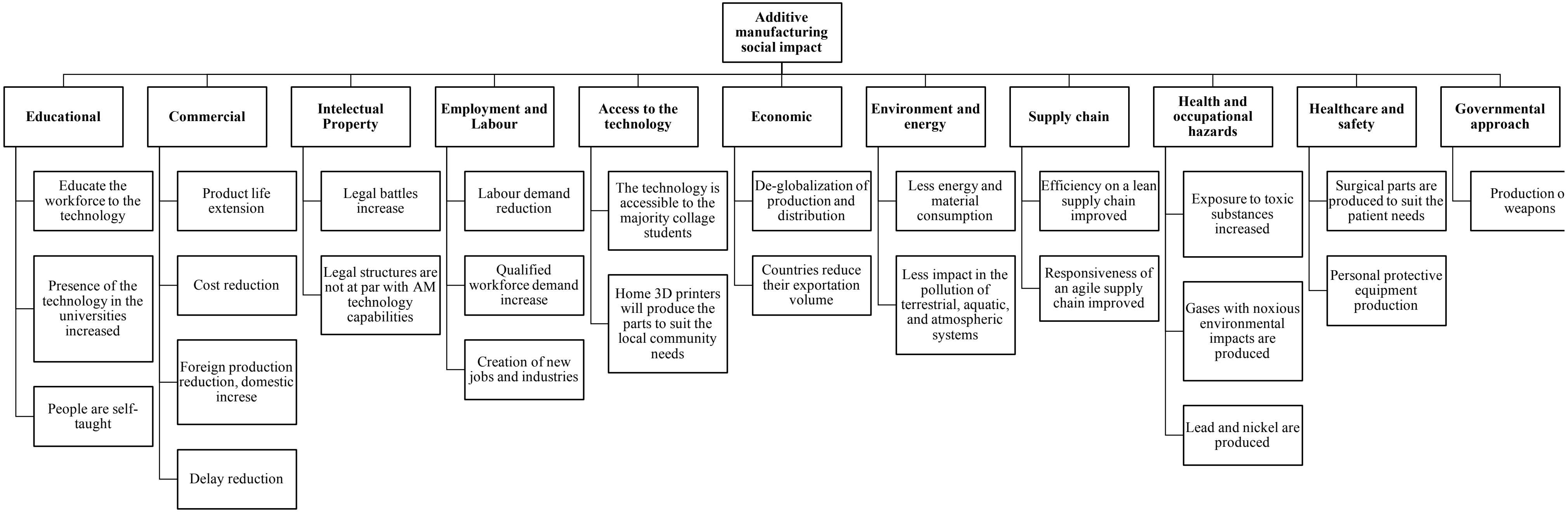


Figure 2-1. Additive manufacturing social impacts

Chapter 3. A typology for additive manufacturing social impacts

In this chapter, the focus will be on classifying the social impacts by stakeholders' categories, and consequently, propose performance indicator for those social impacts. The first part will be designated to define the stakeholder categories. Secondly, the stakeholder categories will be divided into stakeholder subcategories. Lastly, the social impacts identified in the previous chapter will be correlated to each stakeholder category and subcategory.

3.1 Social impacts assessment

To better understand the AM social impacts on the stakeholders, it is necessary to comprehend the direct and indirect stakeholder groups affected by the operations of a manufacturing company (Sutherland *et al.*, 2016). The stakeholder *is any group or individual who is affected by or can affect the achievement of an organization's objectives* (Freeman & McVea, 2001, p. 5). The stakeholder category can be defined, according to the United Nations Environment Programme (UNEP) guidelines (UNEP, 2009), as groups of stakeholders with a unique, or multiple, shared interests in the investigated product system within the context of a product life cycle.

With the social impacts identified in chapter 2, it is now necessary to correspond those impacts to the people involved: the stakeholders. In this chapter, the social impacts will be arranged according to the different stakeholders' group throughout using a product life cycle perspective. The challenge, when treating social aspects, is that the impacts can be transverse to a group of stakeholders, and not stakeholder driven, and they are difficult to measure in a quantitive way.

The literature review (presented in chapter 2) do not identify any study focusing the measurement of AM social impacts. However, there are several frameworks, models, and tools available to measure the social impacts of products and technologies.

Benoît *et al* (2010) affirm that social life cycle assessment methodology (S-LCA) is a methodical process using the finest existing science to gather finest existing data to report about social impacts, both the positives and the negatives, in the product life cycle from the creation to the disposal According to them, the S-LCA has the great potential to increase the knowledge, and endorsing the improvements of social condition in product life cycles. Since it can be used to recognize, study about, communicate, and report social impacts, and prepare strategies and action plans.

There are assessment tools used by companies to facilitate de decision making. There are two main tools for sustainable decision-making. The first one is sustainability return on investment (S-ROI), and the second one is product social impact assessment (PSIA). Laurin & Hayashi (2010) wrote a paper on S-ROI, where they define it has a streamlined, step-by-step approach to recognizing and weighting objectives/criteria that are relevant to each stakeholder. The PSIA is a handbook that has means to evaluate the potential social impacts of a product or a service throughout its life cycle (Fontes *et al*., 2016).

3.1.1 Stakeholders categories

In order to develop a S-LCA, it is important to define who the social impacts are going to affect. Considering this, it is important to identify the stakeholders that are affected by the AM social impacts. The UNEP "Guideline for Social Life Cycle Assessment of Products" provides stakeholders' categories, that participate in any part of the product life cycle, from the creation to the disposal (UNEP, 2009). Additionally, the UNEP "The Methodological Sheets for Sub-Categories in Social Life Cycle Assessment (S-LCA)", divides each stakeholder's category into defined subcategories. This comes in great aid when matching a social impact to a stakeholder. The methodological sheet also proposes a list of performance indicators that can be used to measure the social impacts (UNEP, 2013).

The guidelines propose five main categories of stakeholders for the social and socio-economic impacts:

- Workers / Employees;
- Local community;
- Society;
- Consumers;
- Value chain actors.

Each of these stakeholders' categories represents a cluster of stakeholders that are expected to have common interests, due to their similar relationship to the product, or, in this case, technology. These main categories proposed, according to the guideline, are deemed to be the main group categories potentially impacted throughout the product's life cycle.

The State is considered a multidimensional stakeholder with various roles. According to the guideline, the State has a crucial regulatory role, since they may be the entity responsible for the production of the product, and, they may be impacted by, or, impact with, the product utility.

The reason that the State is not a separate stakeholder category in the UNEP guidelines mentioned, is because the impact of the products' production on government is not referred in the corporate social responsibility framework and literature. However, with the mutation of the goal and scope of a study, it is plausible that the State will be needed to be addressed as a specific stakeholder. Even if the States are not identified as a separate stakeholder category, its distinctive status and role are not overlooked.

The possibility to add categories, such as: NGOs, public authorities/state, and future generations, exists, according to the guideline. The addition of new categories allows the subcategories to be more precise and detailed for a specific stakeholder.

3.1.2 Stakeholder subcategories

The subcategories present in the guideline, for the social and socio-economic have been defined according to international agreements. Because this guideline must be neutral and a referential for all cultures and policies, the work needs to go beyond personal and cultural bias or even political orientation. It is a responsibility, that, when defining the categories, subcategories and inventory indicators, the proper references to international instruments should exist.

The guideline identifies the international conventions on Human Rights and Worker Rights to be a solid foundation for a social life-cycle assessment (S-LCA) indicators framework. When referring social conventions, the guidelines states that these often represent a minimum to achieve, and that the non-compliance, in many countries, can be related with criminal offences. Because of this, the guideline clarifies that when considering the creation of additional categories and indicators, these should surpass the minimal compliance and assess additional and complementary social impacts must be considered.

The subcategories of the five stakeholders' categories, are shown in Table 3-1. For each subcategory founded in the UNEP document, "The Methodological Sheets for Subcategories in Social Life Cycle Assessment (S-LCA)", there is an explanation of the subcategory (UNEP, 2013).

Table 3-1. Stakeholders' categories and subcategories.
Adapted from UNEP (2009, 2013).

STAKEHOLDER CATEGORIES	SUBCATEGORIES
Worker	Freedom of Association and Collective Barging Child Labour Fair Salary Working Hours Forced Labour Equal Opportunities / Discrimination Health and Safety Social Benefits / Social Security
Consumer	Health & Safety Feedback Mechanism Consumer Privacy Transparency End of Life Responsibility
Local Community	Access to Material Resources Access to Immaterial Resources Delocalization and Migration Cultural Heritage Safe & Healthy Living Conditions Respect of Indigenous Rights Community Engagement Local Employment Secure Living Conditions
Society	Public Commitments to Sustainability Issues Contribution to Economic Development Prevention & Mitigation of Armed Conflicts Technology Development Corruption
Value Chain Actors	Fair Competition Promoting Social Responsibility Supplier Relationships Respect of Intellectual Property Rights

3.1.3 Assessment instruments

In order to proper assess the social impact assessment must be done with proper tools and software. With this in mind, is important to refer important social impact assessment instruments.

- SimaPro – it is a LCA software tool, used to measure the sustainable product development, sustainability goals, or research (SimaPro, 2017). With these measurements, the process of decision making becomes simpler, and solid, allowing positive changes on the product's life cycle.
- Global Reporting Initiative (GRI) – it presents a form of standardization in measuring and reporting on social, environmental and economic impacts (GRI, 2017). The GRI guidelines propose a series of performance indicators, in addition to a list of cross-cutting and sector-specific aspects to consider.

- ISO 26000 – it is the normative for social responsibility. This ISO elucidates the companies and organizations in what a social responsible activity or operation represents (ISO26000, 2017). ISO foundations are seven core topics covering social, environmental, and organizational aspects. This ISO is non-sector specific.

3.2 Performance indicators

The impacts identified are prejudicial if the enterprises have no mean to measure them. So, it is important to make a solid identification of the potential impacts but is also equally important to have conscious performance indicators that can are a reliable supply of data to analyze and assess the impacts.

3.2.1 What is a performance indicator?

To Hughes & Bartlett (2002) a define performance indicator is a mixture, or arrangement, of achievement variables that pretend to represent a part, or all, characteristics of a performance. A performance indicator to be valuable should report successful performance or outcome.

According to Searcy et al (2016) the indicators can be divided into two main categories: quantitative and qualitative. The same authors define the quantitative indicators as the numeric information provided based on quantifiable data. The qualitative indicators which are focused on data that cannot be straightforwardly presented numerically are better presented textually or visually. Searcy et al (2016) affirm that both indicators have value, but quantitative indicators have an advantage since are more suited to exploration focused on judgments of performance inside and amongst businesses over time. The indicators can also be semi-quantitative when the data collected is for example questionnaires with “yes” or “no” responses, or, rating scale responses (UNEP, 2013).

The performance indicators are mostly quantitative in business surroundings since they represent the structures and processes of a company (Badawy *et al.,* 2016).

3.2.2 Studies with social indicators

van Haaster et al (2017) defends that an aspect to take in account when designing social indicators is the direction of the impact. The author affirms that the LCA indicators have, in principle, a negative impact, and the objective of the indicator is to decrease the impact. When considering the social indicators, this is not necessarily true since the social impacts can be positive, therefore the indicator can be to increase the impact. Table 3-2 gives an example of some indicators proposed by van Haaster et al (2017).

Table 3-2. Indicators for social impacts

Adapted from van Haaster et al (2017)

INDICATOR (UNIT)	DEFINITION	TYPE	DESIRED DIRECTION FOR SUSTAINABILITY
Safety, security and tranquility Knowledge-intensive jobs (h)	High-skilled employment. Includes workers as managers, professionals, technicians and associate professionals for which education is required	Quantitative	Positive
Total employment (h)	Share of the labour force—the total part of society that is available for work—that is working	Quantitative	Positive
Possibility of misuse	Potential use of the technology that causes harm to people or society. The vulnerability of the novel technology to be used in hazardous ways such as sabotage or terrorism	Qualitative	Negative
Risk perception	Observation of hazard by the general public. The perception of risk can cause instability because of decreasing overall feeling of safety in a society	Qualitative	Negative

3.3 Impacts vs. Stakeholders

The definition of the stakeholders (and their subcategories) supports the identification of the social impacts that could be felt because of the AM deployment. In the document released by the UNEP (2013) the following information is provided for each stakeholder subcategory: the explanation of the subcategory and who is affected; the policy relevance; the data assessment, where is possible to find suggested indicators for the subcategory.

In this dissertation is a proposed a categorization of the AM impacts, previously identified in chapter 2, using the UNEP (2013) stakeholder's subcategories. Moreover, it will be proposed performance indicators for the AM impacts referred in the previous chapter. In case there are no indicators available in UNEP (2013) to measure a social impact, an indicator is proposed by the dissertation author.

The following subsections content is supported on the guideline of the UNEP (2013).

3.3.1 Worker

Of the AM impacts found, five belong to the worker stakeholder's category. The subcategories of these impacts are the "Social Benefit / Social Security" and "Health and Safety".

The social security is recognized as a basic Human Right, protected in the Universal Declaration of Human Rights (1948). Although it is a basic Human Right, the enhancement and extension is still one of the main challenges in this century. The “Social Benefit / Social Security” subcategory is defined by the non-monetary compensation. These compensations include medical insurance, wage insurance, paid maternity and paternity leave, paid sick leave, education, training and others. For this reason, the AM impact “Educate the workforce to the technology” fits the definition since the education and training is a social benefit for the worker. Moreover, if the qualified workforce increases, the organizations have the need to educate and train their workers. Hence, the “Qualified workforce demand increase” also fits the definition.

The sustainable development can be achieved without assuring a healthy and safety working environment. A healthy and safe work conditions are one of the greatest interests of the social policy of the international and European level. The health and safety subcategory is defined by the promotion and preservation of the maximum degree of physical, mental and social well-being of the workers in all occupations. Because of this, “Exposure to toxic substances increased” and “Safety equipment, education and formation” are AM since they related with the safety or well-being of the worker. The “Personal protective equipment production” is also related to the safety of the worker since the AM is a new method to produce protection equipment for the worker.

Table 3-3 matches the AM impacts to the subcategories, and the indicators to the impacts.

Table 3-3. Workers’ additive manufacturing impacts and indicators.

STAKEHOLDER	SUBCATEGORY	AM IMPACT	INDICATOR
Worker	Social Benefit / Social Security	Educate the workforce to the technology[a]	Number/percentage of workers educated by the organization
		Qualified workforce demand increase[b]	Number/percentage of educated workers, by job category
	Health and Safety	Exposure to toxic substances increased [c]	Number/percentage of injuries or fatal accidents in the organization by job qualification inside the company[*]
		Safety equipment, education and formation are required[c]	Preventive measures and emergency protocols exist regarding accidents & injuries[*]
		Personal protective equipment production[c]	
Notes: [a] Gao et al (2015), [b] Garret (2014), [c] Huang et al (2013), [*] UNEP (2013)			

To measure those social impacts:

- “Number/percentage of workers educated by the organization”. Describes the number of workers that the organization gave formation about the technology. It can also be a ratio of the workers within the company that are educated to the technology, by the company. This indicator is quantitative and has a positive desired direction for sustainability.

- "Number/percentage of educated workers, by job category". This indicator reveals the amount of the workforce that is qualified. Describes the number, or ratio, of the qualified workers within the company. This indicator is quantitative and has a positive desired direction for sustainability.
- "Number/percentage of injuries or fatal accidents in the organization by job qualification inside the company". Reveals the number, or ratio, of injuries amongst the workforce in the company, by job qualification (UNEP, 2013). This indicator is quantitative and has a negative desired direction for sustainability.
- "Preventive measures and emergency protocols exist regarding accidents & injuries". This indicator reveals the measures taken to ensure the well-being of the workforce (UNEP, 2013). This indicator can reveal the competence of the measures taken, or even the number of measures taken. This indicator is qualitative, or semi-quantitative depending on the approach, and as a positive desired direction for sustainability.

3.3.2 Society

There were found seven AM impacts that fit in the society stakeholder's category. These impacts are considered in two subcategories: "Contribution to the economic development" and the "Prevention & mitigation of armed conflicts" (table 3-4).

The economic development is an elementary condition in the fight against poverty and hunger. When sufficient wealth is generated, is possible to satisfy fundamental needs that represent the human well-being. The organizations have the possibility of exploring the lower tier suppliers and employees, or they can create a sustainable economic development, by choosing proficient suppliers and productive workers. The economic development of a company can be represented in various ways. When a company creates jobs, generates revenue, provides education and training, makes investments, or promotes researches, is contributing to the economic development. When referring to the "Presence of the technology in the universities increased" AM impact it is not directly related to the companies, but, as seen early, the demand for qualified workforce is increasing, so the introduction of this technology in the education systems is a preparation for the students to generate value for the companies later, contributing to the economic development. The impact "Delay reduction" at the first glance, hardly seems a social impact, but, from the Operation Management prespective, the delays are a waste that a company has. And so, the reduction of the delays, contributes to a reduction of waste, implying an economic development. The "Cost reduction" is an obvious contribution to the economic development of a company, because even if with the introduction of the technology the revenue stream is maintained, with a cost reduction the profit will automatically increase. The impacts "Efficiency of a Lean supply chain improved" and Responsiveness of an agile supply chain improved" are another clear contribution to the economic development since these impacts allow the companies to be more competitive. "De-globalization of production and distribution and Countries reduce their exportation volume" are impacts that can affect positively or negatively depending on what is being assessed, for example, the de-globalization of production is negative for the countries that are losing production, but this is positive for the home countries since they receive more volume of production. The same happens to the exportation volume since the country is exporting is losing volume and revenue, but the country importing is reducing costs. The indicators, in this case, are for the entity that possesses the technology. The "Creation of new jobs and industries" impact is again another obvious contribution to the economic development. To examine the contribution to the economic development of an organization, the data gathered should capture the annual production, the annual revenue, paid wages, investments, research and development costs.

Table 3-4. Societies' additive manufacturing impacts and indicators.

STAKEHOLDER	SUBCATEGORY	AM IMPACT	INDICATOR
Society	Contribution to economic development	Presence of the technology in the universities increased [a]	Number/percentage of graduates trained for the AM use
		Delay reduction[b]	Contribution of the product/service/organization to economic progress (revenue, gain, paid wages, R+D costs in relation to revenue, etc.)*
		Cost reduction[c]	
		Efficiency of a Lean supply chain improved[d]	
		Responsiveness of an agile supply chain improved[d]	
		De-globalization of production and distribution[e]	Economic situation of the country/region (GDP, economic growth, unemployment, wage level, etc.)*
		Countries reduce their exportation volume[e]	
		Creation of new jobs and industries[e]	Relevance of the considered sector for the (local) economy (share of GDP, number of employees in relation to size of working population, wage level, etc.)*
	Prevention & mitigation of armed conflicts	Production of weapons[f]	Organizations' efforts to stop the manufacturing of weapons using AM

Notes: [a] Gatto et al (2015), [b] Atzeni & Salmi (2012), [c] Tuck & Hague (2006), [d] Tuck et al (2007), [e] Garrett (2014), [f] Simon (2013), * UNEP (2013)

For a sustainable development to occur, peace and security are a primary strategic objective. Considering this, it is important to assess the role of the organizations' impact of the development of existing conflicts and forming conflicts. When a tense state between two, or more, different parties caused by different interest, aims of values systems occurs, a conflict is emerging. The guideline refers that are some specific regions around the globe that are known for enduring turbulences, also called, conflict zones. The subcategory “Prevention and mitigation for armed conflicts” also considers if the company is acting inside the conflict zones. Despite the “Production of weapons” impact is not a region oriented, the easiness in the production of weapons may be promoting the armed conflicts in these fragile regions, and in others.

The social indicators proposed are:

- “Number/percentage of graduates trained for the AM use”. This indicator reveals the number, or ratio, of students that finish the graduation with AM technology skills. This indicator is quantitative and has a positive desired direction for sustainability.
- “Contribution of the product/service/organization to economic progress (revenue, gain, paid wages, R+D costs in relation to revenue, etc.)”. This is a set of indicators that should, together, reveal the economic development of a company (UNEP, 2013). The intent is to show how the technology altered the economics of an organization in various areas. This indicator is quantitative and has a positive desired direction for sustainability.
- “Relevance of the considered sector for the (local) economy (share of GDP, number of employees in relation to size of working population, wage level, etc.)”. This indicator shows how the technology is affecting the company’s relevance on the local economy (UNEP, 2013). One aspect of this relevance is the number of employees compared to the size of the working population. The creation of new industries can also be evaluated by the contribution to those new industries in the GDP. This indicator is quantitative and has a positive desired direction for sustainability.
- “Organizations’ efforts to stop the manufacturing of weapons using AM”. The goal of the indicator is to assess the efforts made by the companies to regulate, or even forbid, the production of weapons using AM technology. This indicator is qualitative and has a positive desired direction for sustainability.

3.3.3 Consumer

Two AM impacts were found that match the consumer stakeholder’s category. These AM impacts fit in two subcategories: “End-of-life responsibility” and “Health and Safety”.

The organization, when entering new markets with fairly lenient regulations regarding product disposal and consumer health and safety, should go further than the minimum requirements. This is specifically relevant since the waste produced in the developed countries is being transported to developing countries to be disposed and recycled. The product life cycle has an end, and the end-of-life represents the disposal, reuse or recycling of the product. When the customer has the ability to extend the lifetime of the product, and, consequently, extending the life cycle of the product, it is possible to affirm that the consumer has a direct impact on the end-of-life responsibility of the product. With this, the AM impact "Product life extension" fits this category because when usually comes the time of disposal, the consumer has the ability to extend the life of the product. Considering that is the consumer that will extend the life cycle of the product, the data required to compute the indicator should be collected amongst the consumer. And maybe collected throughout interviews, for example.

The health and safety subcategory pretends to understand if the organizations' products and services perform their intended functions and do not pose any risk to the consumer's health and safety. But also, the objective here is to understand if the technology is being used to help the customers in medical treatments. The AM social impact "Surgical parts are produced to suit the patient needs" fits this description because the production of surgical parts must be regulated so that the materials and other characteristics of the part do not compromise the healing process of the patient. And, on the other hand, there is a need to understand if the AM surgical parts produce the intended effect, that is a positive impact. The data should be gathered at hospital reports, or laboratories that produce the parts for the patients.

Table 3-5 can improve the comprehension of these impacts by connecting them to subcategories and indicators.

Table 3-5. Consumers' additive manufacturing impacts and indicators.

STAKEHOLDER	SUBCATEGORY	AM IMPACT	INDICATOR
Consumer	End-of-life responsibility	Product life extension[a]	Number of products "recycled" by the users using AM technology
	Health and Safety	Surgical parts are produced to suit the patient needs[b][c][d][e]	Revenue of laboratories producing parts using AM Or Number of complaints, by the patients, regarding AM surgical parts
Notes:[a] Gao et al (2015), [b] Melchels et al (2012), [c] He et al (2006), [d] Truscott et al (2007),[e] Popov & Onuh (2009)			

The social indicators proposed are:

- "Number of products "recycled" by the users using AM technology". This indicator pretends to assess the number of products that the users recycle using AM technology, prolonging the life of the product. This indicator is quantitative and has a positive desired direction for sustainability.

- "Revenue of laboratories producing parts using AM technology". This indicator reveals the usage of the AM surgical parts since the revenue of the laboratories that produce the parts is related with the number of patients using this procedure. This indicator is quantitative and has a positive desired direction for sustainability.
- "Number of complaints, by the patients, regarding AM surgical parts". The indicator has the objective to understand if the AM technology is posing a risk to the health and safety of the patients. The indicator measures the number of patients, submitted to AM surgical implants that registered complaints about the procedure. This indicator is quantitative and has a negative desired direction for sustainability.

3.3.4 Local community

In the impacts referred in the second chapter, were identified nine AM impacts that affect the Local Community stakeholder. These nine AM impacts will be arranged in five subcategories: "Cultural heritage"; "Local employment"; "Access to immaterial resources"; "Safe and healthy living conditions" and "Access to material resources". These AM impacts will be associated with indicators. Table 3-6 offers a better comprehension on the subject.

The deterioration of the cultural heritage as the organizations enter new markets can occur during the globalization. For this, is important for the organizations to consider the historical and evolving cultural traditions, as something to preserve. The cultural heritage represents the pillars on how the community behaves: their language, social and religious practices, knowledge and traditional craftsmanship, as well as cultural spaces and objects. The international human rights conventions guarantee the rights of the individuals to preserve their cultural heritage. This cultural heritage can be promoted by the organizations, by encouraging the use of traditional products and craftsmanship product design and production methods. When considering the impact "people are self-taught", the technology is not forced into the community, but the opposite. The community wants to be engaged in the technology. And the impact "Home 3D printers will produce the parts to suit the local community needs" can also be included in the cultural heritage since the community will produce parts custom to their needs, which means that there are no standard parts for all the communities that disrupt the local cultures.

The organizations have the possibility to encourage a sustainable development between the community, through local hiring preferences. The local workers have a unique understanding of the relevant community subjects. Giving preference to the local community when hiring, represents an increase in the income and training opportunities to the community. The AM social impact "Foreign production reduction, domestic increase" can increase the community employment. In the other hand, "The labour demand reduction" impacts suggest that an AM technology production will reduce the workforce needed.

As the organizations develop into developing markets, refining homegrown services, access to information and liberty of expression are important constituents of sustainable development. The organizations, in addition, to learning and preserve the local knowledge and tradition should also pass the knowledge to the community through training programs and education. When the organizations promote the community services, such as healthcare, schooling, and lending programs, they are building the community relations and improving the access to immaterial resources. One way to build this access to the immaterial resources, according to the guideline, is by sharing information, knowledge and transferring the technology and skills to the community. The insertion of the impact "The technology is accessible to the majority college students" in this subcategory is because of the easiness of access to the AM technology, by the college students, promotes the relationship between the community and the technology, or the organization.

The civic health and safety, in emerging countries, usually do not keep up with the economic expansion. Considering this, the organizations should contribute to the local dissertation on public health and safety regulations. The organizations should have an active role in the contribution to the health of the local community. The organization should communicate the potential health and safety impacts of their processes to the communities nearby. They should also have a conscious knowledge of the materials produced. Hazard materials and the pollution emission could lead to negative health impacts to the community. And so, the impacts "Gases with noxious environmental impacts are produced" and "Lead and nickel are produced" are an obvious fit in this category, since they represent a negative contribution to an environmentally sustainable development. The social impact "Less impact in the pollution of terrestrial, aquatic, and atmospheric systems" also fits the definition of safe and healthy living conditions, since it has a positive contribution.

The expansion of economic activities, place a pressure in emerging countries around the globe. These resources are important to the local communities, and so, the access to these resources should be limited and regulated, so that a conflict between the community and the organization is avoided. This access should also be restricted if the organization is contaminating or damaging the material resource. The organizations should promote a sustainable method of their operations. A sustainable method will reduce the potential conflict over material resources. "Less energy and material consumption" is an impact that also serves the definition

Table 3-6. Local Communities' additive manufacturing impacts and indicators.

STAKEHOLDER	SUBCATEGORY	AM IMPACT	INDICATOR
Local Community	Cultural heritage	People are self-taught[(a)]	Percentage of the trained people that were self-taught
		Home 3D printers will produce the parts to suit the local community needs[(b)]	Presence/Strength of the technology in the community
	Local employment	Foreign production reduction, domestic increase[(c)]	Percentage of workforce hired locally[*]
		The labour demand reduction[(d)(e)]	Number of job stations replaced by AM technology
	Access to immaterial resources	The technology is accessible to the majority college students[(b)]	Presence/strength of community education initiatives[*]
	Safe and healthy living conditions	Gases with noxious environmental impacts are produced[(f)]	Quantity of the toxic materials produced
		Lead and nickel are produced[(f)]	
		Less impact in the pollution of terrestrial, aquatic, and atmospheric systems[(g)(h)]	
	Access to material resources	Less energy and material consumption[(g)(h)]	Extraction of material resources[*]
Notes: [(a)] Minetola et. al (2015), [(b)] Pearce et. al (2010), [(c)] Tuck & Hague (2006), [(d)] Campbell et. al (2011), [(e)] Campbell et. al (2011), [(f)] Drizo & Pegna (2006), [(g)] Hague & Tuck (2007), [(h)] Huang et. al (2013), [*] UNEP (2013)			

The social indicators proposed are:

- "Percentage of the trained people that were self-taught". This indicator shows the interest of the people in understanding and improve their skills on the technology. This indicator is quantitative and has a positive desired direction for sustainability.
- "Presence/Strength of the technology in the community". The indicator shows the adherence of the community to the technology. This indicator is qualitative and has a positive desired direction for sustainability.
- "Percentage of workforce hired locally". Shows the ratio of the workforce that are from the local community (UNEP, 2013). This indicator is quantitative and has a positive desired direction for sustainability.
- "Number of job stations replaced by AM technology". The objective is to understand how the technology is going to affect the employment. It quantifies the jobs stations loss because of AM technology production. This indicator is quantitative and has a negative desired direction for sustainability.

- "Presence/strength of community education initiatives". The purpose of this indicator is to assess the presence of the technology in amongst the college students (UNEP, 2013). The goal is to understand if the community promotes activities that engages the students with the technology. This indicator is qualitative and has a positive desired direction for sustainability.
- "Quantity of the toxic materials produced". The indicator shows the quantity of toxic materials produced when using AM technology. This indicator is quantitative and has a negative desired direction for sustainability.
- "Extraction of material resources". The goal of the indicator is to understand the usage of material resources (UNEP, 2013). This indicator is quantitative and has a negative desired direction for sustainability.

3.3.5 Other actors in the value chain

When reviewing the AM impacts, two impacts were found that not impact the other stakeholders above mentioned. These two impacts relate to the "Respect of Intellectual Property Rights" subcategory. These two impacts are listed in table 3-7.

These intellectual property rights refer to the mainstream definition of the assignment of property rights through patents, copyrights, and trademarks. The organization, when holding the property rights, has the capability to monopolize the use of the property for a determined period. For this reason, is important to have legal systems prepared to defend the best interest of the stakeholders. "Legal battles increase" and "Legal structures are not at par with AM technology capabilities" are impacts that show the need to have legal systems better prepared for this technology.

Table 3-7. Other actors' additive manufacturing social impacts and indicators.

STAKEHOLDER	SUBCATEGORY	AM IMPACT	INDICATOR
Other actors in the value chain	Respect of Intellectual Property Rights	Legal battles increase[a]	Number of legal battles regarding AM technology
		Legal structures are not at par with AM technology capabilities[b]	Efforts of government agencies to accommodate the AM technology in the community
Notes: [a] Hornick & Roland (2013), [b] Kurfess & Cass (2014)			

The social indicators proposed are:

- “Number of legal battles regarding AM technology”. The indicator shows the dimension of the AM technology legal problem. This indicator is quantitative and has a negative desired direction for sustainability.
- “Efforts of government agencies to accommodate the AM technology in the community”. The goal with the indicator is to understand if the government agencies are making efforts to accompany the evolution of the technology. This indicator is qualitative and has a positive desired direction for sustainability.

3.4 Model proposal

The prior analysis allowed to identify a 26 AM social impacts for different categories of stakeholders. Figure 3-1 supports the visualization on how impacts are distributed between the stakeholders. The area of the circles is proportional to the number of impacts for each stakeholder. For example, since the stakeholder “Society” has nine AM impacts, and the “Consumer” only has two, the area of the first is four and a half times bigger than the second.

With this is possible to understand that the efforts on minimizing the social impacts are going to be greater for the “local community” and “society” stakeholders than for the “consumer” and “other actors in the value chain”. And so, it is possible to understand that the AM technology will play a more dramatic role in the society and the community. With this, it is important to implement and control measures that surpass the minimum compliance, so that the most affected stakeholders’ categories, theoretically, do not get so disturbed in the social impacts.

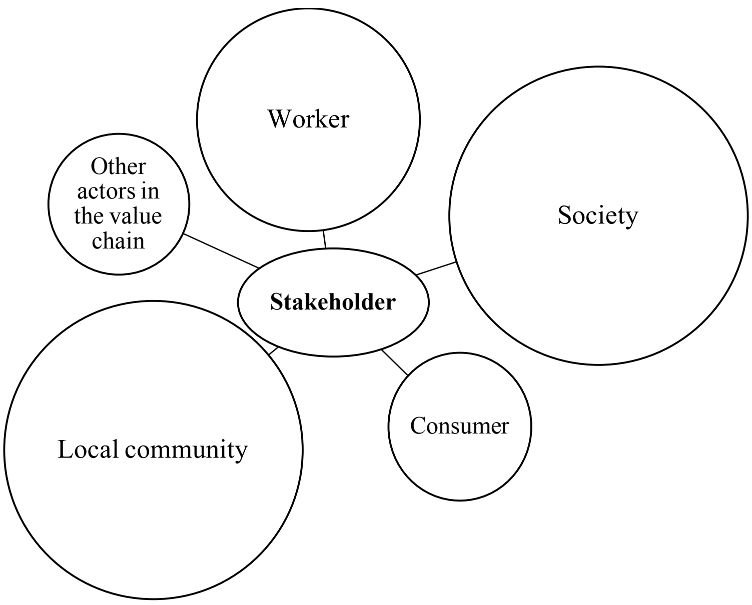


Figure 3-1. Dimension of social impacts by stakeholders' category

Considering the stakeholders' categories, subcategories, and AM social impacts are classified in a typology according to the model in figure 3-2.

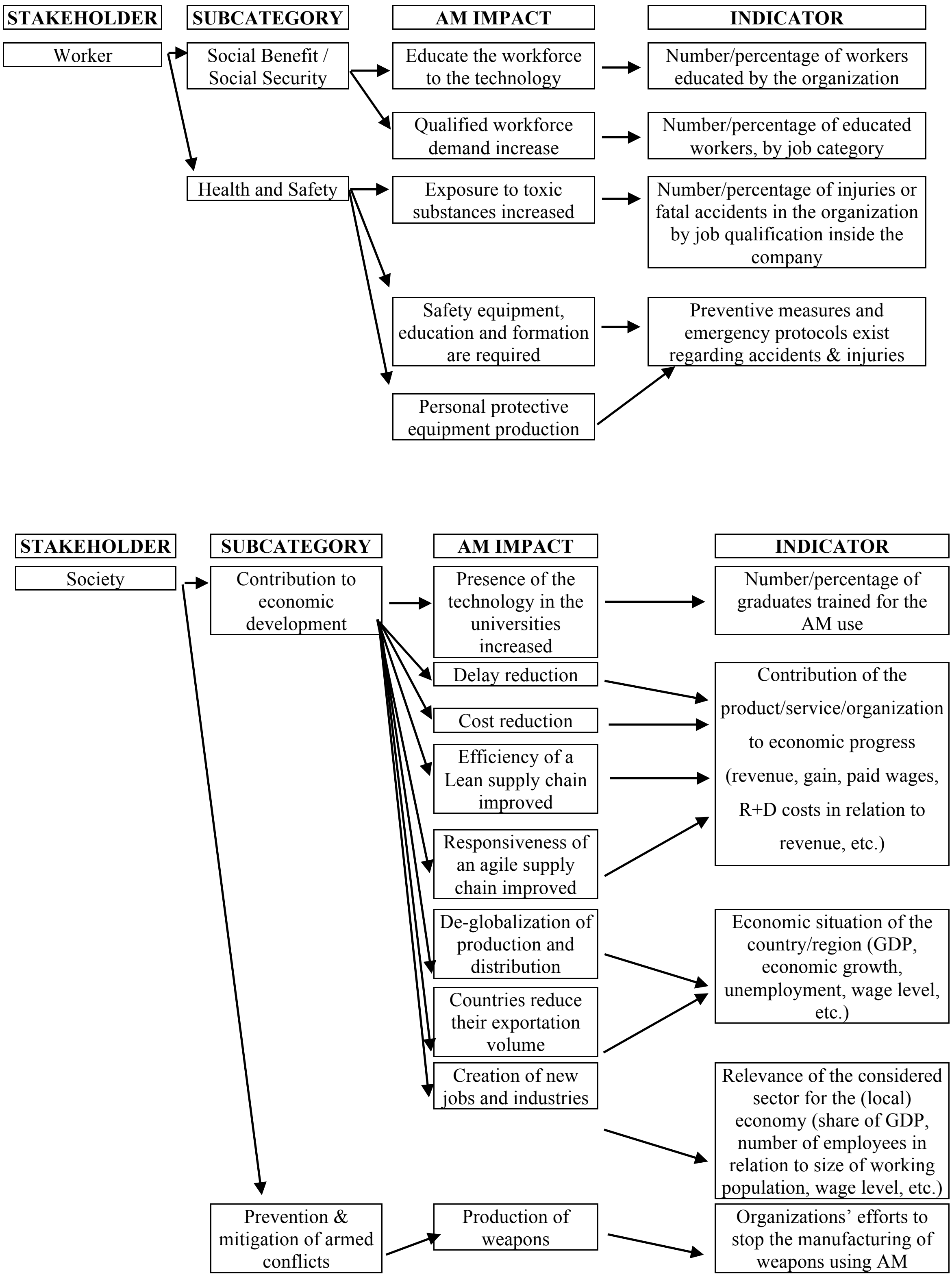
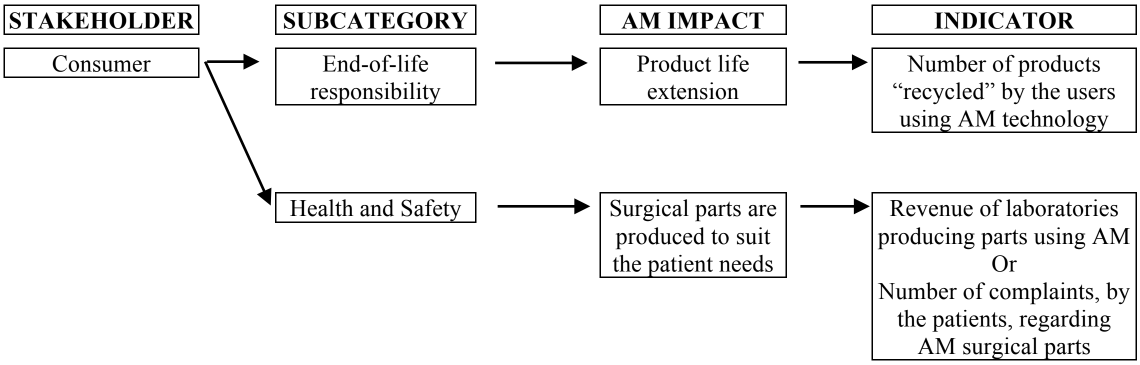


Figure 3-2. A conceptual model for the social additive manufacturing impacts



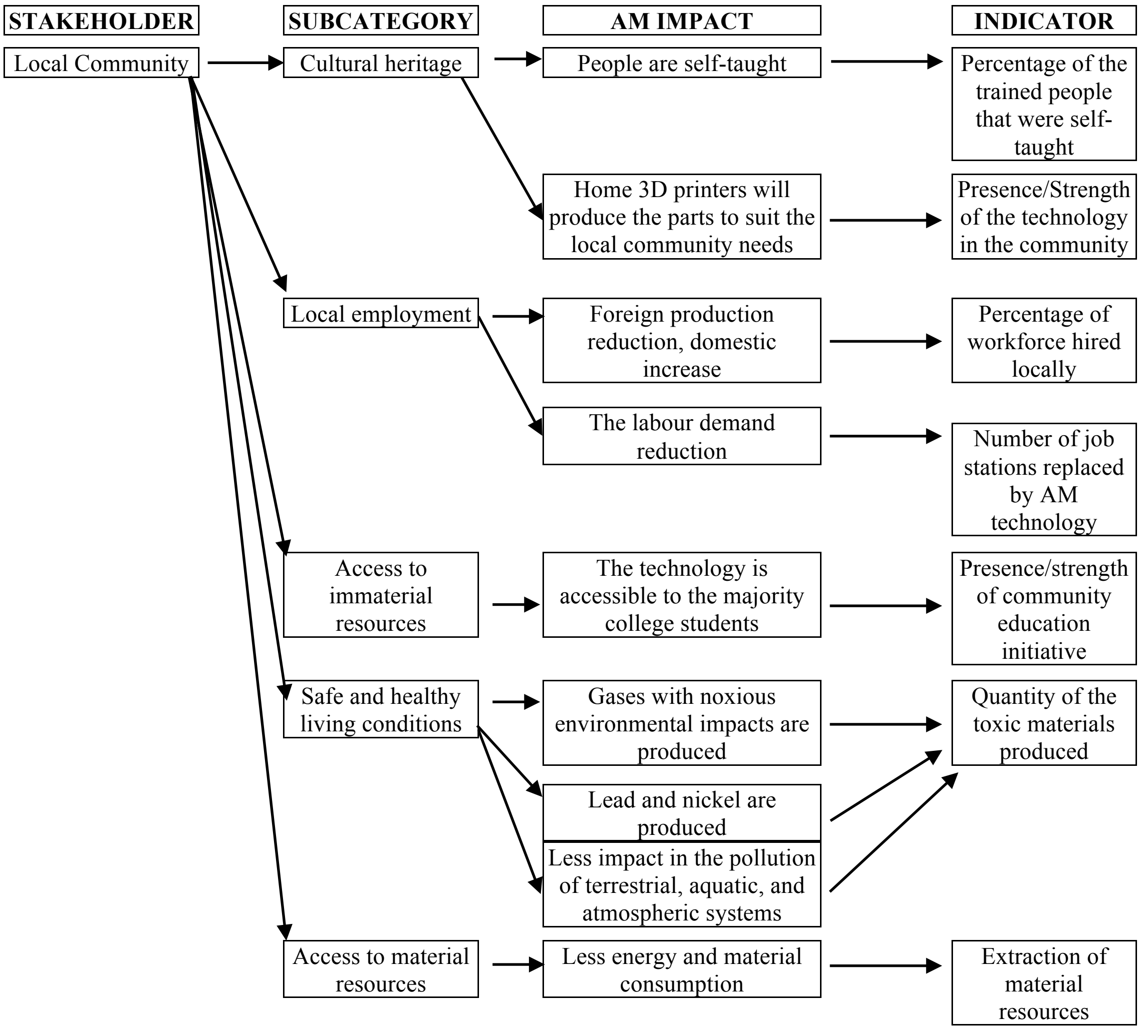


Figure 3-2. A conceptual model for the social additive manufacturing impacts (cont.)

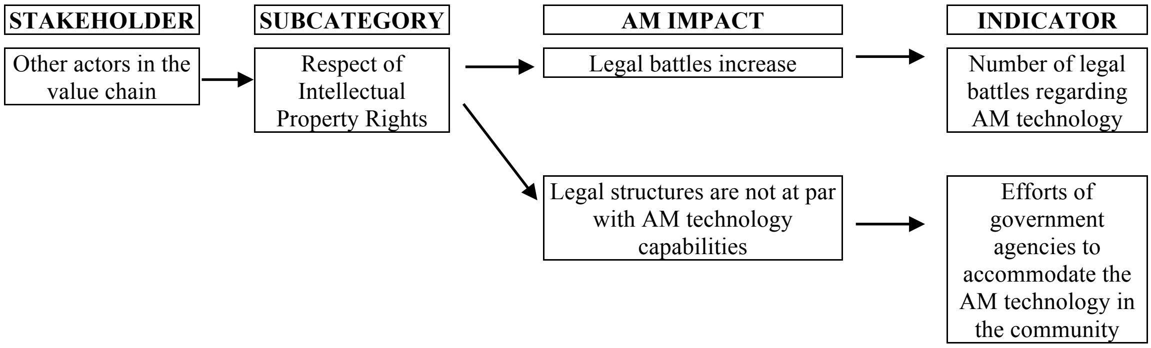


Figure 3-2. A conceptual model for the social additive manufacturing impacts (cont.)

This conceptual model was developed using several subjective and empirical evidence presented in the literature reviewed before. The current proposal follows Meredith (1993) definition of conceptual model, i.e., a set of concepts, with or without propositions, used to represent or describe (but not explain) an event, object, or process. It follows an inductive approach where theory emerges from the analysis of the literature review evidence collected on the topic. Such methodological approach is useful when the purpose is to learn from available data. Moreover, the model also provides a proposal about the indicators for the social impacts.

Chapter 4. Conclusions

In this chapter, the last of the dissertation, there will be an overview of the study, appointed conclusions to the research made, implications of this study, and the limitations that can lead to proposals for future works.

The present dissertation had the objective to better understand the social impacts associated with the AM technology. The goal was to identify the social impacts of the technology. Then propose a typology for the impacts based on the stakeholders affected. For last, in the dissertation, there is a proposal to indicators that measure the social impacts found for the AM technology.

The social impacts of the AM technology are still to be identified. The literature available is still lacking in comprehending this technology in its social strand. The majority of the studies done in this area are about the technology behind the process, the economic advantage when using the process, or to understand the product life cycle when produced using AM. Because of this, the identification of the social impacts was an extensive process of searching authors that analyze the technology in different applications, as aircraft industry, medicine, education, and various others. There was also a consideration on the social impacts of other similar technologies with the objective to understand if they could be applicable to the AM technology. With this, there were identified eleven social categories, or areas, that the AM technology affects. These categories were: educational (e.g. presence of the technology in the universities increased); commercial (e.g. cost reduction); intellectual property (e.g. legal structures are not at par with AM technology capabilities); employment and labour (e.g. creation of new jobs and industries); access to the technology (e.g. the technology is accessible to the majority college students); economic (e.g. countries reduce their exportation volume); environment and energy (e.g. less energy and material consumption); supply chain (e.g. efficiency on a lean supply chain improved); health and occupation hazards (e.g. exposure to toxic substances increased); healthcare and safety (e.g. surgical parts are produced to suit the patient needs); governmental approach (e.g. production of weapons). In total, there were 26 AM social impacts identified.

After the identification of the impacts, there was the need to correspond them to an individual, or organization, that was directly affect by the impact. The identification of the stakeholders was a requirement. For this, it was used the UNEP (2009) guideline, that is used for the social life cycle assessment of the products. This guideline identifies the stakeholders' categories that are involved in the different stages of the product life cycle. Since this is a guideline used amongst various authors and is an esteemed document, the stakeholders´ categories used in this dissertation are the ones proposed by the guideline. These stakeholders are presented in five categories: worker; consumer; society: local community; and other actors in the value chain. With the stakeholders defined, the impacts were sorted. These categories are still comprised of subcategories to better define the strand of the stakeholder that is being impacted. For example, the category worker had subcategories such as child labour; fair salary; working hours; forced labour; and several others.

The last objective of the dissertation was to propose indicators for the social impacts identified. The UNEP (2013) methodological sheets for sub-categories proposed a set of indicators for each sub-category. These indicators can be quantitative, qualitative, or semi-quantitative. Some of these indicators were adopted in the proposal of this dissertation. The indicators that were not gathered from the methodologic sheet, were proposed by the author. All the social impacts listed have an indicator defined and have the desired direction for sustainability explicit. For example, a positive impact will have a positive desired direction for sustainability. This means that the objective is to increase the values of these indicators. The same logic is applied to the negative impacts, that have a negative desired direction for sustainability.

With the information arranged, a conceptual model was created, pretending to enhance the understand the social AM impacts, and be the basis for a future typology on the subject.

A set of policy implications derived from this research:

- Given the current lack of understanding in the social impactions of the AM technology, there is a need for an agreement on how to assess the social impacts of the technology.
- An agreed typology can provide an unambiguous foundation for those involved in ordering assessments, and those engaged in delivering such assessments, to gain a clear understanding of what is required and resources needed to meet the specification.

Also, there are some practice implications that resulted:

- This research is a valuable resource in the identification on the AM technology social impacts.
- There is a proposed typology on twenty-six AM technology social impacts, that informs who the impacts affect directly in the life cycle of a product.
- The social indicators arranged, provide the desired direction for a sustainability.

Since this research dissertation is a breakthrough in the AM technology social impacts, there are a group of limitations encountered when doing the research:

- The AM technology social impacts identified do not represent all possible social impacts for this technology. The research was limited by the few amounts of studies in this area. This means that is possible that various impacts are not considered in this dissertation.

- The typology proposed for the social impacts was based on one guideline. The stockholders used for this typology were the ones that this guideline considered. It is possible that some stakeholders were not reflected in this dissertation.
- The indicators are a proposal for measurement of the social impacts. They were not discussed, so it is possible that more reliable performance indicators exist.
- The indicators are not aligned with an existent framework, such as the Global Reporting Initiative.

This dissertation, as referred earlier, has the objective to be the basis for future work. The proposals for future works are:

- Validation of the proposed typology with a set of specialists in the technology, social and industrial areas.
- Development of specific indicators for different areas of the industry for example aerospace and medical.
- Development of models that allow the quantification of the social impacts in each sub-category.
- Case studies to validate the model.

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