Broadening our horizons. Digital technology, metatechnologies, and their implications for responsible innovation

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ABSTRACT

This paper argues that responsible innovation discourses must consider the changing nature of digital innovation, if they are to stand a chance of steering the development of technology towards democratically-acceptable ends. It explores the extent to which foundational narratives of Responsible (Research and) Innovation (RRI) consider problematic features of metatechnologies – defined here as "core information technologies upon which others are based, and whose use vastly expands the degrees of freedom with which humans can act in the social and material worlds" – and implications for responsible innovation discourse in the digital age. The study finds that references underpinning paradigmatic RRI accounts include digital and metatechnology examples, albeit briefly in some cases, somewhat reinforcing the validity of seminal RRI accounts in the context of new and emerging digital technologies with metatechnological attributes. The need for additional reflection on the problematic implications of digital technologies for RRI is identified, for example with respect to distributed development, and recombinant and network-level effects. The paper concludes that the continuing value of RRI as a discourse to society will depend on researchers' and practitioners' awareness of the potential of these technologies for cascading, downstream innovation.

Keywords: Responsible Innovation; Responsible Research and Innovation (RRI); Digital Technology; Metatechnology; Critical Hermeneutics.

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INTRODUCTION

Responsible Research and Innovation[2] (RRI) provides a framework to align innovation with societal need, and rests on a lattice of assumptions regarding the nature of innovation, the ability to anticipate effects, and the extent to which potentially impacted stakeholders can be meaningfully engaged.

Different RRI accounts frame the need for processes to align innovation with societal needs in different ways. Within an overall understanding of RRI as an interpretively flexible umbrella term (Rip & Voß, 2013), Timmermans and Blok (2018) identify four foundational perspectives originating from the work of von Schomberg (e.g. 2013), Stilgoe *et al.* (2013), van den Hoven (2013) and that of the European Commission (2012a). Each account is developed with reference to different types of technology.

While the challenges of epistemological insufficiency, conflicting stakeholder interests, and limits to transparency identified by Blok and Lemmens (2015) are frequently cited as general problems in applying responsible innovation theory to practice, each of these four accounts is developed with reference to specific technology examples. Because some types of technology pose additional challenges in relation to responsible innovation (for example digital technologies; Stahl, 2015; Jirotka *et al.*, 2017), it follows that if foundational perspectives of RRI did not consider these types, the frameworks they set out may not have fully considered their associated problems.

This may be particularly the case for emerging technologies (those which have been invented, but whose details and potential uses, researchers and end users are not yet fully aware of; Kendall, 1997), and in particular those which enable a very large number of potential uses through onwards innovation. Cressman (2020, p. 21) neatly describes the contextual significance of this in defining innovation as "a background of assumptions and attitudes through which technology is thematized and made meaningful, providing a context that directs technological society towards particular ends while simultaneously foregoing other ends" – in other words, as the assumptions, attitudes, and meanings associated with emerging technologies change, the scope of potential uses and context for directing these technologies to particular ends also changes.

To explore the extent to which foundational RRI accounts are anchored in underlying assumptions about contemporary technologies, this paper addresses the

2 While a distinction can be made between a policy-based concept of Responsible Research and Innovation and a broader Responsible Innovation discourse, as the terms emerged in parallel and have common features (Owen & Pansera, 2019) they will be used interchangeably in this paper.

question 'to what extent do the examples cited by foundational narratives of RRI consider problematic features of digital and metatechnologies, and what are the implications for the foundational assumptions of responsible innovation discourse in the context of societies' increasing use of digital technologies?'.

We begin by assessing the need to consider technologies as foreground phenomena. The paper then develops a concept of 'metatechnology' to consider ways in which some technologies may have a qualitatively greater potential to impact society, and then uses the case of digital technologies to explore the ways in which these features are problematic from a responsible innovation perspective. These aspects are then explored through an analysis of foundational accounts of responsible innovation using a critical hermeneutic approach, with specific attention to the conceptions of technology they reference.

THE NEED TO BRING TECHNOLOGY TO THE FOREGROUND

The tendency of philosophy of technology narratives to consider technology *en bloc* has led to calls to make particular technologies 'foreground phenomena', to reflectively analyse them in such a way as to illuminate features of the broader phenomenon of technology itself. Von Schomberg and Blok (2019, p. 7-8; p. 13) highlight the need to consider particular technological innovations to understand their effect in shaping moral decisions, and to enable us to evaluate the sense in which some innovations differ from each other and are either more or less ethically acceptable, societally desirable, and inherently controllable than others.

The printing press provides an historic illustration. While scholars saw block printing's potential to increase the circulation of religious works, and even expected it "would strengthen religion and enhance the power of monarchs" (Meyrowitz, 1995, p. 41), the potential for social reform and distribution of 'innovative' (in the sense of 'subversive') pamphlets from unregulated presses was not appreciated until the technology was widely available. For the purposes of our argument, the ability of this technological artefact to enable further innovation in the types of material that could be produced, the ways they could be distributed, and the social and other innovations resulting from the distributed material is a feature that differentiates it from others.

In defining 'technology', Arthur (2009, p. 18) helpfully distinguishes potentially different meanings, as:

1. *A means to fulfil a human purpose*
2. *An assemblage of practices and components*

3. *The entire collection of devices and engineering practices available to a culture*

From this perspective, any effort to consider the responsibility implications of a technology must consider attributes it possesses that may influence its use in practice – innovation produces technologies, but technologies can also enable innovation. This position knowledges both that technologies have a tangible form or substance (whether as artefact, or practice) which affects its potential for use, and that this form may be adapted by users in different contexts.

Within the context of emerging technologies, to an extent the challenge of RRI assessment is one of clarity over the nature of what we are trying to bring to the foreground. The concept of 'artificial intelligence' is a case in point – purported innovative technologies may be too vague to be the subject of analysis, and may be better understood as category labels, even as category error (the 'AI effect' – Hainlein & Kaplan, 2019). Blok (2020, p. 17-18) references examples of digital technology in highlighting the need to consider the potential of new technologies to create new world orders, beyond the creation of new artefects and services. This indicates the difficulty of assessing implications of innovative processes before specific uses have developed, and the need to consider emerging, and often constantly changing combinations of new practices to assess the potential for new effects.

TOWARDS A CONCEPT OF METATECHNOLOGY

Because assessing the implications of technologies involves consider their intrinsic features as well as the uses they are put to, features that affect the extent to which they can be reconstituted in use are particularly relevant (Orlikowski, 1992, p. 15). A hermeneutic perspective invites us to consider the potential for different meanings to be invested in an object, to more fully understand how it might impact in practice.

Blok (2020) highlights the idea that, unlike pre-existing understandings of innovation which from either an economic or philosophical perspective are based on identifiable commercial applications or methods of production, disruptive innovations are instead associated with the unknown, and draws our attention to the creation and evolutionary stages of technologies prior to market adoption.

For this reason, we need to consider how the properties of some technologies may predispose them towards different imagined, and potentially as-yet-unimagined uses. Feenberg (2017, p. 137) articulates this in the thought that technology is "not only artifactual, but also refers to the question of what we do when we envisage the world with a technical intention".

Theories of 'disruptive innovation', while contested, liable to reification, and potentially also rationalisation of a fear-driven aspect of commercial imitation, provide a starting point for us to articulate a concept of technology that differentiates those with more limited, and more extensive potential to be reimagined and impact in different ways.

Abernathy and Clark introduce the concept of 'transilience' (1985), defining this as "the capacity of an innovation to influence the established systems of production and marketing" (Abernathy & Clark, p. 3). With an explicitly commercial focus on the US auto industry, they distinguish types of innovation based on the extent to which markets, rather than just producer competences are disrupted. In their analysis, two subtypes are of interest – 'revolutionary' innovations such as radically more powerful car engines disrupt existing competence without creating new customer-market linkages, and 'architectural' innovations which result in changes to established systems of production, the creation of new industries and the reorganisation of old ones.

Utterback (1994, 1996) similarly defines 'radical innovations' as those which can 'sweep away' skills, knowledge, production techniques, and industrial equipment. This connotes a change in outlook, later explored by Bessant (2013) whose concept of 'paradigm innovation' is based on the extent to which mental models of production are changed. Christensen (1997, 2015) identifies two preconditions for 'disruptive technology innovations' – significant changes to attributes of existing products, and significant incentives for new business models compared to the old.

Brynjolffson and McAfee (2014) demonstrate the ways digital technologies and in particular, their evanescent marginal cost of reproduction create these preconditions. For Kodak, digital technologies created a double disruption – digital flash memory provided a more cost-effective replacement to film camera, but within a short period of time substantially replaced the practice of printing copies of pictures with the ability to share memories through social media.

Beyond market-oriented conceptions of radical innovation, we can see from a historic perspective that a number of technologies created the conditions for significant impact through adaptation to further uses and cascading innovation, and from this perspective could be assessed as 'radical', from fire, the compass, and gunpowder, to the printing press and steam power. We can see in each case that impact follows not so much the development of a method or artefact, but its association with expanded uses – the observation that China discovered gunpowder and the compass but applied them to fireworks and interior design is relevant here.

It follows that technologies will have more potential to impact if they have properties that increase the likelihood or extent to which they can be adapted to different contexts and uses – in the hermeneutic sense, in their potential to take on new meanings.

The concept of 'metatechnology' provides a linguistic vehicle to distinguish innovations on this basis. While mutatory aspects were explored in earlier discussions of the philosophy of technology – for example Jonas (1979, p. 38) discusses "the Promethean enterprise of modern technology" – and in nanotechnology debates that informed RRI discourse, the first apparent use of the term is by Bross (1981). The sense of 'meta' here is of oversight and safety, through use of systems to prevent industrial accidents and enhance societal benefits of mammography – in effect, technologies to govern other technologies.

Vallenilla (1999) proposed the term to denote the purpose attached to the development or application of a technology – in Aristotelian terms, its 'final cause', for innovations that...

> ...seek to overcome the traditional anthropomorphic, anthropocentric, and geocentric limits of all previous technology… that often operate outside the bounds of human or natural powers and forms of sensation (e.g., nuclear energy and radar), go beyond enhancing human life as it is given (as with many unintended consequences of technology such as global climate change), or affect not just the earth but even the moon and planets. (Vallenilla, 1999, p. 411

This transhumanistic conception of metatechnology is of limited use, as we can attach an intention to a technology that may exceed its capabilities – I might intend to travel to the moon in a steam-powered rocket, but I am unlikely to reach the outer atmosphere. Similarly, we may not have this intention for a technology, but it may have far-reaching implications, as in the case of the ARPANET.

Braman (2004) defines metatechnologies in relation to their processing potential, and their potential range of outputs:

> Meta-technologies involve many processing steps, and there is great flexibility in the number of steps and the sequence in which they are undertaken. They can process an ever-expanding range of types of inputs and can produce an essentially infinite range of outputs… Their use vastly expands the degrees of freedom with which humans can act in the social and material worlds, and characterizes the postmodern world. (Braman, 2004, p. 5)

This account sees metatechnologies as always informational in nature. The concept is assessed in a historical context as convergences of communication with other materials and social processes, in the first case through the emergence of writing. Braman sees the modern information society and its harmonised information and communication systems as creating a situation in which "information flows have structural effects as powerful as those traditionally associated with the law" (Braman, 2004, p. 35-36), with the consequence that the ability to shape these flows – whether through their design, commercialisation or control – confers significant power. This definition resonates with contemporary discussions of the political power of social media companies.

Mitcham (1995, p. 16), while citing Vallenilla, similarly highlights increasing interconnectivity and ubiquity in postulating a concept of metatechnology that "steps beyond the specific autonomies of modernity", although his subject is technology writ large and metatechnology is indicated as a replacement for the concept of technology that has gone before rather than a subcategory.

In elaborating our idea of metatechnology we can draw on the earlier concept from economics of 'General Purpose Technologies' (GPT), "deep new ideas or techniques that have the potential for important impacts on many sectors of the economy" (Wright, 2000, p. 161). This economics-focussed conception is elaborated by Jovanovic and Rousseau (2005) who identify 'pervasiveness', 'improvement' (in the sense of continuing and cascading improvements, such as those which reduce use costs), and 'innovation-spawning' as the characteristics of a GPT. While 'pervasiveness' may be better understood as an emergent quality, and the authors suggest that beyond these attributes GPTs do not necessarily differ from other technologies, these features, and the extremely broad examples cited as GPTs of 'electricity' and 'information technology' introduce a sense in which we are identifying as significant those technologies which enable the creation of others.

This progenitive aspect is picked up by Glazer (2007, p. 120) who defines metatechnologies as "the core technologies on which innovations are based", albeit identified in relation to marketable product characteristics, and by Romer (2009), who uses the phrase 'meta-ideas' to describe those which support the production and transmission of other ideas.

A different method of assessing what we might call the emancipatory potential of innovations is discussed by Edwards-Schachter (2018), whose concept of disruptive innovation, in contrast to Christensen's (1997) sees disruptive potential as a property of the person or organisation innovating as well as of the item being innovated. A technology not disruptive in one context, may be in another. The emancipatory or enabling aspect of a technology – which we could see as the ease with which it can be applied by new users, and which economists might see in terms of low barriers to entry – is also discussed in the concept of 'enabling technologies' that underpin 'Industrie 4.0' (Kagermann, 2011; Culot *et al.*, 2020). While this concept has been adopted as part of EU industrial strategy (European Commission, 2018), the concept of Key Enabling Technologies (KETs) used here is defined instrumentally, with reference to policies aimed at improving regional competitiveness:

> [KETs] enable innovation in process, goods and service innovation throughout the economy and are of systemic relevance. They are multidisciplinary, cutting across many technology areas with a trend towards convergence and integration. KETs

> can assist technology leaders in other fields to capitalise on their research effort (European Commission, 2018, p. 15-16)

The same source acknowledges that a much wider range of technology types may be relevant to consider strategic considerations, disruptive potential and/or relevance in relation to global grand challenges (European Commission, 2018, p. 20-22). We can differentiate this from our emerging concept of metatechnology in that it is construed in relation to strategic and geopolitical priorities rather than just in reference to the properties of a technology.

For the purposes of this paper, the main contentions are that some technologies may be qualitatively different from others based on the degree to which they enable the innovation of further technology; that this makes them particularly relevant from a responsible innovation perspective in terms of their ability to impact on society; and that this is particularly likely to be the case for digital technologies. To define metatechnology for our purposes, we can amalgamate the definitions of Braman and Glazer as follows: they are *core information technologies upon which others are based, and whose use vastly expands the degrees of freedom with which humans can act in the social and material worlds*.

THE CASE OF DIGITAL TECHNOLOGIES

Digital technologies (those using data in digital form) provide examples of emerging technologies which in many cases have metatechnological attributes relevant to considering alignment with societal needs. Brynolffson and McAfee (2014) provide a highly-cited case for the disruptive potential of digital technologies, with particular attention to their exponential and recombinant characteristics and zero marginal cost of reproduction.

The problematic aspects of digital technologies from a responsible innovation perspective are explored in detail by Jirotka *et al.* (2017), building on earlier work by Moor (1985, p. 269) and others and incorporating evidence from IT researchers and representative bodies. Their observations are summarised in Table 1.

Table 1. Problematic aspects of digital technologies for responsible innovation

Item	Description
Logical malleability and interpretive flexibility	Technology applications are often 'socially produced', and local innovations can result in unexpected uses
Prevalence and impact	Digital technologies increasingly shape labour markets and our daily lives
Pace	Compared to developments in the physical and life sciences, outputs may be developed, released and proliferate in a matter of hours
Difficulty predicting the uses of research outcomes	Researching objects in their contexts of use is often not possible and user adaptation can change the trajectory of digital technologies
Distributed development	Digital technology development is frequently split between different individuals, and often across many organisations[3].
Pacing problems	Impacts of technologies are increasingly only seen once they are in widespread use
Practical issues of embedding responsible innovation into professional responsibilities	It is difficult to define the relative roles of researchers and practitioners at the commercial interface and this requires collective action
Scope, complexity and convergence	The increasingly pervasive nature of technologies, often combined with rapid development, blurs boundaries between systems, features and functionality.

Source: summarised from Jirotka *et al.* (2017).

The problems of scope, pace and logical malleability are of hermeneutic interest – by the time the implications of a digital technology have been assessed, its use may have changed. This can be observed where companies provide APIs and SDKs (automatic programming interfaces and software development kits) to encourage integrations with their service, which can result in unexpected emergent uses of data as in the Facebook / Cambridge Analytica scandal (Berghel, 2018).

The increasing complexity of computational approaches brings new problems. While in some cases we can attribute these to the purposes and values of end users, there is evidence that algorithmic bias may be an intrinsic feature, rather than an avoidable design flaw of big data and machine learning-based approaches, or at the

3 This may involve international arbitrage, for example the coding of images using platforms such as Mechanical Turk by staff in low-income countries. The problem of responsibility attribution between developers and users in complex software development chains is discussed by Wolf *et al.* (2019).

very least is extremely difficult to 'design out' when bias is inherent in the social context of use (Beale *et al.,* 2020; Criado-Perez, 2019; Cheong *et al.*, 2021).

The issue is framed by de Reuver *et al.* (2020) who contrast the ontological uncertainty generated by digital technologies whose uses are determined by end users, with the more general epistemic uncertainty that exists at the design stage of other technologies. In this sense, digital technologies pose a qualitatively different problem, only partially soluble through steps such as broader and/or whole-lifecycle value-sensitive design approaches.

Digital technologies may also have upside implications for responsible innovation, in facilitating the exchange of ideas and open discussion, rendering database searches far more accessible and opening up new research methods (Bautista *et al.,* 2018). It is hard to see how, absent digital technology, academic efforts to research pandemic vaccines and the continuation of conferences and meetings could have taken place at the same rate.

While recent years have seen increased interest in ethical aspects of artificial intelligence and machine learning technologies from governments and organisations, methods of designing ethical concerns into systems are nascent, and regulation in this area chiefly consists of broad principles (Winfield *et al.,* 2019). Stahl *et al.* (2019, p. 376) similarly highlight "gaps in the fabric of responsibilities that govern ICTs".

In considering the metatechnological aspects of digital technologies we should also consider the extent to which they can originate from non-traditional modes of innovation, and may themselves dynamically transform networks of innovation (van de Poel, 2003). By implication, the effect of digital technologies in expanding the potential for different and potentially unexpected uses is potentially multiplicative and nonlinear. Some emerging digital technological trends have particular implications for the pace, complexity and scope of downstream development:

- The increasing tendency of software platforms to provide automatic programming interfaces and software development kits (APIs and SDKs) that allow for downstream development and integrations of services (Borgogno & Colangel, 2019)
- The open-source software movement, increasingly adopted by major software providers (Warren, 2020)
- The creation of low- and no-coding software development tools in general (Koksal 2019), and in particular low- and no-coding tools that allow non-experts to create and use machine learning models
- The increasing availability and scope of large datasets, in general and within organisations (George *et al.*, 2014)

- The exponential increase in internet-of-things connectivity (Nordrum, 2016)
- The development of new forms of digital manufacturing (e.g. Jensen-Haxel, 2011)
- Vertical integration of software platforms enabling the creation of more detailed datasets with the potential for more precise targeting, and limited state antitrust action (Kimmel & Kestenbaum, 2014)
- The growing tendency towards virtualisation and containerisation of software, enabling more rapid deployment and uptake (Silver, 2017).

Returning to the fundamental challenges for responsible innovation outlined by Blok and Lemmens (2015), it is apparent that the features of digital technologies in general, and of these emerging aspects in particular, pose specific problems associated with their 'metastatic' properties. Logical malleability and pace incur both epistemic insufficiency and ontological uncertainty. They are susceptible to differing interests among stakeholders leading to power imbalances, a particular issue in the case of increasingly prevalent machine learning approaches which are associated with algorithmic transparency (Hoadley *et al.*, 2010), and bias issues (e.g. Dastin, 2018), with approaches to transparency often constrained by commercial concerns, in Faustian business models whose nature is only belatedly beginning to be understood (Tibken, 2018).

One way to consider these issues is to suggest that digital technologies increase the 'RRI space' defined by Stahl (2013) based on their potential to significantly extend the range of actors, activities and societal norms that are potentially relevant to consider. In this sense, they will often constitute metatechnologies and as such are a relevant prism through which to assess the higher-order challenges metatechnologies may pose for responsible innovation discourse.

To consider the validity of foundational RRI accounts in relation to these challenges – or conversely, the extent to which they may have been developed with reference to issues associated with a limited range of technologies – we now assess the extent to which foundational RRI accounts have considered digital and metatechnologies and their associated problems.

METHODOLOGY

Critical hermeneutics enables investigation of the axiological and ontological assumptions in published accounts. The application of a hermeneutic perspective to Responsible (Research and) Innovation has been pioneered by Grunwald (2014, 2019, 2020), who draws attention to the importance of understanding the sometimes-contested meanings and technological futures attributed to new and emerging technologies. He identifies benefits of this perspective as avoiding epistemological over-caution, and as preferable to prognostic and scenario-based orientations in the case of 'overwhelming uncertainty'.

For our purposes, we can note that concern is particularly relevant in the case of technologies where there is limited evidence of impact, and high uncertainty over effects. The case of nanotechnology illustrates this – in the context of limited insights from early-stage research of a potentially metatechnological category of innovation, the meanings assigned to technologies came to dominate discussion (Simakova & Koenen, 2013; Fries, 2018).

The method used in this study adopts the approach of the hermeneutic study of RRI's foundational assumptions carried out by Timmermans and Blok (2018). In this case, rather than an inductive approach to discovering axiological assumptions of each account, a combined inductive and deductive approach, of analysing and categorising the technology examples referred to in each account will be used.

The rationale for a hermeneutic study is set out clearly by Timmermans and Blok (2018, p. 5). For the purposes of this study, key features are as follows:

- Critical hermeneutics is a tradition developed by Ricoeur (1981), Ricoeur and Thompson (1981), and Habermas (1978, 1988, 1990).
- It incorporates features of both the hermeneutic and critical theory traditions and aims to transcend taken-for-granted paradigms and critically examine their assumptions and practices.
- The position of the investigator relative to the phenomenon investigated should be considered.

The researcher perspective on this occasion is that of a small interdisciplinary team that includes academic interests in computing and social responsibility and a practitioner-researcher with experience introducing and overseeing the use of systems in organisations, including through contact with user groups and other organisations using third party software. This may be relevant in imbuing sensitivity both to broader responsibility challenges of digital technologies and to the ways organisations and users can adapt and configure software.

Adapting the method of Timmermans and Blok (2018), the approach used here is as follows.

Source selection

The foundational accounts of RRI identified by Timmermans and Blok were adopted as the focus of enquiry. While other accounts of RRI exist, the validity of the selection of these accounts based on the criteria of a comprehensive, original, and influential framework or definition is reflected in the volume of citations the relative accounts have received in the period since publication (Loureiro & Conceição, 2019), and spans both the political, and academic perspectives we have noted can be identified within RRI (Owen, 2019).

For the purposes of this study, the text of accounts was defined as the following. With a view to validity of comparisons, the wordcount excluding references was assessed to contextualise any frequency-based observations:

- EC: European Commission (2012a, 2012b)
- VS: von Schomberg (2013)
- SOM: Stilgoe *et al.* (2013)
- VDH: van den Hoven (2013, 2017)

These sources reproduce those used by Timmermans and Blok (2018), with the exception that for the EC and VDH accounts an additional source is provided by the author which details technology examples considered in the main account.

Analysis of axiological and ontological assumptions per account

These sources were then subjected to critical hermeneutic analysis to identify implicit ontological assumptions. In this case, the assumptions of interest are the reference basis for each account in terms of the different examples of technological innovation they use, and the features of digital technology that are potentially problematic from a responsible innovation perspective they consider. In this sense, there is a focus on identifying and interpreting the examples in the text that illustrate the problems or issues that need to be addressed.

To relate assumptions of sources to the concept of metatechnology introduced above, a deductive coding approach was used. The documents were coded by two team members independently according to a pre-defined coding structure. The results of the coding were compared, any discrepancies discussed and clarified and a final decision made in order to ensure a common understanding was reached. The coding structure was further refined during this process in light of emerging patterns. Table 2 summarises the protocol and definitions applied.

Table 2. Protocol and definitions

Step 1. Identify technology examples referenced by the study	Definition: 'An assemblage of practices and components'. In this sense the focus is on the particular innovation. Include any mention, count number of types not occurrences.
Step 2: Assess whether the technology example is an information technology (IT)	Definition: 'concerned with the dissemination, processing, and storage of information, esp. by means of computers' (Oxford English Dictionary). In particular, that the products are informational in nature or software.
Step 3: Assess whether the technology example is of a type identified in the academic literature as a metatechnology	Definition: the technology is one of the examples identified as a metatechnology in Braman (2004) or Jovanovich & Rousseau (2005). The list used is provided in the accompanying data table.
Step 4: Assess whether the technology shows characteristics of a metatechnology	Definition: technology matches all of: - 'is a core technology upon which others are or can be based' - 'vastly expands the degrees of freedom with which humans can act in the social and material worlds' - 'potential for high degree of reconstitution in use'
Step 5: Identify instances where the account discusses specific challenges of digital technologies	Definition: reference to any of the specific challenges itemised in Table 1
Step 6: Count instances where the account discuss challenges associated with onward innovation / reconstitution in use	Definition: discusses any features of technologies that increase the likelihood of it enabling further innovations

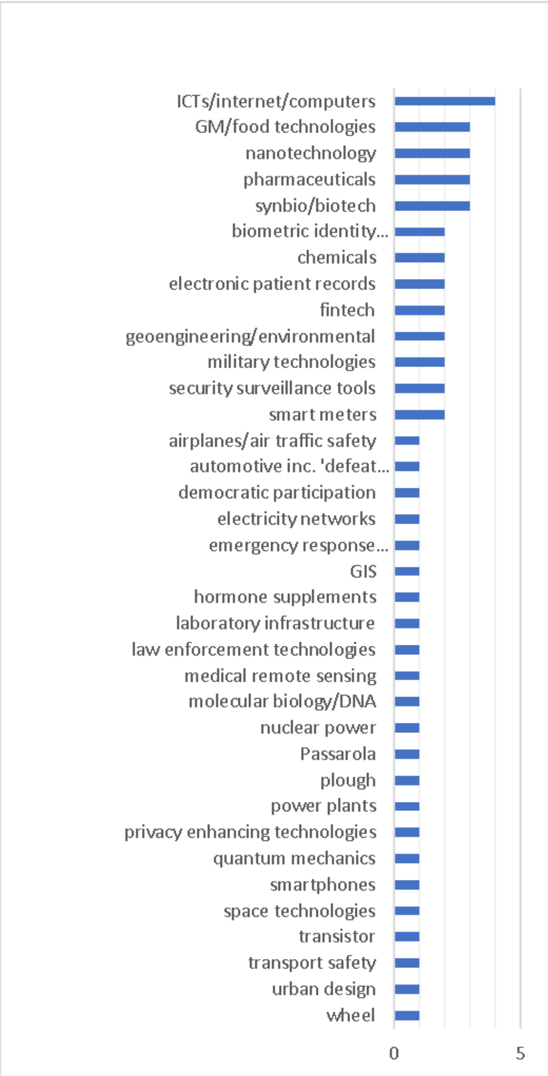
Source: Definitions gathered by the authors (Bryce *et al.*, 2022).

Coss-comparison of accounts

Based on the output of the previous stage, the results from each account were compared to enable a critical reflection on the scope of references.

Figures 1 and 2 show frequency of technology type by account. Table 3 summarises the examples returned by classification as technology, identified metatechnology type and metatechnology characteristic matches, and number of references to digital technology and reconstitution in use issues.

Figure 1. Technologies cited across all RRI accounts by frequency (n=55)



Source: Data processed by the authors (Bryce *et al.* 2022).

Figure 2. Technology categories referenced by account (n=55)

	EC	VS	SOM	VDH
airplanes/air traffic safety				■
automotive inc. 'defeat devices'				■
biometric identity management	■	■		
chemicals		■	■	
democratic participation		■		
electricity networks				■
electronic patient records		■		■
emergency response technologie	■			
fintech			■	■
geoengineering/environmental			■	■
GIS				■
GM/food technologies	■	■	■	
hormone supplements		■		
ICTs/internet/computers	■	■	■	■
laboratory infrastructure	■			
law enforcement technologies	■			
medical remote sensing		■		
military technologies		■		■
molecular biology/DNA			■	
nanotechnology	■	■	■	
nuclear power				■
Passarola		■		
pharmaceuticals	■	■	■	
plough				■
power plants				■
privacy enhancing technologies	■			
Quantum mechanics			■	
security surveillance tools	■	■		
smart meters		■		■
smartphones				■
space technologies		■		
synbio/biotech	■	■	■	
transistor				■
transport safety				■
urban design				■
wheel				■

Source: Data processed by the authors (Bryce *et al.*, 2022).

Table 3. Technology examples cited in RRI accounts by type

Account	n[4]	Wordcount	IT examples	Metatechnology type examples[5]	Metatechnology characteristic examples[6]	Digital problem occurrences	Reconstitution in use problem occurrences
EC	11	22737	6	7	4	10	0
VS	16	10100	6	7	4	4	1
SOM	10	10145	2	4	6	0	0
VDH	18	13034	5	6	3	6	0

Source: Data gathered by the authors (Bryce *et al.*, 2022).

Table 4. Digital technology challenges cited in RRI accounts

	EC	VS	SOM	VDH
Logical malleability and interpretive flexibility	■	■		■
Prevalence and impact	■			
Pace	■			
Difficulty predicting the uses of research outcomes				
Distributed development	■	■		
Pacing problems	■			
Practical issues of embedding responsible innovation into professional responsibilities	■			■
Scope, complexity and convergence	■			■
Reconstitution in use / Onward innovation		■		

Source: Data processed by the authors (Bryce *et al.*, 2022).

4 Number of technology types cited in the account.

5 Proportion of examples that are an identified metatechnology type – see Table 2.

6 Proportion of examples assessed as having metatechnology characteristics – see Table 2.

ANALYSIS

European Commission

Overview

The European Commission account of RRI was set out in a policy statement in 2012 (European Commission, 2012a), and revisited in later publications and declarations before being integrated into funding calls. While Timmermans and Blok (2018) note that RRI literature recognise these accounts as an authentic source of the EC account on RRI, the 2012 statement differs from other accounts in that it asserts a policy agenda – it is a policy document, rather than an academic paper. To enable a comparison on the basis of underpinning technology examples used in constructing the account, the 'Science with and for Society' (SwafS) report on 'Ethical and regulatory challenges to Science and Research Policy at the Global Level' (European Commission, 2012b) presented by the SwafS expert group with EU and US membership is assessed as a source document informing the development of the EC account.

Characterisation of technology examples

A relatively high proportion of examples in the EC source material were classified as having attributes of metatechnologies, mainly because information technologies featured prominently as examples in the source material analysed. The account touches on nearly all the challenges of digital technology identified by Jirotka *et al.* (2017) while adding another (inherent transparency of digital data), although challenges of onward innovation are not discussed.

The prevalence of digital examples may reflect salient political issues for the EC during the account's development in 2010-2012, in particular the development of the the General Data Protection Regulation through the EC data protection reform package combined with the introduction of the EuroSur border surveillance programme and accompanying. While not discussed within the reference documents, the emergence of privacy and data protection concerns associated with EuroSur might otherwise have been developed as an example of the need to anticipate impacts associated with the ability of digital technologies to be adapted for alternative uses (in this case, surveillance beyond that necessary for border security – Marin, 2011).

Von Schomberg

Overview

The von Schomberg account, presented over a series of studies is widely cited in Responsible Innovation literature and is referenced in the Stilgoe, Owen and Macnaghten account. Written during the author's tenure as an official of the European Union, the account has similarities to the EC account but is explicitly a personal rather than institutional vision. The account's emphasis on redefining the 'right impacts of innovation' in broader societal rather than macro-economic terms is substantiated through several examples. In line with Timmermans and Blok (2018), von Schomberg (2013) is recognised as the authoritative account.

Characterisation of technology examples

The VS account provides a broad vista of examples, including digital technologies, offering the largest number in a single study and exceeded only by the VDH account when the latter is considered to include an additional reference paper. Together with the EC account it has the highest number of examples identified as metatechnologies, including discussions on nanotechnology and synthetic biology as well as information technologies, and uniquely among the accounts were the potential of digital technologies to impact democratic participation is considered (p. 7-8), along with two mentions of digital technology challenges the issue of onward innovation: via a discussion of adapted uses of Microsoft Kinect systems, the importance from a responsible innovation perspective of considering the potential for recombinant uses (p. 7), and a discussion on the need for responsible innovation to consider distributed development issues (p. 13) rather than a sole focus on individual responsibility. This latter issue has recently been expanded on in the context of the discourse in responsible innovation in digital technologies, with reference to ecosystems approaches (e.g. Stahl, 2021).

Stilgoe, Owen and Macnaghten

Overview

The account of Stilgoe, Owen and Macnaghten is frequently cited in RRI literature and while drawing on and elaborated in a wider series of papers is broadly seen (e.g. Timmermans & Blok, 2018) as embodied in Stilgoe *et al.* (2013). This paper provides a broad overview of issues and emergent methods in relation to responsible innovation, categorising these in a way which has been widely adopted, particularly in the United Kingdom through the Engineering and Physical Sciences Research Council. There is arguably a difference in emphasis within the account compared to the others on a review of methods, and the use of an in-depth case study, rather than an attempt to illustrate through breadth of examples. The SPICE – Stratospheric Particle Injection for Climate Engineering geoengineering project is used to illustrate the potential for responsible innovation methods to alter technological trajectories, but for the purpose of our analysis is not categorise as a digital or metatechnological example.

Characterisation of technology examples

The SOM account is superficially similar to the EC and VS accounts in the scope of technology examples referred to, but other than brief discussions the focus is on geoengineering as the primary case and no references to the specific challenges of digital technology or onward innovation issues were identified.

Van den Hoven

Overview

The account of Jeroen van den Hoven synthesises a body of work on value-sensitive design (VSD). It is relevant to this study that the approach, which aims to expose and integrate values into design processes originates from studies of information technologies. The approach was set out in van den Hoven (2013), and further studies have strengthened the relevance of VSD to responsible innovation debates (for example de Reuver *et al.*, 2020).

With a view to equivalence of wordcount, the van den Hoven corpus studies for the purposes of analysis was extended to include van den Hoven (2017). This text, while published later, expands on the technological reference points for the theory of VSD-based responsible innovation and is cited as a work in progress by the main account (van de Hoven, 2013), so as with the EC account is assessed as being part of the reference text.

Characterisation of technology examples

The *point de depart* for the VDH account is digital technologies, and the text begins by focussing on the Netherlands electronic patient record and smart meter programme sagas. A wide range of technological examples are cited, with a tendency towards physical engineering disciplines but several discussions of software and human-computer interface aspects are also included. No reference to onwards innovation challenges was identified. While reference to issues such as the contested introduction of smart metering into the Netherlands usefully expose complexity challenges associated with digital technologies, the central thesis – that design teams should actively consider the values they are applying to their development – is liable to challenge in the case of technologies which, once introduced, may be relatively freely appropriated by different actors and which may not realistically be constrained to uses associated with a developer's explicitly intended values.

DISCUSSION

The intent of this paper is to critically examine the underpinnings of paradigmatic accounts of R(R)I, in particular with reference to digital technologies and the concept of metatechnologies, and to consider the broader implications for responsible innovation if these accounts have been constructed using examples that may not consider certain types of technology.

There are two clear considerations in our findings; the first, that, insofar as there is any suggestion that RRI accounts may not have included digital and metatechnologies – and that the discourse may be in need of revision based on this – the findings do not on first inspection support this conclusion. Each foundational account includes digital technologies within its technological references, and also includes references to technologies that could be considered metatechnologies. This suggests that the discourse on RRI, while to an extent grounded within the physical sciences through the prominence of the SOM account – is not inherently limited in its consideration of innovation from a digital technological perspective. This offers scope for the discourse on RRI to continue to influence responsible innovation as practice, as many large scale research projects focus on digital innovation (European Commission, 2021). However, simply identifying digital technologies within the accounts offers only a limited perspective on the realities of the representation of digital technologies, and metatechnologies in particular, within the RRI discourse.

Therefore, secondly, it is worth considering the extent to which the challenges of digital technologies for RRI are considered within the accounts. In many cases references to digital technologies are brief or superficial; whilst a variety of digital technologies are identified, the discussion around the challenges of these technologies is predominantly limited, and occasionally absent entirely. Here, then, the roots of responsible innovation discourse in physical science disciplines show more clearly, as even the accounts that do offer some consideration of challenges in relation to digital technologies, do not generally consider all responsible innovation challenges of digital technology. In particular, the accounts do not (other than the account of von Schomberg) assess issues of distributed development, or onward innovation issues associated with technologies that can be reconstituted in use. The SOM account – potentially the most influential, per Loureiro and Conceição (2019) – is developed through a physical sciences case and does not discuss challenges associated with digital technology or others identified as metatechnologies. This suggests that some problematic features of digital and/or metatechnologies have not been fully considered in foundational RRI accounts.

The overlap in technology examples considered by the accounts (Figure 2 above) highlights the collaborative spirit and contemporaneous timeframe within which the core works of RRI were produced. This may be a source of reassurance in that accounts largely agree in the technology scope they feel is appropriate to illustrate the concept of RRI – but it may also be an indication that just as the discipline of Science and Technology Studies was developed largely in response to specific nanotechnology concerns, Responsible Research and Innovation may at least to an extent be founded on twentieth and early twenty-first century technological problems, with the implication that the methodologies it prescribes may become less relevant for emerging digital technologies.

As theories develop in a particular historic context, it is reasonable to suggest that a restatement of RRI accounts in the 2020s might feature challenges of digital technology assessment and governance more prominently. Equally, this is a challenge – to maintain the constantly self-critical aspect called for by foundational RRI authors, there is a need to revisit the problems that RRI should address, and the techniques necessary to address them, vis-à-vis digital technology. The particular difficulties of applying RRI principles to the development of digital technologies is clearly understood, and some recommendations are beginning to emerge in an attempt to develop RRI into a framework capable of addressing these difficulties alongside promoting socially desirable innovation (Jirotka *et al.*, 2017). However, given the situated nature of the development of RRI within a particular historical-technological context, questions should be asked as to whether a fundamental shift towards ever more prevalent digital metatechnologies might require a reconsideration of RRI itself; can a responsible innovation approach developed to address social and ethical issues in the physical sciences adequately translate to the social and ethical issues of emerging, disruptive digital and metatechnologies? Whilst the answer to this question is still contested, it is notable that doteveryone, a Non-Governmental Organisation, proposed a shift towards a 'responsible by design' (Miller & Ohrvik-Stott, 2018) approach on the basis of specific social and ethical issues in relation to digital technologies, incorporating, for example, fundamental human rights that may be covertly elided by digital (meta)technologies that are cross-cutting in nature.

This study therefore provides general support to the validity of seminal RRI accounts, while highlighting the need for further analysis of new and emerging digital technologies and in particular their capacity for enabling onward innovation. In this sense, Braman's (2007) sense of the degree to which a technology can shape or create new information flows may be most relevant. The concept of 'metatechnology' is in this sense a question of degree, rather than of type – the concepts of 'barriers to entry' and 'marginal cost of reproduction' may provide useful measures of technologies' potential to proliferate and 'mutate', for technology assessment purposes. This may surface the implications of inventions that democratise innovation or enable users to recombine disparate datasets and services such as APIs and low-coding tools, the network-level potential of connected devices at scale, and assumptions inherent in, for example, the movement towards open-source software development.

At the same time, it invites us to consider, in the face of increasingly ubiquitous digital technology, the extent to which the entire apparatus of RRI may still need to be reconsidered. If the notion that responsible innovation implications can be anticipated at an early stage is a central tenet of RRI, but digital technologies increasingly enable an exponentially wider range of applications – and are developed in a distributed fashion such that teams working on components may not be able be aware of their broader implications – we may increasingly need to redefine the locus of responsible innovation further downstream, in the organisations and individuals who configure the use of logically malleable digital technologies. This may be particularly true if the diffusion of digital metatechnologies accelerates the rate at which technological innovation takes place without the input of the scientific community. (Godin, 2016)

This may in turn have implications for the regulation of potential metatechnologies (for example 3D printing), and supports arguments that where uses and societal impacts cannot reliably be anticipated, innovation policy and responsible innovation assessments should increasingly consider prevention, or exnovation of technologies as a valid and potentially desirable outcome. In this sense, our findings support the argument by Owen and Pansera (2019) that for responsible innovation activities to apply meaningfully to the broader innovation ecosystem, given the environmentally, politically and ethically entangled of disruptive technovisionary innovations, it will increasingly be necessary to consider political as well as technical dimensions of governance.

It is also worth reflecting that RRI, in particular, is specifically situated with the European political apparatus (Owen, 2019), and as such may presume aspects of technology use, innovation mechanisms, or responsible innovation practices that are region-specific (Wakunuma *et al.*, 2021). Technologies subject to strict regulation in the West such as facial recognition may not be similarly constrained in other cultures with the result that they proliferate, mature, and develop new applications with global implications. Similarly, low barriers to entry in one region may be insurmountable in others, for example due to issues around access to broadband and computing power, and this may constrain onward innovation. As such, the increasing prominence of digital (meta)technologies also implies the need for an increased focus on non-Western innovation systems. This prospect alone raises questions about the feasibility of the translation of even the fundamental concepts of responsible innovation with respect to technologies with deeply diverse impacts across and between global regions.

CONCLUSION

While foundational accounts of RRI do include references to digital and metatechnologies, the brevity of these references and the possibility that they do not consider all specific challenges associated with these technologies mean that further exploration and theorisation of responsible innovation in relation to digital technologies is required to maintain the relevance of responsible innovation disciplines in the face of emerging technologies and practices. These may need, in particular, to consider the way in which they enable onwards innovation in different cultural and organisational contexts, and to continuously seek clarification of the futures specific technological developments may enable, either themselves or in combination with other emerging technologies.

As a final reflection, Stilgoe *et al.* (2013, p. 32) invoke a viral analogy in their suggestion that emerging technologies pose additional challenges to governments (and by extension, organisations) in the sense that they encounter organisms to which they have not yet developed a regulatory 'immune response'. This may point to new research directions drawing on evolutionary economics methods to develop a 'genetics of technology', but more significantly, it suggests that responsible innovation's potential to inoculate society from technology harms and connect innovations to the 'right ends' is dependent on our awareness of technology's state of the art, and the innovatory vectors through which it develops.

Thus, while this study has found that paradigmatic narratives of responsible research and innovation do not neglect digital technologies and those we can identify as metatechnologies, the continuing value of RRI as a discourse to our society will depend on researchers' and practitioners' detailed awareness of the potential of these technologies for cascading, downstream innovation.

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