Manufacturing 3D Printed Futures: Comparative past perspectives of the political economies of additive manufacturing in Shenzhen and Singapore

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Introduction

This paper considers the extent backcasting potential futures of manufacturing in South/East Asia can offer insight to the coming everyday interactions the public, including workers, will have with the future of manufacturing, design, and automation. It uses empirical histories and perceptions of additive manufacturing in Singapore, Shenzhen and Hong Kong to craft discrete political-economic scenarios of socio-technical systems of manufacture. We view these not from a common push towards further modernisation and development, but rather specific outcomes for the dynamic struggles between state, capital and labor from what Kostakis et al. (2016) term the current experiences of neo-feudal cognitive capitalism. In doing so, we hope to expose and relate new voices to questions of continued industrial development and automation that provide contextually specific data into material pasts and imagined futures. From the specific contexts of South/East Asia our research is designed to take into account the structural forces at work between concerns of accumulating capital or commons and privileging local or global knowledge in the creation of new cognitive-industrial orders. Our scope is narrowed to the logics of a fourth industrial revolution which may include a significant re-decentralisation of manufacture linked to the proliferation of additive manufacturing systems. This paper is the first to consider how, across East Asia, such systems have been deployed in contextually unique 'socio-technical' practices that offer unique trajectories for future social and economic development. It considers these discrete experiences as ways to offer diverse insights to both the past and futures of industrial automation. These questions have direct consequences for the terms in which socially sustainable development is imagined and enacted.

The paper is structured to first give some context to how we understand 3D Printing as a social communicative practice that sits atop additive manufacturing tools/technologies. We thus understand 3D Printing as a socio-technological system that constitutes and is constitutive of the (manufacturing) future it creates. The paper then moves to describe and explain how we come to our theoretical perspective, our methodological assumptions, and the practice of our methods. We then turn to results and discussion, which offers the preliminary analysis of the workshops in Singapore and Shenzhen.

Additive context for 3D Printing

Additive manufacturing, more commonly known as '3D printing', has emerged onto the global stage in recent years as a new and potentially highly disruptive manufacturing technology. We understand 3D printing here not as a manufacturing or even automation technology per se, but is instead as a social and communicative practice currently dependent on digital networks - that to varying extents - share intellectual capital in processes of networked design and manufacture. These practices sit atop additive manufacturing 'printers' that build objects layer by layer from fusing subtrate(s) together in computer controlled mechanical processes. The technical-mechanical history of additive manufacturing is itself interesting in that two individuals' set of patents that introduced computer automation to specific modes of additive manufacture (see Charles Hall 1986 and Scott Crump 1992) seems to have kickstarted the industry and solidified their respective firms (3D Systems and Stratasys) place in it. While this history remains outside the scope of the current article, we are interested in the larger socio-technological trajectories that 3D printing has afforded vis-a-vis manufacturing.

To this end, Heemsbergen et al. (2016) offer a socio-technical history of 3D printing that suggests these technologies have interfaced with political economic concerns and future development in distinct phases. They observe 3D printing through centralised, decentralised, and distributed behaviours that each require and create unique sets of relations between workers and their automated manufacture systems. The first phase involves 3D printing economies of pre-production including rapid prototyping of one-off models as well as functional analysis and testing from centralised firms. Knowledge sharing here is minimal and innovations and intellectual property remain proprietary assets (Kellock 1989, Pham and Gault 1998). A second phase decentralises manufacture from in-house pre-production to production firms that begin to shift supply chain logics and provide cost-efficient utility for industries (Birtchnell, Böhme, & Gorkin, 2016; Krogmann, 2012). Here we can think of aerospace and military applications that use 3D design potentials to reduce weight in applications where economies of scale are less important than efficacy of design (Cohen, 2014). This second phase further stratifies the intellectual property of manufacture (printers) from both workers, including those creating the designs, through the creation of manufacture-as-service industries for elite global firms. Here we can imagine a double helix of large incumbent firms tied to each other - one strand that commissions the work, and the other that is able to field the orders based its enduring structural position to fulfil complex orders. These large 'industrial' 3D printing relationships, while decentralised in one sense around dispersed sites of manufacture, still centralise outputs towards the needs of global elites (Cohen, 2014).

The third phase of 3D printing seems to be perpetually emergent and is defined through networks of knowledge sharing that are more distributed and rely on, to varying extents, logics of peer-production. This phase considers how independent entities (individuals, collectives or firms) evoke new practices of manufacture that are disruptive to established industry. This might include ways that still, as Kostakis (2016) has it, offer emerging forms of peer production that live under the dominance of financial capital, or more transcendent materialisations away from labor-capital divides (Bauwens 2013). These emergent distributed digital maker economies leverage Benkler's (2006) understanding of commons-based peer-production; a prerequisite of productive networked activity is low barriers to re-use of others' contributions and minimal restrictions on that (re)use. The ambiguity of emergence of this third phase in 3D printing present and futures can be observed by proxy data of industry benchmarking. Industry watcher Wolhers and associates (2015) suggest that while 86% of 3D printing revenue sit in industrial applications (i.e. Second phase), 92% of the printers sold were sold to consumers, who use printers outside of established industry hierarchies, and some of who use them outside processes of capital accumulation.

Nevertheless, proponents of 3D printing in the long term predict its impact to be as revolutionary as the Internet, but in a way that explicitly links existent cognitive informational economies with those of distributed manufacture. The sometimes hyperbolic opportunities for disruption are seen through processes that decentralise design, manufacture and consumption choices in ways that create new categories of relationships to personalised means of production. These parrot the ways the internet created new castes of decentralisations of exchange including digital prosumers, patterns of self-mass communication (Castells 2009), and more recently, value exchange (eg. Bitcoin and Etherium). The democratisation of manufacture through digital networks and low cost 3D printing points to new logics of global sharing and local knowledge that foretell of mass-self manufacture and peer-to-peer economies that are less encumbered by centralised industrial capital.

The promise of 3D printing as networked computational automation of the decentralisation of manufacture is not only felt at each distributed node of production/consumption. We can imagine follow-on disruptions to supply chains, (Bogers et al., 2016), product warranties, component upgrades, repairs, and recalls (Kietzmann et al. 2015) drastically reducing and reconfiguring shipping and storage logistics that have ecological ramifications, as well as domains of nation-state based import restrictions (Khajavi et al, 2014). Further these redistributions can be seen to shorten delivery lead times (Li et al 2014) even as the reach of 3D printed products, and the expertise required to manufacture them, continues to expand to geographical diverse locales.

Thus, this vision of the 3D printed revolution in manufacture considers that while that logics of automation might have previously been seen to alienate workers from their labour (see Deyo 1989 for East Asia), there are new emancipatory potentials in diversifying and decentralising what amounts to the means of production through digitally-distributed manufacturing cultures and economies. Specifically, the logics of peer production, more open modes of sharing intellectual capital, and decreasing barriers to entry to become producers are seen to emancipate (Petrick & Simplson 2013; Birtchnell & Urry 2016) those previously made dependent within centralised and hierarchical structures of labour and capital. These hopes are not only situated within technophilic readings of progress, but partially enabled by legal-normative spaces that have opened up in relation to additive manufacturing technologies themselves. For instance, the expiration of various patents on methods of additive manufacture have led to a proliferation of 3D printing manufacturer firms and collectives innovating new ways of printing that enable them to build new types of machines that build new types of machines (Moilanen, 2013; Daly, 2016).

A Material-Theoretical Perspective

One of the purposes of this paper is to better clarify how these (emancipatory) futures are not evenly distributed or imagined across political-economic geographies. We do so by asking our participants to consider their contexts in relation to theoretical endpoints of political economy. The research design, from theoretical perspective to methods, fill in this section. We suggest that context and structural political and economic powers shape the futures of automation as much as a resplendent additive techno-utopianism.

The World Intellectual Property Organization (WIPO) has already pointed to potentially different trajectories for 3D printing in developing economies and remote areas, compared to the (over)developed west in its 2015 Report on the matter. Likewise, our preliminary research of emergent network sharing practices of 3D printing designs in languages other than English suggests that in Asia, there is an emphasis on sharing designs in the service of aiding further manufacturing capacity. This contrasts with the West, where 3D printing design sharing more often centres consumable 'final' products (Fordyce etc al. 2016). Specifically, the largest existent sharing services of 3D printing designs in China (Simpneed and Mohou) offer as metaphors of purpose an industrial vanguard and educator resource respectively, as opposed to the metaphors of marketplace and personal design sharing repository that define equivalent sites in English speaking economies (Shapeways and Thingiverse). Here the west seems to link imaginary ideal users that flow on from biases inherent within the individualistic focus of a Randian Californian ideology to somewhat contradictory sharing cultures proliferate from FOSS communities that are combined in Silicon Valley (Levina and Hasinoff, 2017).

In this sense, we can see that while the west might imagine the empowerment of 3D printing aligned individuals manufacturing own goods, there are other patterns of economy that envision the relationships between (networked 3D printing) technology and labor differently. These alternative patterns of sharing speak to other culturally contextual signifiers. For instance, we might consider 3D printing's futures in Asia through concepts such as 'Shanzhai', if, as Lindtner et al. (2015) explain, we contextualise that concept in relation to the intricate social world of cultural sharing around manufacturing and production in the Pearl River Delta. 3D printing here offers a digital-material acceleration of practices that reconfigure the relationships between workers and their tools more than the products they will be making with them; the ways in which consumer demand is met is a different yet interrelated question to reconfiguring that demand.

The contextual complexities of 3D Printing adoption have meant that the material trajectory of 3D printing so far has proved complicated, contextual, and in some senses, a revolution underwhelmed (Daly 2016). Further, consideration of familiar logics of structural political and economic power that rebuff techno-utopianism (Jasanoff 2004; Marcuse 1941) persist, while the actors which to include are contextually diversified (Chen 2012). In this way, much of the focus on 3D printing outside of established industry applications remains marginal to much of society. For instance, 3D printed guns and sex toys seem to draw most attention, while other more utilitarian aspects of 3D printing does not reach mainstream discourses. Meanwhile, the largest users of 3D printed parts as of 2018 seems to be the aerospace industry (Wohlers 2018), and this is not because of a new democratising wave of home-downloaded flying cars! As such, we need to process the underwhelmed 3D printed revolution in terms that can contextualise not only the geographical and cultural peculiarities of 3D printing practice, but also overarching logics of capital accumulation and knowledge distribution. To do so, our work now turns from the revolution(s) stalled of 3D printing, to work on political economy that can contextualise futures of digital, material, production.

Following Kostakis et al.'s (2016) work on digital political economies, we differentiate ideal types of automated 3D printed industrialisation to situate four ideal types. These ideal types are not meant to define actual trajectories in practice and come with the various caveats ideal types exhibit. They serve here to draw extreme boundaries and expectations that we can use in our methodology of backcasting futures in each location we've held a workshop. The ideal futures are drawn from a two-by-two heuristic made on sets of axes that offer (top-to bottom) centralised versus distributed control of the productive infrastructure and left-to-right, an orientation towards private accumulation of capital versus accumulation or circulation of the commons (see figure 1). We can thus differentiate between knowledge infrastructures that are global and based on capital accumulation, global and based on peer-based commons exploitation, local and capital accumulative, and lastly, centred knowledge sharing that privileges local flows. Each of these serves as specific political-economic end points for emergent socio-technological configurations of 3D printing.

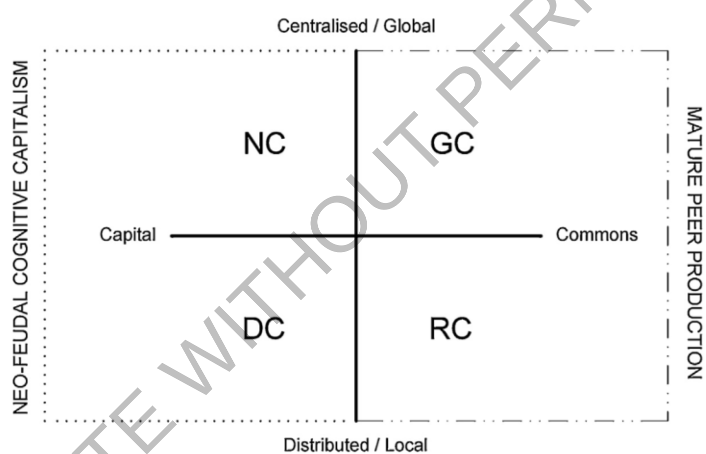

Figure 1. Ideal Futures scenario: four quadrants from two axes: global/local & capital/commons (Kostakis et al., 2016: 87).

Note that a starting assumption of our theoretical standpoint is that traditional proprietary capitalist models of production are arguably in decline (Kostakis and Bauwens, 2014). The decline may be interpreted from a history that is related to techno-economic paradigm shifts (Schumpeter 1975), and may either signal 'crises' in capitalism that are part of its normal functioning (Perez 2002) or opportunities for normative change (Wolff 2010). The extent these theoretical schisms exist suggest, as Kostakis et al. have, that considering a myriad of possible relations that might emerge through through specific paradigmatic shifts is not only useful, but allows consideration of technology (such as network enabled distributed auto-manufacture) in a socio-technical sense that shape and are shaped by the contexts they are situated in and contribute to. Our theoretical perspective that links STS to critical and Marxist orientations might not be new, but its implementation is novel in two fronts. First, we employ these ideals as a provocation for diverse individuals to reflect on in backcasting potential futures of 3D printing. Second we do so through a Multi-level perspective that attenuates any one ideological construct by having participants explicate dimensions of markets, culture, policy, law and technology as ways to make sense of how futures will be constructed. While these dimensions themselves are not meant to saturate categories of social experience, they do force participants to diversify their own ideological comfort zones and consider socio-technical evolutions from multiple perspectives. Our data thus presents novel understandings of how socio-technical imaginaries transition from past to futures both within and across nations within East Asia in relation to narratives of manufacture and industrialisation.

The scope of our work here draws from initial data collected from expert participants in Singapore and Shenzhen, as part of a larger project on 3D Printing and Intellectual Property Futures funded by the UK Intellectual Property Office. The larger project conducts horizon scanning workshops in locations including Moscow (Russia), Rorkee (India), Singapore, Shenzhen (China), London (UK) and Paris (France). These contexts presented.

Our Singapore and Shenzhen workshops took place within a two week period in September 2017. The Singapore workshop was took place in the conference facilities of a centrally-located major hotel and comprised 10 participants from different stakeholder groups, including the Singaporean government, private legal practice, the 3D printing industry, incumbents from other industries, and university researchers; medical 3D printing was well-represented by different participants working in this area. We chose Singapore as the site for our workshop due to Singapore's status as a 'hub' for 3D printing in South East Asia and the point of comparison it could provide as a developed industrialised economy in East Asia to China. The Shenzhen workshop took place at the University Creative Park in Shenzhen and comprised ten participants from a variety of industries and backgrounds including IP lawyers, 3D printing industry representatives, creative industries representatives and academic researchers. We chose Shenzhen as the site of our China workshop given its reputation as a major hub for 3D printing activities. Shenzhen is widely viewed as 'a maker's dream city' and the 'Silicon Valley of hardware' (Lindtner, Greenspan and Li 2015), and is also China's 'first city of design' and the first Chinese city to host a Maker Faire and Fab Summit (Wen Wen 2017).

The horizon scanning format for the workshop was developed by the project team and comprised three parts: the Multi-Level Perspective (MLP) to establish past and present trends and a combination of Ideal Futures scenario constructing and backcasting to scan the horizon. The benefit of the fusion of these methodologies is a multi-dimensional appraisal of foreseeable trends across different countries at different scales. The approach affords precise backcasting to now from the year 2050 with awareness of prevailing discourses around 3D printing and relevant contextual dimensions. This is the first time that these methodologies have been combined, but MLP and Ideal Futures scenario constructing have been used separately in previous studies for other technologies (eg Geels 2002; Geels 2012; Kostakis).

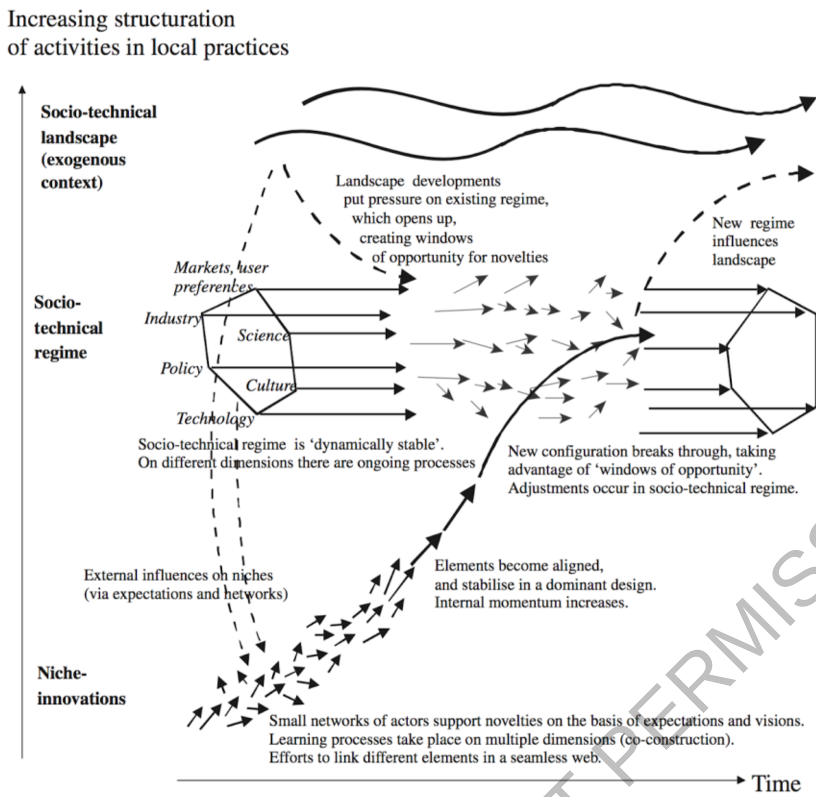

Fig. 2. Multi-level perspective on transitions (adapted from Geels, 2002, p. 1263).

Figure 2. The MLP technology substitution dynamic model (Geels 2012).

The models in Figures 1 and 2 were used as guides in each workshop for the participants to plot past, present or future events and developments at the micro, meso and macro levels in their particular location. In each workshop, the authors took photos of the MLP and Ideal Futures charts with the events and developments plotted by the participants using Post-It notes at each of the three stages of the methodology. The authors kept the Post-It notes that participants wrote on, recordings were taken of the workshop which were transcribed (and translated in the case of the Shenzhen workshop), that supplemented the field notes authors produced from the workshop. Individual participants are anonymous and it is the collective output of the workshops which we use rather than individual opinions.

Results and Discussion

This section presents some initial themes which emerge from the discussion and other data from our Shenzhen and Singapore workshops, concentrating on the participants' (recent) historical experience with 3D printing to the present day, and their backcasting from alternative ideal futures for 3D printing in their particular area. An initial difference between the Singapore and Shenzhen participants' experiences can be found in the date in which 3D printing first emerged into their consciousnesses in their respective cities. The Singapore participants identified that 3D printing emerged fairly early in Singapore, around 1996. In contrast, the Shenzhen participants identified as 3D printing emerging in that city around 2011/2012 with the initial industry segments to adopt it being DIY/makers and education.

This contrast in dates may, however, be explained by the lack of industrial manufacturing experts among the Shenzhen workshop participants - in fact 3D printing techniques have been used in the Shenzhen area in rapid prototyping studios since the 1990s (Li 2018), and at the same time certain prestigious university research institutions in different parts of the country were at the forefront of 3D printing research in China (Long et al 2017). However, the subjective experience of the Shenzhen participants was that they were not acquainted with 3D printing until 2011/2012, which may reflect the dates when the technology became more prevalent.

Policy and Culture

In both Singapore and Shenzhen, government policies had impacted and continue to impact on the trajectories of 3D printing in those countries, according to our participants. Medical 3D printing was strongly represented and discussed in and by the Singapore group, who considered that Singapore's aging population was impacting on the types of 3D printing activity and research occurring there, especially in the medical field. This included government funding for research in that area. However, the Singapore participants felt that overall Singapore was 'behind' other developed economies in Western Europe, East Asia and North America in its adoption and mainstreaming of 3D printing. While somewhat speculative, one might imagine the Singaporean government directed economic foci that do not align with the manufacturing affordances of 3D printing based on established advantages in finance, semiconductors, and petroleum.

For the Shenzhen participants, the Chinese government policies had influenced the take-up and trajectory of 3D printing, in particular, the 'Made in China 2025' programme (中国制造 2025), which can be conceptualised as an analogue to Germany's Industry 4.0 scheme. Made in China 2025 has set out a future vision for China's manufacturing industry including the integration of 3D printing and other forms of intelligent manufacturing. This iteration of a 4th industrial revolution provides a strong context-specific understanding of how automation will be transformative in a comparative sense to other nations which wish to continuing manufacturing, and begs further study. Medical 3D printing was not as prominent for the Shenzhen participants compared to Singapore. This may be attributable to the lack of representation from the medical 3D printing industry segment among the participants, but also due to the cultural environment. Participants identified Chinese traditions concerning the integrity of the body and filial piety as being potential barriers to medical 3D printing technology, which would need to be surmounted in order to promote 3D printing in the medical sector in China. This also highlights the what 3D printing is imagined to automate in the future in each location, with Singapore participants considering the body over external work-based affordances.

Intellectual Property Law

The growth of 3D printing is, as demonstrated above, interlinked with intellectual property and both sets of our participants signalled this foci point. Historically, our participants viewed IP issues as not being a major concern for Singapore-based organisations. But IP is gaining importance: Singaporean organisations are filing patents relating to 3D printing in Singapore and in foreign jurisdictions; and Singaporean organisations are analysing developments in digital supply chains and preparing for possible IP-related tensions. In contrast to some Western stereotypical perceptions of the supposed Chinese disregard for IP protections, in fact IP has played a strong, yet complex, role in the participants' views of the historical trajectory of 3D printing in Shenzhen. The participants pointed to the expiry of certain patents over 3D printing machines around 2012 which they viewed as facilitating Chinese industry's own production of 3D printing machines. However, China has also already experienced litigation concerning 3D printing, one of the first examples of such litigation worldwide despite predictions from some quarters that 3D printing would facilitate widespread IP infringement. Participants mentioned the litigation, in the form of patent infringement proceedings regarding component parts for a 3D printer (extrusion and feeding device), which took place in Zhuhai in 2014. Both parties to the case were Chinese 3D printing firms (Xin and Xiang 2015), and the State Intellectual Property Office of the People's Republic of China declared the claim of patent infringement to be invalid (The Recycler 2015).

Convergence

In the future-oriented part of the participant response, participants in both Singapore and Shenzhen brought up convergence of various technologies via the relations between automation, 3D printing and the Internet of Things. These near-future developments were understood, by the participants in Shenzhen, to also interface with blockchain technologies as they integrated with manufacture. In Singapore, participants specifically pointed to automation in the hospital context as converging already with 3D printing to address challenges presented there by the ageing population. The example was given that 3D printing food in hospitals was already being investigated; it seemed that this historical service industry was understood to be shifting to terms of automated manufacture. This consideration is significant in reflection of Singapore's distribution of employment by industry - which sees the service sector take around 73% of workers (Government of Singapore 2018). Furthermore, participants pointed to the challenges of climate change and exhaustion of natural resources in the future as factors which may encourage further 3D printing of food, and also circular economy practices around waste. The extent that policy, or market dimensions would play into this development were unclear, given a perception of the exogenous nature of climate change and the exhaustion of resource based growth.

There was some acknowledgement of interregional discourse, with the Singaporean participants referencing developments in China on more than one occasion. China's current perceived capacity to (mass) produce cheap items, coupled with Internet platforms such as Alibaba.com to facilitate transactions was viewed by the Singaporeans as a temporary state of affairs that would 'fade away' with better 3D - and 4D - printing technologies. However, the same participants also acknowledged that Singapore was 'behind' China as well as other developed economies in its current 3D printing development. While intra-regional connections were not explicitly mentioned by the Shenzhen participants, they did suggest that a more multicultural approach would be an important factor for future socio-technological developments in China, especially if the future was to be one which privileged socially beneficial scenarios for 3D printing based on increasing flows of the commons over capital accumulation. The participants viewed China to be too culturally introverted at the current time, including with regards to growing 3D printing technologies. However, the same participants also pointed to the new Chinese middle class as a potentially large market for 3D printing technologies, as a group which was inclined to spend money on new technologies and novelties. In general, participants gravitated towards the local-capital quadrant of 3D printing futures in China, where industry would follow a likely commercial track that put social benefit/commons-oriented in the future on hold.

Future 3D printing entities

Actants that were imagined to exist in 3D printed futures were diverse across the locales. Both Shenzhen and Singaporean participants viewed future 3D printing actors to be diverse yet, to some extent, industry-specific. Shenzhen participants considered that there would be two categories of future 3D printing entities: one being very large and competitive, with the other being small but innovative. Considering state run enterprises and Shanzai culture in PRC, we can see the contextual linkage in such forecasting. They also viewed a continuing role for intellectual property including patents in the future of 3D printing, again rebuffing western moral panic's over the Chinese worker's disregard for stable order. Singaporean participants considered that high and low-end types of 3D printing must be distinguished for future trajectories of the technology, and that different industries may also see different kinds of future 3D printing actors. Even within the one industry or sector, such as medicine, there may be globally distributed uses of 3D printing in the dental field, but other types of specialties such as neurosurgery or trauma surgery would still be more centralised. It seemed that by opening up distinct futures to our participants, they were able to differentiate intra-society scenarios that related to ideal future states in a way that enabled disaggregation from a whole. This is, in retrospect not surprising considering the decentralising nature of 3D printing and the network connections that support it.

Conclusion

This paper has outlined preliminary research findings from a futures forecasting exercise where participants in Shenzhen and Singapore considered the socio-technological construction of 3D printing. We offered participants ideal political-economic futures across local-global knowledge and capital-commons dimensions, and then had them backcast the contextual waypoints across markets, culture, policy, law and technology that would guide towards each future. Their discussion identified various contextually sensitive points, but also tended to dismiss the farthest reaches of each proposed future, often reverting to familiar contextual signifiers. Further research, which continues to map the relations 3D printing has with diversified locales within each nation may offer more wholistic understanding than the self-selected participants in our study, which were selected on biases connected to the underlying research project on intellectual property. Nevertheless, this data presents a vanguard of discussion on 3D printing futures outside of western hegemony, and contextualise these futures to pertinent political economic concerns for the 21st century.

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