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Atomically Precise Manufacturing and Responsible Innovation:
A Value Sensitive Design Approach to Explorative Nanophilosophy

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ABSTRACT

Although continued investments in nanotechnology are made, atomically precise manufacturing (APM) to date is still regarded as speculative technology. APM, also known as molecular manufacturing, is a token example of a converging technology, has great potential to impact and be affected by other emerging technologies, such as artificial intelligence, biotechnology, and ICT. The development of APM thus can have drastic global impacts depending on how it is designed and used. This article argues that the ethical issues that arise from APM - as both a standalone technology or as a converging one - affects the roles of stakeholders in such a way as to warrant an alternate means furthering responsible innovation in APM research. This article introduces a value-based design methodology called value sensitive design (VSD) that may serve as a suitable framework to adequately cater to the values of stakeholders. Ultimately, it is concluded that VSD is a strong candidate framework for addressing the moral concerns of stakeholders during the preliminary stages of technological development.

KEYWORDS

Atomically Precise Manufacturing, Design Psychology, Design-For-Values, Ethics, Nanotechnology, Research Policy, RRI, Value Sensitive Design

1. INTRODUCTION

This paper provides a theoretical and conceptual evaluation of the merits of a potentially applicable design framework known as Value Sensitive Design (VSD) for the responsible innovation of a speculative future technology called atomically precise manufacturing (APM). VSD is a philosophically predicated methodology to technological design that aims to account for human values early on, and throughout the design process of technologies. Likewise, APM is the assembly of materials whereby objects are built atom-by-atom. APM is controversial, with some experts doubting its feasibility (R. Baum, 2003; Jones, 2005b, 2005a; Zare, 2004) and others worrying about harmful consequences if APM is achieved (Auffan et al., 2009; Baumberg et al., 2007; Joy, 2000; Phoenix & Drexler, 2004; Snir, 2008). However, the best-case scenarios are dramatic, featuring benefits predicted to be on par with the industrial and computer revolutions (Drexler, 2013b; Freitas, 1999).

APM is one form of nanotechnology. Indeed, the term "nanotechnology" was coined by Norio Taniguchi in 1974 and developed in greater depth in K. Eric Drexler's 1986 APM book *Engines of Creation*. (The APM concept dates to Richard Feynman's 1959 talk "There's Plenty of Room at the

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Bottom.") Today, most nanotechnology research and development (R&D) is not APM, but instead is technology involving simpler nanometer-scale processes; this is sometimes referred to as 'normal nanotechnology' (O'Mathuna, 2009). Many nanotechnology researchers likewise doubt the feasibility of APM and instead favor research on more directly promising nanotechnology directions (e.g., Baum, 2003; Nordmann, 2007, 2014; Nordmann and Rip, 2009; Grunwald, 2010; Roache, 2008; Ferrari, Coenen, and Grunwald, 2012; Michelfelder, 2011; King, Whitaker, and Jones, 2011; Racine et al., 2014). Despite these doubts, current investments and national interests towards the development of APM (Jones, 2014; Lewis, 2016) warrant investigations into how we can ensure the concept, and its convergences with other technologies, is as beneficial to humanity as possible by intervening at the design stages and incorporating the relevant values necessary to achieve a desired end.

Additionally, the research has expressed criticism regarding the value and resources exhausted towards ethical speculation on advanced nanotechnology in favour of more immediate nanotechnology concerns (i.e., Nordmann, 2007; Grunwald, 2010). Three potential responses can be levied to these concerns. Firstly, arguments can be made that rudimentary forms of APM are existent such as biomolecules and ribosomes and they provide a solid foundation for more advanced APM forms (Freitas & Merkle, 2004). Secondly, persuasive arguments have been proposed by Roache (2008) arguing for the merits of speculative ethics for future technologies given their governability being more manageable in the early stages rather than *ex-post-facto* regulatory measures (see also Collingridge, 1980 for arguments why anticipatory analysis of technology is critical). Similarly, although speculative future technologies pose many uncertainties, attention is warranted when the potential impact of those uncertainties prove conceptually large enough (Ćirković, 2012). To this end, I argue that continued ethical speculation on nanotechnology is of value, particularly in analyses that provide novel and potentially fruitful design pathways towards desirable futures.[1]

To the best of my knowledge, this paper is the first to evaluate the merits of the VSD framework on APM R&D. Prior literature on APM has focused on its feasibility (Drexler, 1986; Freitas, 1999; Freitas & Merkle, 2004; Haggstrom, 2016; Huang, Chen, Chen, & Roco, 2004; Roco, 2011; Ross, 2007) and on the implications if it is achieved (Altmann, 2005; Drexler, 2013b; Dupuy & Grinbaum, 2007; Freitas, 2006, 2007; Hansson, 2004; Harmon, Yen, & Tang, 2011; Hughes, 2007; McCray, 2012; Umbrello & Baum, 2018). These studies provide useful information but do not fully integrate the effects of stakeholders and the inclusion of values in the early design stages. Similarly, unlike other research projects that focus on a particular application or subdomain of nanotechnology such as (Timmermans, Zhao, & van den Hoven, 2011) or nanofoods (te Kulve, Konrad, Alvial Palavicino, & Walhout, 2013; te Kulve & Rip, 2011), the decision to focus on APM and its potential impacts should not be misconstrued as an overly general analysis, but instead a widening of the speculative circle of a particular form of nanotechnology in order to more comprehensively assess the merits of early design phase interventions (see for example Umbrello and Baum, 2018).

VSD takes as its initial premise that technology is not value-neutral, but instead is sensitive to the values held by stakeholders, such as the designers, engineers, and users, among others (Friedman & Kahn, 2002; Timmermans et al., 2011; van den Hoven & Weckert, 2008). By doing so, the value sensitive methodology aims to incorporate stakeholder values at the early design phases in order to direct the design and development of the technology in such a way as to successfully map the values.

Discussions surrounding APM R&D resemble decisions for other high-stakes speculative future technologies such as some forms of biotechnology, information and communication technologies (ICT), and artificial superintelligence (ASI). These technologies could be game-changers in their respective sectors, yet they each have impacts on the development and design of each other. The example of ASI is especially relevant because some believe it could have catastrophic results (e.g., Bostrom 2014), the same holds for APM. The possibility of either immense good or immense bad creates a 'great downside dilemma' (Baum, 2014) for both APM and ASI. Thus, a need to determine how technologies like APM effect stakeholders need to be taken into consideration to inform how to address the conceptual, empirical, and technical facets of the technology at an early developmental