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Additive Manufacturing: Exploring the Social Changes and Impacts

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Abstract: Despite the myriad of possibilities and applications of additive manufacturing (AM) technology, knowledge about the social impacts of this technology is very scarce and very limited in some areas. This paper explores how factors generated by the development of AM technology may create social impacts, affecting the health and social well-being of people, quality of life, working conditions, and the creation of wealth. This paper presents the results of an exploratory multiple case study conducted among four Portuguese organizations that use AM technology, aiming to determine their perceptions regarding the social impacts of AM, its effects, and causes. The results confirm that AM technology is mainly seen to create positive impacts on health and safety (regarding physical hazards), on expectations for the future, on leisure and recreation, on low disruption with the local economy, on economic prosperity, on the professional status, and on innovative employment types. Nevertheless, a negative impact was also found on health and safety (concerning hazardous substances), as well as several mixed and null impacts. The main limitations of the research arise from the use of a case study methodology, since the results can be influenced by contextual factors, such as the size of the organizations in the sample, and/or social, cultural, technological, political, economic, and ecological factors. This study gives an up-to-date contribution to the topic of AM social impacts and social changes, an area which is still little-explored in the literature.

Keywords: additive manufacturing; social change; social impacts; 3D printing; rapid prototyping

1. Introduction

The introduction of additive manufacturing (AM), better known as 3D printing, emerges as a disruptive technology that seems to bring with it several changes and impacts to the traditional product lifecycle, conveying new challenges to business models and society in general. AM technology emerged in the 1980s, through the work of Charles Hull [1,2], in stereolithography. Nowadays, this technology is used in several industries to describe an additive process where material is added layer-by-layer to create physical prototypes, parts of products, or a final product, directly from digital data [3,4]. This technology contrasts with the traditional manufacturing methods which use subtractive processes to remove material from a slab of raw material. Many processes use “layer manufacturing”, and the literature identifies this technology with different denominations, such as 3D printing, additive fabrication, layered manufacturing, direct digital manufacturing, and rapid prototyping.

According to Attaran [5], AM enables innovation and the making of low-cost prototypes and mock-ups with a reduction of time. It allows the use of a wide variety of different materials, such as plastics, resins, metals [6,7], glass, ceramics, powders, and rubbers, among others, which can be

applied to various geometries [3,8]. The increasing use of AM in small and tailored productions, enabling customization and more competitive prices [9], is changing business models, bringing with it unpredictable impacts for business rules and society [10–12], and this increasing use could have the potential for degrowth [13,14]. All these factors result in social impacts and changes which are still unknown.

The literature on the social impacts of AM is scarce, making further research on the matter essential [15,16]. Apparently, the social impacts of AM technology are related to job losses [15], intensity of work, employment schemes and types of work, and the development of new skills [11,17]. Social impacts on health and safety at work have also been identified in the literature [15,16]. The increase of population well-being, associated with an increase in life expectancy and quality of life, resulting from AM applications in medicine, is pointed out as a significant social impact [11,17]. Therefore, research on the impacts of AM in real case settings is necessary to anticipate future social impacts. This paper proposes to address this research gap. Four case studies within Portuguese organizations were developed to provide insights into the social impacts of AM. The present study is guided by three research questions:

- RQ1: What are the causes of AM social impacts?
- RQ2: What types of social impacts are expected?
- RQ3: Do they have a positive or negative effect(s)?

2. Background

2.1. Additive Manufacturing

A growing number of companies and new business models based on AM processes are emerging, creating enormous opportunities for the economy and society [18–20]. This technology is used by two groups of companies, those that use low-cost, low-end technologies, and those that use high-end technologies in cutting-edge sectors, such as in biomedical sectors, nanomanufacturing, [21,22] or bioprinting, also known as 4D printing [23].

A significant amount of research has been published on AM technologies, regarding their physical and chemical behaviours, as well as their economic and environmental impacts. These studies proclaim several AM-related advantages, such as (a) design flexibility with complex geometries [5,11,15,21,24], (b) reduced “time-to-market” [5,25], (c) design for customization [26,27], (d) reduced environmental impacts [11,24,28,29], and (e) higher profit due to customer specific solutions [5,15].

However, little is known about the social impacts of AM, and the few studies available on the topic make it harder to understand the matter [11,15,16]. These studies pinpoint several social impacts areas, as can be observed in Figure 1.

The impact of AM on intellectual property rights and policy is not clear [17,30,31], since new forms of intellectual capital property are emerging, such as creative commons licenses, license sharing, or the open source concept [17]. As has happened before with movies, music, and books, traditional forms of protection (e.g., design patents or copyright) might change. AM technology requests new forms of protection and respect for legal rights [17,31].

AM is changing established business models and markets [11,17], namely in terms of product customisation [10–12], the reconfiguration of supply chains [32], the extension of the product life [10,11], the reorganization of logistic systems (i.e., local production models [22]), and the potential for repair, remanufacturing, and refurbishment [10,11]. The possibility of consumers creating and co-designing their very own objects using printers at home, or by easily accessing them, can also change purchasing behaviours, resulting in impacts on society [17,22,33].

The social impacts of AM on education depend on the integration strategy into educational systems [34,35] and on the maturity and gaps of those systems [15]. AM technology brings new challenges, and its impacts on skills and education requirements remain to be studied [17,36,37]. This technology presents high potential, especially for engineering training [34,38], since it allows the use of

physical prototypes for educational objectives [39–42], for the “Teaching Factory Concept” [43], and as part of research efforts in universities [36].

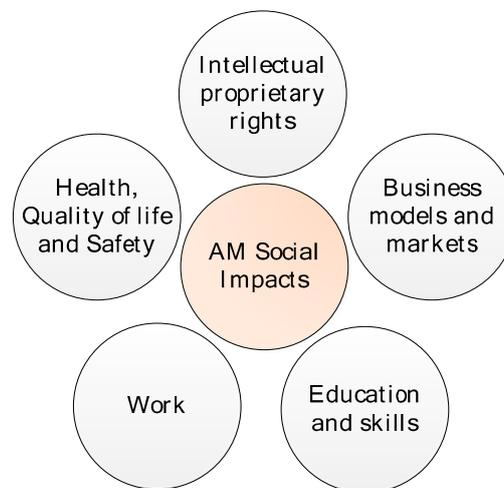


Figure 1. The areas of social impact for additive manufacturing (AM).

The literature provides some evidence of AM technology’s social impacts on work and labour conditions. The apparent “clean” aspect of AM causes little preoccupation about individual safety, caution around the handling and disposal of materials, and consideration of a proper location for the equipment [16]. Other authors refer that AM technology can create unemployment and political destabilization in some economies, leading to changes in labour intensity, employment schemes, types of work, work conditions, working hours, working places, and employment policies, or even in changes in labour laws [15,25,44]. Conversely, positive impacts are foreseen, such as digipreneurship (digital entrepreneurship), allowing the creation of niche markets, access for people without prior knowledge of design and/or production to create diverse product types, and avoiding the need to go to work to big cities, among other social innovations related to the easy self-use and flexibility of AM technology [3]. The adoption of AM technology is also mentioned as positive to “especially aging societies, (that) might benefit from the ability to produce more goods with fewer people while reducing reliance on imports” [28].

The reduction of health costs for the elderly and the rise of life expectancy and quality are mentioned in the literature as AM social impacts [16,28], mainly because of the possible customizations of healthcare products (e.g., surgical implants, orthodontics, etc.) [11,20]. Several authors warn of the terrorism dangers associated with AM technology, as weapons production (i.e., guns, bullets, bombs, etc.) can be facilitated using the technology [28,45–47].

2.2. Social Impacts Definition

There is widespread consensus that social impacts are relevant and should be considered as part of the analysis of sustainability [48]. In the literature, despite recent advances [49], there is still insufficient knowledge regarding social impact assessment (SIA), namely on conceptual and theoretical issues [50–53].

There is no unanimity on the concept of “social impact” and its formal definition, which makes it difficult to distinguish social impacts from social changes, or even from societal impacts. Thus, some authors use the concept of social impact while others use social change to identify the same idea [16,54–56]. Also, the term “societal impacts” is used to refer to social impacts [15]. Several definitions of social impact are proposed in the literature [57,58]. A literature review of 50 papers [59] concluded that changes, which entail effects, cause social impacts. Some of these changes cause phenomena experienced by stakeholders and are recognized as social impacts. This definition, by being so broad, does not allow a crystal-clear identification of the concept of “social impact”. To clarify the concept, the

following subsections contain the definition of social impact, according to widely accepted operational guidelines/frameworks and Vanclay's [54] research.

2.2.1. Social Impact Operational Guidelines/Frameworks

The United Nations Environment Programme (UNEP) guidelines define social impacts as "consequences of positive or negative pressures on social endpoints (i.e., the well-being of stakeholders)" [60]. Social impacts are understood to be "consequences of social relations (interactions) weaved in the context of an activity (production, consumption or disposal), and/or engendered by it, and/or by preventive or reinforcing actions taken by stakeholders (e.g., enforcing safety measures in a facility)" [60]. The term social impact does not include the social change processes.

The UNEP Setac Life Cycle Initiative [60] proposes the use of the social life cycle assessment (S-LCA) methodology to assess social impacts along life cycle stages, considering five categories of stakeholders: Workers/employees, local communities, society, consumers (covering not only the end-consumers, but also the consumers), and value chain actors. This S-LCA approach is aligned with ISO 14040 [61] and ISO 14044 [62], and is well-accepted among professionals and researchers. The problem lies in the difficulty to quantify social impacts in contrast with environmental ones [63], and the scarcity of databases with accessible information concerning them [60].

The Global Reporting Initiative (GRI) [64] is a widely accepted sustainability framework to report social impacts [15,58,65], because it standardizes enterprises' reports on environmental, social, and economic aspects. This reporting system [64] presents 19 categories of social indicators, ranking the indicators as core (i.e., obligatory) or additional, and many of them are qualitative or binary (i.e., "yes" or "no"). This quantification bias makes it difficult, if not inhibiting, to quantify the indicators and comparisons [58].

The International Association of Impact Assessment (IAIA) [66] differentiates between social change process and social impact, because not all social changes cause social impacts. The claim that social change is (any) process affecting people, and the social impact is any experienced effect [56]. Despite the distinction between them, the definitions broadness hinders the quantification of the experienced effects.

2.2.2. Vanclay's Theoretical Framework

Vanclay [54,67,68] established the theoretical foundations of SIA. He discusses in detail the problem of the distinction between social change process and social impacts:

- Social impacts are "experienced or felt in either corporeal or perceptual terms" [54]. They "will vary from place to place, from project to project, and the weighting assigned to each social impact will vary from community to community and between different groups within a given community" [54]. This is a broad concept comprising all aspects that affect people directly or indirectly in one or more of the following topics: People's way of life, their culture, their community, their political systems, their environment, their health and well-being, their personal and property rights, and their fears and aspirations. Vanclay [67] argues that "direct social impacts result from social change processes that result from a planned intervention" and that "indirect social impacts are a result of changes in the biophysical environment".
- Social changes processes "may be the intention of especially designed activities to influence the social setting (intended impacts) or may unintentionally result from these activities" [54]. Vanclay [54] also argues that "many of the variables typically measured in social impact assessment studies are not in themselves impacts, but rather represent the measurable outcomes of social change processes, which may or may not cause impacts depending on the situation".
- Vanclay [54] proposes a list of social impacts covering different dimensions (individual, family, household unit, community, and society) and specificities (corporeal, perceptual, and/or emotional). The conceptualization of the impacts was divided into seven categories (but according to the author it is possible to group them in other ways):

- Health and social well-being: This category is based on health impact assessment (HIA) [69]. Vanclay stresses “while HIA professionals have a wide range of health indicators, they consider that the dimensions listed are the ones likely to be important from a social perspective” [54].
- Quality of the living environment (liveability): This category includes impacts related to the physical environment, like exposure to dust, noise, artificial light, odours, and other similar issues. It also includes how people feel about their environments, that is, the recreational opportunities and the aesthetic quality of their surroundings.
- Economic and material well-being (both on individuals and on communities): In developed countries, employment opportunities, income, and real estate are apparent impact variables, while in less-industrialized countries the workload, for instance, is more important.
- Cultural: This category “includes all impacts (changes) on the culture or cultures in an affected region, including loss of language, loss of cultural heritage, or a change in the integrity of a culture (the ability of the culture to persist)” [54].
- Family and community: This category “includes impacts related to the family, social networks, and the community” [54]. Changes in family structures and communities are examples of impacts included in this category.
- Institutional, legal, political, and equity: In this category, the workload and the viability of government or official agencies is included. Also, it considers alterations resulting from the implementation of projects with great commercial interest, which can create pressure on institutions and governments, violating the human rights of individuals.
- Gender relations: Since “women tend to bear the largest and most direct social impacts” [54], this category encapsulates this social impact.

Despite Vanclay [54] proposing a list of possible social impacts for each category, he warns against its use as a checklist, since it does not encourage analytical thinking about the impact-causing mechanism. Furthermore, he adds that any listing of impacts is context dependent, so researchers must select what impacts should be included and how they should be described, bearing in mind that the level of detail is crucial.

In the case of the social impacts of AM technology, existing studies are scarce. In the face of such arguments, this research proposes a list of the social impacts of AM technology, based on the definition of social impact given by Vanclay [54].

2.3. Social Impacts of Additive Manufacturing

Due to the lack of social impact repositories applied to AM technology, a number of Vanclay’s [54] categories, and their respective list of social impacts, were considered as the foundation for this study. In particular, four categories of social impacts were considered relevant: (1) Health and social well-being, (2) institutional, legal, political, and equity, (3) quality of the living environment (Liveability), and (4) economic and material well-being. Since Vanclay’s list is intended for any topic and it does not focus on AM, the four categories were selected considering the pieces of evidence found in the AM literature, as well as a recent study [70]. The purpose of the study was to map specific keywords, or “pointers”, for social impacts of AM technology. The computer-aided content analysis applied in the study allowed the authors to disclose many significant “pointers”, in which the words “family” or “gender”, for instance, never appeared as an output [70].

Table 1 was compiled using Vanclay’s social impacts list and was completed with the social impacts identified in the AM literature. It provides an overview of the potential AM social impacts and is not an extensive or absolute list of social impacts. For each impact, a description is given according to Vanclay [54] or other authors. In some cases, the impact was defined by the authors of this paper, which is denoted where relevant in the right-most column.

Table 1. The social impacts of AM.

Category	Social Impact	Description	References
Health and Social Well-being	Perceived health.	Impacts on health.	[54]
		Health, safety, and social benefits at work.	[16]
	Mental health and subjective well-being.	Feelings of stress, anxiety, apathy, depression, etc.	[54]
	Change of aspirations for the future for self and children.	Expectations about what will come (more jobs, more economic growth, etc.).	[54]
	Dissatisfaction due to the failure of promised benefits.	Expectations, disappointment, resentment, or dissatisfaction.	[54]
Quality of the Living Environment (Liveability)		Work: Regarding dust, noise, risk, dour, vibration, blasting, artificial light, and safety.	[54]
	Perceived quality of living environment.	Life expectancy and quality of life. Waste management.	[11,15,17]
	Leisure and recreation opportunities and facilities.	Recreational and leisure opportunities.	Proposed by the authors.
	Actual crime and violence.	Crime and violence changes. Printing weapons for illegal purposes.	[54] [28,47]
Economic and Material Well-Being	Workload.	The amount of work that is required to live reasonably.	[54]
	Access to public goods and services.	Facilities for accessing public goods and services.	Proposed by the authors.
		Biological models, medical implants, organs, and prosthetics can be manufactured according to patient's needs.	[21,22]
	Economic prosperity and resilience.	Economic affluence of a community and the extent of diversity of economic opportunities.	[54]
		Professional situation and type of employment.	Proposed by the authors.
	Occupational status and type of employment.	Labour intensity, employment schemes, types of work, work conditions, working hours, working places, etc. Changes in knowledge and skills.	[16,17,44]
	Level of unemployment in the community.	Underutilization of human capital.	[54]
	Loss of employment options.	Loss of employment resulting from new technology. Job and work safety losses.	Proposed by the authors. [15]
	Economic dependence or vulnerability.	Individual or household control over economic activities.	[54]
	Disruption of the local economy.	Disappearance of local economic systems and structures. Capacity to enable indigenous entrepreneurs to design and build more advanced products tailored for local markets.	[54] [71]
Institutional, Legal, Political, and Equity	Workload and viability of government and formal agencies.	Implementation of projects with great commercial interest can create pressure on the institutions and governments.	[54]
		Patents and copyrights could change significantly.	[72,73]

3. Research Methodology

Given the exploratory nature of this research and the need to build theory in this developing research area, a multiple case study methodology was selected for this study [74,75]. Four organizations that use AM manufacturing processes were selected for exploring the proposed research questions. Factors of convenience (namely ease of access) and proximity were important reasons for the selection cases. All of the selected organizations are located in Portugal (Lisbon and the Tagus River Valley).

To collect data related to the social impacts of AM, an interview protocol was designed considering the social impacts identified in Table 1. The main objective was to collect the interviewees' perceptions about factors of AM technology that can lead to changes and the effect of those factors in terms of their social impact (which can be positive, negative, null, or mixed). The interview was comprised of semi-structured questions, as well as questions to encourage interviewees to share their opinions and experiences. Each interview ended with an open question on the "most experienced or perceived impact(s)", so there was a chance to apprehend other items neglected in Table 1. To test the interview protocol, a pilot-run was carried out with two young entrepreneurs who were well-acquainted with AM technology. After that, the interview protocol was refined.

The data were collected over two weeks, through four semi-structured interviews, conducted with the senior managers of the organizations. Each interview lasted about 1.5 h and was electronically recorded. The quality of the data collected was ensured by two means: (1) In addition to the use of a digital tape-recorder, all interviews were conducted by two researchers, and (2) all statements/results were transcribed into a summary text and sent out to the respective interviewee for his/her validation of contents, both in terms of the completeness and interpretation. This direct approach allowed the collection of data on the social impacts originating from AM and the perceived impact direction. The relevant results are compiled in Tables 4 and 5, which are presented later in this paper.

4. Case Study Results and Analysis

4.1. Social Impacts of Additive Manufacturing

The four organizations comprising the multiple case study (Table 2):

- Organization A: 3D Life is a brand (and a business unit) within the company Let's Copy Ltd., a Portuguese small and medium-sized enterprise—(SME). It provides services such as 3D scanning, digitalization, printing, modelling, and short run productions. This company uses ceramic, plastic (PLA), and resin printers, and they work together with other partners using other technologies such as metal printing. The organization mostly makes prototypes for validation and ergonomic studies and creates small print runs for large companies.
- Organization B: Blocks Technology is a Portuguese start-up for the design and manufacture of 3D printers. Initially, the company developed prototypes for other companies, but currently, it designs and manufactures their own 3D printers and sells filaments and maintenance services.
- Organization C: 3D Factory is also a brand (and a business unit) within the company Emerging Objects (a Portuguese SME), which provides services for 3D scanning, digitization, printing, and modelling (technical and prototyping, architectural models/applications, and equipment). Its main products are "end products", (i.e., objects, prototypes of products, and parts). The company also provides complementary services such as modelling, design, and printing for projects. Its primary clients are educational, musicological, and creative services.
- Organization D: MILL—Makers In Little Lisbon is a community of practice. This collective focuses on collaborative work and knowledge sharing. The interviewee of this practice community has the peculiarity of having introduced in Portugal, in 2009, the first 3D printer from the MakerBot Company. This expert has in-depth knowledge of the history of 3D manufacturing in the world and has participated in the process of the expansion of desktop 3D printers.

Table 2. Summary of the organizations under study.

Name	3DLife (A)	Blocks Technology (B)	3D Factory (C)	Mill (D)
Type	Brand.	Start-up.	Brand.	Collaborative community.
Main Products/Services	3D scanning, digitalization, printing, modelling, and short-run production.	Design and manufacture of 3D printers, and maintenance services.	3D scanning, digitalization, printing, modelling, and short-run production.	Knowledge sharing.
Main Customers	End users and manufacturing companies.	Companies.	Educational, museological, and creative services.	Not applicable.
Additive Technology	Ceramic, plastic (PLA), and resin printers.	PLA printers.	PLA, Acrylonitrile Butadiene Styrene (ABS), laser, and resin printers.	PLA printers.

Table 2 characterizes the four organizations. In addition to the table contents, it is noteworthy that all of them are under 5 years old, had a business volume in 2017 of up to 100,000 EUR, and have fewer than 10 employees, all of which have at least a bachelor's and/or licentiate's degree.

4.2. Social Impacts of Additive Manufacturing

The data collected were analysed using a colour coding scheme (Table 3), indicating the agreement between the four respondents on the "direction" of each impact, which was either positive, negative, null, or mixed.

Table 3. Level of agreement between interviewees.

Colour Code	
	All Positive (<i>the 4 respondents agree on a positive impact</i>)
	Positive + Null
	Positive + Negative and/or Mixed and/or Null (<i>i.e., undefined</i>)
	Negative + Null
	All Negative (<i>the 4 respondents agree on a negative impact</i>)
	All Null (<i>the 4 respondents agree – no impact</i>)

Tables 4 and 5 present a list of factors of AM technology that can lead to changes. In addition, they contain a list of social impacts (*i.e.*, the effect of the change). The objective is to show the cause-effect relationship between factors ("causes") and effects ("impacts"). The "causes" (the mechanisms that can generate changes) are the specific characteristics of the AM technology which may help to explain the perceived "impact". The next sub-sections provide the analysis of main results.

4.2.1. Vanclay's Theoretical Framework

Table 4 shows the interviewees' perceptions of the social impacts of AM related to health and safety, mental health, and well-being, as well as expectations for the future.

The first factor, "occupational disease situations", represents the exposure to health risk factors such as a thermal environment, noise, and vibration (*i.e.*, physical risks of the work environment). All the interviewees stated that AM technology has a positive impact on worker health and safety. According to them, this risk almost disappears, because the equipment is noiseless, the machines can run on their own (higher autonomy) and the workers are "removed" from the process, as compared with conventional technologies in which there is a more constant and closer man-machine contact. In fact, some of the respondents emphasized that in many small companies, the factory environment disappears, and everything is similar to an open-space layout, typical of service companies, where the manufacturing zones coexist with administrative workspaces. These results are aligned with the literature [11,15,16], since is frequently referred to as a positive social impact.

Table 4. Cross case analysis of the categories of health and social well-being, quality of life, and institutional and legal level.

Social Impact Categories	Questions	AM Changes Can AM technology lead to changes in the following factors?			AM Social Impacts What is your perception of the factors' Effect on:	Answer				Final Assessment
		No	Does Not Know	Yes		Positive	Negative	Null	Mixed	
Health and Social Well-Being	Occupational disease situations, e.g., thermal environment, noise, or vibration.			ABCD	Health and Safety	ABCD				Green
	Situations of accidents at work, e.g., dangerous machines, burns, electric shocks, or cuts.	ABCD						ABCD		Grey
	Number of hours of mental and/or physical work, e.g., time spent paying attention to the different aspects of the production process.	ABCD						ABCD		Grey
	Situations of particular risks, e.g., inhalation of particles during the production or finishing.			ABCD	Mental Health and Well-Being		ABCD			Red
	Level of stress and/or anxiety at work, e.g., watchfulness stress of the productive process.	ABC		D				ABC	D	Yellow
Feelings of social valorisation/recognition of professional status. Internal or external valorisation.			ABCD	Expectations for your Future	ABCD				Green	
Quality of Life	New recreational and leisure activities, e.g., hobbies or the manufacture of personal objects.			ABCD	Perception of Leisure and Recreation	ABCD				Green
	Level of crime and violence, e.g., ease of making weapons or bombs.	BCD	A		Perception of Real Crime and Violence			BCD		Grey
Institutional and Legal Level	Protection of patent rights, e.g., open source files.		BC	AD	Legal Rights	D	A			Yellow

Table 5. Cross case analysis for the category of economic and material wellbeing.

Social Impact Categories	Questions	AM Changes			AM Social Impacts	Answer				Final Assessment	
		Can AM technology lead to changes in the following factors?				What is your perception of the factor effect on:					
		No	Does Not Know	Yes		Positive	Negative	Null	Mixed		
Economic and Material Wellbeing	Adaptation of products' characteristics to the needs/expectations of the community, e.g., making traditional objects/artefacts.			ABCD	Disruption with the Local Economy	ABCD				Green	
	Creation/disappearance of small local businesses, e.g., local production models.			ABCD		AB			CD	Yellow	
	Customisation/personalisation and creating personalized products.			ABCD	Economic Prosperity	ABCD				Green	
	Reward systems, e.g., compensation by objectives, to guarantee efficiency in production.	BCD		A		A		BCD		Light Green	
	Development of new skills that can be used in new businesses, e.g., digital entrepreneurship.			ABCD		ACD			B	Yellow	
	Creation/disappearance of jobs, e.g., work at home or new jobs.			ABCD		Level of Employment in the Community				ABCD	Yellow
	Educational curricula, e.g., the teaching of AM technology in technical-vocational education.			ABCD	ABCD						Green
	Need to participate in training and professional requalification, e.g., training in new software/hardware.			ABCD	ABCD						Green
	Function analysis (roles), e.g., new tasks within the product design/production processes.	D		ABC	ABC				D		Light Green
	Work organization, e.g., changes in workspaces and layouts			C	ABD	Professional Status and Employment Type	ABD				Light Green
	More flexible work schedules, e.g., adapting human resource needs to the production cycle.	AB		CD	CD				AB		Light Green
	Performance assessment system, e.g., introducing management by objectives.	BCD		A	A				BCD		Light Green
	Responsibility for the tasks performed, e.g., production errors are costly.	CD		AB	AB				CD		Light Green
	Need of teamwork. Need to join different skills.	D		ABC	C				D	AB	Yellow
	Need to develop new skills, e.g., the use of the new equipment and software			ABCD	ACD					B	Yellow
	New work schemes, e.g., remote work/work at home.	A		BCD	CD				A	B	Yellow
	Precarious contracts, e.g., the provision of services and fixed-term contracts based on productive objectives	D		ABC	A				D	BC	Yellow
	Turnover, because of the high demand for specialists in AM technology.	A		BCD	D				A	BC	Yellow
	Resistance to organizational and technological change, e.g., difficulties in implementing new work schemes or changing roles.	BCD		A				A	BCD		Orange

Likewise, in the factor “feelings of social valorisation/recognition of professional status”, all the interviewees agreed that the impact on “expectation for your future” was positive. They justified this, claiming AM technology is seen as something new, revolutionary, modern, and appealing, allowing varied and creative work.

In contrast, for the factor “situations of particular risks”, the impact on “health and safety” is unanimously negative, because there is an added risk on both occupational health and worker safety. This is explained by the increased use of a wide range of raw materials, namely thermoplastics and composites that release toxic particles and fumes, increasing the risk for health, either through direct contact with the skin or inhalation [11,12,15].

Regarding the impacts on “health and safety” caused by “situations of accidents at work” and the “number of hours of mental, and/or physical work”, all interviewees agreed that the effect was null, since the machines are safe, do much of the work without human intervention, and there is already enough know-how on this technology.

Similarly, the impacts on “mental health and well-being”, caused by the “level of stress, and/or anxiety at work”, received a null classification from three interviewees. The exception was the representative of the collaborative community. His justification for the mixed effect caused by “level of stress, and/or anxiety at work”, concerning impact, was that some AM applications are still quite slow, and this could increase stress levels when there are short deadlines to meet.

4.2.2. Impacts on Quality of Life

This category includes aspects such as recreational and leisure activities and the perception regarding the impact of AM on crime and violence. All the interviewees said that this technology allows countless leisure activities, valuing the concept of do it yourself (DIY) and allowing the development of creativity, enabling the production of objects for cultural expression and educational activities. This corroborates other findings in the literature review, e.g., [3].

The possibility of using AM technology to reproduce replicas from museum objects and develop “3D museums” was also mentioned, resulting in opportunities of social inclusion (e.g., people with visual impairment).

About the “level of crime and violence”, one respondent (A) stated that he did not know whether there was an impact. However, the other three respondents stated that there will be no effects, since it is easier to manufacture weapons or bombs by other means. In fact, regarding this question, the three respondents were peremptory in affirming that AM does not increase the risk of violence. These findings are contrary to what is advocated by some authors [28,45], who believe that AM technology can increase insecurity and violence.

4.2.3. Impacts on Institutional and Legal Level

The perceptions of the interviewees regarding their legal rights were divergent. Even though organizations B and C claim to be unaware of the potential impacts, organizations A and D believe that there is an impact: Organization A believes that the protection of patent rights is a factor with negative impact, since AM creates the possibility of numerous copies, compromising patent security. For organization D, this is a factor with a positive impact, since working on open source models is important because the information is entirely available to all. This result is in line with the literature analysed, which considers that property rights and policies are not clear [17,30,31].

4.2.4. Impacts on Economic and Material Well-Being

The main category, “economic and material well-being” (Table 5), includes issues related to disruption with the local economy, economic prosperity, the level of employment in the community, and professional status or type of employment. Since this category includes 19 factors, it was considered helpful to show a relative distribution for mapping both the direction of the impacts and the level of agreement, as can be observed in Figure 2.

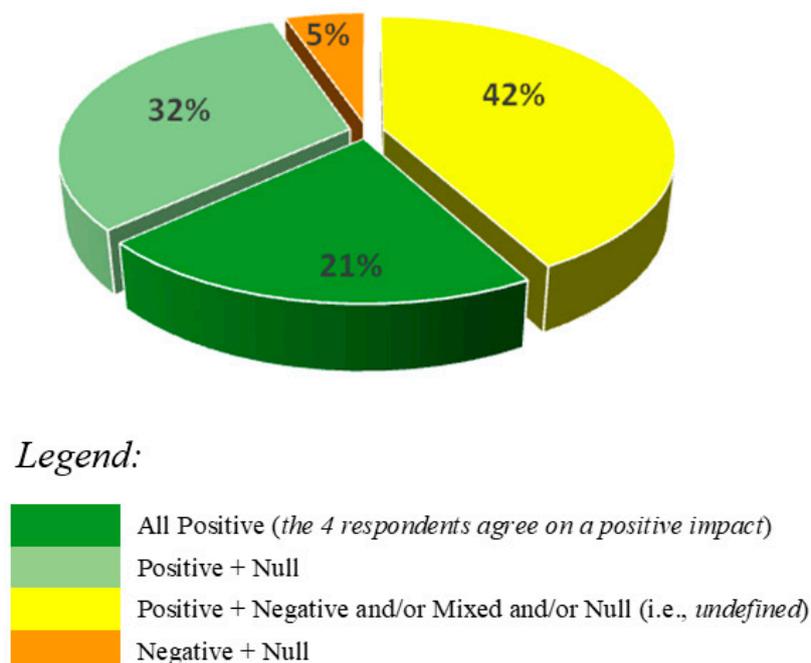


Figure 2. Impacts on economic and material well-being, showing the direction and the level of agreement.

It can be established from the results that the opinion of respondents on the impacts of the category “economic and material well-being” were frequently coincident (Table 5) and mostly positive (Figure 1), since more than half the items are labelled in the colour green (21% + 32%).

Regarding the potential effect of “disruption with the local economy”, all interviewees agreed that the factor “adaptation of products’ characteristics to the needs/expectations of the community” has a positive impact, because the use of the AM technology allows customization and better management of stocks, since these are manufactured upon request. This in line with the literature [25,33].

Furthermore, the changes in the “creation/disappearance of small local businesses” can have both positive and mixed impacts on the “disruption with the local economy”. For a couple of respondents, there was no problem (perceived as positive impact) because they believed that new small AM businesses can coexist with traditional businesses. The other two respondents were unsure and considered “mixed” impacts, since there is still some chance that a few traditional businesses can disappear.

With regards to perceived effects on “economic prosperity”, the respondents were almost unanimous in considering that changes in “customization/personalization” and “new skills that can be used in new businesses” have positive impacts. AM allows acquiring new skills that can be used to develop new business. However, the interviewee from organization B considered that the impacts are mixed, since the development of new skills is positive, but, conversely, it can also create unemployment and poverty due to the low qualification of some workers. Customization was pointed out by all interviewees as a significant change, since it allows the ability to quickly answer customer expectations. This confirms the relationship between AM and customization that is advocated in the literature [5,12,15,47,76]. Most respondents believe that there will be no changes in the “rewards system”. However, one of the interviewees pointed out that AM processes facilitate management by objectives.

The effect on the “level of employment in the community” received a mixed classification by all interviewees when assessing the change “creation/disappearance of jobs”, since this technology promotes both the creation of some jobs and the disappearance of others.

Within the impact on “professional status and employment type”, a wider variety of factors were assessed. All the interviewees were unanimous in considering that “educational curricula” and the “need to participate in training and professional requalification” have a positive impact in professional status and employment. Changes in education and training were referred to by the interviewees as one of the areas which can benefit most from the introduction of qualifications in the domain of AM

technology. One of the interviewees mentioned that recruitment processes in engineering areas are already valuing knowledge of the use of 3D technology. The importance of developing new skills and competencies for AM is also mentioned in the literature as a positive effect [11,17,36,37].

The trend to use “open office” schemes supports the perceptions of the interviewees that “function analysis” and “work organization” have a positive impact on “professional status and employment type”.

Two of the interviewees considered that “more flexible work schedules” has a positive impact, since several portable 3D machines can be easily used anywhere (i.e., the home, office, events, etc.). Two others considered that there will be no impact concerning this factor.

“Performance assessment system” was considered without impact (impact null) or with positive impact (A), because these systems become very objective, allowing the unequivocal verification if the employee has complied with the procedures defined by the company within the stipulated period. All these factors were considered positive by respondent A. This last explanation is also the reason why two interviewees considered that “responsibility for the tasks performed” has a positive impact.

Regarding the effect of “need of teamwork”, there were different perspectives. It is important (and beneficial) to work as a team, because the various stages of production must be well synchronized. If an individual makes an error (e.g., programming the machine incorrectly) it can jeopardize the entire process.

According to three interviewees, the factor “need to develop new skills” has a perceived positive impact, because the evolution of this technology forces employees to be up to date/keep up with the development of technology.

“New work scheme” changes were perceived as generators of positive and mixed impacts on “professional status and employment type”, since these schemes increasingly allow remote work systems, but at the same time, there may be negative impacts that result from an excess of employees who can work from home or other locations. Remote work allows higher professional flexibility, but it can also “isolate” individuals from their workplace and organization, creating risks inherent to “work alone” situations, typically psychosocial risks.

The factors “precarious contracts” and (personnel) “turnover” seem to be related. Both are likely to increase because there is a shortage of AM specialists. At least two of the interviewees (B and C) believe that there are both positive and negative effects. On the one hand, the freelance qualified workers are encouraged because they can easily change from one company to another, creating new opportunities for “self-employment”. On the other hand, this also means precarious jobs, which are justified by the typology of production management “by project”.

Finally, the interviewees’ perceptions of the effects of “resistance to organizational and technological change” on “professional status and employment Type” was that it has almost no impact. However, one of the interviewees considered that the impact is negative, since there is some resistance to organizational and technological change.

4.2.5. Emerging Social Impacts and Factors

Each respondent was asked to pinpoint the “most” important AM social impact(s) and/or factors causing them. Several items emerged as follows:

- Customization: Each person can replicate parts of objects that they need, and/or create/print new parts.
- Decreased consumerism: Repairing becomes easier.
- Increased durability of products/equipment: Due to maintenance/repair of equipment with customized parts, when printed in 3D, the durability of equipment and parts may increase.
- Reduction of stocks: The use of AM technology decreases the need to maintain stocks.
- Environmental problems: It is felt necessary to identify, systematically, different materials by type and to create mechanisms for their classification, separation, and recycling.

- Quality of life: AM technology used for medical purposes enables the production of prostheses, organs, teeth, etc., improving people's quality of life.
- Employment: AM technology can increase unemployment, especially for many unqualified people, despite the counter-effect of promoting a few qualified ones.
- Education: AM technology can be used to improve learning processes.
- Cultural: AM technology can be applied in museums and thematic cultural events, through the rapid reproduction of 3D miniatures (e.g., iconic statues and monuments, dinosaurs in thematic parks, etc.).
- Social inclusion: AM technology can contribute to social inclusion, for example by allowing blind people to experience museums more realistically.

5. Conclusions

This paper presents an endeavour to determine the social impacts of AM and the respective causes of said impacts. An exploratory multiple case study, comprised of four organizations, was developed considering three research questions.

The first research question (RQ1) aimed at identifying "causes", i.e., the main factors originated by the use of AM technology in a productive context that could cause any type of social impact. The research underlined a set of 28 fundamental factors that may create social impacts within the health and social well-being of people (including work conditions), quality of life, legal issues, and wealth generation. Of these, 12 specific factors were pinpointed unanimously by all four organizations as creating changes (column "yes"), namely disease situations, situations of particular risks, feelings of social valorisation/recognition of professional status, new recreational and leisure activities, adaptation of product characteristics to the needs/expectations of the community, creation/disappearance of small local businesses, customisation/personalisation, development of new Skills that can be used in new businesses, creation/disappearance of jobs, educational curricula, need to participate in training and professional requalification, and need to develop new skills. By contrast, at least three factors were likely to have no social impact (null impact): Situations of accidents at work, number of hours of mental and/or physical work, and level of crime and violence. The latter is surprising, since it contradicts other findings in the AM literature [28,45]. However, a list of undefined or fuzzy factors also emerged. The case with the protection of patent rights is one that raises doubts and needs further investigation.

The second research question (RQ2) intended to identify the "effects", i.e., the types of AM social impacts. Following Vanclay's social impacts definition [19], this paper proposes 10 social impacts related to AM, which are organized into four categories and respective subcategories: (1) Health and social well-being, with the subcategories of health and safety, mental health and well-being, and expectations for the future; (2) quality of life, with the subcategories of perception of leisure and recreation, and perception of real crime and violence; (3) institutional and legal level, with the subcategory of legal rights; and (4) economic and material well-being, with the subcategory of disruption with the local economy, economic prosperity, level of employment in the community, and professional status and employment type. The case study results allowed the confirmation of this set of social impacts and unveiled another two, cultural impacts and social inclusion.

The third research question (RQ3) helped explain the cause-effect relationships between AM factors and their social impacts. To answer this question, it was assessed if the impacts were perceived as positive, negative, null, or mixed. Apparently, AM technology has many positive impacts, such as improved health and safety due to a reduction of occupational diseases caused by physical hazard, higher expectations for the future, derived from feelings of social valorisation/recognition of professional status, new opportunities for leisure and recreation, given the chance to develop new hobbies and other recreational activities, disruption within the local economy in a positive direction, with the adaptation of products to the needs of the community, economic prosperity, originating from the increased demand for product customization, and finally, increased professional status and innovative employment types, instigated by new educational curricula and training and qualification schemes.

However, one negative impact of AM technology was identified by all; the possibility to reduce worker health and safety due to particular risks, namely exposure to dangerous substances.

The main limitations of the current study arise from three methodological aspects. Firstly, the use of a case study methodology. The results can be influenced by contextual factors, such as the size of the organizations in the sample, and/or social, cultural, technological, political, economic, and ecological factors. Directly associated with this issue, it should be highlighted that the cases selected were restricted to micro-enterprises. This was due to geographical proximity and to keep a manageable (short) number of homogeneous cases. A subsequent and much more extended study is currently being carried out, including a survey with a large number of enterprises of all sizes and from a variety of activity sectors. Finally, it should also be acknowledged that, in the future, all seven categories of Vanclay's list of impacts should be explored with respect to AM technology.

All in all, the present study, just like a few of its predecessors, appears to corroborate a multitude of positive social impacts for AM technology. However, this somewhat optimistic vision should be tackled with caution and more research work, since AM is still in its early days and other less interesting impacts may still be unknown. Finally, key research directions in the AM technology field can be summarized as follows:

- Developing a more comprehensive study on AM social impacts, considering a larger sample and replicating the study in several countries.
- Verifying if the use of different raw materials and equipment can lead to different social impacts.
- Developing methodologies to quantify (including formal indicators) the relevance of AM technology's social impacts.
- Creating an open database of possible AM social impacts, specifying the differences between the varied raw materials and equipment involved.

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