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The State of the Responsible Research and Innovation Programme: A Case for Its Application in Additive Manufacturing

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Abstract: Since the inauguration of the responsible research and innovation (RRI) framework programme in 2011, RRI has been actively promoted around science and technology communities all over Europe. This article describes the state of the responsible research and innovation program and how it might be useful in the in the additive manufacturing industry. It also presents the results of a pilot study based on the AREA approach of RRI indicating that intellectual property rights, health, and employment are important issues that need to be addressed as additive manufacturing becomes mainstream.

Keywords: Responsible research and Innovation RRI; Additive manufacturing (3D printing); Ethics

Citation:

Introduction

The emerging technology sector is beginning to witness a gradual shift in ideology from rudimentary and sometimes obligatory ethical principles and theories to a more sophisticated and somewhat elaborate approach to ethics called 'responsible research and innovation' or RRI. Policy makers, ethicists, and philosophers like Von Schomberg (2013) have come to the conclusion that an ethical position that focusses on the intentions and/ or consequences of the individual's actions is no longer appropriate for our time.

Thus, rather than simply encourage moral positions that revolve around personal reward and/or punishment, RRI seeks to entrench ethical positions that are also based on broader civic and group expectations. This shift in position, although not entirely new, has been championed by the European Commission since May 2011 under the Horizon 2020 work programme (Saille, 2015, p.152). In the UK, a similar effort is being promoted by the Engineering and Physical Science Research Council (EPSRC) (EPSRC, 2017c) whose belief is that researchers and their funders as well as stakeholders and the public all have a role to play.

The EPSRC is committed to ensuring that it only funds activities and research that are aligned with the principles of RRI to create value for society in a way that is ethical and responsible. As a mark of this commitment, RRI has been made the main instrument through which allocation of research funding is governed (Saille, 2015, p.159) and the EPSRC invests over £800 million each year (RRI Tools Consortium, 2016, p.18) in innovative science and technology research. This likely explains the proliferation in recent years, of RRI research focusing on innovative ICTs and their related fields (ORBIT, 2017; COMPASS, 2017;

Responsible-Industry, 2017; PRISMA, 2018; NewHoRRIzon, 2018) where ethical and social issues are constantly emerging and are more likely to receive funding.

As policymakers seek to 'induce a system enhancing ethical, responsible and sustainable' (Gurzawska, Mäkinen and Brey, 2017, p.1762) innovation in industry, Delpy (2015) a former CEO of the EPSRC insists that RRI is integral to research processes and not a separate item and that it is part of being 'a good researcher' to think of the 'potential impact of research and the potential consequences of research'. It is worth asking then, how such an approach might extend the expertise of the relevant scientist (e.g. social scientists) tasked with promoting RRI? This paper takes the position that RRI as promoted by the EPSRC is not only beneficial for emerging industries like AM by enabling more sustainable outcomes, but also for the social scientist tasked with promoting RRI by enabling greater anticipation of ethical issues and encouraging a more reflective culture. To investigate this, the rest of the article describes the EPSRC approach to RRI, explores its value for research of ethical issues of additive manufacturing (AM), and suggest how RRI might be used to encourage a more ethically responsible AM industry.

The AREA Approach to RRI

Under the RRI banner, the EPSRCs approach for promoting socially desirable research and innovation is commonly referred to as AREA (EPSRC, 2017a). AREA which is an acronym for Anticipate, Reflect, Engage, and Act suggests that in considering ethical issues of technology, researchers and innovators should:

- *Anticipate*: explore possible societal and ethical impacts;
- *Reflect*: reflect on the uncertainties, areas of ignorance, dilemmas, and social transformations;
- *Engage*: broad deliberation, dialogue, or debate to question the societal impact;
- *Act*: Use knowledge gained from the processes to influence the direction of research or innovation

However, it is important to note that the AREA approach is based on the four dimensions of responsible innovation suggested by Owen et al. (2013, p.38) namely 'Anticipation, Reflection, Deliberation, and Responsiveness (or ARDR). According to Miller (2016, p.8), the more "appealing" AREA acronym was created by changing the last two dimensions (i.e. deliberation, and responsiveness) to 'engage' and 'act'. And although Zwart et al. (2014, p.3) argues such metonym (or displacement) caused by shifts like this are hardly ever neutral, in this case it is argued that it is the contrary.

For example, Owen et al. (2013, p.38) in agreement with Pellizzoni,(2004, p.557) who argued that responsiveness "entails readiness to rethink own problem definition, goals, strategies, and identity", suggested that responsiveness involves use of collective processes of reflexivity "to both set the direction and influence the subsequent trajectory and pace of innovation." This is comparable with and corresponds to the 'Act' dimension of the AREA approach which refers to the use of "knowledge gained from the processes to influence the direction of research or innovation". Thus, the concepts of 'Responsiveness' as presented by Owen et al. (2013, p.38) and 'Act' in the (EPSRC, 2017a) AREA approach can be said to connote 'listening' with a view to change course when ethical or societal issues are identified.

The same can also be said of the dimensions of 'Engage' in the AREA approach vs 'Deliberation' in ARDR. Owen et al. (2013, p.38) indicates that deliberation refers to inclusively 'opening up' purposes and dilemmas through processes of dialogue, engagement, and debate. Similarly, the EPSRC (2017a) also suggest that to 'engage' requires 'opening up' visions through broad deliberation, dialogue, or debate in an inclusive way. Both concepts can be said to be in harmony as they both suggest broad and inclusive discussions.

Nevertheless, Jirotka et al. (2016, p.3) has suggested that there are fundamental problems with RRI and the AREA concept and that while it appears simple to understand, by bunching research and innovation together important boundaries and significant differences are blurred. Also, Dreyer et al. (2017, pp.1722–1725) suggest that research (which is about generating knowledge) and innovation (which translates knowledge into valuable product or service) are very different processes with separate issues and so should not be bunched together under governance mechanisms like RRI. It is likely such ideology that has informed a gradual shift in the RRI discourse to that of 'responsible innovation' or RI (Nerlich, 2014; Lubberink et al., 2017, p.182; EPSRC, 2017b; COMPASS, 2017). While this article agrees that there are inherent differences between research and innovation, it however takes the position that the AREA approach to RRI can positively impact on research even in those fields information systems and the social sciences.

RRI in the Additive Manufacturing Industry

One of the emerging technologies that has not received much attention from those promoters of responsible research and innovation, is additive manufacturing (AM). Also referred to as 3D-printing, rapid prototyping, or direct digital manufacturing (Gibson, Rosen and Stucker, 2015, p.1), AM takes digital information from a computer and builds 3D objects from that by depositing materials layer upon layer (Wong and Hernandez, 2012, p.1; Olsson, Hellsing and Rennie, 2017, p.1). It, therefore, enables manufacturers to deliver solutions that are at the crossroads of manufacturing and digital technology (Barnatt, 2014, p.24). The potential for AM to replace many conventional manufacturing processes, enable greater engineering functionality, support new product development, allow new business models and new supply chains to flourish has been well documented (Royal Academy of Engineering, 2013, p.1; Huang et al., 2016, p.1559).

However, like many other emerging technologies, AM has its own peculiar ethical issues that are not well understood and there is indeed a policy vacuum (Moor, 1985, p.266) that needs to be addressed. To this end, Weston and Flick (2013, p.526) have argued that RRI is an important method for 'framing discussion' about 3D printing, that it is useful for 'identifying and engendering responsibility', and also exploring issues like how to "ensure 3D printing is only used for 'good'?". Seeing that RRI is well placed to address the potential implications and societal expectations, there is indeed a need to explore options for its application in the AM industry.

It is important that policymakers, researchers, innovators, as well as stakeholder adopt the inclusive and deliberative approaches being promoted by RRI to assess the ethical issues associated with AM in order to come up with socially desirable and acceptable solutions. The rest of the article describes a pilot study involving participants from SMEs in the AM industry. The study explores the application of AREA framework for anticipating ethical issues of AM, and for reflecting on practices in the industry to determine how they relate with the EPSRCs framings of RRI.

The Pilot Study

A pilot study was conducted with participants from the additive manufacturing industry. The study involved 5 people holding various positions in 3D printing SMEs in the industry around the United Kingdom. They were involved in providing such services as on-demand 3D printing, 3D scanning and modelling, manufacturing, as well as sales and service of 3D Printers and accessories. As shown in Table 1, one of the participants is an important inventor and pioneered the development of the RepRap 3D printer which is described as a self-replicating AM machine. The others also hold important positions such as production coordinator, manager, design consultant, and an intern. Interestingly, all the participants are actively involved in open community-oriented 3D printing workspaces like maker labs, hackspaces, and fabrication laboratories (fab labs).

Table 1 Summary of participants involvement in AM

PARTICIPANT	INVOLVEMENT IN AM INDUSTRY
P1	3D scanning and 3D printing intern
P2	Manager & Consultant (Mechanical Engineering)
P3	Production Coordinator (Product Design)
P4	Design Consultant (Engineering Product Design)
P5	Director of 3D printing organisation; Innovator & Ex-Academic (Mechanical Engineering)

For anonymity, rather than use the real names of participants, they are referred to throughout this paper with the alphanumeric codes P1 to P5. Participant P5 who is the Director of a 3D printing organisation, has a background in Mathematics and Engineering, and while working as an academic at a university in England was actively involved in the invention of the first self-replicating desktop 3D printer. P2 has a background in Mechanical Engineering and is a Manager and Consultant at a 3D printing establishment, and is involved in assembly of 3D printers, 3D scanning, and on-demand 3D printing. Participant P3 who is a production coordinator has a degree in Product Design, works in 3D design and production of 3D printed objects for a company and is a specialist jewellery designer. Another product designer, Participant P4 has a bachelor's in Engineering Product Design is a design consultant who is also involved in design and production of 3D printed objects as well as sales and services of 3D printers. On the other hand, participants P1 is an intern in a 3D printing company where they are involved in 3D scanning, 3D Printing, and sales of 3D printers and accessories.

The participants were interviewed using semi-structured questions that allowed the researcher to explore the relevant research themes. The interviews were audio recorded and then subsequently transcribed for analysis. The analysis was done using qualitative thematic analysis to emphasize patterns and themes within the data. As this research aims to ascertain opaque issues that arise due to AM in order to bring them into view, all relevant themes identified were recorded for analysis. Note that opaque issues as used here refers to ethical or social issues that are not yet well known or understood (Brey, 2000, p.12). The following section discusses the findings of the pilot study.

Research Questions

The research questions explored in the pilot study are:

i. What are the ethical issues of additive manufacturing (AM) technology?

ii. How does responsible research and innovation feature in the AM industry?

Methodology

This research uses an exploratory and qualitative approach that is based on the AREA framework for RRI. The AREA approach was selected not just for its appealing acronym, but for its flexibility as it can be quite easily applied to a variety of situations and technologies (EPSRC, 2017a). Also, like other anticipatory ethics approaches, anticipation is a central theme in the AREA approach making it very useful as it means that foresight methods can be utilised to identify both general and future ethical challenges (Brey, 2017, p.179). Another important reason for the use of the AREA approach is because it complements efforts of major funding bodies like the EPSRC, (EPSRC, 2017a) and BBSRC – Biotechnology and Biological Sciences Research Council (Synthetic Biology Research Centre, 2017) to institutionalise RRI within the UK research and innovation community.

In order to avoid confusion, it is important to clarify that the AREA framework is applied in two important ways in this study – (i) to provide structure for the research and to enable greater and reflexivity during the research process as each dimension of the framework formed an important stage of the study (see Figure 1), and (ii) as basis for determining how practices in the AM industry compares with the RRI framework.

It has been suggested that the 'anticipate' stage may be used to think through the trajectory of research and to describe and analyse intended and unintended impacts of technology (Pearce, Hartley and Taylor, 2014, p.3). Similarly, the EPSRC (2017a) suggest that the 'anticipate' dimension may be used to describe and analyse intended and unintended impacts in relation to the society in terms of social, environmental, or economic impacts and possible implications. Therefore, the 'anticipate' dimension of the AREA framework was applied in 2 ways in this study – first to explore the trajectory of the research in terms of ethical issues of the study and secondly, in determining ethical issues of the technology under study.

Exploring the trajectory of the study required the research to go through standard university ethics review procedure designed to protect individual participants of such studies. The anticipation phase also involved horizon scanning to systematically explore possible societal impacts of additive manufacturing to society. According to Amanatidou *et al.* (2012, p.209), horizon scanning has two main functions – the alerting function which is an anticipation tool for early detection of emerging issues of new technology; and the creative function which aids the creation of new and emerging issues on the basis of analysis of scanned data. An exploratory scanning approach was used to identify emerging issues from a wide variety of sources (Amanatidou *et al.*, 2012, p.209). Using a search process (scanning), early warning signals – also referred to as weak signals (Schultz, 2006, p.5) were identified. This was achieved through a systematic review of extant literature on relevant subjects to quickly develop an understanding of the issues at hand. As suggested by Wakunuma *et al.* (2011, p.3) data was collected from the following sources:

I. Research publications and foresight studies and activities
II. Industry/trade journals
III. Policy-oriented publications (e.g. parliamentary or government publications)
IV. General press and media

Reflective analysis was a vital element of this study and conscious effort was made to reflect not only on the data, but also on the research process as well. That is why in the conceptualisation of the research process indicated in Figure 1, reflective analysis takes centre stage as it is considered not just as a stage in the research process, but as an important link between all the dimensions of the AREA framework.

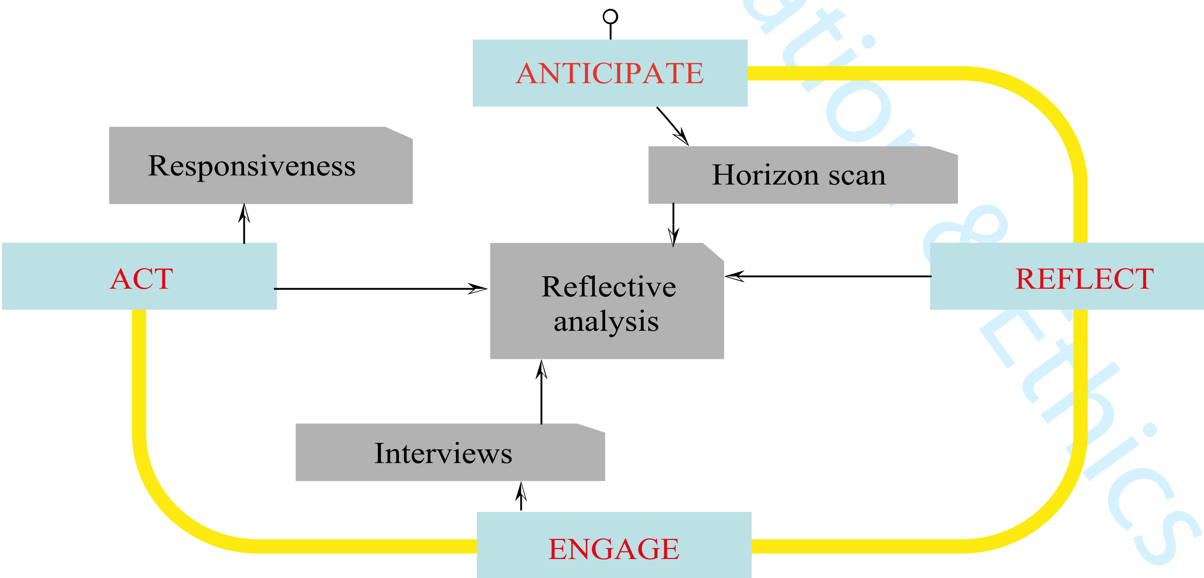

Figure 1 Conceptualisation of the AREA framework for this study

The importance of reflection – the notice that the mind takes on its mental operation (Scharp, 2008, p.25), has since Locke [1632 - 1704] been considered an important epistemological process (Locke, 1690a; Locke, 2007). Molander, (2008, p.5) suggests that reflection has the ability to impact positively on the learning process through careful consideration and 'the ability to review, analyse, and evaluate situations during or after events.' Although reflection may be considered a natural learning process (Finlay, 2008, p.1; Royal Conservatoire of Scotland, 2016, p.1), there is need for reflections to be done with the right perspectives in mind as Socrates' witty remark in the 'head in cloud' (Schuster, 2016, p.108) illustration shows:

> *Thales was studying the stars… and gazing aloft, when he fell into a well; and a witty and amusing Thracian servant-girl made fun of him because she said he was wild to know about what was up in the sky but failed to see what was in front of him and under his feet. (Boys-Stones and Rowe, 2013, p.213)*

Thus, while acknowledging that reflection can be epistemic in nature and can help improve understanding, the researcher recognised the need for the mind to be directed against detracting from the study at hand to avoid such 'head in the cloud' type situations. Consequently, periodic reflection enabled the research to critically think through the 'purposes, motivations and products of the research' (Eden, Jirotka and Stahl, 2013, p.2013).

RRI emphasises engaging with stakeholders or as Reber (2018, p.38) calls it, 'democratic deliberation' with respect to the purpose of research and innovation. Owen, Macnaghten and Stilgoe (2012) suggest that such an approach will enable the 'right impacts' of research and innovation to be reached. And Oudheusden (2014, p.79) argues that deliberative democracy encourages rational-critical debate where participants pay attention to each other and probe their assumptions for the sake of mutual learning and understanding. Consequently, it can be said that a link exists between deliberation and public engagement. Franco (2006, p.813) defines deliberation as 'a form of conversation in which participants collectively seek to reach agreement on how to carry out an action which is of concern to them' and the Department for Business, Energy, and Industrial Strategy (2018) associates such deliberation with engaging dialogues on issues relevant to future policy decisions. It also suggests that stakeholders including members of the public, scientists, researchers, businesses, pressure groups etc. are engaged with. It is no wonder then, that this sort of engagement is at the core of the RRI concept.

For this research, 5 persons from the AM industry were engaged in deliberation during a series of interview sessions. Understandably, this form of engagement does not meet the full requirements of what constitutes a full RRI approach. However, attempts were made to go beyond the regular qualitative research approach using interviews by opening up the discussion to a wider audience. This was done online with the aid of internet relay chat (IRC) using a popular 'Freenode' channel frequented by 3D printing enthusiasts with a membership count of over 1200. Kaur and Kaur (2017, p.118) describes IRC as an electronic chat protocol that enables real-time conversation with people all over the world, and the virtual environment provided was judged to be capable of providing a suitable forum to engage with the community.

Due to difficulties with recruiting participants for other forms of community engagement like workshops, IRC was considered a viable alternative as conversation will be taking place in real time, and the virtual chatting environment provided conditions akin to face to face conversations. Also, it was thought that IRC provided a cheaper option as this study was being conducted without public funding, hence limited resources. Members of the Freenode IRC channel that was appealed to for participation were willing to contribute to the discussions and provided interesting insights on ethical issues of AM. However, the conversation had to be discontinued as one of the participants raised an issue about the groups Freenode policy which was against publishing anything from them. Thus, data collected in this way could be used and the study had to rely on data gathered from interviews with the 5 participants from SMEs.

Responsible research and innovation require actors to 'Act' or to allow the knowledge gained from the processes of anticipation, reflection, and engagement to influence the direction of research or innovation. It entails 'responsiveness' or allowing values that have emerged from the entire process to influence future directions – 'resulting in changes in shapes or direction' (de Jong, Kupper and Broerse, 2018, p.2). One of the ways this was demonstrated in this study was by being responsive to the issues of privacy raised during the discussion on the IRC channel, discarding the very interesting data already gathered, and discontinuing data collection from such a forum.

Findings and Discussion

The participants were asked open-ended questions relating to their awareness of ethical issues or societal concerns that arise from additive manufacturing and how their activities resonate with RRI. An interesting range of responses was obtained, and these were then grouped into two broad themes – ethical issues of AM, and feature of RRI – discussed in the following sections.

Ethical Issues of Additive manufacturing

Analysis of participants response indicate that 7 ethical issues were identified. These included issues around environmental problems, 3D printed weapons, printing of banned objects like swastikas, the impact of 3D printing on intellectual property, business ethics, liability, and health-related concerns. However, due to word limit constraints of this article, only three of these are highlighted as follows:

Intellectual Property Rights

Considering that additive manufacturing enables just about anyone with digital file of any object to print out the physical object (Stahl, 2013, p.7), it was no surprise that the issue of intellectual property rights (IP) was raised by all. One of the participants suggested that 3D printing could be bad for IP rights:

> *I can imagine some case scenarios, where 3D-Printing can be bad for intellectual properties and everything. I think it could be a real issue if someone is spending, I don't know, maybe 10 hours stuck on a design... and if someone just takes this one, do slight modification or something like this... or take his work and reproduce it... that's an issue (P1)*

This participant draws attention to the ease with which users of AM technology can copy the original designs of objects (either by 3D scanning or use of specialised design software) and then reproduce these irrespective of the complexity and time taken to create them, suggesting that such action could result in problems. This analysis appears to agree with that expressed by Widmer and Rajan (2016, p.1) who maintains that AM may create new IP challenges and suggest as example a situation where fan blades previously purchased from manufacturers are scanned and produced at home creating difficulty around enforcing IP rights.

AM presents interesting new challenges to those who own intellectual property rights (Esmond and Phero, 2015, p.9) and a second participant suggests he was concerned and that some big industrial actors were not immune to such fears.

> *The only thing that would possibly be a concern would be things like … intellectual property… yes there can be concerns…they are very scared of 3D-Printing as an industry, so they have taken out a lot of legal action*

against things like that… Some of the bigger Italian furniture brands you know… have taken out a lot of copyright to protect their furniture from 3D-Printing which sounds a bit ridiculous now but you never know in the future if you can 3D scan a chair and reproduce a chair which at the moment is kind of crazy but in the future possibly. So, there are companies that are scared about this 3D-Printing, but I think that also comes from the idea that 3D-Printing will be a household thing… (P3)

This participant (P3) illustrates how concerns around IP infringements due to 3D has also reached those in industry and led some to take pre-emptive action to minimise the impact by obtaining specific 3D printing copyrights to derive full benefits from their intellectual property.

Issues around exclusive benefits from intellectual property have been advocated since John Locke proposed what is now termed Locke's utilitarian theory of labour in which a case was made not just for the private ownership of property acquired through labour, but for the right to enjoying some reward for that property "The labour of his body, and the work of his hands, we may say are properly his. Whatsoever then… he hath mixed his labour with, and joined to it something that is his own, and thereby makes it his property… For this labour being unquestionable property of the labourer, no man but he can have a right to what that is once joined to, at least where there is enough and as good, left in common for others (Locke, 1690b). This suggest that it has long been recognised that the individual who put in the work had a natural right to derive full benefits from the fruits of his labour.

In as much as issues surrounding intellectual property are not entirely new (Machlup and Penrose, 1950, p.1; Baker, Jayadev and Stiglitz, 2017, p.12), AM is able to effect some anxiety amongst designers and manufactures due to the ease with which just about any object can be reproduced. Armed with a digital file obtained easily from the internet, 3D scans, or designed with Computer Aided Design (CAD) software, the object can be printed with or without the consent of the rights holder in the bedroom with a 3D printer that costs very little.

It was however interesting to note that some of the participants didn't really think of intellectual property right was an issue to be concerned about with regards to 3D printing. For example, one of the participants did suggest that they weren't concerned about the copyrights of designs.

I don't care about the copyright of the design... I don't care about that (P2)

In a similar vein, another participant suggested indifference to intellectual property rights issues:

> *I don't believe in patents and copyrights and all that sort of thing (P5)*

Both participants P2 and P5 suggest that they weren't interested in issues around 3D printing's impact on such intellectual property issues as copyrights and patents. And participant P5, an important 3D printing innovator is also a great advocate of the open-source model where ideas that are normally considered intellectual property are made freely available to the public. He said of his own innovative ideas:

> *I release everything about it open source. So, telling people about it, means, face it, we publish it online, letting other people do what they like with it…(P5)*

This participant maintains that not only does he not care very much about the impact of 3D printing on intellectual property rights, he also freely distributes his own innovative ideas. It would generally not be inappropriate to associate these sorts of positions with the open-source community of which 3D printing FabLabs (fabrication laboratories), makerspaces and hackspaces form a subset, and which have had a significant impact on the trajectory of AM. It is worth noting that besides participant P5, all the participants in this research have been part of such open-source communities where values such as sharing, openness, and transparency are emphasised through collaborative work and adherence to open paradigms.

The open source licence whose purpose is to deny exclusive rights to exploit a work (St. Laurent, 2004, p.4) allows modifications, derived works, and their distribution (Rosen, 2005, p.4). An example of the benefits that can be gained from this sort of ideology can be seen in the Replicating Rapid Prototype (RepRap) project which develops self-replicating 3D printers (Jones *et al.*, 2011, p.178). Beginning in 2005, the RepRap project essentially helped to democratised 3D printing after 2 decades of their existence under a closed licence system, by simply allowing open access to its hardware, firmware, and software and now, over 3 million 3D printers are said to exist worldwide (Zivkovic and Battaglia, 2017, p.661). Suggesting that there are benefits to be derived from this type of model. However, while acknowledging the important role open innovation has had on AM's development, Birtchnell et al. (2018, p.16) maintains that it also creates difficulty for enforcement of existing IP rights.

Consequently, the Committee on Legal Affairs of the European Parliament has recognized the specific legal and ethical concerns of 3D printing in "all areas of intellectual property law, such as copyrights, patents, designs, three-dimensional trademarks and even… civil liability" (Committee on Legal Affairs, 2018, p.5). And in a recent motion for a European Parliament resolution to address these challenges it was suggested that the "EU might have to adopt new legislation or tailor existing laws to the specific case of 3D technology" (Committee on Legal Affairs, 2018, p.7). This indicates that fears around 3D printings impact on intellectual property rights are not misplaced.

Health-related Concerns

It is important to note that depending on the type of 3D print technology in question, there are several different types of feedstock used in the printer to create physical objects. For Fused Deposition Modelling (FDM) type 3D printers, the common materials used for printing are ABS (Acrylonitrile Butadiene Styrene) and PLA (Polylactic Acid) (Wu *et al.*, 2015, p.5834; Cantrell *et al.*, 2017, p.90); SLS (Selective Laser Sintering) type printers uses polymers like nylon in their powdered form (Pomell, *et al.*, 2015, pp.185 & 187), while SLA (Stereolithography) type 3D printers uses a liquid photo-curable resin (Taormina *et al.*, 2018, p.214). A brief description of some of the 3D printer technologies is provided in

Table 2.

3D Printer Type	**Description of Technology**
Fused Deposition Modelling (FDM)	Heats up thermoplastic material (e.g. ABS or PLA) to melting point to create a physical object
Selective Laser Sintering (SLS)	Creates 3-dimensional objects by melting powdered plastic polymer like nylon and then depositing it layer upon layer
Stereolithography (SLA)	Uses laser beam to harden liquid photoreactive polymer resin layer by layer until a 3D object is created

Table 2: Description of some 3D printer technologies

When participants were asked about their views on health-related issues that might be associated with 3D printing, they all appeared to agree that not enough awareness has been created about this aspect. A participant noted:

> *… again, I don't think there has been enough studies (P5)*

And another participant complained that even the internet hasn't been very helpful with these sorts of information:

> *... I try to search that on the internet and they don't say something, they say some respiratory problems.... (P2)*

Participants P2 and P5 maintain that there is a dearth of information on health issues that might arise due to additive manufacturing and that there haven't been enough studies in this area. They suggest that they've sought information on this subject online and it yielded only very little information with mentions of respiratory problems. This suggest that the participants are keen to understand how use of the technology might impact their health and how they might prevent any negative consequences. In similar fashion, findings of a recent preliminary study on 3D-Printing hazards by Ryan and Hubbard (2016, p.2) suggest a dearth of information about 3D printing hazards exists, and Oskui *et al.* (2016, p.1) maintains that only little is known about the toxicity of 3D-printed objects.

Nevertheless, all the participants expressed some concern about the possible health hazards of 3D Printing, albeit to varying degrees from participant to participant. One of the participants mentioned safety fears with SLA:

> *... some substances that we use for example… with the SLA printer, it uses a substance which is a liquid that is drawn out, and eh, it gives off a certain resin... it's not the safest material to come into contact with … (P4)*

In this case, the participant appears to be concerned about the resins used in SLA printers suggesting that the resins from which the objects are formed may not be very safe materials. And a similar comment was made by another participant:

> *For resin, if you inhale resins… resin is toxic… it's toxic for your lungs… (P4)*

The participant (P4) suggest that resin is toxic, and that it is particularly bad for the lungs when inhaled. As 3D printers are often used indoors where the quality of air can depreciate quickly especially with poor ventilation, it can be seen why these participants might be worried. A recent laboratory test involving zebrafish embryos at the University of California was conducted to determine how 3D printing might impact health. The test performed by Oskui *et al.* (2016, p.1) assessed the toxicity of different polymers used for fabricating 3-dimensional objects for medical purposes. The results of the experiment showed that most of the embryos exposed to printed parts from stereolithography died within 7 days and that only very few managed to hatch by day 4 with severe deformities. Although human tolerance for the sort of toxicity described here might be much better, the results are nevertheless quite worrying.

With respect to ABS, one participant suggested that this filament which was the most popular material for 3D printing could also be quite dangerous:

> *…ABS which is one of the more popular materials is oil based. There are fumes and odours from that which can be dangerous. Now, of course, you'd need to lean over the printer and be inhaling them for it to have any immediate effect but then again, that's one material…(P3)*

The participant (P3) suggests that the materials used in making ABS filaments gives of odours while printing and that if one leans over a 3D printer using such filament, it is possible to inhale the fumes from the machine which is dangerous. Participant P3 also mentions the popularity of ABS as choice of filament and indeed it is one of the most commonly used thermoplastic materials possibly due to its tensile and flexural strength which is described as 40 – 70% greater than other FDM materials (Fischer, 2011, p.2). So naturally, it would be a thing of concern that any fumes that might be emitted during the printing process may cause adverse health effects.

Another participant maintains that ABS could be cancerous:

> *… if you print with ABS, the fumes are… some substances are 100% cancerous… it's like there is no doubt about that… the fumes of ABS are cancerous… (P2)*

Similar to participant P3, participant P2 suggests that the fumes from ABS are dangerous and that it could potentially cause cancer. The health and safety guidelines of the Pennsylvania State University suggests that 3D printing processes like those in which ABS is used emit fumes and ultrafine particle (UFP) clouds in the nanoparticle or submicron range i.e. 1/10, 000mm (Pennsylvania State University, 2016, p.3). Research by conducted by Stephens *et al.* (2013, p.338) to determine the concentrations of UFP's emission rates for ABS found that up to 200 billion particles per minute ($\sim 1.9 \times 10^{11}$ # min^{-1}) were released. It can be seen why these particles might be of concern to users especially those in close proximity to the printers, as their sizes (in the nanoparticle range) and concentrations mean a good portion of them will penetrate the human body and interact with the organs.

Of particular concern is the presence of ethylbenzene, acetaldehyde, formaldehyde, and 4-vinylcyclohexane in the ABS emissions because they are recognized as carcinogens and styrene, another probable carcinogen (Weber et al., 2016, p.122). Also, isocyanic acid and cyanate ion (NCO^-) are also part of the UFP's emitted by ABS. According to Zontek *et al.* (2017, p.23), these are associated with such ailments as atherosclerosis, cataracts, rheumatoid arthritis, as well as mild eye irritation due to the presence of n-decane. And Azimi *et al.* (2016, p.1266) found that large amounts of styrene which is classified by the International Agency for Research on Cancer (IARC) were emitted by ABS filaments. These results show that there is a need for caution with regards to the use of ABS filaments in 3D printers.

Participants also talked about PLA which is another very popular FDM filament during the interviews. Their comments were in respect to the particle emissions of PLA while printing 3D. One participant wasn't sure what the health effect of PLA are and so responded:

> *…even PLA, we don't know what these fumes can cause...(P2)*

Participant P2's comment again suggests that there is inadequate information about the impacts of PLA to health of users. Nevertheless, another participant suggests that because PLA is an inert material, it appears the odours are not harmful:

> *PLA which is the most common material is very inert. There's no real odour from that, so, it's fairly safe in terms of what we know. Of course, the particles are things we don't know anything about really, but it also depends on where this printer is… (P3)*

This participant agrees with the earlier opinion of participant P2 that there is very little information to about the impact of PLA on health however, he feels that PLA is inert and therefore would be somewhat safe. Now, a material is said to be inert when it is chemically inactive and does not react chemically with other materials. Moyle e*t al.* (2004, p.86) explain that PLA is immunologically inert and so does not trigger inflammatory reactions. And Cuiffo *et al.* (2017, p.580) suggest that this property of PLA is due to it being a starchy substance derived from corn and sugarcane, however, under 3D printing conditions, it undergoes chemical and structural changes due to the presence of inorganic additives. Furthermore, the structural changes increase the potential for reactivity with the atmospheric contaminant, as well as cells and organisms.

In relation to fumes and particle emissions, PLA emits UFPs at about 20 billion particles per minute (2.0×10^{10} #min^{-1}) (Stephens et al., 2013, p.338). And Davis (2017, pp.15&16) suggests that although emissions of Volatile Organic Compounds (VOC) for PLA were much less than ABS (20 different types as against 70 for ABS) key emissions include methacrylate, lactide, acetaldehyde, formaldehyde, and butanol. UFPs and VOCs are hazardous to human health as they are able to penetrate the organs like the lungs and get into the bloodstream (Weber et al., 2016, p.122), and so their presence at these concentrations are quite worrisome.

SLS is another 3D print technology that one of the participants was concerned about. Describing the worrying features of the SLS, the participant said:

> *For SLS process, the powder... this powder can go very deep inside your pores, it can go inside your lungs, and also, it is very flammable… in high concentration ... (P2)*

Participant P2 suggests that the particulate nature of SLS powder given off during printing processes means they can easily pass through body's pores and into then transported to vital organs lungs. The participants maintain serious concern about the impact this could have on health to such an extent that she rejected an opportunity for an important position in an organisation involved in working with printers using this technology. The participant described the situation thus:

> *…I had like a job offer to move from FDM printing to SLS printing and I didn't do it because... I have to sacrifice my lungs and there was a 2 years commitment contract… because you leave your phone there, and then after 3 minutes you are touching the phone and it has a layer of dust and this is everywhere... like everywhere. And I ask them like how many of these would I have inside my lungs after 2 years? And he said to me, if you pose it this way, I can't tell you something… but no men, this would fill every single particle of your lungs... it's so small, it's like 10 times smaller than your pores… (P2)*

The participant indicates that she rejected a lucrative 2-year contract in a 3D printing firm utilizing SLS for their work for fear that the tiny particles given off while printing might cause harm to her health. This participant suggest that her phone was covered in a fine layer of dust just after a few minutes and she wouldn't know how much of this dust she would have breathe in after 2 years.

Thus, a broad literature search of health impacts of SLS printing was conducted to determine what problems might result from use of SLS materials yielding 2 important results. Although one of the mentions simply states that Selective 'Laser Sintering produces harmful fumes' (Kinstlinger et al., 2016), the other, a risk assessment report on 3D printers and products sponsored by Danish 'Ministry of Environment and Food' indicates the presence of Laurolactame also called Azacyclotridecan-2-one (or dodecalactam) in concentrations of 230mg/kg (Ministry of Environment and Food of Denmark, 2017, pp.54 & 55). Interestingly, the Safe Drinking Water and Toxic Enforcement Act (1986) of California colloquially referred to as 'Proposition 65' list Azacyclotridecan-2-one as a carcinogen warning that it 'contains chemicals known to the state of California to cause cancer, birth defects, or other reproductive defects' (Ecomass, 2016, p.9). This suggests that there is a likelihood that some of the particles given off by SLS machines may contain the carcinogenic compound and yet it is not known how this would interact with the human body.

Two important details did come of all these. The first is that there is only very little information out there about how additive manufacturing impacts human health and not much research has been conducted in this area. Also, the findings indicate that despite the lack of information in this area, all the participants have fears about the impact of AM on health. Nevertheless, some of the information available do suggest that technologies like ABS, SLS, and PLA emit particles and fumes that could result in serious health issues.

Impact on Employment

Recently, AM has began to feature in debates about employment as there is worry in some quarters that the technology might have an adverse effect on employment (The Economist Intelligence Unit, 2018, p.6). One of the participants in this research expressed such an opinion:

> *Perhaps more importantly … things like erm, simple reduction in employment. You know if I have a 3D printer, and I printed all the coat hooks in my house – which as it happens, I do, and I have – then somebody who makes coat hooks is out of a job… (P5)*

This participant's viewpoint lays bare the sort employment dilemma that might arise as AM becomes mainstream. He points out that each time an item, in this case, a coat hook is made, it deprives someone engaged in the business of creating such an item some work. In the past, tooling constraints and cost of production meant that prior to the emergence of 3D printers, only manufacturing companies were able to comfortably engage in the production of items like the coat hook. However, with 3D printing such constraints are significantly reduced as anyone with a 3D printer can now easily print many of these coat hooks at home thereby depriving the manufacturing companies of some business. As the technology continues to become mainstream, it is therefore not surprising that some think AM will have far-reaching impacts on employment.

Over the years, as new innovative technologies emerge and become commonplace, concern has often been expressed over the nature of the relationship between new technologies and employment (Handel, 2003, p.3; Roosevelt Institute, 2015, p.1; Nübler, 2016, p.1). Very often, the debate about this relationship revolves around such themes as increased unemployment, suppressed wages, and greater inequality (Bruckner et al., 2017, p.1).

Concerning the future of jobs, a report by Stahl (2013, p.13) for the Institute of Applied Ecology suggests that while the number of production jobs will be significantly reduced, on the one hand, AM will create many jobs in such areas as design, engineering, and software programmers on the other hand. Agreeing with this outlook, a similar report for the European Agency for Safety and Health at Work argues that the implication of 3D printing on workers and their jobs will be twofold – (i.) Some jobs will be lost (e.g. traditional crafts and handmade production of objects), and (ii.) 3D printing will also introduce new jobs like design and creation of hardware such as 3D printers and software for running these machines (Junte, 2016, pp.7 & 8). For now, though, any impact on employment is minimal and determining to what extent 3D printing will disrupt job markets is difficult. Nevertheless, sentiments like those of participant P5 are important as they create awareness that there will be some impact on employment and those that might be affected can then take necessary action.

Features of Responsible Research and Innovation in AM Industry

Recall that the importance of the AREA framework with regards to efforts at promoting responsible research and innovation in the UK was highlighted in the introductory sections. Having identified a number of interesting ethical issues that might result from additive manufacturing, the study then set out to investigate how the elements of the AREA framework are operationalized in the industry by looking at evidence of such activities in the actions of participants. Jirotka et al. (2016, p.4) suggest that embedding RRI in ICT is extremely complex and so it is important to begin with an understanding of how practitioners currently manage their professional responsibilities and then assess how to fit features of RRI to their perception. Thus, identifying the features of the AREA framework (which understandably may not be explicitly labelled as such by participants) is an important step towards 'engendering responsibility' (Weston and Flick, 2013, p.521) in the industry. Note that 'responsibility' as used in this article connotes ethical responsibility or, to what Vincent (2011, p.16) refers to as virtue responsibility manifested by showing commitment to doing what is right.

It was interesting to note that of the 5 participants, only one had heard of the responsible research and innovation framework before participating in this research. This participant (P5) had learned of it by virtue of his activities in academia as he was previously involved in academic research and teaching. The other participants who were from industry weren't aware of the RRI framework and efforts to promote the AREA approach.

In consideration of the foregoing, the researcher having anticipated this scenario had supplied each participant with a research outline summarising both RRI and the AREA frameworks prior to the interviews. Also, the researcher made sure to clarify the various concepts to the participants before commencement of the interviews. The various responses obtained were then compared with the 4 dimensions of the AREA framework with interesting results. The finding indicate that indeed there exist instances of what might be considered 'ethically responsible' behaviour in the context of responsible research and innovation.

Each participant was asked how they may have 'anticipated', 'reflected', 'engaged', and 'acted' in relation to ethical issues arising in their use of AM. One of the participants initially suggested that she hadn't done any of these things, saying '…*I don't have an ethical talent… (P2)*'implying that she felt she lacked the capacity or any 'specialised skills' required for that. Similarly, participant P1 suggested that he hadn't paid much attention to such issues, saying "*…obviously, I don't really think about this, I am not really into that…(P1)*" which gave the impression that using such an approach wasn't something he was conscious about. Consequently, the questions were rephrased, and the participants were able to provide fine details that showed they were already applying some of the principles of the AREA approach.

For example, simplifying the questions using simpler expressions like 'what ethical concerns have you had?' Or 'have you encountered any ethical issues in your work?' and 'how have you responded to these?' The participants were able to provide relevant responses including participant (P2) who contrary to her initial fears demonstrated significant '*ethical talent*' by showing she had the ability to anticipate ethical issues, reflected on their impacts, engaged with the relevant stakeholder, and took appropriate action. By doing her own research about health impacts due to SLS 3D printers (see excerpts from interview in the section on Health-related Concerns) participant P2 was able to correctly anticipate health-related issues with the technology despite the gaps in information publicly available. By questioning her would-be employers, she was able to engage important stakeholders in deliberation about the consequences of constant exposure to the particles produced by the printers. Reflecting on the possible impacts on her health and the future consequences, resulted in her taking action to protect her health from negative impacts that might result from use of these printers by withdrawing her application with the concerned organisation.

Participant P1 who it was previously shown, had serious concerns for the impact of 3D printing on intellectual property (see excerpts from interview in Intellectual Property Rights) indicated how this concern translated into his work:

> *…while we were scanning, we needed some turntables... to have like accurate results... due to vibrations and this kind of stuff. Thing is, we didn't know if we had to buy a new turntable or build one. But if we build one, we are using some existing patents… or we can also design our own where obviously it can be inspired from other product's. So, yea, the idea was then, maybe buy one, dismantle everything, look how it's made and produce... print several others, or design everything from scratch and spend a lot of time to do that… we did both… The thing is, we just looked about the patent, as we are concerned its causing big issue for bigger stuff… (P1)*

This indicates some level of anticipation and reflection on the part of participant P1 as he has suggested that his concerns about intellectual property motivated him to do some research about patents which enabled him to avoid infringing on the intellectual property right of others. It also indicates that at some level, engaging deliberations occurred (likely with colleagues) which helped them take action to avoid infringing on the intellectual property rights of the turntable makers by designing everything from scratch.

A similar line of questioning also yielded interesting details from participant P5 illustrating the manner in which he anticipated ethical issues, reflect on them, engaged with stakeholders, and took appropriate action with respect to his innovations. For instance, on the 3D printer invention called RepRap to which he made substantial contribution, he suggested that he thought about the ethical issues of the technology right at the beginning:

> *at the very beginning of the project, of course I thought about the ethical aspects of it, before doing anything…(P5)*

This suggests that participant P5 took a cautious approach to the development of his innovative ideas by first taking out time to think through the ethical implications of developing the technology.

It has been argued that the framework for RRI 'compels us to reflect on what sort of futures we want science and technology to bring to the world' (Owen et al., 2013, p.34). Recognising this important role of reflection also described by Wangaard (2000) as a powerful tool for developing concern for others, participant P5 indicated he reflected on the dilemma he was faced with and the impacts on society.

> *... so of course, it might (as with all things), cause some damage, and cause some good things to happen, and you know, you try and make a balance. As long as the good things outweigh the bad things, then, it's probably a good thing to do! (…P5)*

Through the process of reflection, participant P5 recognized that his invention could result in some problems while being a force for good. He suggests that as it is difficult to completely eliminate negative impacts (in all things), one should strive for a balance, and that one of the most important considerations should be that good outweighs bad. This appears to be consistent with the ethical theory of utilitarianism (Bentham, 1871, p.2) which Sheskin and Baumard (2016, p.1) which advocates for the justification of moral decisions based on maximum overall benefits and minimal harms. This suggests that ethical reflections did play an important role in the way that participant P5 proceeded with his inventions.

With regards to engagement with stakeholders, P5 demonstrates good understanding of the importance and benefits of doing this as he believed it was his responsibility to let people know what he was doing (i.e. making a self-replicating machine). And in order to get feedback from a broad range of stakeholders, he went public with his ideas:

> *I wanted to tell everybody that this is what I was going to do - make a self-replicating machine and put it out there free and open source, which again I decided to do. And, quite a number of fairly prominent journalists picked up on this and articles appeared in the New York Times, the Guardian, and on the BBC. And so, right at the beginning of the project, people were kind of*

> *interested in this, but from my perspective what that really did that was useful is that people all over the world realised that there was this open source project, to make a self-replicating machine. Because it was open cause, they can get involved and contribute, which they did. And suddenly, I found myself working with a team of researchers that was the biggest research team in any UK university… So, there were all these people all over the world chipping in ideas, and actual designs… my motivation in getting the publicity was that I thought it was my responsibility to tell people what I was going to do, but the actual result was that nobody said, oh you shouldn't do that, or whatever…. but people did say, oh, can I get involved? And so that was how the whole thing got going…*

For this participant (P5), engaging with stakeholders was considered so important that he felt it was his 'responsibility' to publicise his plans right at the beginning of the project and even went as far as utilizing avenues provided by newspapers such as the New York Times, the Guardian, and the BBC. Akin to early deliberative democracy theorists like Mill (1863, p.42) who argue that the only "approach to knowing the whole of a subject, is by hearing what can be said about it by persons of every variety of opinion, and studying all modes in which it can be looked at by every character of mind". This was probably the first open source 3D printing platform which turned out to be one of the biggest research projects in any UK university at that time. And rather than discourage the pursuit of a self-replicating printer, the community of participants proved to be very supportive, resulting in action to produce the RepRap 3D printer.

The findings thus indicate that while efforts to promote the concept of RRI are relatively unknown in the AM industry, there is some evidence that many of the users who understand its potential, do endeavour to act responsibly. This agrees with the findings of Gurzawska, Mäkinen and Brey (2017, p.1762) who contend that although companies do lack knowledge about RRI, it doesn't necessarily mean that they conduct their research and innovation irresponsibly.

Reflecting on the Findings and Research Process

Responsible research and innovation encourage researchers and innovators to be more resourceful and reflective of potential social and ethical implications and impacts of their work. The findings of the empirical research indicate that although additive manufacturing offers an innovative means of manufacturing that is able to transform value chains, it advances some important ethical issues that are relatively unknown. One of the foremost issues is that of health impact which participants have indicated is potentially damaging and yet only very little research has been done in this area. If the situation in other industries that have migrated from analogue to digital forms of production is anything to go by, the impression AM gives is that issues around intellectual property rights may continue to plague the industry for quite a long time especially as the technology advances and its use becomes more prevalent in homes and SMEs. Technological advances have often led to interesting dilemmas about employment and the situation with AM hasn't been any different. That only one participant expressed worry that there would likely be issues with employment due to AM does not diminish the importance of highlighting it. Bringing such an issue to the fore will ensure that individuals whose jobs will be impacted are better informed and possibly enable them to make appropriate arrangements.

That there are ethical issues with additive manufacturing indicates there is need for responsible use of the technology especially with the current level of incongruence of regulatory provisions. The findings illustrate how some in the industry have endeavoured to take issues on board and to act 'responsibly'. However, there were instances where the notion of responsibility displayed falls short of that promoted by RRI. For example, the kind of deliberations that both participant P1 and P2 demonstrated does not fit closely enough with that required under RRI which promotes ethical positions that are based on broader civic and group expectation rather than focusing on the intentions and consequences of individuals actions. Indeed, it appears that the AM industry generally fails in this regard despite its readiness to open up deliberations about developing the technology to a broad audience through the open-source community, issues around ethics and responsibility are not readily discussed and emphasized. The deficit of information regard these very important issues is an indication of this state of affairs and more ought to be done to better anticipate the ethical issues of AM and open them up to a broader audience.

Can the AREA approach help to extend the expertise of relevant scientist (e.g. social scientist) tasked with promoting the responsible research and innovation framework? This article suggests that is the case. The AREA approach formed an integral part of the exploratory and qualitative methodology used in this study and although the core audience targeted are the emerging innovative industries, it did prove useful in providing structure to this study and enabling greater anticipation and reflexivity. It is however acknowledged here that the quality of engaging deliberation demonstrated in this pilot study (with just 5 participants) does not go far enough to that required by a full-fledged RRI framework, attempts were made albeit unsuccessfully to remedy this shortcoming.

Conclusion

At the beginning of this article, the state of the Responsible Research and Innovation (RRI) program was described. The article described the AREA framework which is the EPSRCs approach to RRI and then goes on to make a case for its application in the additive manufacturing industry. To illustrate its usefulness in the type of socio-ethical research common in information systems, the findings of a pilot study on the ethical issues of AM has been presented here. The pilot study, involving 5 interviews with participants from the AM industry, was conducted to test the research design based on the AREA approach.

Due to limitations of space and time for this article only part of the results of the pilot study is presented here. The discussion presented here focussed only on three ethical issues out of the seven that were raised by participants and which were deemed more relevant to the ETHICOMP community. The findings indicate that ethical issues of AM are not well known especially issues around health impacts of 3D printing of which participants suggested continuous exposure to fumes and micro-particles may lead to serious health problems. Impacts of 3D printing on intellectual property was also highlighted, while it was suggested that in terms of employment although there is worry about its impact in some quarters, the ability to create new jobs may outweigh potential job losses.

Also, the findings suggest that many in the AM industry endeavour to act responsibly notwithstanding the deficit of information on RRI in the industry. However, there are issues around dimensions of RRI like those that encourage engaging a broad range of stakeholders on ethical issues and responsibility. Even though the AM industry has been excellent in opening up discussions on advancing the innovation in open-source communities like hackspaces and fab-lab, it appears that issues around ethics and responsibility are not given enough consideration. Thus, this article suggests such forums can and should be at the forefront of opening up discussion on ethics and responsibility in order to incorporate responsibility into the DNA of 3D printing enthusiasts. RRI is a useful tool for making explicit opaque ethical issues that are not yet well known and understood. Besides those engaged in innovation, other researchers like social scientist tasked with promoting the framework can benefit from applying an approach based on RRI in their research.

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Table 1 Summary of participants involvement in AM

PARTICIPANT	INVOLVEMENT IN AM INDUSTRY
P1	3D scanning and 3D printing intern
P2	Manager & Consultant (Mechanical Engineering)
P3	Production Coordinator (Product Design)
P4	Design Consultant (Engineering Product Design)
P5	Director of 3D printing organisation; Innovator & Ex-Academic (Mechanical Engineering)

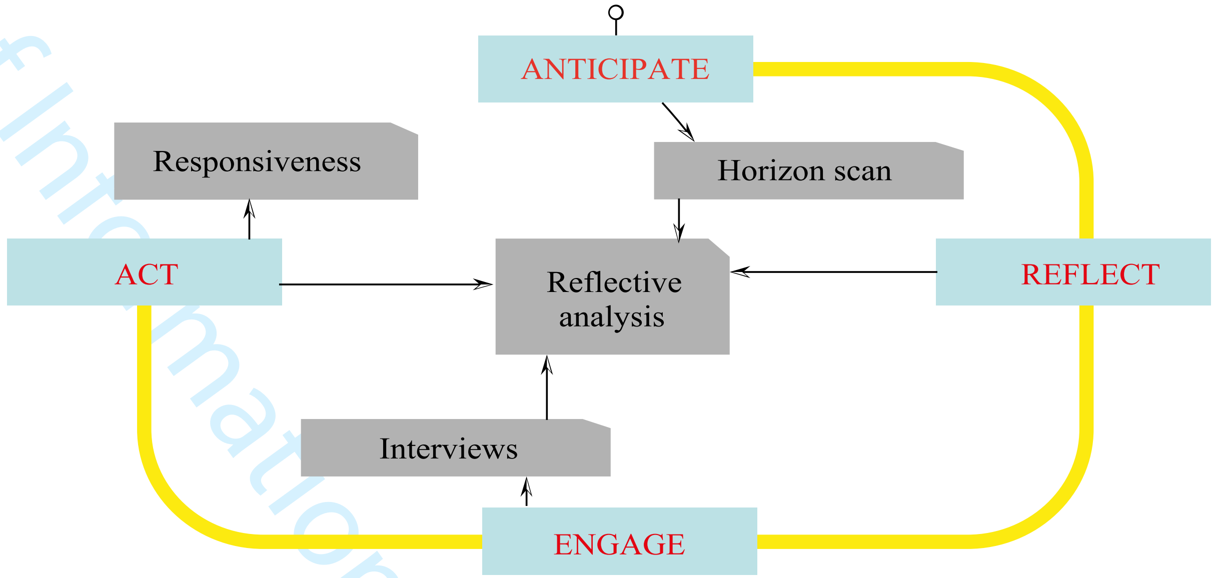

Figure 1 Conceptualisation of the AREA framework for this study