Innovative Material Production in Post-Industrial Urban Economies: The Case of 3D Printing Technology in London

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Declaration

I, Ana C G R McMillin confirm that the work presented in this thesis is my own. Where information has been derived from other sources, I confirm that this has been indicated in the thesis.

Signed: [redacted]

Date: 08th April 2023

Abstract

In post-industrial urban economies, traditional manufacturing has been replaced by more abstract jobs associated with conceptual, design and research activities. Uneven development has been accentuated, and the concentration of services, finance and creative sectors in certain centres has left urban economies more susceptible to recessions. Recently, propositions for sectoral diversification involving a putative manufacturing renaissance to improve resilience and growth gained momentum in media and academia. Some have even argued that this amounts to an Industrial Revolution associated with new technologies. Such propositions are influencing policymakers.

Yet, there is a lack of empirical evidence for these propositions. Addressing this gap in evidence, my research follows the case of activities which have emerged in London associated with 3D printing technology. This study was designed horizontally across sectors, and it employed both qualitative and quantitative methods.

Drawing on the evidence collected, I first argue that instead of reviving urban manufacturing, innovative manufacturing technology in post-industrialism supports abstract tasks, work processes and outputs of the creative and knowledge sectors. Findings showed that people use fabrication technology to improve design processes, expand consultancy, or create new software, rather than producing consumable goods. Second, I argue that technology alone does not change the geographies of production and innovation of post-industrialism. Findings showed new activities co-locating with creative, knowledge and digital clusters in the city core, responding to socio-cultural, labour and accessibility factors consistent with these sectors, regardless of the locational flexibility of the technology. Lastly, I argue that, despite evidence of 3D printing technology not generating an urban manufacturing revival, it can enhance growth and competitive advantage in post-industrial urban regions through the creation of new knowledge and innovation related to existing economic activities. Findings showed that 3D printing activities facilitated initial stages of product development, survival of start-up businesses, and collaborative work practices.

Impact Statement

Industrial and planning policies concerning the development of industrial activities with new fabrication technologies have been published at strategic and at city levels. They have aimed to promote these activities to overcome issues of inequality and difficulty securing continuous growth and economic resilience, consequences of the loss of manufacturing and its replacement by knowledge-intensive sectors in post-industrialism. Within these strategies, visions for the resurgence of urban manufacturing and significant changes in geographies of production of post-Fordism have been articulated. However, knowledge gaps exist regarding how innovation around material production is created, where it is located and how it operates. There is also a lack of understanding of its role in relation to other production sectors and assessment of its capacity to diversify or create value in a post-industrial urban economy. Plugging this gap in evidence through this research will allow policymakers to set effective objectives and design better policies to achieve them.

Through constructing a database of new activities related to 3D printing and analysing them with qualitative and quantitative methods, this research has produced original new insights into the characteristics of activities using advanced fabrication technology. These include their focus on the initial stages of products, their central location preferences and reasons for that, alongside their business trajectories, funding strategies and issues that may halt their expansion. This comprehensive data and the arguments made from their analysis can guide policy away from fashions and inaccurate visions, towards change and effectiveness. Furthermore, it can justify reforming the sectoral perspective which separates manufacturing from services and knowledge production, derived from historic economic progression that currently structures policy instruments such as regulations, funding, planning, etc. and which is not helpful and does not reflect the evolutionary and more nuanced process of innovation with digital manufacturing technologies.

This research is timely as both economic and spatial policies will need to address changing work patterns post-pandemic. There is a risk of simple arguments relying on technological flexibility alone for growth, missing the importance of social and cultural factors in the innovation process and the crucial role of city centres and agglomeration effects. This research highlights how much those factors matter for innovation and for constructing social proximity for effective knowledge sharing. Furthermore, there is potential to support more material production innovation in cities now that some city centre premises have become vacant. This research offers a clear case to help retain some of those premises for these creative activities and to invest in strengthening (if not saving) certain city centre districts from losing innovation cultures.

Lastly, Brexit has brought back a desire to increase domestic manufacturing and change global production chains, as well as an identity discussion that calls for a new industrial revolution to be endorsed. At the same time, the U.K. has lost access to European policies and funds for innovative material production in urban areas, such as Cities of Making (2018). It is, therefore, crucial that new policies are designed in their place, thus this research can have a significant impact in shaping those.

In order to reach out to policymakers, it is planned that this research may be disseminated to the academic community through journal article publications, and a summary of findings will be available for circulation to policymakers once the work is submitted.

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To my (late) father,

Thank you for your advice '...look more into Castells...'

Chapter One

Innovative Material Production in Post-Industrial Urban Contexts

London's economy should in any case be "rebalanced" away from creating paper assets and towards manufacturing (The Economist 2011: 33)

1.1 Introduction

This research emerged from debates in the post-2008 recession years about restructuring post-industrial economies to be more resilient through a higher share of manufacturing outputs and employment in their economic composition. In those debates, an urban manufacturing renaissance could happen in urban contexts such as London because of new manufacturing technologies. This idea interested me because it seemed quite radical. Throughout most of my life I grew up with stories of industry closures, products made in faraway places and industries relocating, and it never seemed feasible to imagine starting to manufacture anything like clothes or appliances at scale anywhere in a Northern urban context. Then, one weekend, I casually bought the Economist, and the special report was on the Third Industrial Revolution (The Economist 2012). In this report about manufacturing innovation many articles anticipated a future where 'we' in the North would be 'back to making stuff'. This future would be one where prosperity and technology went side by side, where people and robots were working together in immaculate factories looking more like laboratories, and where the memories of recession, disparity and uneven development were long gone (The Economist 2012:1).

My sense was that there was a lot of hype in this possibility, and that many of these claims were based on aspirations, even dreams, rather than grounded in evidence. So, I set out to study a real case and design a research project to investigate these claims, choosing the case of 3D printing, the most cited example of new manufacturing technologies in that context. More specifically, I sought to investigate firms and activities, people, and new ways of doing *things* that might reveal the secrets of a *New Industrial Revolution* (Marsh 2012; BIS 2017; Brown 2015; Baldwin 2016; Sissons and Thompson 2012; Rifkin 2011 and 2016) in its early stages. Or if I did not find a *revolution* exactly, I could instead evaluate whether new fabrication technology triggers an urban manufacturing renaissance in post-industrial contexts that can contribute to economic resilience, growth and further innovation, and how exactly. In sum, I was going to investigate innovative material production in a post-industrial urban context through the case of 3D printing technology.

As I later discovered, the resurgence of material production in post-industrial contexts catalysed by new technology is a proposition that has been articulated not just by mainstream media but also by scholars and policymakers. This proposition has been advocated by developers (Caruso et al. 2015), scholars (Rifkin 2011 and 2016; Rothkopf 2012; Nawratek 2017; Thomas 2019; Anderson 2013), public policy (BIS 2012; Tym and Lang LaSalle 2011; Cities of Making 2018) and research organisations such as Nesta and Foresight (Sisson 2011a; Sissons and Thompson 2012; Bryson et al. 2013). This possible resurgence of manufacturing in post-industrialism has been referred to by various jargon expressions like the 'New Industrial Revolution' (Marsh 2012; BIS 2017; Brown 2015), 'Third Industrial Revolution' (Sissons and Thompson 2012; Rifkin 2011 and 2016; Rothkopf 2012), 'Fourth Industrial Revolution' (Baldwin 2016), and more recently 'Industry 4.0' (Cities of Making 2018; Santos et al. 2017; Busch et al. 2021; De Propris and Bailey 2020; Laffi and Boschma 2021; Liao et al. 2017; Fraske 2022; Johns 2020 and 2021).

Some of these jargon expressions present rather utopian and unevidenced narratives about a post-industrial urban manufacturing renaissance driven by technological innovation, and they take positive outcomes for granted (Sissons and Thompson 2012; Gress and Kalafsky 2015; Nawratek 2017; Thomas 2019). Furthermore, as noted by Johns (2021), revolutionary and hype narratives are obscuring a better understanding of the technologies and their potential. Certainly, the hype around manufacturing renaissance or industrial revolutions has provided inspiring marketing to neoliberal agendas[2] – repeating some mistakes of the past when creative city

[2] See Santos et al. (2017) for a review of the European policies and roadmaps related to implementation of advanced manufacturing technologies; and the World Economic Forum's meeting agenda 'Globalisation 4.0: Shaping a Global Architecture in the Age of the Fourth Industrial Revolution'

narratives dominated urban post-industrial regeneration strategies - but not any comprehensive understanding of the emerging activities related to new material production technologies.

As the significance of the technological changes in material production becomes evident (Birtchnell et al. 2018; Johns 2020; Bryson et al. 2013; De Propris and Bailey 2020), theoretical and research implications are thus becoming noticed by scholars like Gress and Kalafsky (2015), Johns (2021) and Liao et al. (2017). They highlight the need for future research from many disciplinary points of view, including the changes stemming from technological innovation for the geographies of production (Bryson et al. 2013; Busch et al. 2021) and theoretical framing of the context of this type of innovation (Gress and Kalafsky 2015) to guide policy directions, which this thesis addresses. Without evidence, there may be a gap between policy assumptions of an urban manufacturing renaissance catalysed by technology, and the reality of practices and outcomes.

Hence, it is pertinent to move beyond aspirational narratives of a New Industrial Revolution as a revival of manufacturing production in the traditional historical sense. Instead, through the evidence collected, this research assesses the potential of technologically aided material production for linking with the other economic sectors of post-industrial regions, its spatial context and spatial implications for the urban space and the growth outcomes that may arise from its adoption in this context.

My study, through analysed evidence, first argues that instead of reviving manufacturing, the role of innovative productive technology in post-industrial urban contexts is to support abstract tasks, work processes and outputs of creative and knowledge sectors. Thus, instead of being linked to a history of manufacturing, innovation with material-producing technology in the case study context will be conceptualised as part of an incremental change in post-industrialism. Some of the key findings of this research which support this argument involve how new technology has accelerated what people already do in consultancy, prototyping and design. Outputs are not always material goods at the end of a production chain, but part of the early stages of production within the knowledge and creative sectors. Further supporting this argument, my data shows that the activities emerging around 3D printing

(2019); Johns (2020) reflects on the politicisation of the technological innovation and the use of jargon expressions.

technology have a lot in common with creative industries, as they are small, employ highly educated people and work across expanded production chains, networking in the agglomerated context of London.

The second argument of my thesis, then, is that technology alone does not change the geography of innovation and production in post-Fordism, separated, as we know it, across regions with abstract development tasks and innovation located in urban centres and repetitive tasks of large-scale production of optimised processes located in more remote locations (Scott 1988b; Moulaert and Swyngedouw 1989; Duranton and Puga 2001; Hutton 2008; Storper and Venables 2002; Jacobs 1969). My findings showed new activities related to 3D printing in London co-locating with creative, knowledge and financial services in the city core despite high rent levels. Moreover, findings showed that new activities emerged in central London as part of existing clusters with certain creative, technical and digital activities, where funding could be obtained, the right people could be hired and in well-connected places. Strategies to remain in those locations involved occupying very small and shared premises, taking on multiple jobs and reducing travel times. The 3D printing technology allowed for great flexibility in location choices, but findings pointed clearly to the need for activities to remain in specific locations. Thus, location and characteristics of the place are shown to have a role in economic activities, as well as influencing the types of activities that can flourish in an area and impact the types of skills and people that will be attracted there. Also, innovation with material production technology occurs in relation to economic activities which have previously taken place in these locations, as argued in evolutionary and path dependency scholarly perspectives (Boschma and Frenken 2011; Neffke et al. 2017).

Further to this, my findings support the thesis' third argument, which is that innovation with fabrication technology can contribute to a post-industrial city's growth and competitive advantage, despite evidence of not reviving the manufacturing share of the local economy. It was found that this technology was beneficial in fostering new creative, services and knowledge activities working at the early stages of product development with good turnover, profit and job creation. New activities emerge in relationship with other London creative industries, either through the types of work they do, or because of the circumstances of their inception. It is found that together they form a system of related diversity whereby knowledge is productively shared amongst people and organisations (Henning and Boschma 2011), which is a positive environment for further innovation. It was also found that the challenges and potential of technology adoption foster collaborative practices of work and knowledge exchange, which translated into more opportunities for innovation and growth as knowledge of experimenting with the new technology was freely shared amongst 'makers'. Collaboration between entrepreneurs across diverse activities, more than competition, underpinned experimentation with the technology, enabled by the agglomeration and connectivity conditions of the context.

When bringing together these three arguments and the supporting findings, this thesis suggests that despite new technologies for material production we have not moved past post-industrialism, where knowledge, services and cultural production replaced manufacturing as the driving growth sectors. Knowledge continues to act upon knowledge for growth generation, and this is facilitated by the agglomerated context and urban concentration of activities in post-industrial regions like London. In this context, the process of innovation associated with new fabrication technologies in post-industrialism is better understood as an integration between a new, disruptive element (the technology) and incremental change from within a region's productive culture and structure. The role of space in the process of economic change and innovation is twofold: it enables the continuity or the link between old activities and new activities through the exogenous factors (people, the local culture and the institutions); and it offers structures to mitigate risks emanating from a new technology application (like funding or formal and informal collaborations).

The remainder of this chapter frames the study. First, it examines the context of post-industrialism and its sectoral composition in more detail, and explains the reasons for the decline of traditional manufacturing alongside narratives concerning the possible resurgence of material production in post-industrial cities which initiated this research. Second, the case study chosen is presented: 3D printing technology. Initially, this was thought of as an industry, but as this study will demonstrate, it rapidly became understood as a technology applied across various industries and sectors. Third, the choice of London for this study is presented as a post-industrial urban context with a clear sectoral imbalance towards services, finance, knowledge, real estate and creative production, but with important particularities such as an industrial past and high land values. Finally, I present my three research questions, followed by a statement on the contribution of this research and an outline of the thesis for the reader's guidance.

1.2 Post-Industrialism and the Resurgence of Urban Manufacturing

This research is set in an urban post-industrial context, where cultural, cognitive, knowledge and professional activities have replaced most of the old manufacturing productive activities (Hamnett 2004; LEP 2014). As in other developed nations, the manufacturing sector has been in relative decline since 1973 in the United Kingdom (Kitson and Michie 2014). In London, since 1971, business services with a stronger specialisation in financial services and media, plus hotels and restaurants (Prothero 2007) have come to characterise the urban economy. Employment in industrial production sectors in London fell by 35% from 1998 to 2008, corresponding to a loss of nearly 100,000 jobs. Whilst these sectors also declined nationally, the rate of loss in London was much higher (Tym and Lang La Salle 2011). As Pratt (1994b) summarises, in London the entire loss of manufacturing employment through the eighties was substituted by the growth of financial services jobs[3]. The decline of manufacturing industry and the simultaneous rise of the cognitive–cultural sectors (Scott 2007 and 2008), a fundamental alteration of capitalism from mass production with material outputs to flexible modes of production with abstract outputs, characterises many post-industrial economies. This process of change and the reasons for manufacturing decline have dominated scholarly debates up to the early 2000s, analysed in literature as the post-Fordist period (Jessop 1994; Amin 1994; Pratt and Hutton 2013).

It is important to caveat that manufacturing has not entirely departed from post-industrial nations (Giloth 2012; Sassen 2009 and 2011), neither from the urban centres nor from the urban peripheries. Some manufacturing activities continue to exist in cities, intertwined and linked with the dominant sectors, directly supporting those activities or servicing residents, including niche consumption markets even within or between areas of high-value land uses (Sassen 2009; Cities Institute 2009; Badgwell 2008). And outside core metropolitan areas, some manufacturing still plays a leading

[3] According to Pratt (1994b), the changing structure of industry and employment of de-industrialisation was more accentuated in London than in the rest of Britain. Specifically, Pratt registered the manufacturing sector declining sharply in London between 1971 and 1991. Further to this, it shrank by 36% in Greater London and by 41% in inner London, showing an even more substantial departure from the more central areas of the city. And, in the decade that followed from 1981, the Banking, Insurance and Finance sector expanded rapidly both numerically and proportionally in London. Moreover, between 1981 and 1991 the manufacturing sector continued to decline by around 40%. The other sector which has experienced consistent growth in London is public administration, health, and education.

economic role in some developed regions, for example in Germany, the Netherlands, Italy (Boschma and Iammarino 2009) and to a lesser degree in some areas of the U.K (Zysman 2003; Van Winden et al. 2011). But none of these are the focus of this study, as the interest is on the particular type of material production associated with new fabrication technologies, that which policymakers, scholars and media have suggested could flourish in post-industrial cities.

De-industrialisation processes and current economic specialisation in sectors of abstract outputs have generated spatial, economic and social imbalances, which those proposing the resurgence of urban manufacturing have thought it might address. The loss of manufacturing in Western nations and the shift to drivers of economic development relating to information and technology, alongside global networks of production (Ernst and Kim 2002) have accentuated polarisation between core and periphery locations (Martin et al. 2015). In post-industrialism, the geographies of economic development are composed of large leading global cities with dominant tertiary and innovative sectors contrasting with declining old manufacturing towns and semi-rural regions (Esser and Hirsch 1994; Sassen 2000) in what has been described by scholars as concentrated dispersion (Ernst and Kim 2002; Crescenzi et al. 2020). At the same time as manufacturing declined in developed nations, it has grown at scale in developing nations, and led to the establishment of today's global value chains (Krugman 1991; Krugman and Venables 1995) by which regions trade and specialise across the globe. But, as post-industrialism and globalisation unfolded, spatial and social divisions deepened. Many people feel left behind, due to augmented polarisation consequences such as regional imbalances (Martin et al. 2015) and escalating social and income inequalities within metropolitan regions (Kersley and Shaheen 2014; Sissons 2011b; Hackett et al. 2012; Scott 2007).

Recreating employment and stimulating growth to address these issues in post-industrial regions has been a challenge for policymakers and city mayors. Scholarly perspectives portraying creative industries as a different type of work characteristic of this late phase of capitalism (Sonn et al. 2018; Scott 1988a and 1997), different from both Fordist manufacturing and from services, have informed discussions and policies. Of relevance is the perspective offered by Richard Florida (2002) as this has parallels with the current hype around a putative New (Fourth) Industrial Revolution. Florida argued the case for growth in post-industrialism based on the ability of places to attract or retain talented people, specifically, a creative class of people. This group would be drawn towards places where a culture of tolerance, attractive urban environments, investment in technology and similar talented individuals would be found.[4] This has motivated policies in many cities through the 1990s and 2000s and, with public investment, cities have delivered new beautified environments with offices and residential uses anchored around iconic culture consumption centres (Evans 2009; Pratt 2009b; Heinze and Hooze 2013). But these strategies delivered less in the way of results than anticipated, falling short in terms of growth and employment creation (Pratt 2008, 2009b and 2010; Pratt and Hutton 2013; Hutton 2008 and 2009; Zukin 2010; Markusen 2006), let alone levelling out inequalities and unevenness.

The recession in 2008, and the subsequent policies of austerity further contributed to the post-industrial divisions and polarisation (Hackett et al. 2012). Visions for the resurgence of urban manufacturing emerged in this context, as a possible solution to the crisis, particularly in relation to the potential of advanced manufacturing (Sissons 2011a; Sissons and Thompson 2012; The Economist 2012; BIS 2012; Tym and Lang La Salle 2011; Ferm 2016; Martinez-Fernandez et al. 2007). Focusing on *making things*, sometimes with technologically innovative methods and sometimes through improving traditional and craft methods, gained popularity (The Economist 2012; Reynders 2014) and began to be articulated as a policy (BIS 2012, LEP 2014; Ferm and Jones 2014) to address the dilemmas of post-industrialism. The *New Industrial Revolution* vision came to prominence alongside the *Creative City* vision. This was a proposition raised in the U.K. and internationally for other similarly post-industrial regions such as Paris (Halbert 2012), New York[5] (Catinella-Orrell 2011; Curran 2010) and Hamburg (Adam 2002).

Promoting urban manufacturing as part of solutions to the financial crisis and to social and spatial inequalities of post-industrialism has received funding from the European Union. The European Commission's political discourse endorsed an

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[4] These are the three 'T's of growth proposed by Florida: Tolerance, Technology and Talent (see Florida 2002).

[5] Several non-profit organizations emerged at the time of the recession to support growth of local manufacturing. For example 'Made in NYC' in New York, and the 'Urban Manufacturing Alliance' an organization working across all U.S. cities to sustain and grow local manufacturing businesses. New York City's former Mayor Michael Bloomberg announced, at the time, an investment programme to reinforce New York's industrial sector, and a trend for locally made, higher quality and small batch products gained strength in New York (Catinella-Orrell 2011).

industrial renaissance with a strong urban manufacturing component through initiatives such as the Circular Economy Package and Industry 4.0 (Cities of Making 2018). The potential benefits of pursuing manufacturing revival in European cities include, in these plans, creation of jobs for the socio-demographic groups most affected by unemployment, triggering further innovation, an efficient and sustainable management of resources and ultimately urban economic growth:

> 'The European Commission (EC) defined a challenge in 2012 to grow industry from around 16% to 20% of GDP by 2020 (EC 2012), issuing several strategy documents as part of an effort to bring back a strong innovative productive base, increase local jobs, promote import replacement, increase value and economic activity. With the advancement of technologies such as high-precision 3D printing, CNC milling, decentralised resource processing, the emergence of the 'maker' culture, new entrepreneurial models and a focus on the circular economy, such a return is possible. Industry and making can be more sustainable, social, better distributed, quieter, non-toxic and adaptable to existing urban conditions.' (Cities of Making 2018, https://citiesofmaking.com/project/what-is-urban-manufacturing/, accessed 9th August 2019)

While the European Commission's focus is on urban areas, in the U.K. investment and policies aimed at reducing risks or obstructions to advanced manufacturing growth have been articulated for the country as a whole, including urban and periphery regions[6]. The Department for Business, Innovation & Skills, for example, had set the growth objectives in 2010 for the country's next ten years identifying investment in advanced manufacturing as the single most important measure to grow the U.K.'s economy, although not focused directly on metropolitan areas as in the EU equivalent. The first growth priority proposed in the department's Industrial Strategy (BIS 2012) was to promote manufacturing across the country, acknowledging however that activities can initially develop around existing agglomerations, particularly if they are spill overs from existing firms or start-ups. In 2017, the new (and current) Industrial Strategy (BIS 2017) maintains a focus on innovation but broadens the industrial scope away from advanced manufacturing to focus more on artificial intelligence, internet-based activities such as big data, as well

[6] Key BIS policies include investment of £60 million for Advanced Manufacturing Research Centre (AMRC), a collaboration between global leaders in the aerospace industry - such as Rolls Royce and Airbus, academia and public administration, and of £25 million in the Framework for Innovation and Research (FIrM), a research facility in Media City UK (Greater Manchester area). Both funds run until 2020.

as clean energy and self-driving vehicles. It argues that a *New Industrial Revolution* based on digital technologies with the magnitude of the historic British Industrial Revolution is already underway.

Visions for implementing advanced manufacturing for wealth creation have also cascaded from the national to the city level in the U.K. For London, specifically, these have been articulated by think thanks and advisory bodies informing city-scale policy, such as The London Enterprise Panel (LEP) and the Big Innovation Centre. For example, The London Plan's evidence gathering for the city's industrial policy quotes the Government's Office for Science:

> '[The Government Office for Science] looked at technology and innovations that might drive future economic growth. It believes there is a future for manufacturing and that "By the 2020s, the UK could lead a 21st-century group manufacturing revolution, fuelled by new technologies, tools and materials, with local bespoke manufacturing-on-demand based on 3D printing and a move to a product plus service commercial models – 'servicisation'." More personalized manufactured goods may imply more locally produced goods both in terms of enabling a more local character to products and also where there is a requirement for just-in-time demand. This is an area where London already shows examples of providing bespoke high value products such as tailoring in Saville Row. The creation of a new market for highly tailored goods may increase demand for industrial type premises close to the market in London. But these may not be traditional industrial units". (Tym and Lang La Salle 2011: 46)

The importance of retaining manufacturing in post-industrial economies has been presented in more scholarly discussions linking further innovation to the knowledge of how things are made, on the basis that an element of tacit knowledge is lost when the design and manufacturing stages are separated (Zysman 2003; Cohen and Zysman 1987; Leigh and Hoelzel 2012). Additionally, manufacturing has been presented as a higher-paying sector for the low-skilled and less educated compared to retail, for example. In this way, it has been portrayed as an important sector to retain to provide better-paying jobs, to drive wage rises across other sectors, and to help boost spending power (Giloth 2012; Leigh and Hoelzel 2012).

More recently, technological advancements in material production start to be investigated as a route to tackle issues of post-industrialism in regions left behind across Europe's metropolitan areas (Santos et al. 2017; Lowe and Vinodrai 2020; Busch et al. 2021; Laffi and Boschma 2021) and in rural contexts (Lafuente et al. 2010). Further to this, some research is emerging about the impact of new material producing technologies on the value chains and uneven geographies of production of post-industrialism. But there is no consensus yet, as some suggest that additive manufacturing technologies are changing the relationship between different actors in production across space (Johns 2020; Bryson and Clark 2013; De Propris and Bailey 2020), whereas others find that the same technologies are not influencing value chains (Rehnberg and Ponte 2018).

The most widely mentioned argument in favour of revitalising manufacturing in the post-industrial economy is as a strategy for sectoral rebalancing to offset downturns of other sectors, thus contributing to better overall economic resilience through diversification (Martin 2012; Pike et al. 2013). The idea of manufacturing and *making things* with the use of new technologies holding potential for growth and employment in post-industrialism is present in policy. For example, The London Enterprise Panel, whose role is advisory on the economic development plan for London, suggests that 'London's growth has been highly dependent on the City, and that sustaining growth may require new engines' (LEP 2014: 7). Sissons and Thompson (2012) went as far as linking growth of technologies like 3D printing to arguments for restoring the balance between production and consumption across the economy.

The promotion of technologically aided manufacturing activities in a post-industrial context to trigger growth and to generate employment in the medium-to-long term can be linked to broader questions of specialisation versus diversification. These would be new activities, possibly with (more or less) links to the existing industries, to local resources and to the local knowledge base. In evolutionary economic geography research, dynamic analyses find evidence for diversification in cities economies (Glaeser et al. 1992; Glaeser and Kerr 2009; Jacobs 1969) as a strategy to create an environment for innovation (Duranton and Puga 2001) and achieve resilience over time (Matin 2012; Pike et al. 2013), particularly in metropolitan areas (Florida et al. 2017). Research has been showing that growth and innovation are essentially a branching process of new firms emerging from within old ones (Boschma and Frenken 2011) and technologies being imported or created in a region, but with path interdependencies meaning that new industries bear a relationship with local knowledge and the local economy (Martin 2012; Neffke et al. 2011; Rigby and Essletzbichler 1997). More entrepreneurial or external firms settling in an area produce short-term growth, but stable growth relies on local firm spill overs and firms relating to the existing city economy (Neffke et al. 2017).

These scholars' research within evolutionary economic geography opens an angle from which to look at the possibilities raised (sometimes assumed) by media and policymakers of reinstating material production and reviving urban manufacturing in post-industrial urban economies through advanced manufacturing technology. That is, if new fabrication technologies can somehow relate to the local sectors and activities of the economy. This research thus gathers new evidence on a concrete case study of technologically enabled fabrication activities set in a specific post-industrial urban context (which I will introduce below). The findings concentrate on the processes of innovation of the knowledge and creative sector-dominated urban economies involving information, communication *and advanced fabrication* technologies. The first two technologies (information and communication) were part of what has been consensually treated as the Third Industrial Revolution (Freeman and Perez 1988; Freeman and Louca 2001; Castells 1996) and have been key to analysing post-industrialism. The last technology, advanced fabrication, constitutes the new element that some have argued delivers the Fourth of those revolutions (Cities of Making 2018; Santos et al. 2017; Busch et al. 2021; De Propris and Bailey 2020; Laffi and Boschma 2021; Liao et al. 2017). My findings thus contribute to a logic of cyclical - and technologically linked - progression of capitalism, which has framed evolutionary economic geography (Rifkin 2016; Laffi and Boschma 2021) and that has successfully explained innovation processes. I will argue that the new material-producing technology is triggering more innovation and growth (but not low-skilled jobs), although within the dominant sectors of the local economy rather than reinstating an urban manufacturing revival. This is an important finding that can inform policy aiming to address issues of post-industrialism and which also advances our theoretical understanding of urban post-industrialism itself and of innovation and the role of space in the process.

Below I introduce the case study - the innovative technology of 3D printing used for material production - followed by the chosen urban post-industrial location, London.

1.3 Innovative Material Production: 3D Printing Technology

This thesis is about material production involving a new fabrication technology, thus excluding, for example, crafted or handmade products as well as any mass manufacturing activities[7] remaining from the Fordist period within a generally de-industrialised economic context. By innovative, this thesis implies the production of physical outputs through methods and practices using new technologies rather than patents in material production, which also tend to be a common measure of innovation in research (Florida et al. 2017; Pratt and Jeffcut 2009). Material production can be defined as 'the output of an economic activity which is physical and tangible and does not need to be consumed immediately' (Illeris 1996, cited in Martinez-Fernandez et al. 2007: 16). In simple terms, this thesis separates the abstract from the non-abstract tasks of production - essentially 'concept and design' from 'making'. This study takes a similar view as to what constitutes material production as the Cities Report (2018) which focused on the role of urban manufacturing in three European cities:

> '1. Involves the transformation of physical materials; 2. Employs labour, tools and/ or machines; 3. Results in a product; 4. Involves 'making' at scale as part of a business model (...). However, it may involve a process which produces low volumes or highly bespoke products. 5. Is embedded in its urban context: The activity involves a web of supporting services, such as logistics, finance, design, and is linked to a market.' (Cities of Making 2018: 10)

In mentioning technologically facilitated material production, this thesis considers technology defined by Castells (1996) as the element establishing the relationship between labour and matter. Examples of recent technological advancements in material production discussed in the literature to date have included (Marsh 2012; Anderson 2013; Rifkin 2011 and 2016; Sissons and Thompson 2012), and frequently confused, material innovations (such as optical fibres, new textiles and new polymers), technological innovations in fabrication (such as 3D scanning, CNC cutters and 3D printing), process and organisational innovations (such as robotics, automation and remote work) and other information innovations (such as cloud computing and internet of things). In some literature, a new technological innovation in material

[7] Mass production as large-scale production of high volume of standardised products put together by low and semi-skilled labour, which has been separated from design, conception stages and where managerial tasks are also detached from the production (Zysman 2003; Pine 1993)

production is considered a driver of change to all sectors of the economy, such as the water-powered and steam engines, which were catalysts for changes across sectors in the historic industrial revolutions (Freeman and Louca 2001; Anderson 2013). And in some other approaches, the claims are more about production process being changed via a combination of new materials, technologies and processes (Marsh 2012; Sissons and Thompson 2012; Bryson et al. 2017). This second set of literature cites software applications that speed up production like CAD software, or robotics and automation introduced in production lines which can then use innovative materials plus fabrication technologies. Both groups consider all various innovations to be set in a world where extremely fast online communication is a given asset, and computerisation of the entire economy is well established. More recently, all these innovations in material production are grouped under the term Industry 4.0 (Liao et al. 2017; Santos et al. 2017; Johns 2020; De Propris and Bailey 2020; Busch et al. 2021; Laffi and Boschma 2021).

The claims of a new manufacturing renaissance due to technological innovation in material production, whether in an urban context or relocating outside metropolitan areas, are not restricted to a single industry or sector. Most commonly, they mention the technology of 3D printing as the most disruptive technology (Marsh 2012; Sissons and Thompson 2012; Anderson 2013; Johns 2020 and 2022), the case study of this thesis. In the way 3D printing is presented in academic, policy and mainstream literature (Sissons and Thompson 2012; Anderson 2013; Tym and Lang La Salle 2011; Economist 2012; BIS 2012; Rifkin 2016; Barnatt 2014; Thomas 2019), it is arguably the most significant case for an enquiry into the possible resurgence of technologically enabled material production in a post-industrial context (De Propris and Bailey 2020), contrasting with and diversifying the dominant economic sectors which tend to have non-material outputs.

The case study of 3D printing has thus been chosen as the case study in this research as a technological innovation in fabrication that could *revive* urban manufacturing, mentioned by scholars, policy documents and the media (Barnatt 2014; Marsh 2012; Sissons and Thompson 2012; Tym and Lang La Salle 2011; Cities of Making 2018). For example, the London Plan's evidence gathering for industrial policy describes a possible scenario of industrial renaissance with 3D printing:

> 'The employment forecasts for London show a continued decline in manufacturing employment. (..) However there is a potential

> scenario in which production employment in London undergoes a renaissance based on new forms of technology such as 3D printing that enables bespoke production close to the market.' (Tym and Lang La Salle 2011: 143)

So, what is 3D printing? And why is it a technological innovation in material production? 3D printing, as a technique, is the process of fabrication that allows an object to be entirely created from scratch, with liquid or powder material being added on by a printing machine according to set coordinates, without the need for any block of material as a starting point for carving. For this reason, it is an additive, rather than a subtractive, production process (as are traditional fabrication processes) with a material three-dimensional output product (Reeves and Mendis 2015; Barnatt 2014; Sissons and Thompson 2012; Rehnberg and Ponte 2017).

There have been different definitions for 3D printing across countries, and at the time of this research in 2015, an international norm was published to define the various processes understood as 3D printing processes as:

> 'A large number of additive processes are now available: The main differences between processes are the way layers are deposited to create parts and in the materials which are used. Some methods melt or soften the material to produce the layers, for example. Selective layer melting (SLM) or direct metal laser sintering (DMLS), selective laser sintering (SLS), fused deposition modelling (FDM), or fused filament fabrication (FFF), while others cure liquid materials using different sophisticated technologies, such as stereolithography (SLA). With laminated object manufacturing (LOM) thin layers are cut together and cut to shape and joined together (i.e. paper, polymer, metal)' (ISO 2015: Wikipedia accessed 2019.08.29)

The technology had its origins in the late 1970s (Zhang 2014), and in 1984 Chuck Hull filed a U.S. patent for a machine that produced objects by a stereolithography process. Hull later founded 3D Systems Corp. in 1986, which started the formal sales of 3D printers a couple of years later and was the first company to produce 3D printers for commercial use (Wholers and Gornet 2013, cited in Zhang 2014; Hickey 2014). The technology has since evolved in terms of the equipment, digital processes and materials used from simple plastic melting extrusion and layering of raw material to form a shape, to currently melting and extruding a variety of complex forms with great precision with a variety of materials including liquids, gels and composite-materials (Reynders 2014; Shapeways.com accessed 24th April 2016). Research on applications of

3D printing has now extended to nearly all sectors of industrial production including biomedical, entertainment, food, fashion, arts, aerospace, automotive etc. An element of the technology is now available to use at home or in small offices at low cost (Reynders 2014; Reeves and Mendis 2015; Sculpteo 2015).

Below are some images extracted from web pages to illustrate the 3D printing processes and the range of scales, materials and objects which can currently be 3D printed.

[redacted]

Top-down, clockwise[8]:

Figure 1.1 3D Printed complex hollowed-out structure and form-freedom, source: http://i2.cdn.turner.com/cnn/2013/images/07/10/3d.printing.jpg

Figure 1.2 Typical 3D printer, available for circa £500, source: http://www.geeky-gadgets.com/reprappro-ormerod-3d-printer-kit-now-available-form-rs-components-for-500-04-12-2013/

Figure 1.3 3D Printing from liquid material, Stereolithography (SLA), source: https://i.ytimg.com/vi/VTJq9Z5g4Jk/maxresdefault.jpg and video available at: https://www.youtube.com/watch?v=VTJq9Z5g4Jk

[8] All websites accessed between May 2015 and August 2021

Figure 1.4 Large scale 3D Printing in clay, source: http://khosann.com/dijital-donusum-yatirimlarindan-ibaret-degil-1-3b-printerlarla-tuketici-uretici-oldu-uretici-de-tedarikci/

Figure 1.5 3D printed concrete columns, ETH Zurich, source: https://ethambassadors.ethz.ch/2020/02/11/shaping-a-digital-building-culture-for-concrete-3d-printing/

Figure 1.6 Desktop 3D printer; 3D Printed food with living elements, project Edible-Growth-by-Chloe-Rutzerveld, source: http://www.dezeen.com/2015/02/26/movie-3d-printed-food-living-organisms-chloe-rutzerveld-edible-growth/

[redacted]

Top-down, clockwise[9]:

Figure 1.7 3D Printed house in China where 10 were printed in one day, source: http://www.treehugger.com/modular-design/more-detail-those-chinese-3d-printed-houses.html

Figure 1.8 3D Printed human part, source: http://www.3dtvdog.com/3dtv-2/experiments-for-3d-printing-of-human-body-parts/

[9] All websites accessed between May 2015 and February 2018

Figure 1.9 3D Printed bicycle in titanium, source: https://3dprint.com/10345/3d-printed-titanium-bicycles/

Figure 1.10 3D Printed structure in concrete as part of the house above, source: http://www.printerbase.co.uk/news/3d-printing-technology-print-houses/

Figure 1.11 Printing a broken piece to repair the broken 3D Printed prosthetic hand damaged while 12 year old played football, source: http://blogs.voanews.com/techtonics/2013/12/20/3-d-printing-brings-new-promise-for-developing-world/

Figure 1.12 New balance 3D printed shoes, source: http://hypebeast.com/2013/3/new-balance-launches-its-own-3d-printed-shoes

It has been stated that 3D printing technology is an innovation that will fundamentally disrupt the way all objects are made by altering the manufacturing process as we know it (Thomas 2019; Johns 2020), with impacts on global value chains and on the regional distribution of production (Bryson and Clark 2013; Gress and Kalafsky 2015; De Propris and Bailey 2020; Johns 2020; Lowe and Vinodrai 2020; Busch et al. 2021) because it is a flexible technology that allows for on-demand fabrication and can be located anywhere. In consequence, it could change all aspects of the commodity chain like design, fabrication, logistics, sales, as well as the spaces of production and consumption such as offices, factories, high streets and homes (Bryson et al. 2017; Busch et al. 2021) and their geographies. For example:

> '3D printing – the ability to translate a digital file into a physical object – has already generated a huge amount of excitement and hype, much of it justified. Its implications for the future of manufacturing, for jobs and for economic geography are immense" '
> (Sissons and Thompson 2012: 6)

Given that 3D printing has the potential to be so disruptive, and it is the most cited example of technological innovation in material production it has been selected as the empirical case for this inquiry on sectoral diversification of post-industrial urban economies involving goods production. The next section presents the specific post-industrial urban context where the case study of 3D printing is investigated: in London.

1.4 Post-industrial Urban Context: London

Acknowledging that the location of activities related to new manufacturing technologies is expected to be mostly urban (Busch et al. 2021), this research locates the technology-led case study for analysing the resurgence of technologically led urban manufacturing in the post-industrial context of London.

It has been widespread practice in economic geography to gather evidence of industrial change with a specific case study set in a specific city or region to explain processes and dynamics of post-industrialism, as my research does[10]. In these analysis, the prevalent view is that space has agency in shaping socio-economic processes (Pike et al. 2007) and thus it is not just a receptacle for or a manifestation of economic growth and development (Scott and Storper 2003). Therefore, the notion that 'space is an integral constituent of economic, social, ecological, political and cultural relations and processes and their geographies condition and shape in profound ways how such processes develop' (Harvey 1982 and Markusen 1987, reviewed in Pike et al. 2007: 1258) means that choosing London as a relevant context to analyse 3D printing activities requires consideration of its manufacturing legacy, its current urban economy, its positioning in relation to other cities in the country, in Europe and globally, plus its high-value land. I will elaborate on these now.

London has a complex history of driving industrialisation, visible in much of its architectural and urban design heritage, as Hall (1962) notes:

> 'the Greater London Plan of 1944 could describe London '*now* the country's most important manufacturing centre' following phenomenal increase in . . . industrialisation' since 1918. (Abercrombie, L.P. 1945, cited in Hall 1962: 10) In fact London was the chief manufacturing centre of the country in 1861, and without doubt for centuries before that. The industries which contributed to this importance gave mid-Victorian London a clearly defined manufacturing structure, even though this structure was much more complex than that of Lancashire or the West Riding' (Hall 1962: 10).

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[10] See Cohen and Zysman (1987) on automobile and heavy industries in the US and Japan; Storper (1992, 1995 and 1997), Hall and Markusen (1985) and Rigby and Essletzbichler (1997) on new technology firms and districts in the US (Californian cities and Boston) and in London; Florida (2002), Storper (1989), Scott (2000) and Zukin (2010) on creative industries in the US and London; and Boschma and Iammarino (2009) on Italian leather industries and Dutch industrial quarters. All will be mentioned in the literature review chapter.

But, having been a leading manufacturing city, London is now a financial, services, insurance and real estate centre (Prothero 2007), as well as a place where creative and cultural industries flourish (Pratt 2009b). London, where most recent production output is abstract, has been characterised by a decline of most manufacturing and traditional industries of material production (Hamnett 2004; Pratt 2009b), and by the rise of services, financial, creative and knowledge production outputs (Prothero 2007; Hamnett 2004; Tym and Lang LaSalle 2011; Scott 2007 and 2008). It is thus a suitable post-industrial context (Hamnett and Whitelegg 2007) to investigate the possibility of resurgence of material production in post-industrialism, and its contribution to growth through innovation and sectoral diversification (Montgomery 1994; Frenken et al. 2007; Frenken and Boschma 2007; Boschma and Frenken 2011).

Setting the research in London also means setting the study within a strong technological and geographical *centre*, a growth pole of firms and industries (Perroux 1955; Darwent 1969) at both the national and international levels[11]. Nationally, London is a centre of growth in a very imbalanced country (Martin et al. 2015) and a primary European growth centre (Hamnett 2004). Further, London is also a global city, a term established by Sassen (2000) to refer to those cities in which control of transnational manufacturing and the global financial system rests, where cultural production influence extends beyond the national systems and where services and products are sold worldwide.

Given those characteristics, London is a high value real estate location for the residential and office sectors[12], which is a key consideration in the analysis of the locational dynamics of innovation related to 3D printing technology. Holland (1976)

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11 Although Perroux (1955) applied his growth pole theory to firms and industries only, the concept has been widely applied to the development of regions (Myrdal 1957; Holland 1976; Hirschman 1958, Darwent 1969), and in this mention I refer to both applications considering that the study is set in London.

12 According to the evidence base for the Mayor's Housing Strategy, 'average house prices in London are six times their 1970 level, after adjusting for inflation' (Cosh and Gleeson 2019: 34), and according to Statista Research Department 'The cost of rent for office space in London is the highest in Europe. In the first quarter of 2020, the West End had average rents per square foot of 112.5 British pounds. The average annual rent in London for prime office space was more than 550 euros per square foot annually than second place Paris' (Statista Research Department 2020).

highlighted that the problem of firm location is a process of uneven competition involving space itself, institutions, plus firm and industry dynamics, beyond the equilibrium suggested by neo-classical theory (Marshall 1890). As London experiences an acute lack of space for small industries and competition from other land uses such as employment, residential and transportation increase, London is said to be 'losing an average of 88 hectares of industrial land every year and the need for housing will increase pressure further' (Brown 2015: paragraph 6). Additionally, there are planning restrictions and local opposition to new industries involving material production, which have been documented and have been discussed in the literature (Ferm 2011; Giloth 2012; Caruso et al. 2015). All these restrictions condition how new activities working with the technology of 3D printing are spatially inter-related with the established economic sectors.

London's characteristics - its industrial history, its economic dynamics typical of post-industrialism, plus its central geographic and technological position driving high land values - are thus essential to this study in urban manufacturing renaissance in post-industrialism because of how a place influences the types of innovation that will flourish there (Boschma and Frenken 2011; Neffke et al. 2017; Florida et al. 2017). Below I set out my research questions.

1.5 The Research Questions

This research investigates the conjecture around addressing challenges of post-industrialism through a diversification strategy involving economic activities with material outputs in urban economies, enabled by new fabrication technologies such as 3D printing. Policymakers are proposing this, in ways that bring into question the current sequences and geographies of production like global value chains and de-industrialisation.

Three research questions have been designed to guide this study, as follows, and they will bear a direct relationship to the empirical chapters of this dissertation:

1. *What activities have emerged in London associated with 3D printing?*
2. *How is the location of the emergent activities associated with 3D printing related to the urban context of London and its agglomeration economies?*

3. *How has the process of adoption of 3D printing technology contributed to innovation in activities across different sectors in London, and what advantage is it creating in this context?*

These questions have been defined to provide evidence-based conclusions about the nature, spatial implications and consequences of the adoption of a potentially disruptive new technology in economic activities of an urban post-industrial region. The first question is an enquiry into what types of production are developing around the fabrication technology of 3D printing to establish if they are diversifying the local economy. The second question concerns how places shape and are shaped by the innovative activities linked to new fabrication technology to understand why innovation presently is arising where it does. And the third question is an interrogation of whether material production technology is triggering growth through innovation in this post-industrial urban context and how exactly.

The case study of 3D printing related activities in London will be analysed along three lines of empirical enquiry relating directly to the three questions above. Each forms an empirical chapter, which presents findings relating to this thesis's arguments, as follows:

- **Characterisation of Activities** which emerged in London associated with 3D printing technology (Chapter Five) focuses on understanding what are these activities and what work is done, providing findings on size, types of work, employment composition and clients. In understanding what the activities are, it can be assessed whether there is any degree of diversification in relation to the dominant sectors in a post-industrial city such as London.
- **Location of Activities** (Chapter Six) is an analysis of the locational trends of the activities, including the places where activities related to 3D printing are situated and the types and sizes of premises they occupy. The reasons why they are, first, exactly where they are in London, and, second, why they are located in London and not elsewhere presents an understanding of the relationship between location, type of innovation and phase of production.
- **Growth and Competitive Advantages** (Chapter Seven) is an analysis of findings into how the 3D printing technology supports the creation of

new knowledge and innovation which bring growth and competitive advantages to a post-industrial context like London. It focuses on how the technology is suitable for early-stage production activities which thrive in this type of context, on the inception and above average performance of the businesses so far, and on the collaborative practices and culture associated with this particular technology.

The next section will elaborate on the wider contribution of this research in relation to existing literature.

1.6 Contribution of this Research

This research is an inquiry into how a new fabrication technology, said to be disruptive (Anderson 2013; Barnatt 2014; De Propris and Bailey 2020), can create innovation and contribute to the creation of value in post-industrial urban economies where most material production has been lost. And, on what role this post-industrial urban space – its production culture and its agglomeration attributes – plays in this process of adopting new productive technologies into complex and networked production chains marked by spatial divisions. The theme of this research thus brings to the attention of economic geography the study of these technologies and their production implications, which have received more attention from other disciplinary points of view (material engineering, management, economics) and have only recently been the focus of geographic research.

Transformations in production and production spaces triggered by the new fabrication technologies remain largely unstudied as recognised by Gress and Kalafsky (2015), Johns (2020) and Liao et al. (2017) who reflect on extensive research agendas needed around these technologies, such as case studies and theoretical framing of implications for geographies of production, to guide policy. Laffi and Boschma (2021) go as far as acknowledging that even with public and specialist interest, and being explicitly mentioned in industrial and urban policies, '…the Fourth Industrial Revolution is attracting full attention, [but] its geography and local determinants are still barely investigated' (Laffi and Boschma 2021:2). Even in the year this thesis is being finalised, Johns (2022) writes that 'the contemporary focus [in fabrication manufacturing technologies] of policymakers and national governments is explained by their understandings of the potential of AM (Additive manufacturing) rather than a realistic assessment of the capabilities of AM' (Johns 2022: 51), to which can be added a lack of understanding of its economic and geographic consequences.

A substantial portion of the existing literature which has influenced policymaking focuses on ambitious possibilities for relocating production in post-industrial regions with new technologies of advanced manufacturing (Johns 2020; Bryson and Clark 2013; De Propris and Bailey 2020), but without the support of case study-based evidence. Some of these (Marsh 2012) bring up examples of large industries located in hinterlands which have adopted 3D printing technology in their production lines as a basis for promoting the growth of smaller industrial units, even home-based units (Jakob 2017) in cities, or the return of manufacturing more generally to post-industrial cities (Nawratek 2017; Cities of Making 2018; Jakob 2017; Caruso et al. 2015; Sissons and Thompson 2012). Other scholars have suggested profound implications for the future post-industrial geographies of production (Gress and Kalafsky 2015; Johns 2020) such as transformations in inter-firm, regional and producer-consumer-relationships (Bryson et al. 2013; Lowe and Vinodrai 2020; De Propris and Bailey 2020) stemming from the new manufacturing technologies. Despite the lack of case studies, the projected transformations and competitive advantages from the technology have been supporting policy directions promoting adoption of advanced manufacturing (see Santos et al. 2017 for a summary of those across Europe). But even reports shaping policy have acknowledged the significant gap in evidence in the subject of urban manufacturing renaissance with new fabrication technologies (Cities of Making 2018; Sissons and Thompson 2012).

Economic geography literature has focused on the evolutionary processes of innovation in recent post-industrialism (Florida et al.2017; Neffke et al. 2011; Duranton and Puga 2001; Crescenzi et al. 2020) with cases centered around information and communication technologies, creative industries and / or manufacturing industries, but without yet addressing innovation relating specifically to material production. These studies have progressed our understanding of the dynamics of innovation at localised and regional levels, but there is no common view on the micro foundations of agglomerated innovation in the present time in relation to the new fabrication technologies. Gress and Kalafsky (2015) argued that economic geographers ought to research these new manufacturing technologies, 'not to miss the boat', so that 'geographers should position themselves to contribute both qualitative and quantitative studies of this industry' (Gress and Kalafsky 2015: 50).

As this thesis is being finalised the first few empirical cases from the discipline have been published. One of these is Laffi and Boschma's (2021) who look at the role played by regional knowledge bases in the adoption of new manufacturing technologies across industrial regions in Europe. They find that regions with a strong knowledge base in information technologies are more swiftly adopting new manufacturing technologies, pointing to a path dependency across those sectors. The other study is Busch et al. (2021) who analyse how new manufacturing technologies are creating value specifically in urban contexts with case studies from German cities. They find that digital urban production integrates design and fabrication, and that in urban contexts they derive value from the proximity to the markets, employees and knowledge, outweighing the flexibility allowed by the digital fabrication technologies.

Considering the importance of the new fabrication technologies, what we know so far, and how much there is to be investigated, the main contribution of my study is thus twofold: empirical and theoretical. There is an empirical contribution to address the gap in case studies, with the chosen case of activities emerging in connection with 3D printing technology in London. Only with case studies like this can the discipline of economic geography advance arguments about the nature of economic transformations arising from new manufacturing technologies and provide support to policymakers. This study is therefore contributing to the analysis of one specific technology (3D printing) within the wide range of new technologies from a geographic perspective. It addresses 'the lack of holistic understanding of the spatial implications of the fourth industrial revolution. So far, we know little about the spatial embedding of industry 4.0 related technologies, path development, the knowledge creation and learning processes during innovation and adaptation of regional economies' (Fraske 2022: 1).

Regarding the theoretical contribution, this research expands understanding of economic progression as a process of integrating breakthrough technology with the region's activities and their incremental development which is particularly relevant in the context of the new emerging fabrication technologies. Theoretically, this means that new technologies do not render path dependency theories useless in face of a new technological breakthrough. The locality where experimenting with a new technology takes place appears to influence the type of innovation outcomes and the ways the technology benefits are used. The local institutions, local culture, and people's networks function both set the tone and establish the usefulness of the experimentation and function as a safety net to counter the risky effects of radical methods of work and need for funding. Further to this, as the technology helps in generating new yet locally related activities, it is contributing to the creation of an agglomeration of related diversity, a concept developed by Henning and Boschma (2011) in which a level of relationship amongst different agglomerated activities, employees or co-located sectors is argued to be fruitful for knowledge diffusion, leading to more innovation and growth.

This research's theoretical contribution extends the theoretical strands of path dependency and clusters literatures in economic geography, contributing to explaining and assessing the processes of industrial development and growth across space. The findings from this research also bridge literature on urban manufacturing renaissance, which is overwhelmingly not from an economic geography perspective, and scholarly approaches from within the discipline focussed on processes of knowledge transfer and innovation as mechanisms for growth in post-industrial contexts. It can be said that the conclusions from analysis of this case study of new manufacturing technologies introduces a disruptive component (the innovative technology) into the evolutionary narrative of economic progression and growth.

As this research is presented at a point in time when technological innovations in material production are becoming significant, the findings are necessary to policymaking, particularly to London. As noted by Crescenzi et al. (2020), 'one of the most difficult questions for geography, economics and development studies is to identify why innovative agglomerations arise and flourish where they do; and yet this is understandably of greatest interest to policymakers. This question takes us from the general factors that lie behind the agglomeration of innovation to the specific geographies of those agglomerations...' (Crescenzi et al. 2020: 22). It is with this in mind that this research offers results which are meaningful to London. Other cities – and post-industrial urban spaces – may find parallels with London and benefit from these findings, or, on the contrary, they may find that specific studies in their locations are also required before following policy fashions. With the evidence gathered, the intention is that policymakers will be better equipped to design their policy instruments to address the reality of innovative practices around 3D printing technology and create policies that are effective in supporting it in ways that can contribute to growth. This is, in the London context, as findings suggest, not in relation to an urban manufacturing revival but in relation to extending and strengthening established post-industrial creative and knowledge industries.

1.7 Structure of the Thesis

This thesis has seven chapters. This current chapter has introduced the proposition of innovation using new manufacturing technologies in post-industrialism, set out my research questions and introduced the 3D printing technology case study, as well as outlined the contribution that this research aims to make to the discipline.

In Chapter Two I present a review of literature centred on the topics of Fourth Industrial Revolution and Industry 4.0. I synthesize scholarly and non-scholarly theories of the impacts and transformation to production, economics and employment resulting from digital technologies of production.

In **Chapter Three** I present a review of several literatures relevant to the topics incorporated in this research. It begins with the presentation of theories and debates relating production changes and new technologies to the evolution of industrial capitalism. It centres particularly on post-industrial transformations such as de-industrialisation and the emergence of new types of industries (such as creative industries), as well as on the recent literature discussing manufacturing revival enabled by many kinds of new technologies and the resulting transformations. This is followed by a review of literature focusing on theories of industrial location. A concluding section presents research findings and perspectives regarding how the economies of cities and regions grow through innovation and knowledge transfer.

In **Chapter Four** I present the research methodology, including a reflection on how the research objectives have been translated into a horizontal, cross-sector, research design and explain my mixed methods approach. There is a correspondence between each research question and the different methods used, and this is described in detail. The chapter also explains how the database of entities of activities which emerged in London associated with 3D printing was created, and how the detailed case studies of enterprises were thereafter selected. In this chapter a map illustrates the locational boundaries of the study in London and this location choice is justified, plus there is a detailed description of the use of the various methods. Lastly, there is a reflection on how these methods and this study are situated in relation to other industrial studies and traditional methods for research in economic geography.

The three empirical chapters respectively focus on characterizing the activities (Chapter Five), locating the activities (Chapter Six) and understanding the processes in adopting 3D printing technology (Chapter Seven). These chapters relate directly to my three research questions.

Chapter Five presents the data and findings relating to the activities that have emerged in London associated with 3D printing. It includes findings and an analysis of what activities there are and within which sectors, the tasks and types of work conducted, and the people involved (founders, owners, employees, clients). It also presents findings about the activities' networks with clients, other firms, and other institutions. The evidence presented in this chapter supports my first argument that the role of innovative fabrication technology in post-industrialism is to support abstract tasks, work processes and outputs of creative and knowledge sectors.

Chapter Six focuses on locational aspects of the activities in the study, particularly on how the location of the emergent activities associated with 3D printing is related to the urban context of London and its agglomeration economies. This chapter has four parts. First, it presents and examines my findings about where the activities are in London, and secondly describes the types of premises they occupy. Third, the reasons why they are in those locations and not elsewhere is explored, and, fourth, the relationships with other locations beyond London are considered. Findings in this chapter provide evidence for my second claim, which is that technology alone does not change the geography of production and innovation as we know it in post-Fordism.. Activities were found to be very centrally located due to the benefits they derived from other related activities, because of the need to attract the right people and funding and also to be well connected, in the same way that other creative, knowledge, digital and scientific economic activities justify their central location in London.

Chapter Seven presents the evidence related to how the process of 3D printing adoption contributes to economic growth and competitive advantages in the London context. I analyse findings about 3D printing technology application in relation to early product development tasks which are successful within London, then document the evolution of the businesses in study including how they were founded and their funding strategies, noting their positive overall performance. The chapter also presents evidence about a major aspect of the technology adoption process I observed – the collaborative practices which helped people innovate. With these findings, I argue that despite evidence of fabrication technology not increasing manufacturing activities in London this technology can bring growth and add value through innovation. The technology triggers activities working on initial stages of products within knowledge and creative sectors - activities which are typical of a London context and with which new activities are related. Advantages for the local economy arise because new activities perform above average for creative industries, and because the adoption of a technology progresses as collaborative practices are facilitated by the agglomerated London context and its concentration of businesses and people.

Chapter Eight is the conclusion where the findings are summarised to demonstrate the study's theoretical contribution to understanding of the economic progression of post-industrialism and the influence of new fabrication technologies in the locally dependent process of innovation. This chapter includes reflections on key findings relating to each of the three questions and a synthesis of the conclusions in relation to relevant literature. It also presents my reflections on why this research matters and its originality, plus a brief consideration of future research streams which this work opens up.

Chapter Two

The Fourth Industrial Revolution or Industry 4.0

Industry 4.0, the Internet-of-Things (IoT), big data, artificial intelligence (AI) and cloud computing. These are few among other terms in vogue that are ubiquitous throughout general newspapers, on company websites or in scientific journals. The terms represent a number of concepts, tools and methods with the ability to change the modern society and industry radically. (Osterrieder et al. 2020: 107476)

2.1 Introduction

Following the introduction to this thesis, this chapter presents a literature review of the works published around the themes of the Fourth Industrial Revolution and Industry 4.0 (its most recent designation), plus the associated ideas of manufacturing renaissance, smart factory and re-shoring. Most literature reviewed is very recent, and it is a mix of scholarly and non-scholarly documents, as only recently these themes became of interest to the academic community (and the number of scholarly publications has grown exponentially in the last couple of years). However, it has been popular in other media for longer.

This literature review sets a background to the thread argument of this thesis - reading the multiple technological innovations (including for material production) and their effects not as a revolution but as incremental changes within post-industrialism's knowledge and informational mode of growth and accumulation.

The chapter first presents the method, approach and material sources used for this literature review (section 2.2), which is a combination of a systematic selection of scholarly articles with very recent publication dates obtained through a database, with other 'grey' documentation of diverse provenience assembled during this research.

Subsequently, the chapter presents the literature contents analysed in four sections. First, there is a summary of the definitions and characterisations of Industry

4.0 (section 2.3), followed by the key concepts related to the technologies of Industry 4.0 (section 2.4). These two sections are more introductory than the ones that follow but essential to understanding the literature contents reviewed. I have then divided the summary of the literature findings into two parts: one part presents future scenarios of transformation across all spheres of development (production, employment and jobs, economics and growth, environment and sustainability), which will possibly occur with Industry 4.0 (section 2.5); the other part centres on location matters and summarises literature perspectives on where new manufacturing renaissance activities would be located - in homes, on highstreets, in offices, in newly created hubs, etc. – and literature theorising and exploring re-shoring of production to western economies as an outcome from the digitalisation of production (section 2.6).

The conclusions (section 2.7) highlight most publications' abstract and speculative nature, the contradictory points of view and the rising interest and exponential growth of scholarly production in Industry 4.0. It notes the significant lack of empirical evidence supporting theories for transforming all spheres of socio-economic development and the emergence of new geographies of production and value chains. It also summarises avenues for research in the field, which have been proposed in some documents reviewed.

2.2 Method, Approach and Material Collection

This literature review was carried out in 2023 (near the submission of the thesis) to provide a source of scholarly and non-scholarly work to enable the final thesis conclusion to better engage with Industry 4.0 literature and their associated concepts of a manufacturing renaissance, smart factory and re-shoring.

The approach followed in this review is based on a 'methodology that locates existing studies, selects and evaluates contributions, analyses and synthesises data, and reports the evidence in such a way that allows reasonably clear conclusions to be reached about what is and is not known' (Denyer and Tranfield 2009: 671). Accordingly, I followed a simple three steps approach to this review: first, material collection, then data analysis and last, contents synthesis, which is commonly accepted as a rigorous methodology for literature review and which is well used in social sciences (see, for example, Wiesmann et al. (2017)).

The review has two sources of documents: one is exclusively academic, very recent, and it was obtained through a systematic selection in a database; the other was obtained throughout the research and thesis preparation over a decade and includes a mix of scholarly (some non-peer reviewed) and non-scholarly articles - also of distinguished provenience such as the Economist, etc.

For this thesis, the critical aspect of this literature review was to build a holistic view of Industry 4.0 and identify its theorisation and main concepts, implications, and current research outcomes or gaps, thus combining these sources was considered appropriate given the novelty of the subject. This approach increases the quality of this analysis and limits pre-disposition to documents of scholarly origin in a theme widely discussed in other sources and with which I engaged during the research, particularly in its beginning when scholarly production was unavailable.

For the selection of the first group of documents, the recent scholarly articles, I used "Elsevier Scopus" because it is a peer-reviewed database in the relevant fields for this theme - social sciences, management and business (see the systematic literature review by Liao et al. (2017), which concludes that most works in this fields are from engineering, materials, computer science, and only a tiny faction from the social sciences). The search was carried out for documents with 'Article title', 'Abstract' or 'Keywords' containing the expressions "Manufacturing Renaissance", "Industry 4.0", and "Smart Factory". These were chosen because they convey slightly different but still overlapping terms, which I have commonly found in the publications gathered during the research years. This way, I ensured the peer-reviewed scholarly articles were on the same subject as the cluster of documentation I already had.

All three database searches were done for articles published from 2015 up to 2023, and the subject areas selected were: Business, Management and Accounting; Economics, Econometrics and Finance; and Social Sciences, which is an extensive range to ensure the most relevant angles relating to the theme of my research were captured in this review[13]. Documents selected for this review were only those published in

[13] According to other literature reviews (see Chiarvesio 2019 and Liao et al. 2017), the subject of Industry 4.0 has been subject to scholarly work recently in fields as diverse as computer science, engineering, and (although with less publications) business, management and accounting, including the specific business sub-fields of operations and supply chain management, production management and logistics. I note that there are not many publications from the social sciences areas yet, let alone Geography.

English and included four key document types: articles, conference papers, book chapters and books. Under these criteria, the search on "Manufacturing Renaissance" returned nine documents, the search on "Industry 4.0" returned 5,813 documents, and the search on "Smart Factory" returned 491 documents.

Given the large number turned by the search for the last two themes, which would have rendered this task impossible, I decided to rely on systematic literature reviews already published on those expressions[14]. For the search expression 'Industry 4.0' there were 30 documents found in the database when results were filtered for 'literature review' keyword only, and the most recent was dated from 2023. Following the same process, for the search expression 'Smart Factory' there were eight results returned when documents were filtered for the keyword 'literature review', and the most recent was also dated from 2023.

The last step was to read the abstracts to ensure that only papers relevant to this research's framing were reviewed. This excluded papers focused on too specific and niche themes as diverse as manufacturing renaissance in specific regions - such as developing countries, Quebec or Poland-; oil industries; corporate social responsibilities; applications for smart manufacturing; warehousing, which does not fall within this thesis' remit. And, following this last step of material selection, the total was composed of seven results from 'Manufacturing Renaissance', fifteen systematic literature reviews from "Industry 4.0", and three systematic literature reviews from "Smart Factory". This selection process led to 25 documents across the three searches, giving a fair overview of the existing theoretical/ conceptual approaches, empirical research and modelling on the subjects relating to this thesis. It was significant that most papers are very recent and that there has been a sharp increase in scholarly production on these subjects in the last three years.

The second group of documents, obtained over the years working on this research, comprises a mix of single-authored or edited books, niche academic publications or non-peer-reviewed academic publications, key papers in the geography field (peer-reviewed), think tank publications and media articles. These documents were published between 2011 and 2022 and are in total 39. The combined review presented in the following sections thus covered 64 documents in total.

[14] There were no literature reviews returned on the search for "Manufacturing Renaissance".

The limitation of this literature review is the subjectivity of some of the choices in the selection of documents, particularly of the second group of documents assembled in a non-systematic and arguably irreproducible way over the years, and of leaving aside papers in the first group which focused on too narrow subjects, potentially missing lateral subjects which is, however, a common problem in literature reviews. However, it provides, I believe, a good account of the works and the theories around Industry 4.0 and the Fourth Industrial Revolution as they stand at the time of this thesis submission across the most relevant fields of study.

2.3 Industry 4.0

Authors have recently identified a new possible phase in production – a new Kondratieff wave – associated with new intelligent manufacturing technologies. This phase has received many designations, such as the New Industrial Revolution (Marsh 2012; BIS 2017; Brown 2015; Anderson 2013; Barnatt 2014), Third Industrial Revolution (Sissons and Thompson 2012; Rifkin 2011 and 2016; Rothkopf 2012; Bryson et al. 2017, The Economist 2012), Fourth Industrial Revolution (Baldwin 2016), simply re-industrialisation (Edwards and Taylor 2017), or the more recent and now accepted term Industry 4.0 (Cities of Making 2018; Liao et al. 2017; Laffi and Boschma 2021; Johns 2020 and 2021; Santos et al. 2017; Busch et al. 2021; De Propris and Bailey 2020; Fraske 2022).

Industry 4.0 emerges as a possible solution to overcome de-industrialisation issues such as regional imbalances (Martin et al. 2015), social disparities between high and low-wage labour (Scott 2007; Kersley and Shaheen 2014; Sissons 2011b; Massey 2007), the reduction of the middle-skill range of occupations (Hackett et al. 2012; Sissons 2011a), and the lack of economic diversification in regional economic portfolios (Boschma and Martin 2007; Martin 2012; Bellandi et al. 2020). Routes out of these problems involve theoretical propositions for the resurgence of manufacturing in de-industrialised regions with new technologies such as 3D printing and many others (Sissons 2011a; Sissons and Thompson 2012; The Economist 2012; BIS 2012; Thomas 2019; Anderson 2013; Barnatt 2014; De Propris and Bailey 2020; Liao et al. 2017; Laffi and Boschma 2021; Johns 2020 and 2022; Santos et al. 2017; Busch et al. 2021; Kumar and Lee 2022), combinations of the new technologies and craft production (Bryson et al. 2017;

Nawratek 2017; Marsh 2012), or even a ‘new convergence of communication and energy’(Rifkin 2011: 2).

The debate and research on Industry 4.0 are frequently linked to the decline of traditional manufacturing and the loss of skilled jobs in economically advanced regions (Bellandi et al. 2020), which has seen those regions’ prospects decline (Cohen et al. 2018). The literature points to Western regions’ loss of control over value chains and material productive capability (Bellandi et al. 2020). The issue has become highly politicised, as seen in the election debates in the US, the Brexit debate in Britain (Cohen et al. 2018) and the Levelling Up Bill, where manufacturing renaissance has been brought to the attention of the public (Mosconi 2015), in regions which were once prosperous and now experience decline. Due to new digital technologies, economics are changing, and two different styles of capitalism –paper capitalism and manufacturing capitalism - are confronted with technological possibilities (Mosconi 2015), particularly the increase in demand for faster delivery times, higher quality and customised products as drivers for digital manufacturing expansion (Zheng et al. 2020).

The chronological and geographical start of this possible new paradigm of development associated with new fabrication technologies is unclear in the literature. Some perspectives focus on the crisis resulting from excessive de-industrialisation, in particular after the Lehman Brothers bankruptcy in 2008 and how it triggered a global recession (Rothkopf 2012, Nawratek 2017, The Economist 2012), seeing it as a turning point when markets began distrusting globalisation (De Propris and Bailey 2020) and turning to local production. Other authors describe the reasons for its beginning in association with the spread of new technologies of manufacturing (Sissons and Thompson 2012; Baldwin 2016; Thomas 2019), and others centre on the development of new green energy sources (Rifkin 2011; Cities of Making 2018).

Scholarly literature points to the growing debate in academic circles about the possible fourth industrial revolution due to new digital production technologies (Zheng et al. 2020) and how it became a growing field of research publication (Lemstra and Mesquita 2023; Stojanovic 2022). Although no consensus exists yet on what defines this fourth industrial revolution (Wanner et al. 2023), Osterrieder et al. (2020) noted that Industry 4.0 was a term initially used in Germany to encompass the digitisation of manufacturing, including products and processes, also known as Smart Manufacturing in the US. Agrawal et al. (2021) defined Industry 4.0 as ‘real-time, intelligent and digital networking of people, equipment and objects for the management of business processes and value-creating networks' (Agrawal et al. 2021: 560). Some scholars go further, drawing a parallel between Industry 4.0 and the historic industrial revolutions, and even pinpointing an exact date when, purportedly, the fourth industrial revolution started:

> 'the fourth industrial revolution or Industry 4.0 emerged in 2011, launched at the Hanover Fair, as part of a high-tech programme by the German government to enhance the competitiveness of German companies based on three pillars: the Internet of Things (IoT), cyber physical systems (CPS) and the Internet of Services (IoS).' (Satyro et al. 2023:2161; and also Govindan et al. 2022)

Nevertheless, Stojanovic (2022) notes instead that the digitalisation of business processes and manufacturing started before the term Industry 4.0 was used, and that papers from 2008 and 2009 already focused on management strategies and engineering using new technologies and even used the term 'smart factory'.

Industry 4.0 can be described as the growth of digital technologies in manufacturing, transforming factories, services, distribution, and management. In a digitised and smart world, data will be shared between products and manufacturing. Production will be coordinated and 'made up of agents that interact intelligently and with decentralised processes control' (Lemstra and Mesquita 2023: 122204). Rad et al. (2022) quote Sjodin et al. (2021) to point out that the outcomes of the digital transformation of producing industries may be an increase in the value of their services associated with products, and Prause and Atari (2017) describe how with Industry 4.0 technologies manufacturing firms will be able to connect to entirely digitised and smart value chains, and in doing so, they will be more flexible to adapt to changing business environments. However, others refer to Industry 4.0 as more encompassing, defining the term as the new socio-technical paradigm where information technology is integrated with production automation technology (de Paula Ferreira et al. 2020). Both approaches suggest that the digitisation of industries will change the entire value chain.

Described as a new industrial age, Industry 4.0 is compared to other industrial revolutions (Wanner et al. 2023; Kumar and Lee 2022; Stojanovic 2022; Govindan et al. 2022) and named a new industrial age already in progression (Liu et al. 2021) as digital technology changes, according to the literature, the way products are made, sold, delivered and consumed. Digital technologies spread to innovative and traditional sectors, potentially changing everything in the supply chains, including procurement, manufacturing, logistics and warehousing (Govindan et al. 2022). There is a tendency to associate the technological possibilities with today's significant global challenges (Stojanovic 2022), as changes in value creation, companies' processes and activities are described in the literature, primarily from engineering and management sources (Ancillai et al. 2023), and much less from social sciences. Studies on the changing relationship between machines and humans in factories come from foresight and technological forecasting fields, particularly tackling the concept of 'smart factory' (see Kumar and Lee 2022 for a review of the emerging smart factory functions, tasks and human-computer interfaces), a characteristic element of the fourth industrial revolution way of manufacturing, with employment, jobs and social implications (Grybauskas et al. 2022).

Nearly all literature reviewed links the availability of manufacturing technology with the renaissance of manufacturing in Western economically advanced regions (Bellandi et al. 2020; Chiarvesio and Romanello 2019) and with companies choosing to locate their standard production in developed economies from the outset (Tavassoli et al. 2015). In sum, whether defined in a strictly managerial and technological way or in a broader sense, Industry 4.0 is seen as disrupting the present value chains and subsequently shaping a new economic, environmental and social paradigm (Grybauskas et al. 2022). Below I synthesise the most important fundamental concepts associated with Industry 4.0.

2.4 Key Concepts and Technologies of Industry 4.0

The proliferation of eye-catching terms such as Smart Manufacturing or Smart Factory, Digital Technology (DT), Cyber-Physical Systems (CPS), Internet of Things (IoT) and Internet of Services (IoS) is significant in the literature (Zheng et al. 2020), as well as lists of technologies and processes associated with Industry 4.0 (see Govindan et al. 2022; Stojanovic 2022 and Satyro et al. 2023).

Digital technology (or DT) is more recently used to allude to all sorts of technologies related to Industry 4.0. However, as a rapidly evolving field, there is no single definition and no consensus on what technologies are part of this, and it is not easy to know all it includes (Ancillai 2023). In undertaking literature reviews, one finds itself trailing behind more recent articles which expand further the concepts. There is a reference to 3D printing, sensors, intelligent machines, mass customised products, data communication technology, robotisation of production, digital twins (DT), cloud technologies or cloud manufacturing, automated manufacturing, home automation, reconfigurable manufacturing systems, smart waste management in the context of circular economy, blockchain, machine learning and reasoning, etc. (Saporiti et al. 2020; Liu et al. 2021; Wanner et al. 2023; Agrawal et al. 2021; Lemstra and Mesquita 2023; Govindan et al. 2022; Stojanovic 2022 ; Satyro et al. 2023). These are all innovative technologies part of the Industry 4.0 paradigm of industrial development, and there is a proliferation of papers focusing on one or a few of these innovations or on sustainability and circular economy-related innovations. In this review, I will not dwell in detail on each of those innovations, technologies or applications, as the interest is on the theorisations and the case of this research is only 3D printing.

Smart factory (or smart manufacturing or factory of the future (Zheng et al. 2020)) is one of the critical concepts of Industry 4.0 presented as a significant technological change within the new paradigm of industrial development. Osterrieder et al. defined smart factory as 'envisaged as a future state of a fully connected manufacturing system, mainly operating without human force by generating, transferring, receiving and processing necessary data to conduct all required tasks for producing all kinds of goods' (Osterrieder et al. 2020: 107476). The idea of the factory of the future is often linked to a change from mass production to mass customisation (Tavassoli et al. 2015). Others refer to smart factories as encompassing all new technologies and processes of value chain organisation involving the IoT and CPS, which is production controlled digitally and intelligently in real-time, which defines the fourth industrial revolution itself (Wanner et al. 2023).

The concept of smart manufacturing evolved in literature from a factory where humans and production processes were helped by automation to a wholly digitalised factory. Most literature centred on smart factory concepts as a primary focus of research is from fields unconnected to this research, such as management of production and decision-making processes or software applications. The social sciences perspective is often about the transition from human to digital processes and organisational changes in the factory (Osterrieder et al. 2020). The most common technologies applied to manufacturing – the early stages of smart manufacturing - are, according to Zheng et al. (2020), more about the process, supply chain management and control of production than the production itself. Smart manufacturing relies on many technologies, such as computing, big data analysis, cybersecurity, additive manufacturing (or 3D printing), visualisation technologies with reality and virtual reality, simulation, and artificial intelligence (Wanner et al. 2023; Agrawal et al. 2021). In studying smart factories, Kumar and Lee (2022) distinguish between two fields of research: the systems (function, task and information) and the user interface and interaction. Their paper asked what functions, tasks and information are used in smart factories. They found four functions changed by digital technology in Industry 4.0: operation and supervision, management, maintenance service and cybersecurity. As the human-machine interface is critical to a smart factory operation, Kumar and Lee (2022) note that those can involve gaze, voice, tactile, gesture and haptic interactions or combinations. Interestingly, implementing those 'smart factory' systems requires extra training of personnel and employees of high cognitive and physical abilities to understand and handle the robotisation and automation demands. A new type of education will be needed to deliver smart factories, according to several authors reviewed in Grybauskas (2022), described by a newly emerging term, 'Education 4.0'.

The Internet of Things (IoT), or the digital information about products and their use which also enables smart manufacturing, is presented as a radical transformation of production due to connecting 'infrastructure, physical objects, human actors, machines and processes across organisational boundaries, enabling the fusion between physical and virtual world' (Zheng et al. 2020). With IoT, products can communicate with products, services, and manufacturers over the internet (Liu et al. 2021), which can generate services. A field of business analytics is emerging on this matter (as reviewed by Wanner et al. 2023).

These two innovations are becoming connected in recent literature, according to Zheng et al. (2020). IoT is crucial for the functioning of smart factories, as it provides real-time information for management and production (Kumar and Lee 2022). Moreover, literature is expanding these two concepts into the new ideas of the smart supply chain, also designated as 'servitization' (Lafuente et al. 2019), which is the expansion of information services on products that influence manufacturing, production management and supply chain decisions. This expansion of services may be where the value increase may become.

Following the review of Industry 4.0 and the critical concepts associated with this revolution, the next section will provide an account of the multiple theorisations around the future of production and the new technological paradigm found in the literature.

2.5 Future Scenarios

In appreciating the potential impacts and new models that may emerge as a consequence of digital manufacturing technologies, theories of future change abound, even if some acknowledge that firms are, in reality, struggling to harvest the advantages from digital technologies that scholars and others have been anticipating (Ancillai et al. 2023).

For many scholars, Industry 4.0 will profoundly alter value chains and production landscapes as we know them, including production and organisations (Liu et al. 2021), and growth opportunities are emerging from the new manufacturing technologies. This, it is argued, is changing value networks, business models, and business operations in manufacturing (Wanner et al. 2023). For example, Bellandi et al (2020) argue that this growth derives from the possibilities these technologies open up for small producers of small batches of personalised products located in advanced economies. Furthermore, they link this scenario with the changed geography of production to 'a more distributed manufacturing, whereby customers source or commission the making of products locally' (Bellandi et al. 2020: 55). To others, not just manufacturing but everyday life will be transformed by these digital technologies, as, we could be living in smart homes (Aheleroff et al. 2020 reviewed in Zheng et al. 2020), and small enterprises, located anywhere even in rural areas, can be selling their products and be part of the value chains with much-extended customer relationships (Perekwa et al. 2016).

Regarding the nature and changes in production, this (supposedly) new phase in industrial capitalism associated with new productive technologies has been described as production for mass personalisation (Marsh 2012), a step forward from mass customisation of, for example, just-in-time production of post-Fordism. Also called personal fabrication (Barnatt 2014), mass personalisation can be defined as the stage where objects can be tailored again to each consumer as in craft production but made in large quantities to serve the much larger population of the industrialised world. Each product can be unique, such as glasses tailored to each person's facial features, as technology allows.

Described as triggered by recent fabrication technology, such as 3D printing, CNC, 3D scanning, internet of things, and laser cutting (Rifkin 2011, Marsh 2012; Sissons 2011a; Sissons and Thompson 2012), this new phase of capitalism related to the re-industrialisation of western economies has been associated to significant changes in production geographies. These are the transformation of value chains as we know them because of industries re-shoring from low-cost countries back to advanced economies (Bryson et al 2013; Johns 2022), the emergence of new significant places of innovation linked to the flexibility of the technologies (Gress and Kalafsky 2015; Busch et al. 2021) and the re-shaping of value chains from global to regional scales (Johns 2021; De Propris and Bailey 2020).

The re-industrialisation phase has also been designated as 'customised capitalism' (Bryson et al. 2017: 111) a 'paradigm change' (Santos et al. 2017: 972), characterised by a type of production which can replace mass production with 'alternative means for the production of small, often customised products, as well as creative art' (Bryson et al. 2017: 111). This production process could involve a combination of intelligent automated and manual craft processes (Marsh 2012) or boutique manufacturing (Nawratek 2017), aided by the new fabrication technologies (such as 3D printing) as well as by information and design technologies such as CAD and parametric design tools. Furthermore, it means meeting the demand of nearly everyone finding precisely what they need, and when they need it, locally. In this phase, it has been argued, making and consumption can be brought together so that the maker can be closer to the final user or be even the final user him/ herself (Barnatt 2014).

Positive futuristic visions abound in literature (Johns 2020), from theoretical and hypothetical points of view, rather than being empirically driven. Some nostalgic views frame the need for re-industrialisation with new intelligent technologies in the Western world: 'It seems that developed countries are losing the ability to create their own history, not to mention to decide about the fate of the world' (Kurnicki 2017: 32). Conjectural views of the new industrial revolution sometimes present 'hopes of simply going back to where we once were, creating manufacturing jobs' (Rothkopf 2012: 87), as a response to the loss of manual labour in de-industrialisation, whereas other views acknowledge that some work has been superseded by technology and estimate more job creation opportunities in the roles of control of technological production (The Economist 2012).

Bryson et al. (2017), in their spatially driven perspective about the fourth industrial revolution in Britain, theorise that the change is about home-based manufacturing gaining momentum again, as well as workshops and studios, in reference to a return to the agrarian modes of production and its characteristically crafted production processes with production on-site, not separated from a dwelling or from other activities. But they see it as part of the new technological transformation, something designated as 'digital manufacturing' (Bryson et al 2017: 111), mixing up the descriptors of the new revolution: on the one hand, spatial and on the other technological.

In parallel with the more technologically-driven views, some propositions for production change towards re-industrialisation link technological innovation and the possible changes in production to changing urbanism (Baker 2017; Hatuka and Ben-Joseph 2022), to social outcomes and even to progressive political reform (Rifkin 2016; Edwards and Taylor 2017). Re-industrialisation is presented in the literature as an opportunity to address problems such as wage inequality (Kurnicki 2017), resilience and climate change adaptation (Rifkin 2016; Edwards and Taylor 2017), congestion, and gentrification (Nawratek 2017; Cities of Making 2018; Jakob 2017).

An ecologically driven perspective on the New Industrial Revolution, another angle of theorisation, is presented by Rifkin (2016) and by research funded by the European Commission (Cities of Making, 2018). In Rifkin's view, the new economic growth wave will be linked to smart green digital technologies driving sustainable development with social outcomes, such as employment opportunities, more equality, reversing climate change and a lasting collective ecological conscience. He argues that this revolution has started and refers to the recent Digital Europe Plan by the EU as an evidence-based high-level strategy document. Rifkin (2016) argues that the EU is laying the policy foundations for this new industrial revolution, which will have an effect not just in Europe but also across the world, including in developing nations. This revolution will involve the creation of 'a super Internet of Things infrastructure' (Rifkin 2016: 9), which will allow objects and people to be interconnected and to exchange information through the Internet. According to Rifkin's argument, democracy will expand further with the full exchange of information, and data analysis will provide the basis for increased productivity. As a result of this policy, Rifkin argues that European manufacturing businesses will be able to become more competitive again.

Further, with all information about objects freely available, Rifkin argues, marginal costs will decrease to close to nil, and a Sharing Economy will thus consolidate. In his perspective, which can be noted makes substantial unsupported and not evidence-based leaps, the digitalisation of information (Facebook, Youtube, iTunes) drove many traditional information industries out of business (newspapers, books, music), just as the digitisation of things now will drive many traditional goods and services industries out of business. In his words:

> 'The evolving Internet of Things will allow conventional businesses enterprises, as well as millions of prosumers, to make and distribute their own renewable energy, use driverless electric and fuel-cell vehicles in automated car-sharing services and manufacture an increasing array of 3-D printed physical products and other goods at very low marginal cost in the market exchange economy, or at near zero marginal cost in the Sharing Economy, just as they now do with information goods' (Rifkin 2016: 10)

Edwards and Taylor (2017) present re-industrialisation as possible and necessary for post-industrial regions due to various circumstances such as contraction of global economic activity, rising wages in low-cost countries, trade wars and nationalist policies and increase in transport costs due to fuel taxation or climate change restrictions. In their view, re-industrialisation will form part of a process of transformation of urbanism to a more progressive system, including humanising labour experiences and transforming labour relations and productive practices, redistributing wealth, and addressing – as per Rifkin's main point – the need for environmentally friendly production through local manufacturing. They also uphold that the revival of productive industries in post-industrialism is economically viable and could drive growth, as productive firms would benefit from other firms in agglomerated urban environments.

The work of some of these scholars theorising the nature of a possible re-industrialised period in Western capitalism has also highlighted that in a context of a manufacturing revival, new manufacturing technologies can develop transactional and knowledge links to the productive activities which are still present in post-industrial global cities (Baker 2017; Bryson et al. 2017), with mutual benefit.

Regarding the changes in jobs resulting from automation, some scholars present very negative perspectives on the disappearance of jobs and increased inequality

(Acemoglu and Restrepo 2018). In contrast, others suggest the emergence of many new highly skilled jobs and new professions, even in replacement of those which robots will do with benefits to society, comparable to the disappearance of jobs pre-industrial revolution (Perez-Perez et al. 2018; Grybauskas et al. 2022). Some suggested that the implications from Industry 4.0 for jobs – largely without empirical evidence as yet - will involve people being their bosses or working a combination of self-employment and employed functions, and people working from remote locations and even never meeting their colleagues or employers other than virtually, or just receiving tasks through apps (Starr-Glass 2019; Mpofu and Nicolaides 2019). Therefore, investment into education to form new skills to work within a new Industry 4.0 era will be needed, predominantly linked to engineering and information technologies (Motyl and Filippi 2020, reviewed in Lemstra and Mesquita 2023), nicknamed Education 4.0.

In most theorisations, Western de-industrialised nations must embrace Industry 4.0. It is suggested that the rise of mainly European nations will depend on embracing technological innovation and re-establishing productive manufacturing through a mix of market forces and state support (Mosconi 2015). In defence of the manufacturing renaissance, Mosconi states that it will increase productivity in the European regions and consequently raise living standards. However, it is suggested in his book that continuing on the trajectory of a services-based economy will not have the same long-term effect. He links the argument for a manufacturing renaissance to a changing model of capitalism, which relies on manufacturing production for growth. However, he acknowledges that a set of services such as finance, communications, and transport has registered exponential growth in the last decade, but he links it to manufacturing outside Europe or uses the cases of Germany and Italy, which have successful manufacturing, to support the theory. It is hard to see then why only with the reshoring of material production can those high-value generating services continue the same economic contribution, even when Mosconi states that the value is not on what you make, but on how it is made. Big statements like 'it is hard to see how without a solid manufacturing base can a modern economy succeed' (Mosconi 2015:5) are part of a thesis that, as others, also states that there is already a rebirth of manufacturing emerging (Wanner et al. 2023), but not backed by empirical cases, and often simplified into the promotion of manufacturing in many ways still akin to the one which has departed from western regions.

Based on the production changes that the recent technologies allow for, Bellandi et al. (2020) propose an alternative model of development with a manufacturing renaissance in advanced economies: small and local manufacturing units that will renew local manufacturing specialisms, bridge traditional sectoral boundaries and challenge the dominance of large tech corporations, whilst addressing social and environmental problems. Their alternative model is specifically designed for the remaining European productive sector. They go a long way to explain that an exploration phase of product creation is linked to a region's ability to combine tacit knowledge with codified knowledge which has been the post-Fordist success of many Western regions that retained material production, such as in Italy, for example. Thus, it is unclear why they use regions with manufacturing to argue for a manufacturing renaissance. Nevertheless, they note that this is followed by an exploitation phase of production where processes are reproduced, which tends to become repetitive and less innovative. So they state that successful SMEs can be quickly taken over or controlled by large tech firms located elsewhere as their production and associated management becomes more digital and relies less on the locality. Moreover, with it, they would see their margins reduced and lose the ability to innovate continuously. The ability to prevent this declining path depends on the strength of the local institutions, including publicly funded ones, and the key is to maintain the quality of production and highly skilled labour in the region. Their alternative model would be implemented with four governance structures: the local universities, pro-active regional governments, innovative SMEs and civic groups and their participatory actions. They see this being possible with Industry 4.0 technology, as it can develop professional, creative processes and highly personalised ways of producing and downscaling production. They argue that building local interdependencies between small manufacturing units is vital to avoid losing knowledge to other regions. This is the basis for the manufacturing renaissance in advanced regions. However, further to this, they suggest that the value of Industry 4.0 technology may be to be used in complementarity with professional and creative processes that meet customer demands and highly personalised services. Once again, it is hard to see how this means a manufacturing renaissance or reshoring of material production more than simply incorporating material production technologies as part of creative and professional services.

Further to this, they argue that the future of work is a combination of tacit and codified knowledge, which can happen in their alternative economic model composed of smart micro manufacturing enterprises, ‘a feasible model for growth of SMEs’ in these regions (Bellandi et al. 2020: 59), but without case studies to demonstrate that feasibility. This, in their perspective, can be threatened by obsolete digital infrastructures, insufficient adoption of new technologies and lack of skilled workers. However, they briefly explore another way manufacturing renaissance can create value in advanced regions due to Industry 4.0 technology. Bellandi et al. (2020) note that the ways customers relate to products is changing and that innovations like the Internet of Things (IoT) and Internet of Services (IoS) mean that there are services associated with products – like data analysis, platforms associated with the functions and use of products, media outlets, etc. And interestingly they note - and refer to Lafuente et al.’s theory (2017) - that near manufacturing units there may be complementary knowledge services and knowledge-intensive businesses of high value, which need to be located in proximity and in advanced regions due to the types of labour they rely on. This has been defined as territorial ‘servitization’, the notion that services and knowledge-intensive industries can drive the rise of manufacturing jobs in advanced economies (Lafuente et al. 2019), dependent on a value-added fit between services and productive industries. To highlight that the value is in the services or knowledge, not in the manufacturing, Chiarvesio and Romanello (2019) even suggest that products may be given for free and that the consumer would just pay for the digital services associated with the product. Tavassoli et al. (2015) also suggest that the new technologies may create more highly-skilled jobs because future fabrication technologies will require skills more commonly available in the Western world.

Very recent research starts to (finally) move the discussion from the realms of futurism and possibilities to gathering empirical evidence to establish what changes new manufacturing technologies may bring to geographies of production, noting that we must not disconnect from the past industrial history of places in the analysis. Notably, Busch et al. (2021) argue that new digital production requires specific urban locations because of how these industries directly connect with their customers – which tend to be other urban knowledge and creative urban industries – so that they can deliver personalised solutions and products. Based on the analysis of firms employing digital manufacturing technologies in nine German cities Busch et al. (2021) find that digital production industries demand highly skilled labour of the kinds found in the cities and are more capable of delivering the personalised solutions they trade the closer they are to knowledge institutions such as universities. They also find that these relationships cannot be replaced by digital means, which is a significant finding aligned with the conclusions of this thesis.

Making a similar point regarding the importance of a region's industrial and economic past for the establishment of industries adopting new manufacturing technologies, Laffi and Boschma (2021) are also among the first researchers to have gathered empirical data on the adoption of digital manufacturing technologies across European cities. Specifically, they inquired about the links between regions which innovated and grew during the most recent post-industrial paradigm based on information and communication technologies and the implementation of the new digital manufacturing technologies. They note that it is still hard to define or narrow down digital manufacturing technologies for their study, as this research finds too. However, to what is relevant to this study, they have included 3D printing technology as one of the critical technologies. Their outcomes point to a strong relationship between the two paradigms of industrial development, potentially anticipating the position of this thesis that the new fabrication technologies are supporting the abstract tasks, work processes and outputs of the creative and knowledge sectors, which continue to characterise an extended post-industrialism. Laffi and Boschma (2021) acknowledge this possibility though, stating that 'when it comes to interpreting the present techno-economic trends, the picture is less well defined' and that we may even be in 'an extended phase of an ICT technological paradigm', as they 'observe a certain degree of continuity' (Laffi and Boschma 2021: 2) between the two paradigms.

Sustainability and Circular Economy outcomes from the digital manufacturing transformation is other topic commonly found in the literature related to Industry 4.0 (Zheng et al. 2020). There is extensive literature arguing that with new manufacturing technologies production will be more sustainable (Ching et al. 2022; Satyro et al. 2023), and there is an increased interest in understanding how digital technologies can contribute to Circular Economy (Liu et al. 2021) and help to decouple economic growth from resource consumption through new production processes, reconfigured value chains and data input to the production system (Bressanelli et al. 2022).

Industry 4.0 has the potential to contribute to various aspects of sustainable manufacturing, such as: 'business model innovation, customer-oriented manufacturing, employee productivity, harmful emission reduction, improved manufacturing profit margin, intelligent production planning and control, manufacturing agility, manufacturing productivity and efficiency, new employment opportunities, resource and energy efficiency, reduced manufacturing costs, safe and smart working environment, supply chain process integration, sustainable product development, and sustainable value-creation networking' (Ching et al. 2022: 130133), although not all manufacturers will have the capacity to adapt, and adaptation is likely to be an evolving progress.

A systematic literature review on the intersection between Industry 4.0 and sustainability was carried out by Piccarozzi et al. (2022). They find that most papers suggest that Industry 4.0 has a largely positive impact on the sustainability of production and manufacturing – although they do review some negative perspectives found in the literature and that there are some papers from management studies on new business models to deliver greater sustainability (including economic, social and environmental pillars) through digital transformations. Most papers they review concentrate on economic sustainability links to Industry 4.0, and some relate social sustainability with Industry 4.0 and argue that digital innovations may bring positive social innovations. Papers pointing to the environmental sustainability of Industry 4.0 primarily focus on waste management, improved energy consumption and reduction of carbon emissions (Grybauskas et al. 2022). Another angle to sustainability in the papers reviewed by Piccarozzi et a. (2022) is the efficiency of resources deriving from digital and smart management. The sustainability of Industry 4.0 may, however, be a progressive transformation and evolutionary transition (Broadbent and Cara 2018; Ching et al. 2022).

Digital technologies can facilitate the penetration of circular economy principles in business models, as it opens up the possibility of data linking waste to resource reuse and helping adapt value chains (Bressanelli et al. 2022). Agrawal et al. (2021) reviewed scholarly publications on the recent trends in integrating Industry 4.0 with Circular Economy propositions. They highlight that many publications see this integration as critical to societal advancement in combating climate change, wage inequality and even Covid. According to them, Industry 4.0 and all its technologies can be used to reduce energy and resource usage, to change consumers' habits to return and re-use products, and to benefit ecosystems. Moreover, smart logistics or smart transportation can also positively contribute to Circular Economy. In their review, they summarise the research sub-topics emerging in how Industry 4.0 can be linked to the circular economy as: studies in smart and circular supply chains, which are about how digital technologies and IoT can help consumers return and reuse products, can generate improvements to recycling systems and can aid re-manufacturing; studies on business models of Industry 4.0 and their efficacy to a Circular Economy with recommendations to changes to better address sustainability; sustainable practices for a circular economy with case studies; digital circular economy or the impacts of industry 4.0 technologies in the transition to circular economy business models; and smart disassembly for remanufacturing and recycling.

Social sustainability effects from Industry 4.0 appear more disjointed amongst scholars and non-academic authors (Grybauskas et al. 2022): Academia tends to note negative possibilities for society, such as rising inequality and high unemployment resulting from the disappearance of jobs as a result of automation, or because it is being implemented within the same old neo-liberal business models, even if some economists prefer to keep a half-full perspective noting that there will possibly be more highly skilled jobs to compensate partially for the disappearance of most low skilled jobs; more mainstream literature tends to emphasise the positive impacts that Industry 4.0 will have on society and to lack any discussion on the hypothesis of less favourable scenarios.

Many of these theories of future scenarios highlight how funding and incentives for implementing Industry 4.0 will be critical to their happening. Many incentive initiatives already promote Industry 4.0 across countries: Germany, the U.S., the E.U., France, the U.K., Singapore, South Korea, and China (Wanner et al. 2023). However, more place-based industrial policies are expected (Bellandi et al. 2020), for example, public support for the four governance structures - universities, civic groups, SMEs and regional administration – and across multi-disciplines, which may be neither too localist nor place-blind. These industrial policies would address large metropolitan regions, which scholars already see dominating the development of Industry 4.0, but which may be associated with smaller regions and even with rural areas (Starr-Glass 2019; Mpofu and Nicolaides 2019). Bellandi et al. (2020) call for place coordination and place-based policies. They suggest in their conclusion that integrated policies for developing Industry 4.0 in economically advanced regions could be synonymous with sustainable development policies. However, the increase in productivity expected from Industry 4.0 will have environmental resources consequences unless cleaner production strategies are applied, and for that, intervention from public bodies or NGOs is necessary (Satyro et al. 2023).

An integrated industrial European policy is another proposition to deliver Industry 4.0 anticipated benefits (Mosconi 2015), promoting necessary structural changes to re-establish a manufacturing renaissance. In fact, it has already started as the EU's tech policy includes increasing investment in a mix of human skills and R&D, with examples such as the Research programme Horizon 2020 or Cities of Making 2018. Moreover, broader EU reforms may even allow for a supranational research and innovation policy.

To encourage more manufacturing renaissance and its benefits in creating jobs, Tavassoli et al. (2015) suggest that more direct incentives to the manufacturing sector would bring production back to regions of developed economies from where it was moved decades ago. In contrast, Lafuente et al. (2019) suggest that creating manufacturing jobs from knowledge-intensive and service industries is more likely to emerge from bottom-up processes and that it is very uncertain what role policy can have to incentivise this.

It becomes clear from this review that many future scenarios are already driving policy direction. They include matters as diverse as: economic growth models; new business models and their use of new technologies and processes; circular economy and sustainability outcomes; changes to jobs and labour structures; and new forms of production, new services and value chains. However, there is arguably significant inconsistency in the scenarios and interpretations, and they generally remain abstract and conceptual, even if linked to other strands of older literature. Moreover, the amount of empirical evidence and data is troublingly scarce for some of the scenarios and claims presented, and the two studies which have ample evidence (Busch et al. 2021; Laffi and Boschma 2021) are pointing towards more evolutionary and subtle changes in industries as a result of technological adoption.

2.6 New Locations of Production and Re-Shoring

Regional scientists, urban theorists, economic geographers and economists have recently been publishing perspectives on the implications of new manufacturing technologies for the location of innovation and spatial distribution of production, such as global value chains (Bryson and Clark 2013; Gress and Kalafsky 2015; De Propris and Bailey 2020; Johns 2020; Lowe and Vinodrai 2020; Busch et al. 2021). Nearly all works published so far assume that these new technologies and resulting new forms of production lead to new spatial trends that will look vastly different from post-industrialism (Busch et al. 2021; Johns 2021; Pegoraro et al. 2020), notably because material production may be reinstated in de-industrialised areas. These reconfigurations of production geographies are articulated as tackling issues of post-industrialism in regions left behind across Europe's metropolitan areas (Santos et al. 2017; Lowe and Vinodrai 2020; Busch et al. 2021; Laffi and Boschma 2021) and in rural contexts (Lafuente et al. 2010). There are two clusters of works published: one cluster of literature focuses on anticipating and describing the new places of production – mainly works from social sciences and grey literature; another, more scholarly and generally from the management field of studies, focused on the reconfiguration of supply chains as a consequence of Industry 4.0 and on possibilities for relocation of manufacturing in advanced western economies.

New Places of Production

The first cluster of literature almost overwhelmingly acknowledges that the locations of activities related to new manufacturing technologies will probably be urban (Busch et al. 2021), whether due to the ways these industries work in direct connection with their customers - which tend to be other urban knowledge and creative urban industries - or due to the increased knowledge intensity of this type of production (van Winden et al. 2011).

Crucially, this literature does not distinguish clearly between the locations of activities which are more akin to manufacturing (i.e. have material outputs for consumption) and the location of activities which are more aligned with creative and knowledge industries (i.e. have material outputs as part of a creative process for example, or do not have material outputs at all). Moreover, in the vast majority, the considerations are not backed by case studies, a significant gap my research aims to address.

Authors predicting a new industrial revolution based on a manufacturing renaissance with new fabrication technologies have made suggestions as to what the future spaces of material production would look like and where they would be located: people's own homes (Barnatt 2014; Bryson et al. 2017; Jakob 2017); small industrial units in high streets (Jakob 2017; Caruso et al. 2015); and high tech-occupied spaces in suburban and outer areas with few people controlling or operating sophisticated machinery (Barnatt 2014)

Other scholars take the vision one step further and reimagine the entire urban space planning and commodity chain reconfigured. Nawratek (2017) presents a progressive vision for the relationship between new spaces of production (i.e. new manufacturing units) and the urban areas where they may be located and their development. In this vision, ideas of mixing industrial and non-industrial uses are seen as beneficial to growth, thus different uses would be spatially linked. State funding, generally used for implementing regeneration projects, would be used instead to fund small factories and technical schools, which is seen as the trigger for further development in this vision. This contrasts with the most common driver for development in urban regeneration of former industrial sites: cultural and leisure activities of consumption rather than production outcomes (Pratt 2008). In his 'Industrial City 2.0' approach, Nawratek argues, more equal social structures would be generated, reverting the neo-liberal regeneration approach's propensity for escalating social inequality.

Similarly promoting the mix between industrial and other urban land uses, Hatuka and Ben-Joseph (2022) explore the spatial implications and physical design of integrating what they have designated as 'contemporary manufacturing' into the city's residential and office areas. They conceptualise this mix as the New Industrial Urbanism, suggesting that urban designers and planners may shape cities with integrated industry in the future. Based on ideas around the Fourth Industrial Revolution, they suggest that 'factories could now be built as hybrid buildings in mixed-use neighbourhoods' (Hatuka and Ben-Joseph 2022: 41), as they are quieter, clean and small. Their perspective, as many others challenged by this thesis, associates manufacturing industries of the kinds that have left Western nations and new technology-related activities without realising that the activities they refer to may not be producing final consumables at all. Thus they could be more appropriately described as activities of the cognitive-cultural knowledge sectors, which is why they can mix well with other land uses in denser urban areas. It should be noted, in the context of this review, that the case studies presented by Hatuka and Ben-Joseph as 'industrial' are: one of food production (thus a perishable item which cannot be transported for long distances and therefore requires a more central location); several campus or buildings of technology companies for software, web and telecommunications development including Ericsson, Amazon, Google, Microsoft, etc. which almost certainly do not manufacture any outputs in those high-value urban locations and most likely look like offices; plus pharmaceutical firms which work on biotechnology and health sciences equally performing investigation and knowledge tasks with highly trained professionals near academic institutions.

The 'Health-Tech Corridor' (Kruth 2017) is another vision centred on novel places of material production for urban, economic, and social development in a scenario of a manufacturing revival in post-industrialism. As others described, it uses state-funded education institutions, but in this case, they would be associated with a large health institution at the heart of development. Again, economic growth would be long-term, and high business and income tax would fund the not-for-profit institutions around the new industry.

To address the current public detachment from production spaces, Baker (2017) proposes that the actual factory of the new industrial revolution would be the centrepiece of urban development, triggering growth around it. This proposal parallels the early stages of industrial development, where production spaces were central to urban life and closer to homes. But now, in his proposals, an architectural design of "transparencies" (i.e. glazed buildings for manufacturing production) would be required to make this a success, re-connecting production with people in a future manufacturing renaissance scenario. Moreover, the factory is seen as a showpiece with cultural value in the urban area where it would be located.

There are more straightforward perspectives on the flexibility of technologies such as 3D printing, arguing that the material-producing places of the future will be high streets and homes and that a resurgence of material production with new technologies will overlay with the current places in contemporary cities and that these will adapt (Bryson et al. 2017; Barnatt 2014; and Jakob 2017).

In all this literature, there is a gap in evidence, thus why most of these suggestions assume that the flexibility of the technology alone can determine a new geography for innovation and manufacturing production in particular.

It has not been acknowledged in much of this literature that there is a need for linkages with services, particularly with the knowledge and creative industries that characterise the post-industrial economy of cities. Nor was there much consideration for the need to attract people to work with the technology (or would innovative material production be fully automated as in Barnatt (2014) or Osterrieder et al. 2020?), and for the need to thus be in areas which are well connected, where people already work, and which have local charisma and leisure offer.

However, a second group of published work is emerging with some evidence, although thin for now. It establishes a better link between the new material-producing technologies and the knowledge and creative economy. Consequently, it acknowledges that clustering theories and what we know about innovation in the centre of cities is still relevant to analyse where activities related to new manufacturing technologies may be located: 'Research on clusters and Industry 4.0 shows for instance, that 'the interactive character of learning and peculiarities of knowledge creation introduce geographical space as necessary dimension, which must not be neglected even in the era of Industry 4.0' (Gotz and Jankowska 2017: 1639 cited in Busch et al. 2021: 1802).

One of these studies includes the analysis of firms employing digital manufacturing technologies in nine German cities by Busch et al. (2021). They find that digital production industries demand highly skilled labour – of the kinds found in the cities and are more capable of delivering the personalised solutions they trade on the closer they are to knowledge institutions such as universities, and that these relationships cannot be replaced by digital means. This also implies that clustered and central locations are essential for activities using new manufacturing technology, which they call DUP (digital urban production), and which are not really replacing manufacturing for final consumption.

Further, Rehnberg and Ponte (2018) find that 3D printing is not influencing value chains and uneven geographies of production in post-industrialism when analysing two scenarios asking precisely if a revolutionary technology like 3D printing can alter the way production is organised across time and space. This study uses evidence from the aerospace and automobile industries, and the case study thoroughly backs it.

Moreover, Laffi and Boschma (2021), another of the few published evidence-based studies, find that across European regions, the geography of industries adopting new manufacturing technologies broadly overlays with the locations of more advanced technology, manufacturing and communication industries of the typical post-industrial economy. This study thus suggests that the geographies of innovation and spatial production distribution relating to new manufacturing technologies like 3D printing may not be changing production geographies as we know them in recent years as much. They attribute this coincidence to the path dependency of innovation, and suggest a relationship between post-industrialism's more advanced creative and knowledge industries and the new emerging manufacturing technologies.

It can be noted that evidence of the impact of new manufacturing technologies on the spatiality of production is starting to emerge. It is moving the analysis and discussions away from disruptive perspectives towards narratives of continuity and evolution, thus not so distant from established theories on the location of industries and the geographies of production and innovation. However, much is there to be interrogated, particularly given the novelty of the technologies, which this research aims to do.

Re-shoring

New locations of production resulting from Industry 4.0 is covered in scholarly literature that originated in managerial and business studies, focusing on the creation or change of production value chains, contrasting offshoring with reshoring.

In this literature cluster, terms that describe relocating manufacturing in advanced western regions can be reshoring, backshoring, onshoring and insourcing. However, the first is by far the most used term. (Weismann et al. 2017; Hartman et al. 2017). Shoring definitions can vary slightly: Some focus on the return of manufacturing production to the headquarters location; others focus on production being relocated closer to the demand market; and others stress the relocation of production to more mature markets. Reshoring is generally described as a location choice based on cost reductions related to the decline of cost advantages of offshoring. It also appears as a consequence of the changed demand or as being about ownership when re-internalising production is the critical aspect. Some authors indicate that the outsourcing vs insourcing framing of the manufacturing location also relates to ownership of the production. For example, outsourcing means being produced by others, just as insourcing means being produced by the same organisation. In all cases, it is pointed out that reshoring refers to relocation, thus not the first choice of production location.

The term reshoring is applied to manufacturing/material production, not services. It appears in literature as part of re-industrialisation policies in Western counties, or manufacturing renaissance (Tavassoli et al. 2015), or related to technological innovations in manufacturing, now commonly described under the umbrella term Industry 4.0 (Barbieri et al. 2018).

Cultural differences and lack of intellectual property rights have been described as barriers to offshoring, leading to reshoring (Weismann et al. 2017). Literature in business and management areas links new manufacturing technologies with the possibility of reshoring production, arguing that in the coming future new technologies will increase productivity and change the costs of production in regions such that we can experience a reconfiguration of value chains to include more material production in developed nations (Chiarvesio and Romanello 2019; Tavassoli et al. 2015) or to be closer to markets and consumers (Rehnberg and Ponte 2018; Weismann et al. 2017). Some even state that 3D printing may render offshoring and economies of scale redundant all together, which may lead to the regionalisation of production and change in distribution networks (Chiarvesio and Romanello 2019), affecting the size of factories and logistic plants. More nuanced scenarios are proposed, for example by Rehnberg and Ponte (2018), where innovative manufacturing technology is used in complementarity with traditional manufacturing processes. Digital value chains, created by new digital technologies to include products, services, equipment and businesses, may also become critical in production relocation as they respond to customer needs and mass customisation (Lemstra and Mesquita 2023).

Another theory of the reshoring of production is articulated by Tavassoli et al. (2015) who link the manufacturing renaissance to a new phase of production which they call the fourth phase – when a product is standardised and its production offshore, and then its standard production returns to the country of its initial concept development. They present four reasons for the manufacturing renaissance in developed regions: first, the rising wages in developing countries, which is discussed by other authors as well (see Sirkin et al. 2014); second, what they describe as the 'declining business milieu' in emerging economies – which is the reduction of available cheap workforce in developing regions due to improved living standards and the better labour rights in those countries impacting speed and profitability of production; third the new manufacturing technologies – i.e. 3D printing and others which, in their view, are competitive compared to economies of scale of large batch standard production and which will require less and less labour as they evolve – the concept of a smart factory; and fourth the rising demand for western and locally made products. Finally, other authors mention risk resilience and supply chain flexibility (Weismann et al. 2017) as reasons for the growth of material production in Western economies.

However, amongst many similar theorisations of reshoring already happening or about to start without many documented cases, a few cases are emerging with different findings. Cohen et al. (2018) stand out, asking whether global value chains have been recently changing, whether offshoring or reshoring has been increasing, and why. They use a large sample of companies engaged in global manufacturing and examine individual firms' decisions to modify their global value chains. Their paper explains research results that manufacturing is indeed undergoing some significant restructuring of value chains, as Hartman et al. (2017) indicated as well, but that while there is some reshoring, most firms are still offshoring. In their research, labour costs no longer seem to be the sole reason for location decisions, and a more complex combination of factors determines industrial production location. These changes are, according to their results, seen across multiple industries. Although contrary evidence exists in the literature pointing that labour costs are still an essential aspect of offshoring but not in isolation. The Boston Consulting Group argues that now some products may be produced more affordably in the US than in China (Sirkin et al. 2014) and labour costs offshore are increasing (Hartman et al. 2017). This may also justify the research findings by MFG.com cited by Tavassoli et al. (2015) that 21% of manufacturers in the U.S. brought back part of the production closer to the U.S. in the second quarter of 2011; or Hartman et al.'s (2017) findings assessing a small group of prominent American manufacturers and concluding that they based their location decisions on a model which included labour costs plus other factors such as productivity and quality, even if overall, executives reported many doubts during their decision-making process for the best location of production.

While some state – without too much evidence – that reshoring is a trend (Tavassoli et al. 2015) to be then later cautious and state that 'the return of manufacturing to the west should be kept in proportion' (Tavassoli et al. 2015: 276), research assessing the actual scale of reshoring is beginning to emerge. For example, Cohen et al. (2018) also ask (in their sizeable recent case study research) which role the three main productive regions of North America, China and Western Europe and the developing regions of Southern Asia and Eastern Europe have in the global value chains restructuring process. They query which regions have seen investments and divestments and what the variation is across industries. They find that China remains the most attractive production location with the highest production flows of investment, followed by Eastern Europe. This includes investment in capital-intensive production, automation and high-tech manufacturing, thus not only labour-intensive production. Even within the restructuring of global value chains, firms still choose to locate essential production in developed economies and use developing economies as production hubs. Their findings highlight 'that cost is no longer the major driving force. Instead, market access, quality and supply-chain related factors have emerged as dominant drivers for increasing production volume in China' (Cohen et al. 2018: 397). However, they note that manufacturing is growing in North America and that while it may see some manufacturing renaissance, that is not due to the reshoring of domestic firms. Their data points to a decrease in production investment in Western Europe in favour of both China and North America, which explains the growth of manufacturing in the US – but not relocating from low labour cost regions.

Regarding the balance between offshoring and reshoring, Cohen et al. (2018)'s study, arguably with the most comprehensive sample of firms recently examined, finds that 76% of their sample firms continue to offshore production, whereas 32% is reshoring in the context of broad global manufacturing chains restructuring. As they note, this does not indicate a trend for reshoring. The reasons for the manufacturing renaissance are not due to relocating from low labour-cost regions but to more complex factors brought together in decision-making processes. To reinforce these findings, they state that there are more decisions to decrease than to increase production in North America. They also found that most firms were not increasing or decreasing production and that restructuring the global value chain was about relocating production in association with investment in automation and changing markets. Hartman et al. (2017) consistently find that when American firms are reshoring, they adopt temporary short-term strategies, not a long-term increase of production in the western developed regions.

In studying the adoption of Industry 4.0 technology by firms in the north of Italy, Chiarvesio and Romanello (2019) could also not identify a relationship between the adoption of Industry 4.0 technologies and the internationalisation of companies, meaning that there was no link established between changing the geography of production – either reshoring or offshoring - and the adoption of industry 4.0. Moreover, consistent with Cohen et al. (2018)'s findings, 'despite the Industry 4.0 investments made in main factories in home countries, none of them have backshored or reshored yet' (Chiarvesio and Romanello 2019: 371). However, the story is not harmful to the Italian region, as they found that the new technologies were applied in various tasks in different activities of their value chain, ranging from design to post-sales and production to distribution. They highlight that there was innovation in both process and product creation and that it increased productivity. Some companies tended to use the new machines in vertical integrations, and others went a step further and achieved both vertical and horizontal integration, a 'smart factory'. These companies have been investing in R&D for many years, and the increase in productivity was mainly due to including services, for example, related to IoT. There was also to note an increase in quality and flexibility of production and diversification of production due to the technology, which opened new market opportunities.

The (still rare) empirically-backed literature concludes that Industry 4.0 can improve productivity and production possibilities for advanced regions, thus leading to some reshoring. But equally, it will increase production quality in offshore locations (Cohen et al. 2018), challenging the scenario of a manufacturing renaissance. What becomes clear is that even if this cluster of literature uses more evidence, there we are far from a consensus on the effects of Industry 4.0 on the location of production.

2.7 Conclusion

It has become evident from this literature review that the definitions of Industry 4.0 and its key concepts are still evolving but are becoming more consistent. The recent use of the term Industry 4.0 is helping works move away from the narrative of an Industrial Revolution towards a narrative of change associated with the digitalisation of production and new technologies, a subtle but significant change of focus, which is bringing the subject to the attention of scholars. Thus, much academic work has been published in the last five years, particularly in business studies and management (less in social sciences).

This review has highlighted that multiple future scenarios are articulated in academic and grey literature, overwhelmingly hypothetical, even if linked to more currently accepted strands of scholarly literature. I have summarised and synthesised perspectives focused on changes like jobs, new growth models and socio-techno paradigms, organisation of production, or how everyday life can change due to Industry

4.0 technologies. I have also reviewed how literature links technological changes with new places for production and the manufacturing renaissance in Western economies. A vast range of perspectives and angles becomes apparent across the works studied, with no consistency or trend and many contradictory positions.

It is even acknowledged in some of the literature reviewed (Bellandi et al. 2020; Chiarvesio and Romanello 2019) that despite theorisations that Industry 4.0 can change productive paths and the current mode of development in many dimensions, it is still not fully understood what the changes may be. For example, there are still few cases allowing exploration and understanding of the effects of digital technologies in production (Osterrieder et al. 2020) or how they are best applied (Lemstra and Mesquita 2023; Zheng et al. (2020). Furthermore, there is a significant lack of all kinds of empirical evidence and data (Grybauskas et al. 2022; Johns 2022; Gress and Kalafsky 2015; Liao et al. 2017), including on sustainability which is one of the most endorsed outcomes of Industry 4.0 (Ching et al. 2022). This is true across all fields of study, as 'very often, the issue of Industry 4.0 remains on an abstract level and it is very difficult for practitioners [referring to management, operatives and manufacturing companies] to understand exactly how to exploit this new revolution concretely' (Zheng et al. 2020: 1944). To this conclusion, a relevant summary of what has been written to date about Industry 4.0 is provided by Rad et al. (2022): First that there are confusing facts and data associated with a generally positive perspective on the transformational changes and possibilities with little focus or discussion around the challenges and negatives; and second a tendency of articles to concentrate on one technology or a few and generalise findings to all other technologies. I add that there is also a tendency to emphasise and grow - almost out of proportion - the nature and impact of future changes resulting from Industry 4.0, alongside a tendency to disconnect those future changes from the present and from co-located economic activities.

Due to the lack of empirical studies to underpin theories, many works reviewed suggest avenues for future research, of which I have selected a few which would need to come from social sciences including geography due to the spatial implications: how manufacturing reshoring and creation of manufacturing jobs is linked to the growth of knowledge intensive services, defined as servitization, and the locations where this happens successfully (Lafuente et al. 2019); how Industry 4.0 technology improves the industrial base of the region, and if it favours a more significant concentration or dispersion of material production (Chiarvesio and Romanello 2019); the exploration of how new digital manufacturing technologies can be more environmentally advantageous (Zheng et al. 2020); evidence on the technologies themselves, including challenges and successes and the interaction between technologies (Rad et al. 2022); evaluating the scale of reshoring (suggested by Tavassoli et al. 2015 but already being addressed by research such as Cohen et al. 2018), and the relative influence of each factor in the location decision of firms; the impacts on automation and job displacement, social inequality and regional imbalances and consumption divestment (Ching et al. 2022); and even the consequences from the technologies to spatial inequalities from a planning and geography points of view (Lazzeretti et al. 2022). Regarding the relationship or impact between Sustainability, Circular Economy and Industry 4.0 technologies, Agrawal et al. (2021) proposed several avenues for future research, such as guidelines for the integration of technologies and outcomes, applications of technologies, analysis of the supply chain in this context, and precise models reproducible for the application of technologies and outcomes. Piccarozzi et al. (2022) suggest empirical research into business models of Industry 4.0 and applications for sustainability outcomes.

Throughout this literature review, I have laid out theoretical views with which this thesis engages in general. I do not engage with any specific scenario or technology effect, but with the overarching notion most of them subscribe to - that of a disconnection with the present due to a disruptive series of technologies, and the discharge of the evolutionary links, sometimes ignoring the crucial role of space in socio-economic and even technological progression. The point has been to bring together different propositions critically, sometimes pinpointing where their apparent faults may be. I do, however, highlight that what we start to know through the few empirical studies emerging now (Laffi and Boschma 2021; Busch et al. 2021; Rehnberg and Ponte 2018; Cohen et al. 2018; Chiarvesio and Romanello 2019) is that there is a more continuous relationship between post-industrial economic activities and those adopting the new fabrication technologies, which align with the arguments of this thesis.

Chapter Three

Theoretical Perspectives on Production and Industrialism: Location of Industries and Growth Through Innovation

Cities have always been important engines of economic growth, but they are assuming an even greater importance in today's knowledge-driven innovation economy, where place-based ecosystems are critical to economic growth. (...) Cities are not just containers for smart people: they are the enabling infrastructure where connections take place, networks are built and innovative combinations are consummated. (Florida et al. 2017: 92)

3.1 Introduction

This chapter presents a review of scholarly perspectives which have informed my research. It provides an analysis of scholarly work addressing production in the evolution of capitalism, particularly post-industrialism including its main interpretations and processes which through innovation lead on to growth. The chapter is organised in three parts, related to the structure of this thesis's empirical chapters and my themes of enquiry.

The first part of the chapter, section 3.2, reflects on perspectives explaining the impact of technological innovation and the organisation of production in capitalist accumulation and evolution, frequently described as "revolutions". It provides a historically organised literature review of changes in production and associated social systems including: Fordism, post-Fordism and its various theoretical interpretations which shaped economic geography for a significant period of time; and beyond Fordism into post-industrialism. On the basis of the research reported in this thesis, I will offer an alternative view, moving away from propositions of major transformations towards a more nuanced, continuous and embedded view of innovation, which sees innovative material production as integrated in the knowledge and creative sectors of post-industrialism. This is to adopt an evolutionary perspective.

The second part of this chapter, section 3.3, addresses the location of industries as a background to the contribution of my study on why current innovation linked to new manufacturing technologies emerges and flourishes where it does, and what that means for our knowledge of the location of innovation more generally. I review early models of industrial location, followed by theoretical perspectives on the location of manufacturing industries as a result of deindustrialisation whereby manufacturing relocated from city centres to urban peripheries, or further afield.

Lastly, section 3.4 reviews the ways in which innovation drives growth in post-industrialism. It considers diversified versus specialised agglomeration and literature findings on how a diversified environment can deliver resilience and growth in the long term. This section also addresses the problems of the limitations and degrees of diversification, as well as the ways in which knowledge is transferred between industries, firms and individuals to enable successful innovation in post-industrialism. This economic geography literature is particularly relevant to support the claim developed in this thesis that, in an agglomerated environment like London, activities emerging in connection with fabrication technology can generate growth and contribute to further innovation, rather than reviving an old manufacturing sector. They can be understood as creating an economic environment of related diversity where activities are related to each other and can more easily detach into new activities, new firms, new products.

To conclude the chapter, I reflect on the key points emerging from the literature review (section 3.5), and point to the evidence gap in most literature concerned with manufacturing revival in post-industrialism, as well as the disconnect between literature on this topic which is overwhelmingly not from economic geography and the lack of focus on this topic in the discipline. I note that my work aims to address these points, contributing to the evidence base with my 3D printing case study, and adding to an understanding of the role and the location of innovative material production in present post-industrialism.

3.2 Production and Industrialism

This section elaborates on analyses of how production and its geography has changed in relation to available technology and how it relates to economic growth and accumulation processes in industrial capitalism. It assesses different accounts of this change in terms of their usefulness to contextualise the contemporary innovative material production aided by the latest fabrication technologies with which this thesis is concerned. This section of the review is organised chronologically. First, I discuss the notion of reading the evolution of capitalism through the lenses of technological developments (3.2.1), which arguably emphasizes technology over other factors of change, as my own research does too. I will then review theorisations of production changes and their association with modes of capitalist accumulation of each key period up to Fordism (3.2.2), then in Post-Fordism (3.2.3), and lastly in the present post-industrialist era (3.2.4).

This literature forms a background to my research, as I aim to contribute to our understanding of the impact of the most recent technological changes in material production on recent post-industrialism. Engaging with two approaches in economics that interpret economic systems as temporary cycles resulting from technological breakthroughs or path dependencies and continuities, my findings challenge perspectives arguing that some of the most recent technological innovations in material production amount to a new industrial 'revolution'. Instead, this research supports an understanding of the role of innovative fabrication technology in post-industrialism aligned with continuous and evolutionary perspectives as the case study of 3D printing has shown that this technology is used within activities of the knowledge and creative sectors. Within these sectors, I find evidence for this technology's potential for more innovation and renewed growth in agglomerated urban contexts where collaborative production processes are fostered by the spatial conditions. But this growth has not come about in a disruptive manner, as this research's case analysis finds that new activities emerging around this technology are related with previous employment of the founders, with their academic backgrounds, or even their hobbies.

3.2.1 Technological Change and the Evolution of Capitalism

This section considers the relation between technological change and cycles within capitalist evolution, reviewing perspectives which argue that changes happen disruptively when new technologies emerge (Schumpeter 1947; Freeman and Perez 1988; Flusser 1993; Perez 2010; Dosi and Nelson 2013), as well as those which consider that evolution is a more progressive process and path dependent (Tomaney 1994; Martin and Sunley 2010; Neffke et al. 2011; Frenken and Boschma 2007). Both perspectives are relevant to my enquiry into the role of a technology said to be potentially disruptive for the entire economy (Marsh 2012; Sissons and Thompson 2012; Anderson 2013) and for the spatial expression of global value chains (Johns 2020; De Propris and Bailey 2020).

It is generally accepted that the evolution of capitalism bears a relationship with technological change (Perez 2010; Dosi and Nelson 2013; Florida et al. 2017; Boschma 1999; Laffi and Boschma 2021). For this reason, some authors have framed the most recent digital technological innovations, including material fabrication, as the beginning of a new phase of capitalism akin to a new industrial revolution (Marsh 2012; Brown 2015; Anderson 2013; Barnatt 2014; Rifkin 2015; Johns 2020).

Considering the key definitions, Alain Touraine (1971) and Daniel Bell (1976) contrasted capitalism with statism (socialism or state capitalism) as an economic system where the means of production and the surplus generated by production are privately owned. In this context, they defined production as the act of appropriating and manipulating 'matter' with the resource of 'tools' to obtain 'products' which can be used for consumption, as society needs, or invested. Matter includes nature, human-modified nature, human produced nature and human nature itself. In this process new value is created and surplus is generated, which can be reinvested either in the means of production or instead on items or activities destined for society's representational purposes. Production, productivity and value generation are therefore dependent on the relationship between labour and matter. This relationship involves technology, defined by Castells (1996) as one element acting upon the matter and part of the suite of means of production whether engines, sources of energy, or more recently knowledge and information.

The observations that industrial capitalism progresses in a cyclical chronological manner (with successive periods of growth, stagnation or recession followed by new growth again) in association with technologies was first proposed by Kondratieff (1925). In his theory, industrial capitalism has progressed in waves which have been named after himself. As illustrated in Figure 3.1, the Kondratieff waves have been defined by: the steam engine and cotton production; railways and steel; electrical engineering and chemistry; petrochemicals and automobiles production; and information technology.

[redacted]

Figure 3.1 Kondratieff's waves, source: Internaszonalderivative work: Agmen [Copyrighted free use], downloaded from: https://laptrinhx.com/winter-is-coming-2873246148/

There is some debate, though, as to whether the emergence and adoption of new technologies are disruptive in nature or are processes of continuity and co-existence of multiple technologies (Bryson et al. 2013). The more disruptive perspective stems from the work of Joseph Schumpeter (1947), who referred to technological changes as industrial mutations, emphasizing the non-equilibrated and organic nature of economic development in capitalism and its dependence on technological evolution. Schumpeter theorized capitalist growth as a process of technological change (Perez 1983 and 1985; Freeman and Perez 1988) with successive creation and destruction. His theory of innovation and entrepreneurialism supports the view that a new technology like 3D printing could be disruptive and could trigger the creation of new firms in an entirely different sector in an area like London – such as urban manufacturing activities.

Reading technological adoption and the emergence of new growth cycles as disruptive has been presented in literature as 'Industrial Revolutions' by authors in economics, sociology and economic geography fields (such as Freeman and Perez 1988;

Flusser 1993; Perez 2010; Dosi and Nelson 2013; Boschma 1999; Florida et al. 2017). The concept of an Industrial Revolution supposes the emergence of new technological standards for production which render the old ones less productive (Freeman and Louca 2001). Revolutions are seen as forces of capitalism in search of a new equilibrium which only exists at a few points (Freeman and Louca 2001).

These views of economic progression as innovation breakthroughs followed by more growth, contrast with the neoclassical readings of economic growth based on equilibrium and further specialisation and labour division (Piore 1980; Florida et al. 2017). The role of innovation and small business cycles triggered by entrepreneurialism is not part of the equilibrium models. Freeman and Louca (2001) refer to this same point, noting that 'since change is the decisive feature of capitalism and it means a permanent tendency to disruption, and since equilibrium has no welfare advantage as it means no progress, innovation is alien to rational-equilibrating decision making' (Freeman and Louca 2001: 43).

Historical analysis of capitalism typically relies on Kondratieff and Schumpeter's work. Freeman and Louca (2001) overlay long economic cycles the 'Kondratieff's Waves' onto Schumpeter's innovation business cycles and social and institutional systems to argue that technological changes give rise to new socio-economic arrangements. Each technology defines an era, along with the underlying institutions which enable them. They read the transition across eras in relation to both the changes in political and power arrangements, plus the diminishing returns of the more established technology, which then is overtaken by the new disruptive technology setting a new era.

A recent advocate for the idea that a new industrial revolution is about to happen, Rifkin (2016), also analyses industrial revolutions in connection with technology innovations. But Rifkin argues that the triggers for such revolutions are three technological elements: new transport modes, new energy sources and new technologies for communication. Based on his historic analysis, these three aspects need to be co-present to interact for an industrial revolution to happen. The technology of additive manufacturing here in study has been very clearly associated with this type of disruptive change in capitalism. Gress and Kalafsky (2015) have gone as far as suggesting 'that we must prepare for the possibility that additive manufacturing may foster what amounts to a Schumpeterian surfboard riding a Kondratiev-like wave in the manufacturing sector and its numerous supporting service industries' (Gress and Kalafsky 2015: 44).

But in the debate on whether technology adoption is a disruptive or gradual process of capitalism evolution, other authors have argued that technological change is more continuous, evolutionary, path dependent (Tomaney 1994; Martin and Sunley 2010; Neffke et al. 2011; Frenken and Boschma 2007) or that old technologies co-exist with the new ones in different social paradigms across time and place (Piore and Sabel 1984; Hughes 1982; Sabel 1989; Massey 1984). And it has also been shown by others that not just technologies, but political changes can kick start or slow down growth (Crafts and Venables 2003; Livesey 2018). This is something we can observe in London, and which has been highlighted by scholars who have noted that despite de-industrialization and the shift to knowledge sectors, some traditional manufacturing remains viable in London (Ferm 2011 and 2016; Ferm and Jones 2014; Giloth 2012; Sassen 2009 and 2011).

Furthermore, there are scholars who have pointed to gradual changes and described the role of the socio-institutional systems underpinning continuous technological change (Aglietta 1979; Lipietz 1988; Jessop 1994). Other perspectives, equally arguing that capitalism evolves more gradually as technology changes, have also pointed to the role of changing work processes in increasing growth, which sometimes are associated with the adoption of new technology (Rowlands 1975), such as for example considering the separation of tasks and the division of labour an outcome of the electrical energy powering faster factory machinery. This rational for a continuous interpretation of technological change and its impact on the growth cycles of industrial capitalist is relevant to the argument of this thesis, as it has been argued that advanced fabrication technology will have an impact on the entire value chain of production including in urban contexts (Busch et al. 2021).

Having now established the relationship between technological change and the evolution of industrial capitalism, including both the disruptive and the evolving approaches, the next section will review literature which explores the dynamic changes in production over historic periods up to the present time. These form a background to the present discussion on whether recent innovation in fabrication technologies is triggering a new period of growth (Thomas 2019; Johns 2020).

3.2.2 From Craft Production to Fordism

This section sets out how production evolved in relation to available technologies up until de-industrialisation in some northern contexts as a background to the narrative of re-industrialisation of urban economies which this thesis engages with. Besides describing phases of production in association with technologies, which have a parallel with the suggestions of a new production phase in capitalism based on digital fabrication, this section also introduces concepts related to industrialisation which will are used throughout the thesis.

According to Marsh (2012), there have been many production phases in history related to how products are designed and manufactured. The first phase in production was characterised by 'low volume customisation', which was associated with craft-making in artisan production. This means that everything was made in small quantities as needed, and each product was tailored to the client or user. Dejean (2015) notes that multiple systems of values, including collective cultural meanings were attributed to the various craft technologies and to tools in primitive, agrarian and feudal societies. In this approach, which dominated production up to the beginning of industrialisation, design and making were fully integrated spatially (Darley 2003) and followed a temporal linearity.

The second phase in production was characterised by 'low volume standardisation' (Marsh 2012) whereby some small parts of objects, or simple objects such as bricks, were designed to be interchangeable. With this approach, production became quicker than in the previous one-off manually crafted items, and productivity increased. This approach coincided with the development of the steam powered engines, and it marks the beginning of capitalism and industrialisation in the late eighteenth century (Marsh 2012). Production was organised mostly through entrepreneurships and partnerships between capitalist factory owners employing workers directly, evolving later to joint stock companies, which started to subcontract to craft workers (Freeman and Louca 2001). The changes also included a major shift in the sectors of occupation of the population through the nineteenth century up to the twentieth century from agriculture to industry (Rothkopf 2012). In these changes, the factory emerged as the space of production which replaced homes and workshops (Rowlands 1975; Darley 2003), and with it the spatial and labour separation of tasks in production begins. It is relatively consensual among scholars that from the late eighteenth century there has been an acceleration of the growth rate and accumulation propelled by these changes in production (Freeman and Louca 2001).

The third historic phase in production was 'high volume standardisation' or 'mass production' (Marsh 2012), known simply as Fordism. It has had different definitions and different periodisation. To some authors it has been defined as an industrial innovation, the mass production (Piore and Sable 1984), and to others as a social arrangement between capitalists and labour that enabled the division of labour and expansion of markets which led to an increase of productivity (Aglietta 1979). Either way, Fordism took some time to evolve to its most extreme format, realised in automotive production where extensive standardisation of parts allowed for the greatest division of labour in production history. Cars were made in a line – the assembly line – with workers repeating the same task and passing the model to the next worker in a continuously flowing sequence (Pine 1993).

The Fordist design approach to objects with many repeated and interchangeable but inflexible parts plus the reorganisation of material production in large scale allowed for greater division of the production tasks and consequent greater division of labour in manufacturing. With this, the craftsmen skill used to make objects in previous periods was substituted by low-skilled workers and machinery, repeating tasks to speed up the process and eliminate human error (Piore and Sabel 1984). Pine summarised the four principles of mass production as 'Interchangeable parts, specialized machines, focus on the process of production and division of labour' plus eight additional principles which are 'Flow, focus on low costs and low prices, economies of scale, product standardisation, degree of specialization, focus on operational efficiency, hierarchical organisational with professional managers and vertical integration' (Pine 1993, table 2-3: 15).

In this period, the high level of standardisation and the division of labour spread to other industries and new materials and technological innovations also happened at this time, such as the electric motor, the internal combustion engine, the steam turbine, chemicals as dyes and plastics, steel, aluminium, and more. These were applied to automobiles, aircrafts, steel railways, ships, telephone, electrical power stations, etc and with associated Taylorist[15] organisation and management systems, great growth of

[15] Frederick W. Taylor developed a system of scientific management characterised by an extreme separation of mental and manual tasks. In his industrial organisation, production lines were structured

firm size and market expansion took place (Freeman and Louca 2001). Exponential urbanisation accompanied this mode of production, with industries in Fordism creating vast agglomerated urbanised regions with satellite suburbs for the workforce, also the consumption market. These were particularly in the U.S. and some regions of Europe such as the Midlands in England and the Central European Benelux region extending to the Ruhr (Scott 1988b). It is worth pointing out however that mass production was much more widespread in the U.S. and that, in reality, 'Fordist efficiencies and economies were to prove far less viable in Europe, and especially in Britain where traditional craft unions and wide distrust of mechanization at all costs meant a slow and troubled introduction of moving assembly lines and standardized components' (Darley 2003: 153). But ultimately, the breakdown of production in tasks, labour and space under Fordism set the basis for further disintegration of production stages, maximising value and accumulation across global locations in the period that followed.

3.2.3 Post-Fordism

Having established and summarised the evolution of production in relation to available technologies during industrialisation in the northern and western contexts in the previous section, this section reviews literature which concerns itself with de-industrialisation and associated changes in urban economies in the same regions. These processes are the root of the discussion on whether urban economies like London could re-industrialise and kick start a new wave of growth from new technologies, which triggered this research. I therefore review in more detail below literature concerning the shift from mass production to flexible production and the expansion of supply chains globally that resulted in the loss of manufacturing in contexts like London.

There is relative consensus amongst scholars (Amin 1994) that since the 1970's a new phase of capitalism emerged – post-Fordism, with forms of production and socio-economic organisation that superseded the previous mass industrial production

into individual motions and unnecessary time was eliminated to increase productivity of workers. This, coupled with incentives for good performance, was the basis of mass production and it raised productivity particularly in American industries in the twentieth century.

paradigm. The term post-Fordism has also been interchanged with terms such as post-industrial, postmodern, fifth Kondratieff wave. The causes of this change have been debated; for Castells (1996), it has been triggered by alterations in labour processes, politics and growth in global economics not by changes in production and technology alone, for Tomaney (1994), it represents an intensification of trends already seen in Fordism (such as the creation of semi-skilled types of work rather than crafts or purely manual and integration of tasks into smoother processes with the help of computers used in production control), while for others it derived from a crisis of Fordism (Freeman and Louca 2001) and specific technological innovations such as the computer and micro conductors (Sabel 1989; Perez 1983 and 1985; Marsh 2012) and the automobile and motorways (Garreau 1991). Either way, scholars have identified a meaningful change in paradigm of production from Fordism characterised by a slowdown of productivity even with further division of labour, increased competition between countries and new countries entering the competition field, plus alterations in consumer preferences towards more niche products which standard designs and large production batches could no longer satisfy (Boyer 1988, cited in Elam 1990:64).

Despite diverse perspectives on the causes of post-Fordism, there seems to be unanimous acknowledgement that the impact of the transition had profound implications on former industrial cities of the West. As Ash Amin argues:

> 'it seems indisputable that the salience of so many of the icons of the age of mass industrialization and mass consumerism appears to be diminishing. Under threat in the West appears to be the centrality of large industrial complexes, blue-collar work, full employment, centralized bureaucracies of management, mass markets for cheap standardized goods, the welfare state, mass political parties and the centrality of the national state as a unit of organization. While, of course, each individual trend is open to dispute, taken together they make it difficult to avoid a sense that an old way of doing things might be disappearing or becoming reorganized' (Amin 1994: 3)

Production evolved towards 'high volume customisation' or 'mass customisation' (Marsh 2012), as the rigidity of mass production was replaced with objects designed with common elements and with kits of parts that could be combined to achieve a higher level of personalisation and variation. In this more flexible way of producing, well exemplified by the Japanese car industry in literature (Pine 1993; Freeman and Louca 2001; Schonberger 1982), the variable parts are made when needed, so-called 'just in time production' (Zyzman 2003; Sayer 1986) to avoid large batches and storage. This approach appealed better to the consumer needs while avoiding wasting entire batches if the market conditions change. Flexibility in production became key to the success of industries.

In the post-mass production phase, vertical disintegration of manufacturing developed across global geographies, helped by information and telecommunications technology and low transport costs (Krugman 1991). Massey (1984) summarises industrial location studies which have suggested that the latest phase of post-Fordism has augmented the de-skilling of workforces, particularly the removal of control over production with the breakdown of tasks in increasing specialisms. She also observes that this has been even further expanded with the use of information and communication technology systems. She quotes Aglietta (1979) and Perron's (1981) arguments on the continuous decentralisation of production both functionally and spatially, and on how this has led to geographical implications such as the spatial separation of the production chain and the labour process. In contrast to these more traditional studies, Massey (1984) argues that different labour processes co-exist, as do different political regimes (Tickell and Peck 1992) and they in turn reflect spatial change, and that all kinds of factors define the fluctuation and imbalances between labour and location. According to her perspective, separation of control and production in mass production and further separation of concept and manufacturing did not cause geographical separation per se, but made it possible.

The changes in production, and in society and economics, extended to the division of labour gaining international scale, as both highly qualified and low-skilled workforce became easily interchangeable across global locations as needed by the job markets. With it, we saw the emergence of the multinational corporations in various sectors (Iammarino and McCann 2013) exploiting the differences in wages across regions, labour skills and labour laws (Amin and Robins 1990). Design, production and management became ever more fragmented, while de-regulation of capital markets and information technologies fostered flexibility and speed in capital exchanges. This has had geographical consequences, as some regions became 'threshold countries' or 'new industrializing countries', where mass production relocated to. At the same time, traditionally industrialised regions in the West either became regions of decline and unemployment, such as many cities across Europe and America, or they became global metropolitan control centres (Esser and Hirsch 1994; Sassen 2000), such as the focus of this study, London.

The nature of these changes in post-Fordism was the particular focus of economic geography scholars since in the 1980s through to the 2000s (Barnes et al.2007; Sonn, Hess and Wang 2018). Scholars tried to interpret the changes in production and in economic activities in connection with social and institutional adjustments, particularly in the northern contexts. A significant body of research took the form of industrial studies and analysed extensively and thoroughly new industries and their organisation (Storper 1992, 1995 and 1997; Rigby and Essletzbichler 1997, Florida 2002; Scott 2000; Zukin 2010). Other studies adopted instead a more political, even activist position (Harvey 1987b; Peck 2005; Markusen 2006; Zukin 2010), bringing to the analysis of the changing structure of the economy political perspectives including a concern with the weakening of workers' unions, and the increased profit from financial transactions compared to manufacturing which some have ascribed to the alignment between capitalists and politicians.

My research sits in the tradition of the industrial studies of post-Fordism, as it is itself an industrial study. It is, however, much less orthodox than most post-Fordist industrial studies, given it follows a technology across sectors rather than a single industry, and it uses a combination of methods to answer the questions. This will be further discussed in my methodology chapter.

Below I will review the post-Fordist debate perspectives, as they expanded to very holistic discussions, which Elam (1990) and Amin (1994) broadly group into Regulatory, Neo-Schumpeterian and Flexible Specialization perspectives, designations now well accepted in the field.

The Regulatory Perspective

The Regulatory perspective was one of the most prevalent theorizations of the restructuring of capitalism after Fordism (Tickell and Peck 1992) which included various strands of Marxist political economy. The most prevalent was the French School. According to Tickell and Peck (1992) its major legacy has been to link the role of the state and social institutions with the cyclical nature of capitalism defined by sequential, permanent crisis and restructuring. The theory thus looks at regulation of economic life which points to the interaction of economic activities and social processes (Painter 1995).

This relationship of regulation was theorised through two principles: Mode of Regulation and Regime of Accumulation. Mode of Regulation can be broadly defined as the social and cultural norms and practices of society and institutions which regulate the system of accumulation (Aglietta 1979). It encompasses not just the state which would 'promote product, process, organizational and market innovation and enhance the structural competitiveness of open economies mainly through supply-side intervention; and subordinate social policy to the demands of labour market flexibility and structural competitiveness' (Jessop 1993, cited in Painter 1995: 33) but also inter-firm relations, the centralization or decentralisation of production (Elam 1990). Regime of Accumulation is the economic relationship between investment, production and consumption, a constant between demand and supply of labour and capital (Painter 1995) leading to capital accumulation and economic growth over a certain period or consistency, or to some defined as a capitalist phase (Tickell and Peck 1992). Regime of Accumulation may be defined as 'over an extended period of time there is a certain convergence between the transformations of production (amount of capital invested, distribution among the branches, norms of production) and transformations in the conditions of final consumption (habits of consumption of wage earners and other social groups, collective expenditures …)' (Lipietz 1988: 31).

According to Regulation Theory, a regime of accumulation will reach a point of crisis when its mode of regulation will not support it anymore (Aglietta 1979), and institutions and the state will be forced to find a new relationship of balance to allow further accumulation to realise and thus a new Regime of Accumulation would emerge (Tickell and Peck 1992; Jessop 1994; Boyer 1990), realising a regulatory process or tendency to regulation (Lipietz 1987; Dunford 1990).

However, within the Regulation Theory framework, there were varying angles of focus on the triggers of the crisis of Fordism and on the traits of the new mode of regulation that ultimately explained the structural changes of the economy in post-Fordism. Aglietta (1979) centered on the exhaustion of the Fordist regime of accumulation due to rise in real wages attained through the bargaining power of labour unions and narrowing margins of profit leading to declining investment in technologies in the major industries. This would have driven industries to outsource and decentralise production, with effects on the consumer market's purchase power. The declining rates of profit and investment were also described as a consequence of the peripheralization and internationalisation of labour (Scott 1988b; Moulaert and Swyngedouw 1989), with firms adopting flexible labour practices such as multi-tasks and subcontracting (Scott 1988b) as technologies allowed for it and for rapid changes in production (Cooke 1988; Gertler 1988; Scott and Cooke 1988) in response to the changed consumer market. A greater focus on the consumer market as the changed regulatory mode was also a central part of the debate (Aglietta 1979; Schoenberger 1988) including changes in consumption preferences (Zukin 1990). Other factors such as the oil crisis (Aglietta 1982) or the rise of interest rates during the 1970s (Lipietz 1985) were pointed out as the external national level factor for the change in regime of accumulation. These, coupled with labour resistance to extreme Taylorist rigid practices of work (Tickell and Peck 1992; Harvey 1989), paved the way for an inefficient state intervention. Scholars of the regulatory perspective emphasized how the Keynesian regulatory state philosophies of Fordism were replaced by an alternative Schumpeterian Workfare State – essentially a receding role of the state in the economy (Jessop 1994; Scot 1988b; Harvey 1989; Gordon 1988) and even by new popular capitalism (Jessop et al. 1988) and deregulation at national level (Moulaert et al. 1988; Hirst and Zeitlin 1991). This new macroeconomic arrangement further shaped the decline of collective labour power (Gertler 1988), allowing for further rise of flexible practices and a new flexible regime of accumulation (Scott 2004).

Despite its popularity and the significant body of work on post-Fordism produced under the Regulatory perspective, it has been challenged on several levels. Painter (1995) summarises the critique as fourfold: Theological (seeing history as unfolding on an inevitable logic of development); Functionalist (a cause-effect binary relationship whereby the crisis of Fordism are causes of Post-Fordism); Technological Determinism (the assumption that social development derives from new technology, which however is only present in some scholar's perspectives); and lastly the emphasis on the coherence of a mode of regulation, with new developments only being significant between modes of regulation. Tickell and Peck (1992) offer however less of a critique, but more the view of a continued 'research programme (…) with links which have yet to be fully established' (Tickell and Peck 1992: 24). The missing links are most importantly the lack of research on the modes of social regulation by contrast with the prevalence of studies on the changed regime of accumulation, as well as the inconsistencies on spatial manifestations of what has been described as part of the same new Flexible Regime of Accumulation (Harvey 1987b).

But the merit of this approach, argued by some (Elam 1990) to be most encompassing than other perspectives, is that it integrates the socio-institutional conditions with the technological advancements and the economic outcome, and 'a generic interest arises in the mutual determination of economic and political processes' (Elam 1990: 66).

The regulatory theoretical framework has only partially influenced my own approach to my case study and my pursue of an understanding of innovative activities using manufacturing technology in a post-industrial context: in its view of development as unfolding; and in the definitions of regime of accumulation and mode of accumulation, which other frameworks reinterpret too. However, both the neo-Schumpeterian and the flexible specialisation perspectives, which follow, have proven more useful to my reflections because of how they emphasize the role of technology and of work processes in economic development.

The Neo-Schumpeterian Perspective

The Neo-Schumpeterian perspective on the changed economic, social and productive arrangement of post-Fordism has a base that can be traced to Kondratieff's theory of long waves to describe economic cycles, elaborated in the 1920s, and to Schumpeter's (1947) development of these a decade later focusing on the role of the entrepreneur and cycles of creative destruction that propel new economic cycles.

With the Neo-Schumpeterian approach, a unique techno-economic paradigm characterises each long wave, which establishes its own socio-institutional framework sustaining that arrangement for some time. Amin (1994) has usefully compared the techno-economic paradigm to the Regime of Accumulation and the socio-institutional framework to the Mode of Regulation of the regulatory approach. And, despite both approaches evidencing a cyclical interpretation of economic changes, the key difference is the salience of technology over the socio-cultural sphere in the Neo-Schumpeterian analysis.

For scholars associated with Neo-Schumpeterian (e.g., Perez 1985), the techno-economic paradigm was defined by a key factor, a dominant new technology considered in a broader sense, and change from one paradigm to another would happen when technological innovation is all encompassing, not just anecdotal, and superior to the existing dominant technology to drive a significant advantage across the whole economy:

> '…qualitative changes in capitalist production exceeding the simple sum of engineering trajectories – completely new worlds of work with new standards of efficiency; new models for management; new locational patterns; new high growth sectors and a redefined optimal scale of production' (Perez 1985, cited in Elam 1990: 45).

With technological leaps, the transition from one paradigm to another carried with it profound transformations of the socio-institutional systems, as:

> 'certain types of technical change (…) have such widespread consequences for all sectors of the economy that their diffusion is accompanied by a major structural crisis of adjustment, in which social and institutional changes are necessary to bring about a better 'match' between the new technology and the system of social management of the economy – or regime of regulation' (Freeman and Perez 1988: 38).

The problem of technological determinism (Elam 1990), and of positioning technology changes and adoption as an outside element relative to work practices, labour organisation and socio-cultural contexts was one of the key criticisms to this approach (Amin 1994), as well as the causational role of technology over socio-institutional systems (Nielsen 1991 summarised in Amin 1994). Elam (1990) refers to Sayer's (1985) point of lack of studies of individual work cases amongst the vast evidence collected by Neo-Schumpeterian's research to demonstrate this issue.

Scholars of Neo-Schumpeterianism tried to address this criticism by starting to integrate technology adoption with the socio-institutional systems that enable that adoption in their analysis (Amin 1994). Technology adoption was not seen as a linear process by scholars of this approach, but as trajectories over time or even constellations (Nelson and Winter 1977; Dosi 1982; Perez 1983). Some argued that for the innovation to be implemented over time, social systems needed to be in place, as well as ways to diffuse and communicate the innovation. In line with this perspective, an enabling related system was necessary. Perez (1983) had originally pointed out that the speed of adoption could be affected by existing infrastructures and social systems which for example could create regulatory frameworks that make it harder for the new technology to be adopted.

The speed of adoption of a technology has been linked to two types of infrastructures by scholars (Freeman and Louca 2001; Perez 1983): the physical infrastructure such as transportation and communication, and the science-technology infrastructure such as the skills of a group of people. Freeman and Louca (2001) discussed Perez's conclusions that institutional changes worked together with technological changes to drive growth as:

> '…system changes cannot take place except through a combination of profound social and organisational, as well as technical, innovations, and this necessarily takes a long time' (Freeman and Louca 2001: 144).

For Neo-Schumpeterian scholars (Perez 1985; Dosi 1982) Fordism was the fourth techno-economic paradigm defined by mass production industries and mass consumption markets, with oil and petrochemicals as the main sources of energy and a supporting Keynesian state. They also identified a structural crisis of Fordism (Freeman and Perez 1988), in their view resulting from oligopolistic industries with limited competition environments which were slow to change and incorporate innovation. With wage increases, their productivity gains were constrained and the labour relations at the time were rigid to address this decline, while political systems modified their priorities (Amin 1994) and the Keynesian state failed to address the technological changes (Freeman and Perez 1988).

Post-Fordism was rendered as the fifth long wave, or period of sustained growth, defined by the information technology paradigm (Perez 1983 and 1985, Freeman and Perez 1988; Freeman and Louca 2001):

> 'the Fordist mass production paradigm based on oil, automobiles and consumer durables encountered increasing social problems in the 1970s and 1980s, such as the OPEC crisis of 1973 and 1979, the environmental pollution associated with fossil fuel consumption, and the increasing dissatisfaction with Fordist work-styles. The slow-down in productivity growth, the much higher levels of unemployment of this period of structural crisis, and the problems of managing inflationary pressures stimulated the acceptance of ideas such as a 'change of techno-economic paradigm' and the widespread critique of the old mass production paradigm. However, it was only when computers, microelectronics, and telecommunications offered a new, technically reliable, and

> economically efficient mode of growth on a large scale that the new constellation could take over as the chief engine of growth.' (Freeman and Louca 2001: 314).

Based on the creation and development of semiconductors[16] and the subsequent expansion of computers in the second half of the twentieth century (Marsh 2012), this fifth period was also seen as more pervasive than previous technological paradigms, and it was assessed as influencing major social and political changes (Perez 1983). Scholars observed the 'dramatic nature of this technological revolution' (Freeman and Louca 2001: 301).

There were two key factors identified in this revolution: the computer and the internet, much in the same way as today advanced fabrication technologies have been associated with the next industrial revolution (Cities of Making 2018; Santos et al. 2017; Busch et al. 2021; De Propris and Bailey 2020; Laffi and Boschma 2021; Liao et al. 2017), the context narrative which forms the background to this research. The computer, based on Intel's microprocessor technology in the 1970's became affordable and spread to everyone's house, school, offices, etc. The internet profoundly changed consumer data, access to information, privacy, social relations. This fifth wave of technological innovation recognised by neo-Schumpeterian scholars also included hardware, software, telecommunications, the internet contents, mobile phones and biotechnology (Freeman and Louca 2001; Marsh 2012).

Scholars noted that it has been with the implementation of these technologies that certain economies have grown at exponential rates – the U.S. since the 1990's, and others since the 2000's. In their analysis, Freeman and Louca (2001) identified the financial market as an organisational and institutional outcome of the technological innovation in this wave, as it drove innovation by investing capital to further innovation but for that it aggressively targeted all forms of savings. The easy access to information for all people rendered many hierarchical levels unnecessary driving organisational changes. The hierarchical structures of Fordism were replaced by the

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[16] Semiconductors are 'electronic devices in which many single components capable of acting as electric 'switches' are packed onto a small piece of material. The basic job of each component is either to let electricity through, or block it, with its exact behaviour governed by electronic instructions fed via a software program. By being either 'on' or 'off', the switch can handle the digital language of the compute code' (Marsh 2012:11)

network firm (Freeman and Louca 2001), and networking inside and outside the firm, both over the internet and in person, gained importance. Castells (1996) claimed that with information, networks replaced the entrepreneur, the firm, the family and the state as units of economic organisation, which he considered the new stage in capitalism. Networking became crucial for growth when the bodies of knowledge produced increased exponentially side by side with degrees of specialism. This became key particularly for knowledge, services and cultural sectors which replaced manufacturing as the driving sectors of this wave of growth, and it can be demonstrated by the 'rapid growth of collaborative research, joint ventures, consultancy, various types of licencing and know-how agreements, joint data banks, and, of course, innumerable forms of tacit informal collaboration (...) however these changes all have to be seen in the wider context of society as a whole' (Freeman and Louca 2001: 327).

To conclude, the neo-Schumpeterian interpretation of the changes in production, economy and social systems stemming from the decline of mass production in northern contexts continues to be pertinent today as new fabrication technologies are associated with a new growth wave and possible reshoring of manufacturing (Johns 2020; Bryson and Clark 2013; De Propris and Bailey 2020). The emphasis on technological innovation as a trigger, disrupting existing equilibrium and reorganising the geographies of production are recurring themes in the emerging analysis around new production technologies (Santos et al. 2017; Lowe and Vinodrai 2020; Busch et al. 2021; Laffi and Boschma 2021).

The Flexible Specialization Perspective

This approach differs from the other two, as noted by Amin (1994), as scholars of this approach focused on the empirical changes in production itself, rather than on theorisation or deterministic accounts to describe and explain production and economic change which had dominated from the 1970s. Scholars of this approach focused on conceptual analysis of the crisis of Fordism, the changed production paradigm and the changed geographies of production (Piore and Sabel 1984; Hirst and Zeitlin 1991). These contributions are perhaps less clear conceptually because of the concentration on empirical analysis – for example, Hirst and Zeitlin (1991) situate Flexible Specialization analysis outside post-Fordism analysis in regard to industrial change.

Essential characterization of Flexible Specialisation was conducted by the work of Piore and Sabel (1984). They identified two industrial divides with respective labour processes and production organisation, which according to them co-exist, and at certain points in history one becomes predominant over the other. They claim that these paradigms characterize major periods in economic history and social organisation within industrial capitalism, and that there are industrial divides, when institutions, governments and industries favour one paradigm over the other. They identified crafts and flexible specialization as one of those paradigms, as opposed to mass production and labour division: Fordism was the mass production paradigm, characterised by special purpose technology, standardised goods produced by semi-skilled workers and a mass consumption market underpinned by a Keynesian government system (Storper 1989; Sabel 1989); post-Fordism was characterised by flexible specialisation of labour in production, an industrial paradigm rooted in craft production, involving skilled workers in the production of varied and more customised goods (Storper 1989; Sabel 1989; Hirst and Zeitlin 1991).

Flexible Specialisation scholars first attributed the change in production and the re-emergence of craft production to a new phase of industrialism, while studying the new clustered firms in Italy (Boschma and Iammarino 2009; Tomaney 1994). They identified flexible specialization as 'craft production replacing mass production as the industrial paradigm' (Tomaney 1994: 160), arguing that a new phase of industrial capitalism was developing, designated as the second industrial divide (Piore and Sabel 1984).

While there is no clear concept in this approach about how transitions happen from one paradigm to another (Amin 1994), scholars of this approach also identify a crisis of Fordism from the mass production structures themselves, plus market saturation of standardised products (Elam 1990) and a growing demand in consumption trends for non-standardised products, which were not deliverable by the rigid production organisations of Fordism (Tomaney 1994). Sabel (1989) also noted the rise of new technologies which allowed for varying production outputs and more flexible production practices, most notably the computer which allowed for smaller batches and more specialised ranges profitably (Sabel 1989). By the 1970s, as international competition rose, firms became also more cautious about technology investment as it could became obsolete sooner with consumer changes, and instead adopted more flexible production strategies such as subcontracting, outsourcing, and flexible technology which soon became more available. As such, in the new period, the previous rigid division of labour was no longer an effective means for raising productivity (Elam 1990), and a new type of industrialisation more akin qualitatively to crafts became more productive:

> 'Flexible specialised production systems seem better at surviving current conditions than the mass production systems they are displacing' (Sabel 1989: 104)

Storper (1989) summarises Piore and Sabel's (1984) essential characteristics of flexibly specialised industries as producing a varied and constantly re-worked range of goods for a consumption market of various tastes. These were done using flexible and more adaptable machinery for various tasks, which did not require investing in new technology every time a product changes, and which could be used by skilled workers combining functions of conception and execution, like what happens in craft production. Lastly, new firms were now competing but also cooperating in networks established over regional business markets.

Flexible Specialisation scholars observed and researched a shift in geographies of production (Sabel 1989; Storper 1989), from the corporation unit in Fordism to the industrial region in post-Fordism. Industrial districts of economic activity inherit the Marshallian district characterisation of the 1920s, no longer specialised but instead a matrix of production or production clusters, as later becomes prominent in literature (Porter 1990; Hall 1998; Glaeser and Kerr 2009; Neffke et al. 2011). These districts were formed of small to medium sized firms (Hirst and Zeitlin 1991) working in collaboration and subcontracting relationships (Sabel 1989; Storper 1989; Amin 1994). Key areas were the focus of flexible specialisation studies, most notably the Third Italy (Boschma and Iammarino 2009), West Germany's Baden-Württemberg (Sabel 1987, mentioned in Sabel 1989), Japan (Tomaney 1994; Elam 1990), Denmark (Kristensen 1987, mentioned in Sabel 1989) and Silicon Valley and Route 128 in the United States (Storper 1989; Scott 1988a; Saxenian 1985, mentioned in Sabel 1989). Regional economies are said to become the new model of urban industrialisation (Sabel 1989), transactionally related, at the same time more localised and more internationalised (Amin and Malmberg 1992).

In the new production paradigm, firms reorganise in smaller units, and expand inter-industry relationships (Sabel 1989; Storper 1989). These are accompanied by changes in managerial practices (Sabel 1989), blurring of hierarchies and extended relationships with subcontractors in the region to be able to meet demands for variation in outputs and more just in time production (Zyzman 2003; Sayer 1986; Elam 1990). Piore and Sabel (1984) suggested that mass production systems were characterized by prevalent managerial control, and that large corporations reorganised, and the control systems also flexed to address labour discontent and the dismantling of the Keynesian welfare support system. However, Tomaney (1994) notes that the absence of managerial control over 'craft work' was assumed rather than demonstrated in Flexible Specialisation analysis, and that forms of craft competence may also be embedded within a complex structure of collective labour effectively subordinated to strong managerial control, meaning that flexibility and re-skilling of workers may not have the advantages for labour that was assumed by Piore and Sabel (Tomaney 1994).

This Flexible Specialisation approach was also criticised for its dual opposition of the two industrial divides, and the point on returning to 'craft' in post-Fordism as unsophisticated and disregarding the role of Fordist corporations is controlling markets and influencing politics (Amin 1994; Elam 1990). Its lack of theorisation has also been pointed out (Amin 1994), but it may perhaps be its major strength, as it has carried the greatest weight in more recent case studies of new industries and industrial studies.

3.2.4 Beyond Post-Fordism

The post-Fordism analysis gave way to research on the new knowledge economy and the cognitive-cultural activities that came to characterise post-industrialism since the 1990s. Many scholars presented the transformation from an industrial to a post-industrial economy (Bell 1973, cited in Walker 1985) marked by the decline of industries with material outputs (Hamnett 2004; Pratt 1994b, 2009a and 2009b) and the flexibilization of production systems (Sabel 1989; Tomaney 1994; Scott 1988a and 2007; Storper 1989; Amin 1994) as the rise of services, knowledge and creative-cultural industries which gained the highest share in the sectoral composition of western urban regions (Prothero 2007; Hamnett 2004; Tym and Lang LaSalle 2011; Scott 2007 and 2008). Walker (1985) distinguished two aspects of this transformation, on one hand the services which have replaced goods as the principal output of the economy, and on the other, from a labour perspective, the types of service jobs which have replaced industrial jobs as the principal occupation of workers in these urban western regions.

Here I will review literature addressing the key activities that have become dominant in post-industrial urban economies, when the so-called 'knowledge economy' has replaced manufacturing as the engine of economic growth (Bell 1973, cited in Walker 1985) in many western regions. The literature reviewed in this section thus offers interpretations of the present as it is this economy which has been argued to lack in material outputs and in manual jobs, thus requiring diversification through the revivalof manufacturing with the application of new fabrication technologies (The Economist 2012; Rothkopf 2012; Nawratek 2017; Thomas 2019; Anderson 2013).

Below I expand on particular aspects of the characterisation of post-industrialism as studied by others, such as the nature of the predominant economic activities enabled by information technologies once manufacturing has declined, and the redefined social and economic geographies which have resulted from that. This thesis acknowledges these characteristics and argues that the types of new activities here researched, which have more recently emerged in relation to material production, are an extension of many of the activities that have come to characterise post-industrialism. In this sense, this thesis argues that we have not quite moved beyond post-industrialism and the respective growth wave, despite technological clues that may have indicated otherwise.

Cognitive and Cultural Post-Industrial Economy

The most recent production systems are, according to Scott (2007), based on innovative, knowledge, financial, services and creative industries as the most productive activities, alongside the reduction in output from manufacturing. The predominance of the cognitive-cultural industries as the most productive source of growth defines contemporary western economies. Here production involving digital technologies and flexible organisations sustains innovative sectors, diverse products which can be more flexibly produced and quickly changed, and a range of personalised services (Scott 2011). Scott (2007) summarises the post-industrial production system as:

> 'The cognitive-cultural dimensions of contemporary capitalism are identified by reference to its leading sectors, basic technologies, labor relations systems and market structures. Cognitive-cultural systems of production and work come to ground pre-eminently in large city-regions. This state of affairs is manifest in the diverse clusters of high

> technology sectors, service functions, neo-artisanal manufacturing activities and cultural-products industries that are commonly found in these regions' (Scott 2007: 1465)

Digital technologies are largely employed in the predominant activities, and workforce is flexibly employed in more abstract tasks employing social and intellectual skills. Competition between firms is now global, with certain products and certain firms dominating the market (Fujita and Krugman 2004). The use of knowledge and information as the engines of production increase in post-industrialism have been theorised by Castells (1996) as Informationalism. He argued that in the post-industrial mode of capitalist development information is the key element when knowledge acts upon knowledge as the main source of productivity.

The knowledge and cultural economy rely on human interaction–- whether human capital or institutions- to expand (Storper 2010), and employ a variety of intellectual and creative skills (Scott 2011) which have shaped society and urbanisation in post-industrialism (Hall 2004). 'The social structure of the late twentieth century was being shaped by the emergence of this new mode of development, Informationalism, historically shaped by the restructuring of the capitalist mode of production' (Castells 1996: 14). Defining the changed social relations in post-industrialism as the network society, Castells' assertion of the culture of the new network society is attributed to interactions of cultural, economic, political and technological factors of post-industrialism, but he does consider that the early development of Informationalism was triggered by technological changes (Freeman and Louca 2001). The technological revolution of computers and internet was, he argued, shaped by the neo-liberal forces leading to advanced capitalism which replaced the welfare Keynesian state, and they served it better and continue to serve late post-industrialism transformations. Castells argued that, although interactive, these are two distinct processes, capitalism restructuring and the rise of Informationalism.

The cognitive and cultural economy in post-industrialism has been associated with new patterns in urbanisation (Scott 2007; Scott 2000; Harvey 1987; Hall 1998), characterised by large metropolitan regions of global influence which concentrate the workforce (Sassen 2000; Esser and Hirsch 1994), which are localised agglomerations of production and consumption (Scott 2007; Harvey 1989). Sassen (2000) described the transition from industrial Fordist production to post-industrialism as part of the redistribution and re-organisation strategies of production into global production chains, with the ‘control centres’ located in what she describes as the strategic places, the global cities which coordinate production across the globe. Many low-skilled, low-wage workers are also attracted to these areas, often from developing countries, and they tend to carry out complementary jobs (Scott 2007; Sassen 2011).

Amongst the types of industries that have flourished in this most recent phase of capitalism, the creative industries have been some of the most researched and documented, particularly as their contribution to growth tended to be overstated in policies targeting areas suffering from de-industrialisation (Nawratek 2017; Evans 2009; Pratt 2008, 2009b, 2010; Hall 2004; Peck 2005).

The definition of what constitutes creative industries and the creative economy has been interpreted differently by organisations and authors. While some included in the creative economy industries with jobs that involve individual creativity (DCMS 2015; Bakhshi et al. 2013), others distinguished cultural and artistic industries from other fields of creative industries to define the creative economy more broadly, including even transactions between various industries with innovative outputs (Landry 2008). Others analysed the creative economy considering that creative production is distinct from the consumption and retailing of cultural products (Pratt 2008), pointing out that creative jobs can be undertaken within other knowledge industries without cultural outputs and that non-artistic occupations also play a role sustaining cultural industries. Some definitions leave out of the creative economy industries producing software and electronics – like many of the activities which are part of this research, including that of the DCMS, even if the nature of jobs is creative because the outputs are not of cultural or artistic value. The outcomes of the performance of the creative economy, its scale and its appropriateness to replace jobs and value of outputs lost with de-industrialisation thus depend on the definition which is adopted in the analysis. To address this issue, presently it is common in policy to have assessments done on the value and weight of creative industries in both terms: per industry and per number of workers performing creative tasks (see for example the London Plan 2016; Creative Industries Federation 2020; Togni 2015).

Creative industries gained traction as part of solutions for the problems of regional inequalities and uneven development characteristic of post-industrialism (Hall 2004). They attracted policy focus to counteract the effects of de-industrialisation, similarly to what is happening with the urban manufacturing revival or new industrial revolution-oriented policies (Cities of Making 2018; BIS 2017) and arguments (Busch et al. 2021; Hatuka and Ben-Joseph 2022), some of which have been replacing creative city policies (Nawratek 2017; Busch et al. 2021).

The creative city policy models were largely informed by the works of Landry (2008), Florida (2002 and 2004), and Schuster (2002). Florida, arguably the most distinguished (and contested) scholar informing those views concluded that 'regional economic growth is driven by the locational choices of creative people – the holders of creative capital – who prefer places that are diverse, tolerant and open to new ideas.' (Florida 2002: 223). Florida (2002 and 2004) argued the case for growth based on the ability of places attracting or retaining people, specifically a creative class of people. This was taken up by policy makers struggling to overcome regional decline in areas which were left depleted after the departure of Fordist productive industries. According to Florida, the creative class would be driven towards places where a culture of tolerance, investment in technology and similar talent were found[17], and these should be promoted by the public sector so that places could return to growth and rebuild a new economy after the decline of its former manufacturing sector. In the early 2000s the creative industries have often been presented as the 'great hope for new prosperity' (Heinze and Hoose 2013: 517) and as drivers for the rest of the economy. Their promotion through attracting a creative class of people was argued for a wider regeneration outcome. Significant examples of places investing and relying on these ideas for overcoming post-industrial decline include the Basque city of Bilbao, Hamburg, and Manchester Salford Quays, all former ports and heavy industry centres.

Other scholars vehemently contested Landry's and Florida's thesis (Peck 2005; Hall 2004; Pratt 2008) and argued that jobs instead attract people and lead on to growth (Duranton and Puga 2001; Storper 2010; Ostbye et al. 2017) and policies should, as a more effective alternative, be directed at job creation, wealth redistribution and democracy (Scott 2007; Pratt 2008, Peck 2005; Zukin 2010; Markusen 2006; Graeme 2009; Chatterji, Glaeser and Kerr 2014). The creative city policies gained nick names such as the Bilbao Effect (McNeill 2009) or the Cappuccino City (Nawratek 2017), as evidence emerged on ineffective examples (Evans 2009; Pratt 2009b, 2010; Hall 2004; Peck 2005; Boren and Young 2012) which did not deliver job creation targets, and

[17] These are the much discussed three 'T's of growth proposed by Florida: Tolerance, Technology and Talent (Florida 2002).

instead were vehicles for transferring public investment to the hands of private developers. Authors pointed out that creative industries, even in cities where they succeeded to contribute to growth, do not always offer the quality of jobs that policy makers thought they would (Pratt 2011; Heinze and Hoose 2013; Peck 2005). Researchers documented the difficult realities of the creative occupations: low pay, inability to continue social reproduction, lack of learning opportunities, reduced social diversity and precarious work contracts despite the intellectual and soft skills they require to perform their jobs.

Post-industrialism created a global system of competition, where regions or cites try to win over their neighbours by attracting investment and people (Hall 2004). They aim to create the conditions for innovation that can sustain growth, which is challenging for many regions of the northern contexts after the loss of manufacturing. Many sectors in the post-industrial economy rely on soft local factors for success, such as the location choice of certain enterprises, government functions, a culture of self-employment in an area, or cooperation between firms and local education institutions, particularly the creative industries (Heinze and Hoose 2013). And despite many places aiming to create new technopoles or new global centres of cultural production (Hall 2004), economic structures of the past and local cultures – labour culture, institutions, events, universities, heritage – exert an influence in the outcomes (Evans 2009; Hall 1998; Zukin 2010). Pratt (2010) consequently argued against a single policy model applied in different contexts, including regulatory. In conclusion, not all places where manufacturing industries have declined have had the same success in transitioning to the cognitive-cultural economy, and an uneven pattern of development characterises post-industrialism.

Residual Manufacturing in Post-Industrial Cities

With the rise of cognitive and cultural production not all manufacturing disappeared from post-industrial city economies. It has been argued that, despite significant decline, there are still some forms of manufacturing production remaining in post-industrial global cities, including in central boroughs (Giloth 2012; Sassen 2009 and 2011; Badgwell 2008). Following de-industrialisation, the collapse of Fordism and rapid closure of large production units, some cities still maintain small, specialised manufacturing units, frequently producing for the dominant economic activities of the city (Sassen 2011) or fabricating specialised consumption items (Bagwell 2008). These have been said to be often forgotten by city planners, or even threatened by planning regulations that prioritise office or residential uses (Sassen 2011; Ferm 2011 and 2016; Ferm and Jones 2014; Giloth 2012; Baker 2017). According to Giloth (2012), these may preserve tacit knowledge and labour expertise that may be valuable for the establishment of a successful new advanced manufacturing sector. This might be very city-specific, as directly associated with other dominant activities in the city–- arguably each city is unique in this respect (Scott 2000; Sassen 2011).

Regardless of each individual cities characteristics, there are common characteristics of manufacturing activities still viable and functioning in today's post-industrial cities–- activities with a deep level of local embeddedness, and very locally networked both in terms of its customers and its suppliers (Sassen 2011). Today's remaining urban manufacturing is often customised and organized in flexible labour chains (Sassen 2011), and in many instances the outputs of one sector is used by other sectors either as an input of production or an enabler of another economic activity. At the firm-level, these linkages manifest themselves in the form of customer-supplier relationships. Some remaining producing firms in post-industrial cities have supply chains comprising of many other urban firms (BIS 2012). Drawing on research in Williamsburg, Brooklyn New York, Curran (2010) argues that flexibility, creativity, and innovation of the new cognitive and cultural economy of post-industrialism can also be found in more traditional manufacturing activities remaining active in post-industrial cities. Edwards and Taylor (2017) go further, arguing that due to the significant role of residual manufacturing in cities, particularly supporting other sectors of the urban economy, the term post-industrial may be rather misleading.

But many of these manufacturing activities have been recently disappearing and have not been safeguarded by planning systems as well as they should have been if they are important to other sectors, as reported for example in London (Tym and Lang laSalle 2011; Ferm 2011 and 2016; Ferm and Jones 2014). The latest London Plan has acknowledged the need for no net loss of existing industrial land in the city, and supports combination of industrial with other (mostly residential) uses in new developments. But preferences for industrial occupiers that help to market the more profitable residential component of the schemes continues to lead to displacement of the original (more traditional) manufacturing occupiers, a form of industrial gentrification (Ferm 2020). Thus, the opportunity for traditional manufacturing remaining operational in inner post-industrial cities establishing links with the new emerging advanced manufacturing activities may already be compromised.

In her thesis, Ferm (2011) reflects on the recent loss of remaining manufacturing businesses in city areas. She identifies four reasons, none of them relating to the viability of these businesses themselves. The reasons summarised by Ferm are the inability of manufacturing to pay for central locations due to the increase in land values (Buck et al. 2002), political motivation, real estate speculation and associations between different actors – developers, policy makers, politicians, landlords – (Curran 2010). Financial sector pressure, and media campaigns (Zukin 1988) and the absence of public and political support for industrial growth in cities (Curran 2004) have also been pointed out as reasons for the recent closure of manufacturing in post-industrial inner-city areas. Other explanations have been presented from perspectives of gentrification (Curran 2007 and 2010; Marcuse 1999), and on the continuous commodification of urban space (Harvey 1987a). As Fraser (2012) notes, new contemporary global capitalism uses city growth and re-development as its means for expansion, and de-industrialization processes have provided both the purpose and the land necessary for investing the surplus. The emphasis on large office floorplates and on large residential blocks with amenity and good daylight levels requiring large development plots has reinforced the threat to small manufacturing units remaining in post-industrial cities (Fainstein and Campbell 2012).

This literature review now progresses through to the characterisation of the (allegedly) next phase of industrial capitalism which would follow after post-industrialism, based on an emerging technological paradigm involving new manufacturing and digital fabrication technologies. This thesis directly addresses this literature, stating that the evidence here collected points in a direction away from urban re-industrialisation and more towards an extension of post-industrialism itself, as new technologies (like 3D printing) are adopted by knowledge and creative sector activities.

A few conclusions can be raised from reviewing interpretations of the periods of industrial capitalist change and associated technological paradigms that matter to this thesis. First, the reading of production and associated economic systems through a technological paradigm point of view (Schumpeter 1947; Freeman and Perez 1988; Flusser 1993; Perez 2010; Dosi and Nelson 2013) is appropriate to frame the way this research has been designed, as well as the starting point of the enquiry on a possible new industrial revolution which clearly derives from a Kondratieff's economic history approach.

Second, accepting the breakthrough theories of capitalism progression as a useful reading of industrial history that can be combined with perspectives which argue that change can happen within the growth cycles as a process of continuity and that many technologies can co-exist at the same time (Tomaney 1994; Martin and Sunley 2010; Neffke et al. 2011; Frenken and Boschma 2007). Further to this, it is useful to appreciate that these perspectives also argue for the importance of the economic history of a region for the ways in which technologies are adopted in the area, and that this includes the role of social systems like local cultures and institutions in shaping the type of economic change that happens.

Third, considering the periods reviewed, the constant dichotomy (and tension) between mass and personalised types of production in relation to technologies, plus the nature of work that results from those technological paradigms–- whether more manual, repetitive, abstract, individual, controlled or collaborative–- are issues that permeate through all of the industrial changes summarised and that continue to shape the discussions around the present new fabrication technologies and their possible influence into a new period of growth.

The following section will now consider literature related to this research's second question on the location of emerging activities associated with 3D printing technologies in post-industrial cities. It will address the relationships that have been theorised between types of industries and their location, as well as between growth periods and the respective technological paradigm and the industries' location. Understanding what types of industries are located where and why there can also provide a useful basis to associate 3D printing activities this research finds and follows with the types of sectors and the economic paradigm these activities belong to.

3.3 Location of Industries

This review on the location of industries lays the foundation for the argument of what the location of new emerging activities related to 3D printing in London means for the geographies of innovation: more generally that location of innovation is primarily dependent on labour availability, agglomeration and socio-economic aspects of an area more than on technology; and more specifically, that new manufacturing technology is not shifting geographies of production structured around global value chains to localised manufacturing renaissance in urban cities, and instead helps to cement early stages of production and control of the process in centres of innovation like London.

Here I review key literature of industrial location and land use distribution in urban regions that explained the trends observed in industrialisation and de-industrialisation periods. These are being challenged by the present discussions in regional studies which assume that the emergence of new manufacturing technologies fosters the creation of new forms of productive value creation with spatial implications for urban spaces such as counteracting the effects of deindustrialisation (Busch et al. 2021) and changing production from spreading in multiple locations–- the global value chains to a single urban location integrating all stages of production (Johns 2021; Pegoraro et al. 2020).

This review on location of industries is thus structured in two parts: first where manufacturing, knowledge and creative industries are located, how that has evolved in recent industrialisation and de-industrialisation processes and the theories and models which have explained those spatial patterns. Following that, I review the recent perspectives in literature regarding where activities associated with new manufacturing technology are anticipated to be located and reasons given for those locational assumptions and hypotheses. Some authors propose that remote suburban locations will be important, others that these might be located in private homes due to the flexibility of technologies such as 3D printing. This review will highlight a couple of specific gaps in knowledge, such as the lack of empirical cases to back the theories and propositions of locational changes in production as a result of digital fabrication technologies, and the lack of spatial dimension implications in other literature concerned with the study of new manufacturing technologies.

3.3.1 Models and Theories of Industrial Location

Economic geographers and economists have been studying the location patterns of industries for decades. In early industrialisation, theories aimed at explaining manufacturing location factors as it conflicted with other land uses (such as residential) in inner urban areas (Von Thunen 1826; Marshall 1919). Later, as industries grew in scale and relocated to the edge of urban areas, models were constructed to address land values and congestion problems (Perroux 1950; Alonso 1964), as well the distribution of public funding and new infrastructure (Park and Burgess 1925). More recently, scholars have been concerned with de-industrialisation processes and offshoring of manufacturing, as well as with the rise of new economy industries with different locational trends (Piore and Sabel 1984). In all these decades, spatial implications of technological change have been a key part of the theories, as my study does too with particular regard to the technology of 3D printing.

Early Models of Land Use Distribution

In the early industrial revolution, the location of manufacturing was explained by the availability of water as this was the main power source, and later by proximity to distribution routes, such as canals and railways (see Darley 2003). Factory complexes were centralised and residential areas were in proximity for access to labour force who did not travel long distances and worked exceedingly long hours. Due to the insalubrious and overcrowded conditions of the places where people lived and the pollution derived from the nearby factories and transportation, cities started to be seen as problematic in themselves by authors such as William Morris, who described 'the hell of London and Manchester' (Morris 1902, cited in Batty 2008: 769) and Engels (1892).

Several theories concerning how land uses are distributed and organised in space have been developed since the nineteenth century alongside industrialisation. The early theories were concerned with the price and demand for agricultural land, and as the industrial revolutions progressed and production changed, theories and models focused on explanations of the structure of urban land. These included either the structure of economic activities or the location and prices of residential uses.

Neoclassical economists, understanding value in the economy as defined by the market, where equilibrium between labour, price, amount produced and profit is determined by an externality–- the trade value–- provide us with two strands on the theory of location of industries. Adam Smith, in the Wealth of Nations (1776), acknowledged that rent varied with the fertility of agricultural land. Ricardo (1817), also based on agricultural land, presented the theory that the most fertile land would pay higher rents and that the difference was given by the increase in productivity and that this resulted in competition amongst farmers for the land. Ricardo focused on the differentials in fertility, but neither Smith nor Ricardo offered actual methods to determine land values.

Not yet designated as bid-rent theory, and still on the basis of agricultural land, Von Thunen in 1826 combined land costs with transportation costs, and developed a theory whereby the farmer is expected to maximise its profits from the land as a consequence of exploiting the use of the land and the transportation costs given by the distance to the city. This resulted in concentric rings, the Thunen rings, which represent the spatial structure of agricultural production.

Alfred Marshall (1890) devoted a chapter on urban land values, where he emphasises the importance of location. He concludes that the industrial demand for land is in all respects parallel to the agricultural, and he also points to the question of size of the parcel, and to the bidding process for the land whereby the land is contested by potential users and the highest bidder wins. Alfred Marshall's conceptualisation, elaborated in Industry and Trade (1919) from the analysis of industrial districts in nineteen's century Birmingham, England, points to the notion of 'industrial district' being established based on the social division of labour found within a particular region. He recognised a relationship between the location of firms and their economic efficiency. The notion of Marshallian district has explained why businesses of the same type cluster together, which is the basis for the arguments for economic advantages for industries arising from specialised agglomerations (Duranton and Puga 1999; Henderson 1974). Marshall's theory has provided a basis for spatial policies promoting for example new technological clusters in regions lagging behind.

In the late 1920s, with the rebuilding of the British post-war economy, industrial location entered a new stage, as the new roadways and the new trustworthy electricity network opened up edge sites for factories. There, a labour force was also available due to suburban housing expansion, and so many industries settled in places such as

Wembley, Park Royal, Perivale and Ealing in the outskirts of London (Darley 2003). Many of these are still industrial sites today. In tandem, entirely new towns were masterplanned and built from scratch[18] to either house a growing population away from industries – creating the principle of separating industries from residences, or to create towns centred around an industrial complex but where manufacturing could healthily be located next to worker's homes[19].

Following from Marshall's work, in the 1920s Haig (1926) conceived a theory of urban land versus agricultural land, where he adds the concept of 'friction costs' which are the transportation costs seen as overcoming the question of proximity to a certain extent, therefore explaining complementarity between rents and transportation. The most convenient arrangements would, in a Marshallian equilibrium, determine the lowest costs and explain both values and land use distribution.

Transportation networks expanded and larger Fordist industries located along the edge motorways. The notion of 'growth pole' was then developed by Perroux (1950) as an explanation for the agglomerated location of industries outside urban centres during servicisation processes, particularly in the United States and in Britain. This follows from the idea that, as the firm grows, other smaller firms will be attracted to the same location. In this way, economies of scale will develop and generate a network of suppliers. The growth pole notion supposes larger and smaller firms, and does not therefore explain the concentration of firms of comparable size.

The bid rent model was influentially developed by Alonso in 1964, on his theory of location and land use. Bid rent models represent the way activities are distributed in

[18] These include Ebenezer Howard's Garden Cities Movement where the industrial zone and the railway station are the outer rings of the town separated from the residential quarters. The Garden City principles were applied first across England for example in Letchworth, Harlow, Welwyn, Hampstead, and later exported to countries such as India, the U.S, Germany, France. The Garden City model is still a reference in current town planning practices, including in government funding strategies for development. See for example the Garden Communities presently funded by the Department for Levelling up, Housing and Communities.

[19] Plans of industrial towns during the early industrial revolutions, both in Britain and in Europe included for example the plan by Salt near Bradford, named Saltaire, Bourneville near Birmingham for Cadbury, New Earswick near York for Rowntree (Darley 2003), and others associated with certain brands of products such as the Bata Ville in France or the Ford Factory in Dagenham, Thames Estuary. In these, the factory assumed a distinguished location, many times central to the plan and central to urban life.

the city space, which result in concentric rings or sectoral diagrams. It explains the way price and demand for land uses varies according to its distance to the centre. It is based on the notion that different activities are prepared to pay different prices for the land according to the profit or value they can derive from that location, and that the activities who derive greater advantage outbid the others for the land. The amount they are prepared to pay is represented by the bid price curve. Land use is therefore associated to land value. In Alonso's model the city is viewed as located in a featureless plain, and land is equally available, freely bought and sold. Both buyers and sellers are assumed to be knowledgeable of the market and the theory is modelled within an equilibrium condition, assuming also that the individual taking the decisions is an Adam Smith's 'economic man' and will decide rationally based on economic value only. Alonso's theory is one of the most influential explanations for land use distributions for combining economic activities and residential uses in urban space, although the fundamental assumptions of the theory form the basis for criticisms and more recent developments on theories of land uses distribution.

But changes in the location of industries and alterations in the distribution of land uses in urban regions in the 1970s and the decline of Fordism started to highlight some of the insufficiencies of these earlier models (Kivell 1993). These changes gave rise to new theories and new angles for the analysis of the location of industries which will be reviewed in the next sub-section.

Relocation of Manufacturing and Clustering of Knowledge and Creative Industries in City Centres

In post-Fordism, the shift from manufacturing to information and knowledge economy was accompanied by a process of decentralisation and relocation of manufacturing uses, and city centres experienced some decline from the 1970s through to the end of the twentieth century. Many large industries decentralised and located in peripheral areas, frequently near motorways, and railway lines. These trends were particularly strong in the United States (Garreau 1991) associated with dispersion of residential land uses, but also in Britain despite green belt planning policies established to contain the same type of expansion and suburbanisation (Hall and Markusen 1985). These trends created new locational patterns of land uses, both regionally and globally. Bid rent models alone could no longer explain the post-industrial tendencies of manufacturing activities to locate in peripheral areas, nor the tendencies of the new cultural and knowledge activities to concentrate in central city areas and cluster together, as their location is not solely determined by the balance of revenue potential in a particular location given by the costs of rent and transport (Kivell 1993).

The separation of design, production and consumption across geographies in post-Fordism led to places of manufacturing production spreading further across the globe (Massey 1984) and Global Value Chains[20] were formed. Most material production located to regions with lower labour costs where certain work cultures could be trusted. As described by Esser and Hirsch (1994), 'the advantages of these locations are based less on their geographical situation, but increasingly result from the availability of a qualified workforce, the combination of specific industrial services and research capacities, advantages of contacts and agglomeration, as well, of course, as favourable political conditions for capital. The 'post-Fordist' metropolitan city is less than ever the product of natural conditions of location but rather of economic strategies.' (Esser and Hirsch 1994: 80). Recent models, like the New Economic Geography (Krugman 1991; Krugman and Venables 1995; Fujita and Krugman 2004), explain these as a result of the declining costs of transport, including mostly maritime connections and containerisation.

Associated with this global order, we have seen in post-industrialism the emergence of global cities (Sassen 2001), defined as exceptionally large metropolitan areas which control the financial and production systems, and where cultural and innovation production influences the whole world and where products made elsewhere are marketed, sold and consumed. Castells (1996) argued that material resources for the agrarian and industrial city have been replaced by knowledge and information in the era of Informationalism, and that this led to new land use locational patterns. In his theory, three kinds of localities are important: those that provide synergetic,

20 Global value chains (GVC) can be defined as the 'full range of activities that firms and workers do to bring a product from its conception to its end use and beyond' (Gerrefi and Fernandez-Stark 2016, cited in Livesey 2018: 180). Technological improvement and the costs of transport, access to resources and markets and trade agreements have facilitated the fragmentation of production across global locations according to the comparative advantage of locations. Global value chains (OECD, 2012) is a framework of analysis originated in the 1990s. GVC analyses where value is created in the production chain, and determines where the 'lead firms' are located.

innovative knowledge for high level activities; international command centres; and locational flexible areas for office and manufacturing functions.

With the relocation of material production and break down of material production in geographically distinct stages and spaces, creative production has grown to form an important part of the economies of the contemporary metropolis in western global cities. Following a period of decline of the inner-city areas, now activities such as cultural and creative industries, knowledge and high technology locate in central areas of cities (Hutton 2008). This process of redevelopment of inner areas of cities in the established post-industrial context, and the growth of creative industries has been associated with the fragmentation of supply chains globally, where the post-industrial global city has retained the initial stages of product creation and value-added functions (Duranton and Puga 2001; Storper and Venables 2002). Redevelopment of inner-city areas–- for both residential uses and creative businesses -has also been associated with the more flexible forms of labour characteristic of the post-industrial economy (Scott 1988a and 2007), where the growing social division of labour has been identified as a central force in capitalist development (Sayer and Walker 1993). In post-industrial sectors of production, the structure of production is thus articulated in dense networks of vertically and horizontally disintegrated production processes (Scott 2007). As pointed out by Zysman (2003), this has represented a fundamental shift in the organisation of production, supply chain and distribution channels since the beginning of industrialism.

The urban nature of creative industries, and why they have tended to be in cities, and inner areas particularly, has been widely pointed out and presented as both a consequence of the socio-economic changes of the post-industrial context and of the industries' intrinsic processes of work. These include availability of specialised people and pool of workers, social relations and social networking, the need and availability of places for encounter–- the social urban spaces, facilitated by central city built and inhabited density (Storper 1997; Scott 2000; Foord 2012).

A distinct perspective by Zukin (2010) connects the location of creative businesses in central city areas with the desirability created by the media around artists' lifestyle and loft living. She highlighted the role of media in fostering this contemporary urban experience of the post-industrial city, and that technology has also had a significant contribution to the location of the creative sector in the centre of cities, alongside the rise of certain types of consumer culture. Other scholars also associated the location of creative industries focused on consumption - rather than production–- in city centres (Pratt 2008) with the growth of the experience economy and the creation of local identity in a post-modern socio-cultural condition (Harvey 1989), as post-industrial cities became places of consumption and leisure (Pine and Gilmore 1998; Lash and Urry 1994).

Foord (2012) reviewed an extensive body of literature on the reasons why creative industries are typically located in urban areas, which are, in summary, access to complex production chains; diverse specialised labour markets; publicly funded arts and cultural organisations through which cultural / creative 'products' are circulated; reduced transaction costs, for example when a group of individual creative professionals are organised around a project; support for collective learning and knowledge transfer; creative workers seeking some stability of work which is very challenging, but can have more chances of happening in cities and a larger flow of people and ideas to come by (Scott 2006, Chapain et al. 2010, Pratt 2006, Van Heur (2009), Markusen (2006) and De Propis and Hyponen (2008) reviewed in Foord 2012). The range of customers that allow for experimentation with customers or audience has also been argued for the creative economy concentration in urban areas (Potts et al. 2008).

The work of the Industrial Divide theorists Piore and Sabel (1984) associated localised agglomeration of knowledge and innovation industries with the changes in production from Fordism to post-Fordist flexible specialisation, where groups of smaller firms replaced one large, big firm (Hirst and Zeitlin 1991). Piore and Sabel's work also highlighted the role of government and cultural institutions where marketing of an area or incentives may explain the new industrial locations. With their Piore and Sabel's work and the observations of how, on one hand new economy industries cluster in city centres, and on another new manufacturing production is divided into small, networked firms clustered in certain outer regions there has been a renewed interest in the work of Marshall (1919). His theory on the benefits of agglomeration and on the specialised nature of clusters (Storper 1989; Amin 1994) have provided sound explanations for the formation of new industrial districts in western economies such as Third Italy (Boschma and Iammarino 2009), and Silicone Valley (Storper 1989; Scott 1988a) have provided the foundations for government support to regions in bids to overcome effects of de-industrialisation. The location of industries become at the same time more localised and more internationalised (Amin and Malmberg 1992).

In post-Fordism much was analysed about the new unevenness of industrial location and development and the formation of industrial clusters of Marshallian characteristics (Sabel 1989; Storper 1989; Porter 1990; Hall 1998) due to the subcontracting relationships established in flexible production chains. Following the observation of the competitive advantage of clusters, Porter (2000) defined clusters 'as geographic concentrations of interconnected companies, specialised suppliers, service providers, firms in related industries, and associated institutions (e.g. universities, standards agencies, trade associations)' (Porter 2000: 15). He argued that the success of a firm and its location is not only due to firm's factors but also to agglomeration externalities, which are generated by clustering.

Scott (2002a) summarised the benefits of agglomeration, or clustering as fivefold: 1) Interfirm transactional relations, both traded and untraded which refers to availability of more supplies for example and reduction of transaction and transportation costs, as well as risks associated with that; 2) Local labour markets, which are efficiencies obtained from availability of more labour locally, attracted to the businesses agglomeration, with the appropriate (and local) knowledge; 3) Structures of learning and innovation, which are local knowledge occurring from many firms clustered and from workforce exchanging views, getting together at business events etc, as well as from local institutions gathering and reproducing that body of knowledge; 4) Institutional infrastructures, which refer to benefits arising from a local institutional framework directly related to the local business needs and designed to reinforce the region's competitiveness; and 5) Physical infrastructures, which can offer economies of scale in agglomeration and be better and more viable in those conditions.

The cluster theories however tend to leave out of the analysis the cost-based competition or the 'diseconomies of agglomeration' as described by Turok (2004), which are that agglomerations increase the demand for land, which in turn increases land prices and rents for all land users. Further to this, cluster theories for the explanation of the location of industries were challenged by scholars as being in essence an equilibrium-static model (Duranton and Puga 1999 and 2001), which therefore could not account for the path-dependency of places, meaning the history of production and of firms in that location (Martin and Sunley 2010; Storper 2013; Tomaney 1994) which explains why not all clusters are successful.

Lastly, there are alternative perspectives to flexible specialisation on the contemporary location of industries and the inadequacy of traditional location theories and models to explain the location of modern industries. Briefly, scholars analysing the transition from Modernism to Post-Modernism (Harvey 1987b and 1989; Lyotard 1984) have suggested those locational patterns have changed from modern technocratic, rationalist standard forms of production to post-modernist heterogenic fragmented and even undetermined arrangements, and this has led to chaotic locational patterns of industries. Likewise, an alternative theory based on chaotic fractal interpretations of contemporary urban land use urban patterns has been proposed by Hillier (2004-2007, 1st Ed. 1996) to explain the location of non-residential uses in urban areas as a function of accessibility levels along routes, the foundations of the space syntax discipline. And, the gentrification literature, originally concerned with the displacement of working-class residents from housing by higher income people (Glass 1964; Slater 2006 and 2009; Lees et al. 2008; Marcuse 1999), has also provided explanations for the relocation of manufacturing industries away from city centres. In these perspectives, the displacement of industrial uses in the centre of cities has been caused by the expansion of residential gentrification in well-connected areas. These theories have been advanced for example in the analysis of cases such as Williamsburg in New York and East London (Curran 2004, 2007 and 2010; Hutton 2004 and 2009; Zukin 2010).

Given we are potentially in the beginning of a technological paradigm shaped by new manufacturing technologies, the usefulness of these models and theories is to set a basis from where the location of this new wave of innovation can be analysed. Can (should) we do away with the bid-rent model, and key concepts like clustering and replace them with something else because a new portable flexible technology like 3D printing mean that clustering is not necessary and that the value of a central agglomerated location is irrelevant for the economics of production? And could the global value chains and de-industrialisation be reversed, could material producing industry return to western economies and production revert to single locations in urban areas? Most present literature on the location of new manufacturing technology related industries present perspectives that could challenge–- in some form–- the theories and models here reviewed. The next sections expand on those scholarly perspectives..

3.4 Growth through Innovation

The question of how cities can generate and sustain growth has been a key discussion in economic geography, particularly since processes of industrial decline have affected western cities. Many city policy makers have dealt with the problem of how to add jobs, and how to re-start and sustain growth after industries of mass production departed to other regions. Returning to 'making things' and re-industrialisation has been articulated as a hypothesis to sustain growth and jobs, particularly in association with advanced manufacturing technologies. The argument for the pursuit of sectoral diversification involving manufacturing in post-industrial cities as a strategy for resilience and growth, which this research takes as its starting point, has many routes in literature which are reviewed here.

I will review first the concept of resilience, followed by perspectives and research addressing diversification versus specialisation of business agglomerations in relation to economic growth. Lastly, I will review the most recent research outcomes on how innovation processes in post-industrialism take place, including how they rely on exchanges of knowledge through a combination of formal and informal channels - both physically and virtually - and how agglomerated environments facilitate these exchanges which are vital to creative and knowledge sectors.

3.4.1 Resilience

The concept of resilience applied to urban economic systems gained momentum in research after the 2008-2012 recession, when there were debates about how the economy of a region is affected by or can overcome downturns. These are an inherent characteristic of capitalist evolution in the perspective of those which described growth as cyclical with moments of disequilibrium, such as Schumpeter, the Neo-Schumpeterians and even the Regulationists.

The concept of resilience, according to Martin (2012) who combines it with the economic notion of hysteresis, is the ability of a local economy to recover from a shock, crisis, or disruption. Martin quotes Hill et al. (2008) on the resilience definition as:

> 'the ability of a region. . . to recover successfully from shocks to its economy that either throw it off its growth path or have the potential to throw it off its growth path' (Hill et al. 2008, cited in Martin 2012: 4)

Besides being used in relation to extreme events such as earthquakes, storms, floods, etc. in engineering, governance and disaster management, the concept of resilience has also been more recently adopted by evolutionary perspectives in economic geography (Boschma and Martin 2007; Martin 2012). In these studies, a region's economic performance is argued to be path dependent, meaning that a recession can affect a region for a long time, impacting its long-term performance and even turning the course of its performance irreversibly. Thus, resilience emerges as a very desirable objective for an economic system. Regional economic resilience in this research is thus viewed as per Martin's perspective:

> 'having to do with the capacity of a regional economy to reconfigure, that is adapt, its structure (firms, industries, technologies and institutions) so as to maintain an acceptable growth path in output, employment and wealth over time'. (Martin 2012: 10)

A region's ability to be more resilient has been associated to the innovativeness of existing firms, entrepreneurialism culture and existing labour (Hall 1998 2004; Martin 2012), as well as to the diversity of a region's portfolio (Conroy 1975). The first set of reasons can be related to characteristics of local institutions and to the local socio-cultural arrangements. The second argument is more related to business fluctuations, market changes, labour and material availability affecting in distinct ways different industries, comparable to the financial 'investment portfolio' strategy (Martin, 2012). In sum, resilience can be gained through a combination of socio-economic factors with deliberate strategies for economic diversification spreading the risk of recession across diversified sectors, assuming they would not all have downturns at the same time.

3.4.2 Diversification for Growth and Innovation

The advantages of clustering and the question of innovation for growth has not always been answered from the same perspective and specialisation versus diversification analysis exists. In fact, arguments of specialisation were influential for a long time, and are still relevant to contrast with the arguments for diversification which are becoming more prominent.

As reviewed by Duranton and Puga (1999) the theories of how regions grow can be grouped in: static theories focused on internal geography of cities, static theories focused on inter-city relations and dynamic theories, where perspectives of analysis over time are integrated. The first two offer explanations for specialised agglomerations as advantageous for growth, whereas the third theoretical approach explains that diversification is, over time, a better strategy for growth. This division between static and dynamic theories can also be routed in economics, as distinguished by Schumpeter (Schumpeter 1910, quoted in Freeman and Louca 2001), who in the early twentieth century points out that a dynamic view is necessarily an evolutionary view, even if it were a movement towards equilibrium.

The first set of static theories, most notably the neoclassical Marshallian perspective on the costs of production (Marshall 1919; Romer 1986), assumes that specialisation and monopoly generate further growth. Savings are achieved when common resources are shared, and when more of those resources are commonly shared, greater efficiency is achieved. These resources would be the local pool of labour, local supplier linkages, institutional resources, infrastructure, and local knowledge spillovers, from where firms received increasing returns. Equally, monopolies restrict ideas from dispersing, therefore adding up value through efficiency. This theory, also modelled by Henderson (1974) explains the equilibrium of a city's economic system in a point in time, where there is economic advantage in specialisation due to shared costs, and low trade and low transportation expenditures across different city regions. In this perspective, it is also assumed that production increases with increase of employment in one sector.

In MAR (Marshall- Arrow - Romer) model, as it is also known, the three effects from specialisation are the knowledge transfer which generates further innovation, transport costs and labour market pooling. This assumes that knowledge transfer externalities happen positively only between firms of the same industry, fundamentally through processes of imitation, business interactions, and exchange of skilled workers across firms. These are known as localisation or Marshallian Externalities. In the Marshall model, concentration of industries helps growth due to knowledge spillover between neighbouring firms of the same sectors. This leads on to the growth of that sector, increased specialisation, and in turn leads on to further economic growth of the region (Duranton and Puga 1999).

Porter (1990) also argued for specialised agglomerations as a growth strategy, as part of his theory on clustering of activities and firms for rising regional and national performance. But, instead, Porter saw advantage in the competition rather than monopoly across same sector firms located in specialised clusters.

The second set of static theories, a vast body of research commonly grouped as the New Economic Geography, also argues that further growth is achieved through greater specialisation. This model of analysis is based on an inter-city perspective, where regions tend to specialise to reduce production costs when trade and transportation between regions remains affordable. Through general-equilibrium modelling of an entire spatial economy, which according to Fujita and Krugman (2004) is a distinct feature of this analysis, the New Economic Geography theory developed by Krugman (1991) and Krugman and Venables (1995), explains that cities will specialise as they trade, due to low trade costs. Other associated activities are not excluded and are acknowledged in the model as they exist within the specialised cities set in a global trade system. But, according to this theory, those activities do not justify the cities' diversification as they are explained as subsidiary of the main activity and dominant sector. In New Economic Geography cities trade with what is cheaply produced elsewhere. In this way, according to this theory, cities are subject to forces of anti-diversification for economic reasons.

> 'That is, in general equilibrium, it should allow us to talk simultaneously about the centripetal forces that pull economic activity together and the centrifugal forces that push it apart. Indeed, it should allow us to tell stories about how the geographical structure of an economy is shaped by the tension between these forces. And it should explain these forces in terms of more fundamental micro decisions.' (Fujita and Krugman 2004: 141)

These two types of theories model urban economic systems in a given point in time, arriving at specialisation as the preferred strategy for growth (Duranton and Puga 1999). In more recent dynamic theories, by contrast, diversification strategies lead on to further growth, and it is on this basis that this research has proceeded to research the prospects of advanced manufacturing driving a revival of productive industries for resilience of the urban economic system in post-industrialism. This dynamic set of theories, analysing urban systems over time, show that diversified agglomerations grow more than specialised agglomerations, but that there are indeed forces of concentration and dispersion that result from economic development, and those dynamics help explaining the urban economic system as it takes shape.

These theories consider that the benefits arising from agglomeration can be of two types combined: localisation externalities, like the equilibrium models, which are benefits for industries of the same sector clustered together emerging from shared labour, shared institutional frameworks, shared infrastructure etc. and urbanisation externalities, which are gains that result from clusters of many different kinds of activities when sectors cross innovation, technologies, even labour (Scott 2002a).

In contrast with the previous static theories, the arguments in support of diversification to achieve resilience and growth derives from Jacobs's (1969) perspective that work leads to more work, and that knowledge spillovers which might occur between industries in a locality, as much as within industries, have the potential to generate new work and new firms. These are commonly described as the Jacobs's Externalities or urbanisation externalities. The argument is based on innovation emerging from the interactions between people in agglomeration, from outsourcing of work and from branching out. Jacobs (1969) argued that diverse, mixed city economies with smaller sized firms, rather than monopolies and large firms would generate more positive externalities and, in competition, would speed up the adoption of technology generating further innovation.

This is a view related with Schumpeter's approach to economic cycles, as entrepreneurship is in this context fundamental for growth. It was described by Allen as 'the function of carrying the adventuresome innovation' (Allen 1991, cited in Freeman and Louca 2001: 52). In this notion, growth is fixed to technological innovation in that it depends on the ability of the entrepreneur to disrupt equilibrium from within the system.

But not much evidence has been presented to support such views, and only recently has research been able to provide empirical evidence for Jacobs's externalities. Key studies speak to the question posed in this research, as to whether urban growth and resilience may be achieved through sectoral diversification, particularly through industries with material outputs in a context of a knowledge dominated economy like London. My study on the activities which emerged in London in connection with 3D printing presents evidence related to, on one hand, how an agglomerated environment like London is a breeding ground for innovation related to a new technology. On another hand, it points to the limits of that innovation, which are such that the activities found in this study are found to be closely related to the existing economic sectors.

Glaeser et al. (1992) asked more specifically whether diversity triggers further growth in comparison with specialisation. By looking at 170 largest U.S. cities in the period of 1956 and 1987, they found out that smaller firms, diversity, and local competition fostered urban growth, whereas specialisation reduced employment growth. In their research, they find that industries grow faster in cities where firms in those industries are smaller than the national average size of firms in that industry. In their conclusions:

> 'interpretation of this evidence is that interindustry knowledge spillovers are less important for growth than spillovers across industries, particularly in the case of fairly mature cities.' (Glaeser et al. 1992: 1151).

Glaeser et al.'s research (1992) demonstrates that Jacobs's diversification arguments have merit in regard to growth, by contrast with the arguments for specialisation when a dynamic model is used. The study also shows that regional economic growth is co-related with the presence of many small firms, and not a few larger firms. They suggest, in the same paper, that the research on growth should change its focus from analysing certain industries or sectors, to following instead spreads of ideas across sectors.

In a more recent paper, Glaeser and Kerr (2009) argue that the answer to the question on how to return to growth, as posed by the recent recession, should be answered with more small firms in more diversified environments. This is based on a study of American urban regions which showed that:

> 'cities whose number of "firms per worker" was 10% higher than the average in 1977 experienced 9% faster employment growth between 1977 and 2000. Data can be misleading, of course, so it's reasonable to wonder whether industry structure, tax policy, or some other special circumstance skewed the results. The answer is no: Even adjusting for such variables, the relationship between small firms and job-growth rate stands (...) Compared city industry clusters: similar clusters of same industry in different cities, and similar clusters of different industries in the same city. The result still stands: the industry clusters with firms of smaller size experienced greater employment growth' (Glaeser and Kerr 2009: 26)

Feldman and Audretsch (1999) also argued that sectoral diversification has a positive effect on innovation, as in a diversified agglomeration knowledge gets recombined and becomes a source of innovation, and this process has been noted as being self-perpetuating (Storper 2013), as innovative and growing regions continue to attract more people, particularly in today's global context of labour mobility.

This process of knowledge transfer and innovation has been documented in the London context as well, the focus of my empirical study, for example in the digital cluster and the creative cluster around Shoreditch area. In the context of the 2008-2012 recession, Foord (2012) described the dynamics of the digital cluster, including its sector combinations, markets, and firms. Its strength was contrasted with the faltering position of the longstanding local arts and crafts creative industries, and its vitality was associated with the risky experimentation across co-located sectors in which unrelated knowledge and activities were being combined. It is also stated that it emerged in this location due to the previous clustering of creative industries, the older arts and crafts, pointing to an earlier set of arguments mentioned on the importance of local characteristics and local institutions being also influential for re-starting growth after a recessionary event and for continuing innovation.

Although the discussion has been framed so far in terms of Diversification versus Specialisation, as the case for Diversification is set, it is also true and observable that specialised agglomerations continue to exist, and some do not just decline. This has been associated in literature with firm and product life cycle, where there is a role for specialised cities as well in the complex global urban system. Different cities are related to distinct phases of the product life cycle: diversified cities are suited for innovative firms, and specialised cities are better tailored for the later stages of the product. Duranton and Puga (2001) established the link between innovation and local diversity, arguing that firms at the innovative start-up stage will locate in a more diverse agglomeration as they benefit and thrive on the processes of knowledge transfer as described by Jacobs.

The effects of externalities resulting from specialised agglomerations have been found to be slightly stronger in low-tech sectors, while the positive impact of Jacob's externalities increases with increasing technological intensity (Henderson et al. 1995). Cross-fertilizations and spillovers may therefore be more useful in high-technology sectors and at the early stages of product. Neffke et al. (2011) provided further empirical evidence of the hypothesized link between agglomeration externalities and the life cycle stage of production. This association between the production life cycle and the type of city had already been hinted at by Glaeser et al. (1992), when they argued that:

> 'One could argue, alternatively, that industries have a life cycle, and externalities are important only at the beginning, when new products are introduced.' (Glaeser et al. 1992: 1134)

More recently, Duranton and Puga (2001) argue more strongly, and with evidence, for this relationship between the product cycle and the type of city. In their research:

> '[We] derive conditions under which diversified and specialized cities coexist. New products are developed in diversified cities, trying processes borrowed from different activities. On finding their ideal process, firms switch to mass production and relocate to specialized cities where production costs are lower. We find strong evidence of this pattern in establishment relocations across French employment areas 1993–1996' (Duranton and Puga 2001: 1454)

The analysis by Duranton and Puga (2001) on cities being nursery places for matching, learning, and sharing is significant in this context, highlighting that knowledge sharing and cross fertilisation of ideas happens with the vibrancy or 'buzz' (Storper and Venables 2002) of diversified agglomerations. Urban diverse concentration, as a space for breeding products and production processes, is the preferred context for start-up and smaller firms. When a firm has found the ideal process and wants to scale up, it relocates to areas where it can grow and where rents are lower, and where it can find specialised labour, to specialised cities, which are normally in more peripheral areas, the edge cities (Garreau 1991). Firms that relocate to more peripheral regions do so at a later stage of their product development once their production process is set. Or simply outsource their product to other locations and continue developing new innovative ones.

At product 'incubation' stage firms tend to seek out the mutually supportive environment provided by a concentration of other similar firms (Duranton and Puga 2001), and in city centres firms they can benefit from various positive agglomeration effects, such as for example what Scott (2002b) finds in the analysis of the clothing industry in central Los Angeles. These are not just availability of labour and proximity to facilities and other similar firms but also marketing, established tastes, mutually reinforced links like the cultural economy of Hollywood Academy, a fashion event as well as a movie event. He also noted the establishment of education programmes tailored to this industry needs. These are particularly important in creative and innovative industries. But, as firms grow and expand, they become more self-sufficient and less dependent on other firms or the availability of such externalities and can take advantage of lower land costs in more peripheral locations (Duranton and Puga 2001). So, in this way, cities are subject to forces of dispersion and agglomeration at the same time and over time (Duranton and Puga 2001). This process of perpetuating economic growth is self-feeding and self-enforcing, circular and cumulative.

Research by Henderson et al. (1995) also suggests that diversification is important to attract new and more innovative sectors, rather than the more traditional ones. Their view is also that diversification does trigger a steeper growth path. However they caveat that the sectoral history of a region seems to influence the location choices and the performance of some industries. This is a point consistent with evolutionary perspectives in economic geography which highlight limits to diversification based on regional production culture.

In summary, it can be said that there is a robust body of literature supporting the perspective that material producing activities using innovative manufacturing technologies may contribute to growth in a post-industrial de-industrialised region, where it can establish links with other sectors and be part of innovation processes at the initial stages of product cycles. But, despite scholarly evidence to support the case for innovative activities emerging in diversified environments (Feldman and Audretsch 1999; Henderson 1995; Glaeser and Kerr 2009), and to that contributing to a city-region's growth, there is also a body of literature taking that further and asking whether there is a limit to how diverse the activities can be. They refer to not just the existing activities, but also to the new activities emerging.

My next section will focus on reviewing what others found about how diverse can an environment be to become a useful innovation setting, and on the level of variation found in most new activities in such environments. As I find in this study that new emerging activities related to 3D printing in London are supporting and related to the existing knowledge and creative activities, other's recent research reviewed below already pointed to such potential finding.

3.4.3 Limits to Diversification

Although sectoral diversification is the perspective under which a material production revival with advanced manufacturing technology could flourish, as presented in literature proponent of urban manufacturing revival (Bryson et al. 2017; Rifkin 2011; Nawratek 2017; Rothkopf 2012; Edwards and Taylor 2017), it is important to caveat that an extensive body of other literature has argued for limits to sectoral diversification. In the context of this thesis these are important to review because advanced manufacturing is a relatively distant sector to the predominant sectors of Financial, Services, Knowledge, Real Estate and Culture which currently form the baulk of the sectoral composition in the London region, the place for this study.

These limits are fundamentally the nature of that diversification itself, commonly described as the degree of relatedness between industries found in a region. Relatedness is the concept developed by evolutionary economic geographers to analyse the nature and evolution of industries in a region regarding their level of technological similarity. In other words, it is a measure of knowledge or technological proximity (Rigby 2013; Essletzbichler 2013; Kogler, Rigby and Tucker 2013).

It has been concluded in various research papers following different methods of measurement that sectoral diversity may increase innovation and exchange of ideas, but if there is too much diversity it may mean that there is no common knowledge base and knowledge exchange is not effective. In other words, too little similarity between industries may impede knowledge exchange altogether. This means that there are effectively limits to the extent of diversification (Essletzbichler 2007). Research finds that there is a need for a level of commonality between the industries in the region (Frenken and Boschma 2007), but also not too much similarity as it has also been found to have the counter effect, designated as the cognitive lock-in (Nooteboom 2000). Frenken et al (2007) reached similar conclusions on the positive relationship between related variety in Dutch regions, and Boschma and Iammarino (2009) found the same conclusions in Italian regions. For these reasons, growing regions are likely to diversify by branching out into industries with a level of similarity to those already existing there (Boschma et al. 2005). There are however several unanswered questions in this field (according to Essletzbichler 2007), particularly on the precise levels or intervals of relatedness required for a region's resilience and growth.

Knowledge transfer happens arguably then between related people, firms and industries in a diversified agglomeration, and most significantly at the early stages of production, when innovation is most prominent. Having considered perspectives on the context where innovative activities happen, and how they relate with the existing activities in a city region, my focus now turns to the actual process of innovation and of knowledge transfer. Several perspectives on this subject will be reviewed next because they offer reasons why promoting advanced manufacturing in an urban context like London may be advantageous to the local economies, even if a manufacturing renaissance is to be discarded. I start with the role of innovation in altering economic cycles, particularly in capitalism, which is key to my research's enquiry on the potential for growth associated with new fabrication technology. And, as I find through my evidence that knowledge transfer based through active collaboration is key to the diffusion of new technology and associated innovation in London, I review below scholarly work focusing on various types of collaboration in processes of innovation.

3.4.4 Processes of Knowledge Transfer for Innovation

Scholarly research conclusions on how and why innovation happens where it does extend to a variety of arguments such as factors of location and proximity, path dependency when new activities emerge from other established activities, and history of the place. There are also perspectives arguing for various degrees of combinations of the above, including both territorial and non-territorial factors. Most perspectives point out that innovation happens when knowledge is successfully transferred between individuals, and firms of the same or similar sectors (Duranton and Puga 2001; Boschma and Frenken 2011; Glaeser 1998; Boschma et al. 2009; Essletzbichler 2013). These processes are fundamental to innovation in contemporary urban economies centered on knowledge sectors. And while recent research has been produced on this subject by evolutionary economic geographers, it is recognised that more is needed in relation to innovation triggered by new manufacturing technologies more specifically (Laffi and Boschma 2021). Below I synthesise what most key findings are within current literature, and what those suggest for this thesis.

In recent research, evolutionary economic geographers have started to construct evidence-based arguments on how and why exactly innovation happens in certain regions, arguing that the type of innovation that emerges dependents on a region's economic portfolio (Neffke et al. 2011). The pre-existing mix of economic activities in an area and their degree of similarity matters to how effectively knowledge is transferred between individuals and across firms and institutions (Boschma and Frenken (2011). Growth happens normally by processes of branching out of industries into related but slightly different new industries. Scholars emphasize both agglomeration plus related diversification as most effective for knowledge transfer and for successful innovation to drive growth: Boschma and Frenken (2011) identify four mechanisms for knowledge transfer at the regional level, which include 1) the diversification of firms; 2) the entrepreneurship in the form of spinoffs; 3) labour mobility; and 4) individuals networking. In continuity, Essletzbichler (2013) presents three ways through which knowledge gets exchanged and transferred as innovative processes take place: 1) Through workers in geographical proximity with a common knowledge base; 2) through customer and supplier linkages, when presence of more customers increases competition among suppliers and then triggers innovation; 3) when firms form divisions or subdivisions of related products and techniques.

According to Duranton and Puga (2001) knowledge is transferred and exchanged in agglomerated regions through processes of sharing (pool of labour), matching (skills with work needs) and learning (from other people). Research highlights the key role of sharing being facilitated through spatial proximity as one the drivers of growth (Storper 2013; Foord 2012), and one of the reasons for the advantage generated through the clustering of firms. Clustered firms watch and learn from each other, monitor, gossip, imitate, share – and innovate (Storper 2013). Spatial proximity, a key issue in economic geography, has been described as fundamental for the processes of innovation and learning that occur in the formation and transfer of tacit knowledge, which is described in literature as local knowledge, personal, subjective and internalised (Polanyi 1966). It has been argued (Glaeser 2011) that through direct, many times unplanned, face-to-face encounters, social learning processes develop, as it is a characteristic of human beings to learn from each other.

People moving across firms are another way knowledge gets transferred to other firms, a key mechanism for growth facilitated by agglomeration and by concentration of similar firms as labour moves more easily between those (Glaeser 1998; Boschma et al. 2009; Essletzbichler 2013). Thrift (2000) conceptualized the creative agglomerations in post-industrial cities as 'spaces of circulation' intended to produce situations where creativity and innovation takes place. But it has also been argued that other proximities foster innovation too, and that distinct types of spaces produce different types of knowledge, meaning that space has agency in the innovation outcome (Amin and Cohendet 2005).

The literature distinguishes thus five types of proximity, which lead on to knowledge being successfully transferred (Boschma 2005), or not: 1) Cognitive proximity which refers to people sharing a common knowledge base normally within an organisation so that communication and knowledge transfer can be productive; 2) Organisational proximity referring to relations between or within an organisation; 3) Social proximity meaning social connections in terms of friendship and life experience which enable knowledge transfer and which have been the focus of a significant body of literature who argued that all economic processes are embedded in social relations (Granovetter 1985); 4) Institutional proximity which concerns the common values between institutions at the group or institutional level, as opposed to the individual level of social proximity; 5) and Geographic proximity which implies physical proximity unlike the other types. While the last implies a physical proximity, it is said to enable the other proximities but not exclusively (Amin and Cohendet 2005).

For many of these proximities to be effective in facilitating knowledge transfer, recent literature argues that a degree of relatedness to the level of skills is necessary for effective communication and exchanges between people, firms and within firms as well. Firm productivity increases only if new workers added as part of growth have complementary skills to those in the firm, rather than either hugely different or just identical (Boschma et al. 2009; Noteboom 2000; Essletzbichler 2013; Frenken and Boschma 2007). This is because cognitive proximity facilitates communication. The kind of knowledge transferred with labour mobility processes matters, in terms of how that knowledge matches the knowledge base of the receipting firm, so that growth effectively happens (Boschma et al. 2009). Boschma (2005) maintains that proximity or clustering per se is not the condition for knowledge transfer. In his argument, a degree of relatedness – meaning cognitive proximity - is required too for knowledge to be transferred and be useful for innovation and result in growth of the region. One of the key discussions now emerging (Gress and Kalafsky 2015; Liao et al. 2017; Laffi and Boschma 2021) in relation to the new manufacturing technologies is the degree to which these will be sufficiently related to existing industries in an area to create the related diversity environment which triggers growth, as this research investigates.

The notions and distinctions between tacit knowledge associated with locality, and of codified knowledge associated with global networks are also interesting to review in this context. It has been typically pointed out that distinct types of knowledge are consequence of different types of spatial relations (Storper and Venables 2002). However, there are expanded theoretical notions arguing that tacit knowledge can be transferred not just in co-located encounters, but also across virtual encounters, meaning that relational proximity can be attained at a distance (Amin and Thrift 2002; Amin and Cohendet 2005, Urry 2004). In this literature, the argument is that the processes of innovation can happen without physical proximity if there is some degree of shared interest and relatedness.

Other scholars highlight that tacit knowledge happens not exclusively locally but also at distance, particularly with the reach, speed and complexity of the technologies of information (Urry 2004). Associations between individuals and groups can happen successfully over the internet when there is a common interest, and economically useful knowledge is produced when there is neither physical nor relational proximity (Grabher and Ibert 2013). This contradicts Storper and Venables (2004) much discussed notion of local 'buzz'. Now virtual environments offer the opportunities for the same processes to occur, as people share, gossip, imitate over the internet and across the globe. Conversely, I have found evidence for effective knowledge exchange both virtually and with physical proximity in my case study.

The notion of 'spaces of knowledge', defined by Amin and Cohendet (2005) as disconnected from territorial proximity fits the virtual spaces of knowledge exchange which my research followed - such as online forums, open-source communities, online groups which be presented in more detail in my methodology and empirical chapters. As argued by the same authors, this space of knowledge 'may be no less social, less tacit, less sticky, less negotiated than physical space' (Amin and Cohendet 2005: 470). However, they did not exclude the importance of the physical proximity for knowledge exchange, and neither did my findings.

Despite the increase in communication technologies and globalisation, and contrary to what was originally argued would be consequential (O'Brien 1992; Gray 1998), the contemporary inner-city space continues to be a more contested location for businesses, in particular for creative and technology industries. Spatial proximity seems to still enable the other kinds of proximity and, subject to relatedness, knowledge transfer processes. With globalisation, the creative industries have been stretched across a tension between local and global linkages, where place and local culture matters (Robertson 1992; Scott 1997), and this is certainly the case in my findings. Scholars like Sassen (1991) and Graham (2004) argue that the importance of location has been indeed accentuated by globalisation and by the post-Fordist capitalist restructuring.

Another widely considered argument in innovation geographies that is relevant to the analysis presented in this thesis concerning innovative material production in post-industrialism, is the influence of the country in which firms are located, and its industrial and regulatory framework. Research has highlighted the role of national systems to trigger knowledge transfer for innovation, and how national and home-base institutions shape learning and competitiveness (Amin and Cohendet 2005; Gertler et al. 2000). Some cities have historically been centres of innovation; As observed by Glaeser (2011), Storper (2013) and Hall (1998) some cities thrived and declined once – Athens, Rome, Lisbon, Detroit, etc and some cities have succeeded and declined and then prospered once again and again – London, New York. If collaboration and sharing are social forms of relations with economic content, it has been argued that this is likely to be more frequent in cities with a previous history of cultural and leisure activities, openness, diversity of people, public realm, mix of uses and density (Evans 2009).

These locational tendencies of innovation in the centre of cities mean that certain urban locations will continue to be fought over for productive activities and thus land on those areas will be scarce and more expensive. These perspectives align with my findings on the relative importance of technology versus people, area's identity and proximity with other related activities for effective knowledge transfer and innovation. All factors which a city like London already has in place.

3.5 Conclusions

In this chapter I presented a critical review of relevant literature organised as per my themes of enquiry: production activities, location and innovation for growth. The section on production and industrial capitalism explained how production changes are related to economic cycles, and discussed various perspectives interpreting some of the key periods identified in industrial capitalism: the period up to Fordism when manufacturing production was key to economy and society in most western urban regions; post-Fordism when manufacturing departed from those regions and was replaced with knowledge, cultural and service sectors; and beyond post-Fordism concerning more recent interpretations of production and economic outcomes of de-industrialization such as creative city visions.. This section of the review forms a background to the proposition of an urban manufacturing renaissance rooted in previous cycles of industrial capitalism, as well as offering a background understanding of the present post-industrial context. I note particularly how the changes in post-Fordism have been so profound that theorising it became a key concern in economic geography, a tradition which my research follows. But I do challenge the most recent propositions and suggestions of a new manufacturing revolution (although mostly not by Economic Geographers), and I draw attention to their lack of evidence. Instead, it is proposed that a focus on technological change is a useful path to follow in search of an understanding of the latest trends in post-industrialism, adopting a Neo-Schumpeterian perspective. But I suggest a more nuanced interpretation of changes in relation to material production innovation is needed, in a tradition set by flexible accumulation and regulation theory scholars. In terms of the research reported on in this thesis, I suggest the hypothesis that material production in post-industrialism aids abstract tasks within the knowledge and creative sectors, amongst related sets of activities.

In the section on location of industries I reviewed literature concerned with how land uses are distributed in urban areas, particularly industrial uses. I reflected first on the early classical bid-rent models, which still form the basis of today's land valuations, but could not explain the relocation of industries in post-Fordism, nor the unevenness of their distribution. Explanations for de-industrialization of city centres and clustered industrial location, such as the gentrification perspectives on manufacturing displacement and the notions of clustering due to agglomeration externalities were presented. These are important for this thesis because most gentrification pressures are still current in city centres and create a significant challenge to businesses locating in those areas, and because the notions of clustering advantages already point to the success of firms being linked to their context – in terms of proximity to other firms, institutions, etc. The reader may recall here my argument that based on the historical evidence, a flexible technology alone does not change the location of innovation. Rather, and more in line with Porter's clusters theory, I propose to explore empirically the location of new manufacturing units in a scenario of manufacturing revival. My own evidence on the basis of activities which emerged in association with 3D printing in London is for clustered locations almost exclusively in the city centre, near other activities such as creative industries, and close to other tech and knowledge start-ups to attract the right people and benefit from an area's identity in terms of funding and marketing. This is discussed in Chapter 5.

The next part of this chapter focused on perspectives on the conditions for innovation, resilience and growth, as a background for my argument that growth and advantages can be gained from innovation associated with material production in a post-industrial city like London. I presented the literature concerned with diversification as both: an aim to ensure resilience of the economic system – as spreading the risk across sectors avoids recessions affecting one only sector; and as a feature of a beneficial type of agglomeration for innovation – as different activities, firms and sectors can exchange technologies, labour and knowledge which lead on to innovation. But I also reviewed recent research pointing out that there are limits to the level of diversification in terms of its role in triggering innovation. This research highlights that a level of relatedness – commonalities, is key to the success of a diversified economic system, meaning that there are enough shared aims so that communication and learning happens easily, resources are relevant to all, and innovation occurs. Therefore, the resulting concept of related diversity is a nuanced and useful notion for interpreting the outcomes of my study which finds innovation related to material production technology in London happening in relation to the knowledge, creative and services sectors. Further to this, I reviewed literature concerned more specifically with the process of knowledge transfer between people, firms and institutions. I presented conclusions of scholars who argue that distinct types of proximities allow for exchange of knowledge and for innovation – including physically and virtually, as well as the work of others who maintain that physical proximity is key to collaboration, justifying why many cities remain places of innovation.

Reflecting on literature gaps, the key aspect to highlight is how most literature is yet to address what the new manufacturing technologies bring to the relationship between innovation breakthroughs and capitalism growth cycles, and in particular what a potential new cycle of growth may be. Likewise, location arguments have not yet been tested in relation to the new fabrication technologies which are particularly flexible and less tied to location when compared to traditional manufacturing plants and production processes. And there is also research missing in the literature in relation to how the emerging technologies can diversify more specialised knowledge economies, to what degree new activities are related to existing activities in a region, and if they can successfully contribute to the region's growth.

This chapter, together with my introduction on the purpose of studying the proposition of urban manufacturing renaissance in post-industrialism associated with new fabrication technologies in Chapter One, and the review on Chapter Two of literature concerning a putative New Industrial Revolution, has provided a sound basis from which to pose some more detailed questions to guide this research. The next chapter sets out the research design and methodology, the location of the study and the application of the research methods.

Chapter Four

Research Design and Methodology

... the field of economic geography never evolved in a sequential, linear fashion, through a series of identifiable methodological phases. There is no grand narrative with a beginning, middle and end on which we can draw. And in many ways, we would not want one. But it does make telling the story challenging. (Barnes et al. 2007: 4)

4.1 Introduction

The methodology designed for this research is *sui generis*. As the case study is a new technology and the intention was to follow new emerging activities, the common classifications used for industrial studies were not available, and the database for the analysis had to be constructed from the outset. Additionally, the research questions required more than statistical data analysis to compile business performances, structure of activities and locational data. It required also a more in-depth understanding of how people worked, why they were in the locations found and what premises looked like, plus an understanding of the culture of making. These required that, as a researcher, I needed to get more involved in the activities and participate, immersing myself in the making culture of London and connecting personally and online with some key actors. In this way, this is yet another atypical economic geography study in terms of the research subject, and in its design and methodology. The methodological approach adopted and its epistemology delivered key findings to bridge the knowledge gap around new technologically led material production. And it brought together different paradigms of enquiry within economic geography – the scientific positivist analysis typical of studies of the industrial revolution, the case study approach from post-Fordist industrial case studies, and the critical participatory approaches of more political and ethnographic research that followed. This study is thus an original contribution to the discipline from a methodological point of view.

This chapter starts with defining *what* is being studied, and *where* (section 4.2). The focus is on the activities directly associated with 3D printing technology emerging in the Greater London region within the M25 London. After these definitions, Section 4.3 provides a justified explanation of *how* the research was approached and its design, in relation to the propositions which this thesis seeks to assess - the possibility of a new manufacturing revolution based on new production technologies; or the potential for diversification of post-industrial urban economies through manufacturing with new fabrication technology. The chapter continues with an overview of methods employed in my research in section 4.4 and with how they relate to the research questions set out in detail in section 4.5. Here, the three primary research questions are recapped and divided into detailed research questions, which are listed alongside the relevant methods used during empirical evidence collection. In the following section 4.6 I describe the process of creating a database of activities, a unique starting point for an economic geography study which is characterised by an epistemology which lies between positivism and critical theory. In section 4.7 I present a detailed explanation of the process of selection of detailed case studies for in-depth interviews, and in section 4.8 a more precise description is provided of how and when the various methods were used, and how the individuals or firms were examined to answer the questions.

Lastly, a reflection on how the research design and methodology compares with other industrial and post-industrial case studies is provided in section 4.9, expanding my point on the originality of this methodological approach before chapter conclusions are presented in section 4.10.

4.2 Defining the Object and Location of this Study: Emerging Activities Associated with 3D Printing Technology in London

The phenomenon here in study is the possible resurgence of production with physical, material outputs within post-industrial urban economies, as it offers the possibility for their diversification. It has been characterised as a new type of material production, or simply 'making things', employing innovative technology, discussed as the engine for a possible urban manufacturing revival (Rifkin 2016; Marsh 2012; Nawratek 2017; Jakob 2017; Bryson et al. 2017) in post-industrialism. And, within the new technologies suggested for this revival, 3D printing is the most common, and it has thus been chosen as the case for this research.

The object of study for this research is the wide range of activities which emerged in association with the 3D printing technology, including the production of hardware and goods of all kinds plus the related services and software. The activities found are designated as *entities* in the empirical chapters, as they include private sector firms and individuals, plus not for profits and publicly funded enterprises.

The choice of study object was not without its problems, as there was no Standard Industrial Classification (SIC) for these activities – the UK's system for classifying all types of industrial and business activity, nor other classification, or list, or even definition of what constitutes 3D printing related activities. Therefore, the list of all entities had to be produced and classified manually at the start of the empirical data gathering, based on an interpretative judgment of what should be included in the study. But, the definition of activity was left broad, and relied on the actors themselves – people involved in the technology - for the study to be as comprehensive as possible. In other words, there was a modified objectivity at the outset, where I as researcher had to collect and interpret data to generate the list of entities – my database - before starting any analysis. As such, this study possibly constitutes the first comprehensive listing of these new activities at a given point in time and space – 2015 to 2017 in London. Further details on how the list was collected, classified and organised are explained in section 4.6.

London was the choice of location for this study in material production in post-industrial urban economies. There could have been other choices - European or American post-industrial cities that have experienced large-scale departure of manufacturing and their replacement by knowledge and service industries, and which have had recent policies in support of manufacturing renaissance[21]. However, the feasibility of the study is a major researcher's consideration and, in this case, only my city of residence was a feasible option due to time available and financing of the project. And, London has been included within the top five global post-industrial cities (Ferm and Jones 2017), for its knowledge and creative industries growth following its rapid deindustrialisation (Prothero 2007; Pratt 1994b; Pratt 2009b). Plus, it has been subject

[21] See Halbert (2012) for Paris, Catinella-Orrell (2011) and Curran (2010) for New York, Adam (2002) for Hamburg.

to interest in manufacturing revival (Ferm and Jones 2014; LEP 2014) despite its exacerbated land values. Furthermore, London's size means that one could expect a fair representation of new activities associated with 3D printing.

Choosing a major post-industrial city instead of a post-industrial outer region or second tier city, less dense and less contested too, is important for several reasons as follows. First, most people of the planet already live in large cities, and this trend, which started with industrialisation, is likely to continue[22] (United Nations 2018). Many of those cities (particularly in the Global North) have also experienced similar de-industrialisation processes, whilst retaining functions of control of strategy and direction of innovation within global production chains (Scott 1988b). This study is likely to have a bigger impact given this choice, as its findings will be relevant to those cities too. Second, there are important relations between production and urban space, as the success of industries in urban context has been widely researched and attributed in the first instance to scale economies (Myrdal 1957; Perroux 1955; Holland 1976) and factors of agglomeration (Marshall 1919; Romer 1986; Jacobs 1969; Glaeser et al. 1992; Porter 1990; Scott and Storper 2003). Third, there are relations between types of activities, firm location and product cycles such as those argued by Duranton and Puga (2001) that make it more likely that a new and innovative type of production and higher level of entrepreneurship will be found in an urban area. And fourth and last, literature promoting the manufacturing renaissance has many times argued in favour of an urban manufacturing sector (Nawratek 2017; Jakob 2017; Bryson et al. 2017; Catinella-Orrell 2011; Curran 2010). As summarised by Caruso et al. (2015), cities may become attractive to manufacturing industries as places of opportunities again as in the industrial past, because they attract more people thus more customers, they have better accesses and reduced transportation costs and more diversified economies.

Lastly, in establishing London as the case for the study, one last matter remains, which is the boundary of the study. As with any case, when boundaries are determined, they cut across geographies, and the way of defining a boundary in fact depends on the purpose for which it is defined. There are many ways to define a city and its metropolitan area, and many discussions have taken place in literature about what

[22] The United Nations Department of Economic and Social Affairs estimates that 55% of the world's population currently resides in urban areas and predicts that 68%, more than two thirds, will do so by 2050 (United Nations 2018)

constitutes London effectively (Buck et al. 2002). In this case, the administrative boundaries were considered to be sufficient for this study because this area is representative of the wider London functional region, including both central and peripheral zones within one administrative body – all the 32 inner and outer London boroughs, plus the City of London fall within the Greater London Authority (GLA). Hence, it was defined that London's limits are the limits of its most outer boroughs. This boundary is shown in Figure 3.1. In this way, entities included in London boroughs have been listed, whereas entities located outside the boundary of Greater London were excluded even if they identified themselves as part of the London 3D printing scene - firms that had a Hertfordshire address for example. This inclusion and exclusion choice was undertaken during the initial listing process.

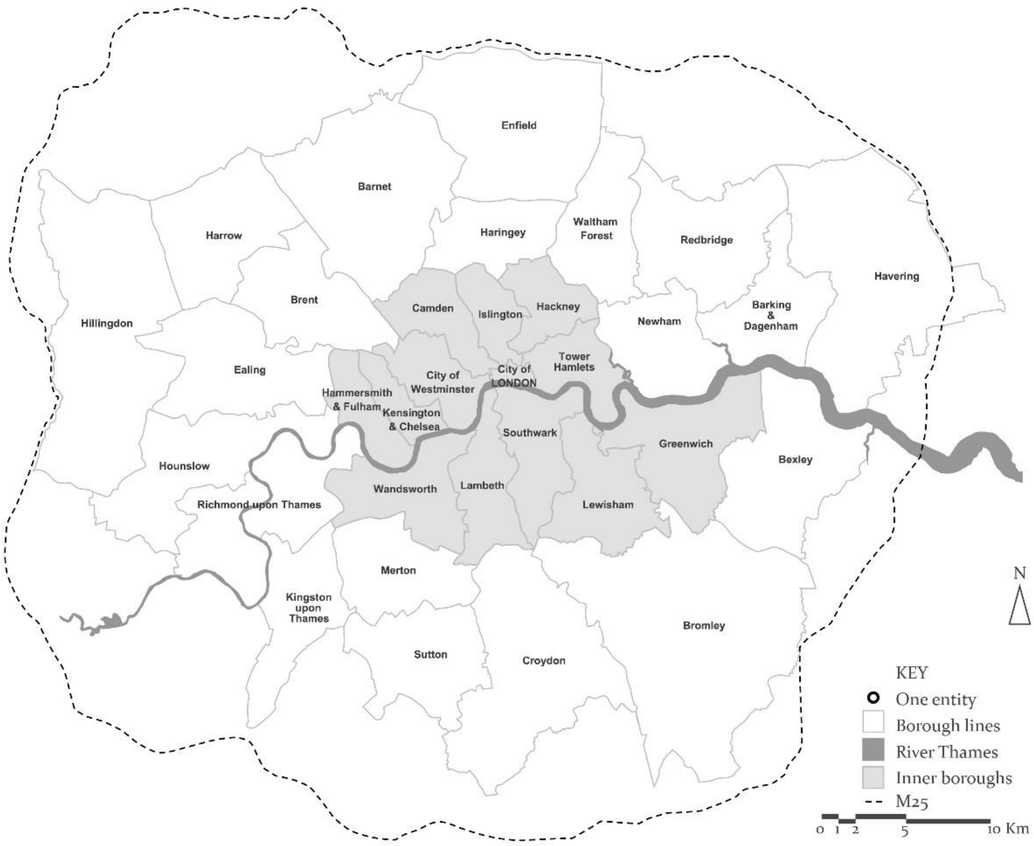

Figure 4.1 London boroughs, the geographical extent of the study

This choice of location directly addresses the gap in evidence relating to the urban manufacturing renaissance in urban areas, leaving aside the cases resulting from application of new additive manufacturing technologies in large industries located outside metropolitan areas, which may be the subject of other studies to follow my own.

4.3 Research Approach and Design

My research has been designed across sectors, horizontally to ensure that it could provide answers to the three questions, and hence deliver the evidence to the role of urban manufacturing renaissance for diversification of a post-industrial economy.

There could have been two possible routes into this study: one would have been to follow how the technology of 3D printing is applied to an existing sector or industry, for example how it is used and how it changes the medical sector, or how it is used and changes architectural design. But this would have been like, for example, examining how computers changed the medical sector or architectural design three decades ago. Which would not mean in any way that the sectoral balance of the economy *in general* was changing and diversifying because of a new technology. In this way, a technology could be studied and provide insightful information about how technology is adopted and how it changes production processes in chosen industries, but not how it is possibly (or not) triggering diversification and resilience by extrapolation, which is a claim that can only sit *outside a given industry* and in relation to overall sectoral balance. The other route, which this study follows, is a horizontal cross sector analysis of new firms and activities that emerged with 3D printing technology to understand if the technology is creating a new distinct sector linked to material production, urban manufacturing.

In this spirit, this study focuses on new activities which emerged in relation to the 3D printing technology, considering that there can be a wide range of activities stemming from the technology, which are not only the act of 3D printing itself. It was defined that this study would thus follow firms, single users, institutions, press, communities etc – all collectively designated in this dissertation as 'entities' if they include themselves, self-identify or list in databases as part of a 3D Printing *Industry*. Even if finding and following all of these, because it is such a new technology, was not without problems in terms of gathering data, as explained in the previous section.

An additional consideration regarding the term *Industry* should be brought to light, for the reader's (possible) delight and (most certain) clarification. The notion of a 3D Printing *Industry* was originally pursued at the start of this study because most firms and media mention a 3D Printing Industry (Sissons and Thompson 2012; or the magazine itself called 3D Printing Industry for example). The 3D Printing *Industry* is defined 'as public and private 3D printer manufacturers, software providers and bureau services' (Barnatt 2014: 29), and indeed this term carried through most of the research process, only to be discarded later due to the confusion it was generating. It turned out that I could not find such thing as a 3D Printing *Industry*, apart from those who manufacture a 3D printer, and what was found was a miscellaneous group of activities which called themselves 3D Printing *Industry*, doing very many different things. So, in the end, this study turned out to be about new activities which directly emerged from the 3D printing technology itself.

This study adopts a technologically framed perspective to the enquiry. In doing so it draws from a neo-Schumpeterian interpretation of economic cycles which was also one of the significant lines of analysis used in interpretations of post-Fordism (Amin 1994; Elam 1990) by scholars like Perez (1983), Freeman and Louca (2001) and Dosi (1982). This neo-Schumpeterian approach to post-Fordism has been criticised for its technological determinism (Elam 1990), which is the view that institutional change and socio-economic outcomes are a result of the techno-economic paradigms, rather than agents of technological change in themselves. Despite this criticism, a technologically framed perspective has been applied to explain the succession of historical industrial revolutions (see Freeman and Louca 2001), and recently to understand the rise of the cultural and creative industries as potential counterpart to the financial, insurance, real estate and service industries particularly during the recession of 2008 (Pratt 2009a). Following a technology instead of an industry or a sector is therefore an appropriate thread to this enquiry, which started from the ideas of a New Industrial Revolution as the rebuilding of manufacturing production with new disruptive technologies.

As such, my research takes a more horizontal approach, cutting across sub-sectors and industries. But it does not intend to distance itself, and instead my research still sits in continuity with many industry case studies located in city regions carried out by scholars who developed interpretations of post-industrialism within a flexible specialisation or evolutionary approaches (for example Scott 1988a, 1997, 2000 and

2007; Storper 1992, 1995 and 1997; Hall and Markusen 1985; Rigby and Essletzbichler 1997; Zukin 2010; Boschma and Iammarino 2009; Foord 2012). In this continuity, my research uses a technology case study to provide evidence for the process of innovation around material production in current post-industrialism.

Having presented my research focus, its epistemology, approach and justification, I will now continue the chapter describing the methods used in the process.

4.4 Research Methods Overview

This research uses a combination of quantitative and qualitative methods. The view is that a combination of methods was appropriate to gain a more complete insight into the activities in study, but also to be able to benefit from the processes of triangulation and offsetting of information such as when comparing survey responses with interview answers to the same questions, and to be able to find material for the three research questions. Bryman (2012) summarises the ways of combining quantitative and qualitative research in social sciences as genuinely thinking through data and opening the possibility of unexpected results which was of interest to this enquiry given it is focused on emerging activities. This research's methods are thus a combination of a top-down outset quantitative analysis of the activities with more detailed, even participative, qualitative data gathering and its examination.

At the outset stage of the research, I have created a list of 131 entities by consulting databases as well as by attending industry events and sources such as news and trade fairs. Once this list was frozen, the empirical study started using a wider range of methods. The list was classified extensively, and statistical analysis was conducted using Excel. The categories were grouped and graphs were generated to help visualise the results of the classification. In this analysis, the aim was to gain a preliminary understanding of what were the trends in the list, which categories had more and less weight, and how the entities were distributed and grouped.

Afterwards, more methods were used to continue studying the 3D printing activities listed, including extensive mapping, plus surveys and their subsequent statistical analysis using once more Excel and graphs. The next action was to create a representative sample of activities to follow in more detail. This led to interviews to those representative cases, photography and site visits, informal conversations and email exchanges with a few people, plus attending industry presentations, and participating in groups, meetings and community forums. In parallel and in the background, desktop studies continued to investigate the activities, references, places and premises, the people involved, company registrations, funding, etc through internet research and additional emails. These steps and actions, which the next sections of this chapter will elaborate on, are diagrammed in Figure 3.2 for the reader's clarity.

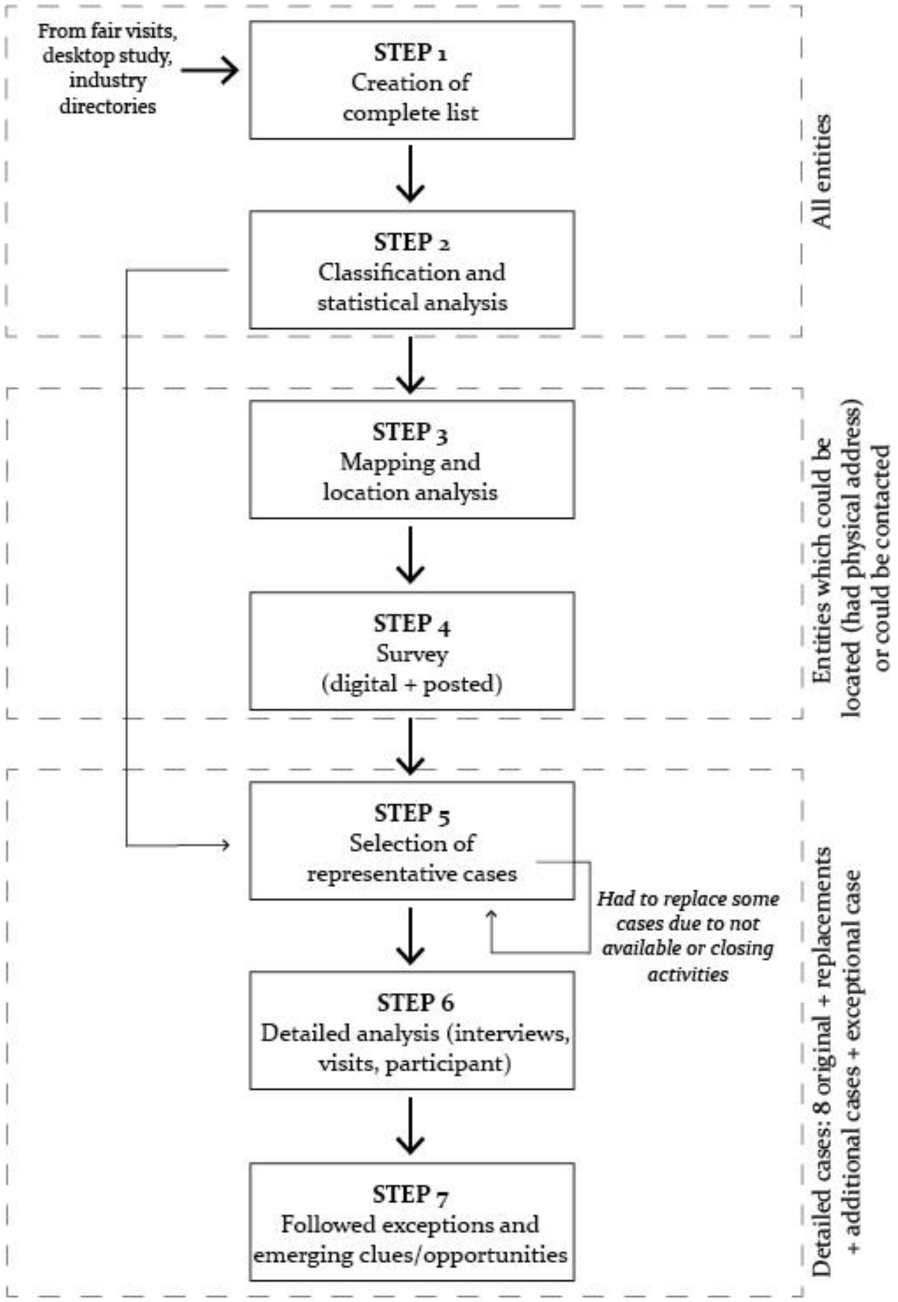

Figure 4.2 The research steps

Given the scope of objectives, to understand the activities which emerged in London associated with the 3D printing technology in a holistic way, this research used various methods combined to be able to answer a wide range of question types. Quantitative methods were more useful for asserting what, where, who and how much, whilst qualitative methods of analysis were more useful to gather insights on the how and why of the organisations and their processes. Objective information was gathered about the activities, such as location, number of people, size of premises, date of foundation. These are important findings since there were no comprehensive empirical studies on these new activities in London at the time. And more nuanced information about the activities was gathered as well, particularly through the interviews and site visits, as well as group participations. These uncovered an important angle on the ways people interacted both online and in person, and about the communities organised around 'making'.

This approach, using combined methods, is aligned with trends in other recent industrial studies, as it is no longer common for these studies to adopt only quantitative statistical methods (Scott 2000) as had been practice in the past. Recently it has become more common that industrial studies employ a wider range of methods to gather more insightful and holistic knowledge, with awareness of the appropriate caveats and framing limitations. Using combinations of methods in complementarity has become more established in other social sciences too, with the recognition that quantitative analysis alone does not need to be entirely linked to positivistic reasoning anyway (Flick, 2002). However my research stretches this trend yet further, as it has involved my own participation even more than most recent economic geography research, because of the novelty of the subject and the lack of data to draw from. I recognise thus that in my research there is a mix between positivist moments and critical moments: sometimes the subject of study was concise and the methods were more top-down such as in statistical analysis, whilst at other times I was immersed in the investigation, for example when participating in forums. It was useful to adopt this multi-method strategy, and to be able to freely move between methods, as I could better follow clues emerging through the data as investigation unfolded, and insightful and original data was gathered.

4.5 Answering the Research Questions

My research questions (see section 1.5) have been defined to provide evidence-based conclusions about the nature, role and processes of urban manufacturing renaissance in post-industrialism particularly in terms of its potential to add resilience and diversify local economies. The three primary questions of this research are thus about: what activities emerged in London in association with a potentially disruptive manufacturing technology (3D printing) and in relation to other economic sectors; about districts, spaces and places that hosted and fostered innovative start-ups and branching out processes to provide an understanding of why contemporary innovation emerges and flourishes where it does; and about how adopting this new technology contributes to growth and what advantage it can create within a post-industrial city like London.

For gathering data and information to answer the three primary questions, I subdivided each question into small empirical research questions, to be answered with the most appropriate methods. Further to this, I directly associated each research question to an empirical chapter of the thesis. Table 3.1 details this correspondence.

Table 4.1 Correspondence between primary questions, empirical chapters, empirical research questions and methods used

Primary Question 1: **What activities have emerged in London associated with 3D printing?**	
Empirical Chapter: Characterisation of Activities: Production, Sectors and People	
Empirical research questions	*How to answer/ Methods*
What are the work activities of entities associated with 3D printing?	List creation, list classification and its statistical analysis Desktop studies Surveys and its statistical analysis Interviews Visits to industry fairs Non-participant group observations and dialogues
Who are the founders, the employees and others involved in the activities?	List classification and its statistical analysis Desktop studies Surveys and its statistical analysis Interviews

	Non-participant group observations and dialogues
With which sectors are these activities associated?	List classification and its statistical analysis Desktop studies Surveys and its statistical analysis Interviews Visits to industry fairs Non-participant group observations and dialogues
What connections do these activities have, considering both clients and collaborators?	List classification and its statistical analysis Desktop studies Surveys and its statistical analysis Interviews Visits to industry fairs Non-participant group observations and dialogues
Primary Question 2: **How is the location of the emergent activities associated with 3D printing related to the urban context of London and its agglomeration economies?**	
Empirical Chapter: **Location of Activities: Spatial Distribution and Factors**	
Empirical research questions	*How to answer/ Methods*
Where are the 3D printing related activities located in London?	List classification and its statistical analysis Mapping Desktop studies
What do their spaces of production look like?	Desktop studies Surveys and its statistical analysis Interviews Photography and site visits Non-participant group observations and dialogues
What determined the locational choices of entities? / Why are these entities in London and in that particular location in London?	Desktop studies Surveys and its statistical analysis Interviews Non-participant group observations and dialogues
Do these entities intend to (or must) move out of the current location? Why or why not?	Surveys and its statistical analysis Interviews Non-participant group observations and dialogues
What happens in different locations?	Interviews Non-participant group observations and dialogues

Primary Question 3: **How has the process of adoption of 3D printing technology contributed to innovation in activities across different sectors in London, and what advantage is it creating in this context?**	
Empirical Chapter: **Growth and Competitive Advantages: Technology Applications, Activity Paths and Collaborative Practices**	
Empirical research questions	*How to answer/ Methods*
What are the innovative production processes used by the various activities?	List classification and its statistical analysis Interviews Visits to industry fairs Non-participant group observations and dialogues
How is this new technology changing production processes and ways of working?	Interviews Visits to industry fairs
What else is contributing to innovative production and outcomes in these activities?	Desktop studies Interviews Visits to industry fairs Non-participant group observations and dialogues
What is the future progression of the 3D printing technology, its scaling and applications likely to be?	Desktop studies - Press Interviews Visits to industry fairs
When and how was the organisation founded/ When and how has the activity started?	Desktop studies Surveys and its statistical analysis Interviews Non-participant group observations and dialogues
Are these activities viable? How is the activity financed?	Surveys and its statistical analysis Interviews Non-participant group observations and dialogues
What are the success and the challenge stories?	Desktop studies Interviews

4.6 Compiling and Classifying a List of Entities

The research was conducted initially with the creation of a complete list of entities because such list did not exist yet. This process of constructing a database of activities included extensive search and archival analysis over available internet or printed directories of what people and media called the 3D Printing Industry (3D Hubs, 3D Printing Business Directory and 100K Garages), trade fairs participant's lists (the London 3D Print Show 2015 and the Makerfaire UK), media (Dezeen and 3DPrint), relevant institutions' lists of registered entities related to 3D printing technology (the Institute of Mechanical Engineers and Nesta), plus general online Google search. In addition, if during the period of creation of the list someone mentioned a new entity had formed or closed – in interviews or articles, the entry would respectively be added or removed from the list. After crossing out duplicated entities, this list accounted to a total of 131 entries.

In the creation of this register of activities which emerged within London in association with 3D printing technology during this study, the confirmation of location in London was the key criteria for each entry. This confirmation was done via the address or region reference that the entities made available, which was then verified online, through email or calling directly. As such, all entities with a London address clearly explicit, or those defined or confirmed as 'London located within a London borough'[23] even if without a full address were included in the list. Therefore, all activities with an address outside London or that confirmed themselves as not within a London borough, even if listed in London databases were excluded. This 131 list formed the entire *population* in study, meaning all the entities to be then classified and analysed.

This list includes firms, industry associations, hobbyists, single owner/ single practitioners, media, online communities and marketplaces. These were then classified one by one according to the type of work they do, their sector(s) of work and their location (in terms of post code, and borough). Contacts (phone, websites, key person) and brief description of activity, and company registration information was gathered for all entities too. This classification comprised of the items listed in Figure 4.3 and formed the basis for the initial statistical and mapping analysis of the full list. This classification was also the basis for the selection of a smaller sample of cases that could represent well the activities found and be studied in further detail. The next section describes this selection process.

[23] This is an important point to note – some entities defined themselves as part of the London 3D Printing Industry, but not all had addresses that could be found or, upon contact, did not want to disclose or make public their exact physical location and preferred to operate online only.

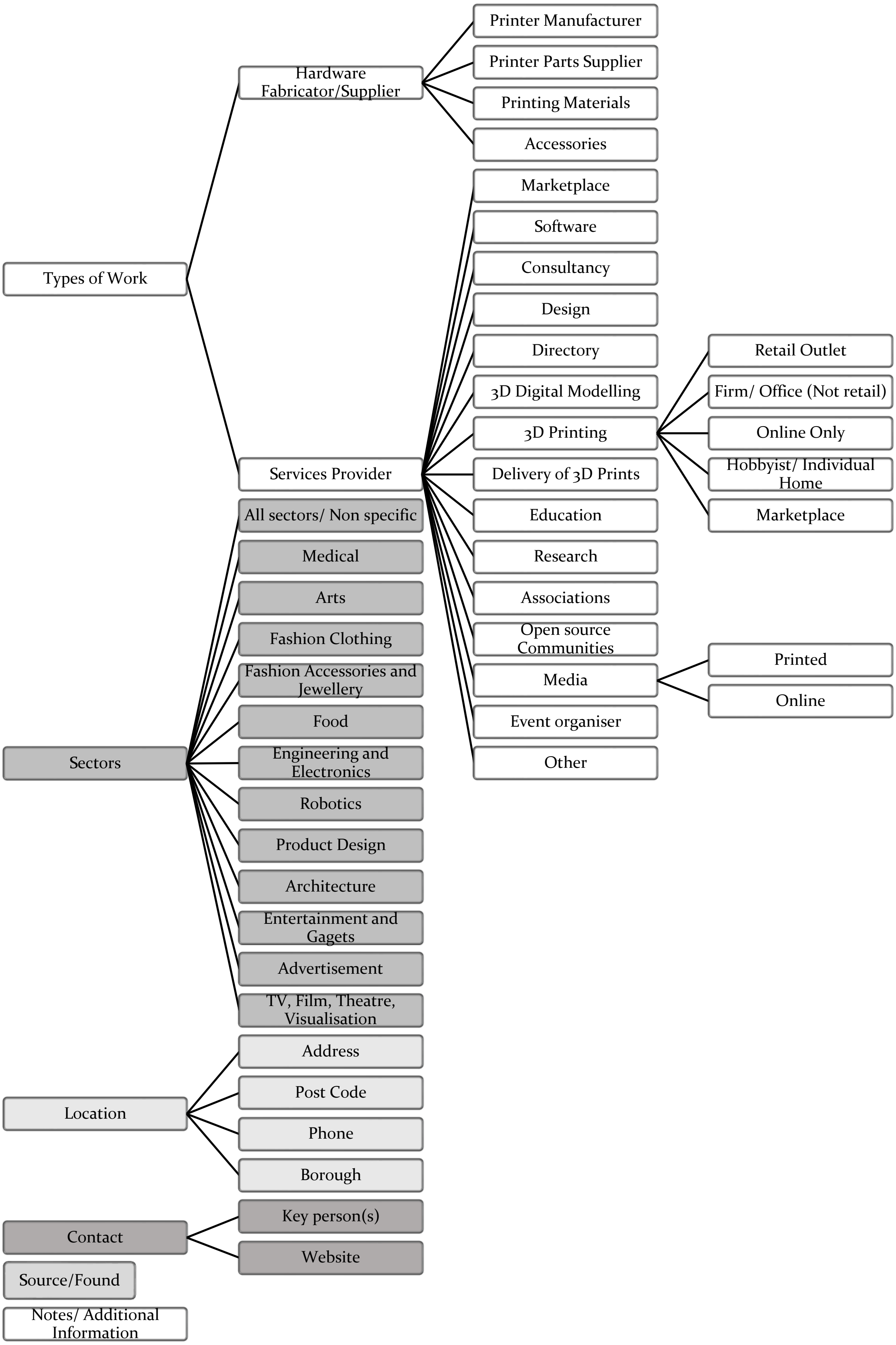

Figure 4.3 Classification of the list of entities

4.7 Case Studies for Detailed Investigation[24]

An important choice in the research process was to select from within the 131 entities list a sample to follow in greater detail. The aim was to understand the general trends of the activities to extract findings of sufficient weight and relevance. Therefore, the selection had to be a small number I could follow in good detail, representative as possible of the wider list, and of enough size to provide valid generalisable conclusions. This was achieved through a combination of proportional sampling plus taking advantage of occasional opportunities for information gathering.

The next sub-sections refer to the process of selection of the cases which were investigated in greater detail. I describe first in sub-section 4.7.1. the statistical process of finding the most common trends across all categories of the 131-list classification (statistically the mode), to guide the selection of a small sample of activities with the same category proportions, a batch of eight representative cases – an initial aim that proved insufficient. As some of the first eight did not accept to proceed to interview, replacement cases for interviews had to be selected, which will be explained in sub-section 4.7.2, alongside the reasons why the original cases were still investigated in detail, even though interviews were not consented. Lastly in sub-section 4.7.3 I explain how three other entities were added to the selection for detailed investigation, as they volunteered for supporting the research via e-mail and for providing additional information after answering the survey. In this sub-section I also explain how a less common case in an outer London borough was added to the group for further investigation, to help understand key differences of location through contrast. Through all these stages I constructed a group of 18 cases (14% of the total list) plus an additional case of an outer London borough which were investigated in greater detail.

4.7.1 Choosing the First Eight Representative Activities

[24] All firms, organisations and / or individuals mentioned in this section and throughout the thesis have been attributed pseudonyms to protect their identities and ensure confidentiality of information. These were however created in ways that maintain the character of the original name in terms of language, wording, format and length to still convey the original character to the reader.

The first action was to select eight proportionately representative activities from within the 131 list of 3D printing related activities found in London. The process was conducted as follows:

a) Classification of the 131 list and proportional correspondence for a sample of eight

The starting point was to analyse the proportions of each classification topic within the total list[25], so that the same proportions could be applied to the representative sample of eight. Proportions were considered in relation to:

i) Number of sectors of work

Table 4.2 Analysis of number of sectors that entities work on and their proportion for the 131 list plus resulting proportion for a sample of eight

Number of sectors that entities work on	*Total number*	*% of total*	*Resulting number of case studies according to same proportion*
Working in 1 sector only	105	80.2%	6
Working in 2 sectors	11	8.4%	1
Working in 3 sectors	5	3.8%	0
Working in 4 or more sectors	10	7.6%	1
TOTAL	131	100.0%	8

ii) The sectors that entities work on

[25] Refer to the classification categories in Figure 4.3

Table 4.3 Analysis of sectors and their proportion for the 131 list plus resulting proportion for a sample of eight

Sector	*Total number*	*% of total*	*Resulting number of case studies according to same proportion*
All sectors /Not specific	83	44.4%	3.6
Medical	7	3.7%	0.3
Arts	7	3.7%	0.3
Fashion/ Clothing	6	3.2%	0.3
Food	1	0.5%	0.0
Engineering/ Electronics	9	4.8%	0.4
Robotics	1	0.5%	0.0
Product Design and Prototyping	25	13.4%	1.1
Architecture	18	9.6%	0.8
Entertainment and Gadgets	14	7.5%	0.6
Advertisement Agency	3	1.6%	0.1
TV/ Film/ theatre/Production/ Visualisation	7	3.7%	0.3
Jewellery/ Fashion Accessories	6	3.2%	0.3
TOTAL	187	100.0%	8

Note: The total in this table does not add up to the total of entities. Given that some entities work on more than one sector, the total is more than 131. Also, the resulting proportions are not whole numbers, thus case numbers were approximate to the closest decimal.

iii) The number of distinct types of work involved in the operations of an entity

Table 4.4 Analysis of types of work involved in an entity's operation and their proportion for the 131 list plus resulting proportion for a sample of eight

Types of work involved in an entity's operation	*Total number*	*% of total*	*Resulting number of case studies according to same proportion*
1 type of work only	60	45.8%	4
2 types of work	35	26.7%	2
3 types of work	23	17.6%	1
4 or more types of work	13	9.9%	1
TOTAL	131	100.0%	8

iv) Location per London borough

Table 4.5 Analysis of location per borough and their proportion for the 131 list plus resulting proportion for a sample of eight

London borough	*Total number*	*% of total*	*Resulting number of case studies according to same proportion*
Camden	12	9.2%	1
City of London	6	4.6%	0.5
Westminster	9	6.9%	1
Greenwich	2	1.5%	0
Hackney	7	5.3%	1
Hammersmith and Fulham	1	0.8%	0
Islington	6	4.6%	0.5
Kensington and Chelsea	2	1.5%	0
Lambeth	2	1.5%	0
Lewisham	3	2.3%	0
Southwark	4	3.1%	0
Tower Hamlets	10	7.6%	1
Wandsworth	4	3.1%	0
Barnet	1	0.8%	0
Brent	1	0.8%	0

Ealing	3	2.3%	0
Haringey	1	0.8%	0
Hounslow	2	1.5%	0
Kingston upon Thames	2	1.5%	0
Merton	1	0.8%	0
Newham	1	0.8%	0
N/a – Exact Location not available (locationless entities)	51	38.9%	3
TOTAL	131	100.0%	8

Note: As the proportional equivalent for a sample of eight did not result in whole numbers and Islington and City of London resulted in 0.5 each, it was defined that one entity of the representative sample would have to be located either in Islington or in the City of London.

b) Excluding the least representative cases according to proportions

As the aim was to gather a representative batch of eight, cases with uncommon characteristics were excluded, as they most likely would-be particularities rather than representative of the trend. Below are the exclusion steps and the ways in which some of these exclusions were compensated:

- Excluded for detailed study entities working across three sectors, as there were only five of those within the total 131. This was considered acceptable as firms working within multiple sectors are covered by cases working across four sectors which are more prevalent than three.
- Excluded for detailed study entities located in boroughs where less than four activities were found, as these are less representative locations. Although as these are mostly the outer boroughs, an outer borough special case was later followed up in detail so I would not completely exclude outer London location issues from my findings. This case, the Romford Makers, was not within list of 131 entities as it was an activity starting to be formed, not an existing operation at the time of list gathering. Its process of inception was an interesting case to follow as I will describe in empirical chapters.

- Excluded for detailed study entities operating only in the three least common sectors: Food, Robotics and Advertisement.

c) Selecting eight representative cases

The task involved generating several combinations of eight cases which met all the proportions above, as many combinations are possible. The generative process meant that the order in which the cases were chosen influenced the overall group composition result[26]. For this reason, the categories 'Location' and 'Number of sectors entities work on' were given higher weight and priority than the category 'Types of work' involved in the operations. For the impossibility of having cases in all sectors due to the proportion not being whole numbers, the choice of one combination over another was taken considering which combination gave at a wider range of sectors in the sample of eight. The process resulted in the first batch as shown in Table 3.6.

Table 4.6 First selected batch of eight activities and their classification

Case	*Firm/ entity*	*No. of Sect.*	*Description of sectors*	*No. of Act.*	*Description of types of work*	*Location (Borough)*
1	BrownBear	1	Not specific	1	Open source/ community	Westminster
2	Eszilook	1	Not specific	1	3D Printing firm	Hackney
3	Paul's Hub	1	Not specific	1	3D Print individual	Online/ Not available
4	Medical Prints 3D	1	Medical	2	Print firm and Research	Camden
5	City Fab Lab	1	Not specific	1	3D Print Makerspace	City of London
6	Heterotopia	2	Engineering/ Electronics and Architecture	4	Software, Consultancy, Design and Research	Online/ Not available

[26] For example selecting one case in a borough that can have just one representative within the eight, and considering its sector of operation means that no other case can be chosen in the same sector, so the order of the criteria is relevant to the sampling result.

7	Fantazy Moss	1	Jewellery/ Fashion Accessories	2	Marketplace and Design	Tower Hamlets
8	Patricio Frater	4	Fashion/ Clothing, Product Design and Prototyping, Architecture and Entertainment and Gadgets	3	Consultancy, Design and 3D Digital Modelling	Tower Hamlets

d) Conclusion: How the eight detailed cases are representative

The eight detailed cases are a proportionate sample of the most common characteristics and trends of the 131 entities which emerged in London in association with the 3D printing technology. The cases are representative of the balance between types of work and number and sectors within which they work on. They are also located proportionally in the most common London boroughs. Additionally, a proportion of detailed cases do not have a fixed address as in the 131 list.

3.7.2 Replacing the First Eight Case Studies by Equivalents to Obtain Interviews

The intention was that the first batch of eight activities were all going to be interviewed, visited and investigated in further depth. But, after having contacted them several times, it was evident that some were not going to cooperate. They were either not available for interviews (Medical Prints 3D), did not answer the phone nor replied to emails (BrownBear), or went out of business during the process (City Fab Lab, Heterotopia, Fantazy Moss). For this reason, a new selection process had to be run again, following the same proportions, so that unavailable cases could be replaced, and I would still have a representative sample for interviews.

Given how long it took to obtain definitive responses from the original eight cases, more than one replacement was contacted at the same time to speed up the process. When more than one accepted, I did not reject any case, and the interviews were conducted, so there are consequently more than eight interviewed cases, which extended the evidence and stories gathered. Table 4.7 shows the replacements for interviews plus the doubled-up cases, which resulted in a total of ten.

Table 4.7 Correspondence between initial cases and replacement cases for interviews

Case	*Firm/ entity*	*Accepted Interview*	*Replaced by*
1	BrownBear	No	Print Point 3D
2	Eszilook	Yes	N/a
3	Paul's Hub	Yes	N/a
4	Medical Prints 3D	No	Models & Gadgets (M & G) with its associated Medical / Dentistry firms
5	City Fab Lab	No	City Hackspace
6	Heterotopia	No	SB Hub and Micro Tech
7	Fantazy Moss	No	Atelier León and 3D Masters Shoreditch
8	Patricio Frater	Yes	N/a

In addition, the background desktop research done on the initial eight cases was still used as part of the empirical detailed study, and the reasons why they could not participate in the study were explored as much as possible, particularly the closures, as they revealed interesting insights of businesses' performance. Further to this, I had already enrolled in a community within the original eight cases (BrownBear), and I continued that access. I also exchanged emails with some founders who did not have availability for interviews but were happy to answer questions over email.

After this process of selection and replacements, I had therefore 15 cases for detailed studies including ten for interviews plus five only for desktop research, email exchanges and/or community participation. Afterwards the group of activities for detailed investigation continued to expand as follows.

4.7.3 The Complete Group of Detailed Case Studies

During the empirical data gathering, four more cases were added to the group of activities investigated in greater detail. These are three entities which replied to survey and offered to share additional information for this research, plus one with who I exchanged several emails: Story Lab, CUCKOOZ and The Werewolf. Additionally, a special case which emerged from Paul's Hub interview was added too, the Romford Makers. This was a new entity which had not formed part of the 131 list, as it was starting to be set up at that point. I was allowed to get involved in the group and be a participant to better understand its foundation and the issues around an outer borough activity.

Table 4.8 presents the final summary of the complete 18 case studies plus Romford Makers investigated in detail, for the reader's clarity. They are also introduced to the reader at the outset of Chapter Four, as their examples will be widely mentioned in the empirical chapters. More information on these cases is also included in Appendix A.

Table 4.8 Complete list of entities studied in detail: 18 cases plus Romford Makers

Case	*Firm/ entity*	*Type*	*Form of Detailed Investigation*
1	BrownBear	Original batch of 8	Community participation and desktop study
2	Eszilook	Original batch of 8	Detailed interview and desktop study
3	Paul's Hub	Original batch of 8	Detailed interview and desktop study
4	Medical Prints 3D	Original batch of 8	E-mail exchanges
5	City Fab Lab	Original batch of 8	Desktop research on closure
6	Heterotopia	Original batch of 8	Desktop research on closure
7	Fantazy Moss	Original batch of 8	Desktop research on closure
8	Patricio Frater	Original batch of 8	Detailed interview and desktop study
9	Print Point 3D	Replacement case for interview	Detailed interview and desktop study
10	Models & Gadgets (M & G)	Replacement case for interview	Detailed interview, site visits and desktop study
11	City Hackspace	Replacement case for interview	Detailed interview, site visits, desktop study and community participation
12	SB Hub	Replacement case for interview	Detailed interview, site visits and desktop study

13	Micro Tech	Replacement case for interview	Detailed interview and desktop study
14	Atelier León	Replacement case for interview	Detailed interview, site visits and desktop study
15	3D Masters Shoreditch	Replacement case for interview	Detailed interview, site visits and desktop study
16	Story Lab	Additional case	E-mail exchanges and desktop study
17	CUCKOOZ	Additional case	E-mail exchanges and desktop study
18	The Werewolf	Additional case	E-mail exchanges and desktop study
+	Romford Makers	Exceptional case (not a listed entity)	Community participation and site visits

It can therefore be concluded that this selection process was not linear, but it delivered a suitable selection of cases for the study. Consistent with this research's mixed epistemological approach, selecting cases for further detail study was a mix of a top-down typical sampling process with the freedom to take advantage of opportunities for insightful information as it emerged during the research.

4.8 Use of the Methods

This section explains how various methods of research were employed.

Classification of Entities and Statistical Analysis

The 131 list was classified as per Figure 4.3, and afterwards analysed with use of Excel. Graphics were produced to visualise outcomes. Some are part of the empirical analysis chapters.

Mapping

Maps with the location of the entities as classified in the long table were produced using AutoCAD and Adobe Illustrator software, and a layer system was created to find out about overlapping patterns. When classifications were completed, the maps were split per type of activity so that clustering of types of activities could be analysed.

Desktop Studies

Information was collected online through the various organisation's websites, authored articles referencing them, you tube interviews, advertisement and specialist press (which is predominantly online only too). This search produced the classification as described in section 4.7 and complemented the analysis by other methods. This method was applied to the extensive list, as well as to the detailed cases. Printed material was also used to investigate and collect information about activities when it was available.

Survey and its Statistical Analysis

The survey (as included in Appendix D) was set up in Survey Planet, an online survey platform. It was prepared with 21 questions including multiple choice with or without an option for adding bespoke comment, 'yes or no' questions plus an essay type question. Responding takes somewhere between five and fifteen minutes, depending on length of comments.

Between January and June of 2017, the total 131 entities were contacted to request if they could kindly fill in the survey. Initially all entities were contacted via email and repeated with a second email for those which did not reply initially. Further to this, to try and achieve a higher rate of responses, a letter was posted to all those who had not responded twice, containing a brief introduction to the research project and the printed questionnaire plus a stamped return envelope for posting back surveys without any costs to respondents. Subsequently, the responses which arrived by post were entered in the digital survey platform to be included in the statistical analysis and output graphics. In total, 33 entities completed the survey, which is a responding rate of 25.2%.

Interviews

Between May 2015 and July 2017 ten semi-structured interviews were conducted. These included all the pre-arranged interviews with representatives of the final detailed case studies, in person or using Skype, plus one casually arranged interview with a reporter at the London 3D Printing Show, in person. Appendix D has the base questions used in the interviews as the starting point, and the participant consent form made available to participants in the beginning. When appropriate, the interview expanded beyond the initial questions. Table 4.9 presents the full list of interviews and the dates when they took place.

Table 4.9 List and details of interviews

Date	*Entity*	*Interviewed*	*Interview Location*
23rd May 2015	Disruptive Magazine	Reporter	London 3D Printing Show
9th February 2017	Atelier León London	Jean-Antoine David, Co-Founder and Director	Atelier León Studio, adjacent to Jean-Antoine's flat, Bow
13th February 2017	Paul's Hub and City Hackspace	Paul Lewis, Sole owner of the hub, City Hackspace Board Director and Meetup organiser	City Hackspace, Hackney
26th February 2017	Patricio Frater	Patricio Frater, Sole owner	The Gallery Café, Hackney
13th March 2017	Eszilook	Slavis T. Prioli, Founder and Director	Skype
4th June 2017	Print Point 3D	Martina Ricci Calabria, Global Community Manager	Skype
5th June 2017	Models & Gadgets (M & G)	Aleksander Demus, CAD Production Manager	My office. On a previous occasion I had visited M & G's studio in Camden and had met Aleksander there in advance

14th July 2017	SB Hub	Mirek Iliescu, Founder and Director	SB Hub offices, at a warehouse co-working space in Clerkenwell
20th July 2017	Micro Tech	Rajiv Agrawal, Founder and Director	Skype
21st July 2017	3D Masters Shoreditch	Santiago Sebastian, Co-Founder and Director	3D Masters Shoreditch workshop, at a unit in a workshop complex in Shoreditch

E-mail Exchanges

Information was also gathered from people who were not available for a full interview in person, but who were happy to answer my questions via e-mail. These have been listed in Table 4.10.

Table 4.10 List of contacts by e-mail

Date	*Entity*	*Respondent*
30th January 2017	Story Lab	Mike Haussmann, Founder
6th February 2017	CUCKOOZ	Chris Lansbury, Information Officer
6th February 2017	The Werewolf	Ronald Nicosia, Founder

Photography and Site Visits

The premises where activities were and the people who responded or attended meetings were photographed. Consent was always requested beforehand when photographing people and interiors. When photographing external buildings, no consent was requested as sometimes there was no one there and it was seen from a public highway point.

In addition to the sites visited for interviews, several other visits of nearly half of the entities from the 131 list were conducted too, to examine the types of buildings and context where activities were based. A small selection of those photos has been included in the analytical chapters when relevant.

Visits to Trade Fairs

For this research, the London 3D Printing Show was visited during the days 21, 22 and 23rd of May 2015 at the Old Truman Brewery, Brick Lane. Documents such as hard copy pamphlets were collected, internet websites were visited and registered on, talks attended and other relevant industry-specific publications acquired which proved an extremely useful insight. In addition, a MakerFaire UK was attended, and although it covered the entire country, only the London listed cases were of interest. During these fairs informal conversations with industry members took place, not recorded, but explicitly agreed for the use in this study. As included above in Table 4.9 a reporter was formally interviewed.

Participation in Groups/ Forums/ Communities

In the makers' culture it is common to freely share knowledge in meetings and in online forums. I thus attended two meetups for observation and discussion with the participants. This included signing up for the groups (as these meetings are not public and only opened to group participants) and attending the London 3D Printer User Self-Help group at the City Hackspace, plus joining the Romford Makers group at a pub in Romford. In addition, I participated in two online forums registering online with BrownBear, the open-source community, and with City Fab Lab. I also created a 'pretend hub' to register at Print Point 3D and be able to enter forums with others on this platform. Please refer to Table 4.11.

Table 4.11 List of groups (as a group participant)

Group	*Type*	*My Participation*	*Discussions and Interviews*	*Position as Researcher*	*Location*

Print Point 3D	Online hubs directory with community chats	Registered in July 2016 and created 'pretend hub'	Online informal discussions/ reading open forums; Interview with Martina Ricci Calabria, Global Community Manager (via Skype)	Identified only for the one-to-one interview. My hub remained unidentified otherwise. Note: there is no requirement for identification for any participating hub.	N/A
BrownBear	Online open-source community	Registered in December 2016 and participated as member of various forums	--	Anonymous, with initials only. Note: there is no requirement for identification for anyone enrolled.	N/A
London 3D Printer User Self-Help	Online Meetup group which organises meetings in person	Registered in November 2016. Attended group meeting 13th February 2017	Conversation with all attendees at the meetup session (7 people attended)	Identified, read consent forms.	City Hackspace, Hackney
Romford Makers	Local group which organises meetings in person	Registered in November 2016. Attended group meeting 14th February 2017	Conversation with all the meetup session (9 people attended)	Identified, read consent forms.	The Royal British Legion Pub, Romford

There were two approaches to revealing my researcher identity during this process: On the situations where I participated in person (as opposed to virtually), I introduced myself as a researcher and explained clearly what the purpose of my participation and conversations was, and I read the participant consent form as included in Appendix D. In the online engagement, where I met people virtually, I remained anonymous or used a pretend name as a hub, thus no one was aware of my intentions as researcher. I have benefitted from the fact that people in online communities wrote as if I was part of their makers group, and so may have used more authentic *pals'* language in the belief that we all shared the same knowledge. As there is such a range of makers' specific vocabulary relating to the technology and across the communities, this proved interesting and insightful, and an effective way to better understand how information is shared process in this community. I do not consider this unethical as there was no confidential information being shared because these are open-source websites, open communities or shared marketspaces. Furthermore, there is no requirement for forum participants to identify at all, and many others also use pseudonyms or coded usernames.

4.9 An Industrial Study?

Since this research is exploring the possibility of urban manufacturing renaissance through the case study of activities associated with 3D printing, a new technology, it can be said that this research is in some form an industrial study of which there have been many significant examples in economics and economic geography, ever since Marshall studied the Birmingham industrial quarters (Marshall 1919). Industry studies have been the basis of economic models (not always linked to geography and spatial matters such as those of economists as Chamberlin (1933)), as well as the basis of economic geography perspectives (linked to spatial factors, refer to examples in the upcoming paragraphs), and both have translated into economic and public policy. There is thus a substantial background legacy to this type of research, which is worth considering to situate this study and this methodology.

But while it can be said that this research is *some kind* of industrial study, a matter for reflection is what type of industrial study this is, and with what other industrial studies it bears affinities. This can be considered with regard to the type of methods used in this study, as well as in relation to the discipline of economic geography itself and its changing methodological approaches over time.

Before the 1980s there was some consensus about what economic geography was studying – Industries – and about the quantitative methods employed in such research, largely based on surveys and census data. Economic geography was really about industrial geography, and typically many industrial studies relied on methodological approaches using the firms and/ or industrial estates as the base source of evidence. These methodologies distinguished the firm(s) from their environment and relied on data such as employment structures, firm organizational compositions or new firm formation data for analysis (Pratt 1994a), thus subsiding almost entirely within the scientific paradigm. Some key historic industrial studies were structuralist in nature and represented unavoidable paradigms for what industrial studies can be, and of what structuralism itself is about, such as the Condition of the Working Class in England in 1844 (Engels 1892), in Manchester.

Up to the 1980s, economic geography research focused on finding causes for general patterns observed for large groups of industries or sectors and aimed at descriptive and more general explanations of regularities for the whole group. Large-scale samples were thus the focus of investigation, and methods of study included surveys, statistical analysis of substantial amounts of data, fully embracing taxonomic grouping such as Standard Industrial Classifications for example.

But as the industrial, political and economic landscape changed so profoundly in the 1980s, so did the perspective on what industrial studies could be and the methods by which they could be undertaken in economic geography. Former empiricist and structuralist paradigms of analysis were dismissed by scholars like Doreen Massey as only including locational factors (Massey 1984), thus missing social and institutional changes and not suitable to address the radical changes occurring in the post-Fordist period. The very idea of Industry and of a Sector was brought into question, and this was partly because the new division of labour and vertical disintegration of production made it particularly challenging to frame studies within existing taxonomies (Storper and Scott 1986; Barnes et al. 2007).

This was however a highly productive time of industrial research, many times with a much more political angle on the study than the industrial studies that preceded it. The discipline of economic geography expanded considerably in scope: there were many industrial studies focusing on the changes in industrial organisation, flexible specialisation, technology firms and districts, and everything else to do with changing production beyond productive industries to include services, corporations, networks. These studies included all types of industries and technologies such as heavy productive manufacturing, traditional industries such as furniture or clothing, automobile industry (Cohen and Zysman 1987), new technology firms and districts (Storper 1992, 1995 and 1997; Hall and Markusen 1985; Rigby and Essletzbichler 1997) and creative industries (Florida 2002; Storper 1989; Scott 2000; Zukin 2010). As the object of study expanded and empirical analysis shifted away from larger groups to almost rely on a few case-studies entirely, so the methods changed from quantitative to qualitative analysis (Barnes et al.2007) including in-depth interviews, ethnography, participant observation, focus groups, discourse analysis, activist engagement.

But narrowing the object of study, embracing multi-methods of mostly qualitative nature and interdisciplinary discussions triggered criticism in terms of lack of rigour and evidence, as well as mixing standards and relevance of findings with deep causal relations in individual cases which would not be representative cases (Markusen 1999).

Even though there was a change from quantitative to qualitative methods and in the disciplinary understanding of what an industrial study can be, according to Barnes et al. (2007) the discipline continued to be discrete about its methods and this change itself was not as linear as it may appear, and the authors refer in fact to a 'disorderly methodological history of economic geography' (Barnes et al. 2007: 14).

Now, thirty years later, my research on the activities that have emerged in association with 3D printing technology inherits aspects of both approaches in scope and methods. Regarding scope, my object of study presents some similarity to a former study of a typical industry at the outset, being broad and all-inclusive at the point of gathering 131 entities list likely to include all such activities in London in that period. But, in fact, it crosses multiple sectors as it will be shown in the next chapters. There is the presumption that a whole group is captured in the complete 131 list formation, so that the study could effectively proceed, since such list did not exist before. However, soon after, the object of this industrial study was narrowed down to a small selection of case studies, chosen with the perspective that these cases needed to be representative of the list anyway. Regarding the methods used in the detailed cases, they are a very heterodox mix of quantitative and qualitative types, ranging from surveys to ethnographic approaches such as visits to sites and participation in online groups.

As explained, new activities emerging from a new manufacturing technology is the object of critical examination, and it includes many new technologies and operations which are still unfolding. Therefore, these had to be enquired beyond the empirical measurement of firm or firm cluster or business park data, as such data does not fully exist anyway, and it was apparent from the start that these activities needed to be found first. This study includes interpretative and modified multi-methods to even produce a list of entities to investigate, and epistemologically rely on the researcher's interpretation for entities data gathering and classification at the outset, something which was unusual to most typical industrial studies which for example could rely on SIC catalogue and business registers. Moreover, in this study it was always accepted to investigate as far as the cases allowed to, following clues and information as it emerged such as when invited to participate in the Romford Makers group because of following Paul's hub. There was a certain *go with the flow* approach which provided further insights to the cases and brought richness to the findings, even if sometimes outside the direct realm of the research questions.

As this study clearly borrowed from the different approaches and methods as needed and when needed, certain industrial studies were used as references. On a more structuralist analysis the key reference was primarily Hall's study of the Industries of London (Hall 1962), on the case study empirical analysis they were Allen Scott's studies of the geography of various image-producing industries in Los Angeles and in Paris (Scott 2000), and on a technology case a key reference was the tech city industries study in London's Old Street by Foord (2012). If some of these influences are seen in-between the lines of this analysis it is no coincidence as they were every day reading presences in the work. But even in comparison with these last two, this research is far more interpretative and ethnographical, and epistemologically more participatory, particularly when analysing the makers' culture and their practices.

My findings are thus also a mix of general large-scale explanatory conclusions with individual in-depth contingent relations and features. They are a mix of characteristics representative of all activities with some which will be particular to a specific location or a type of activity. This approach to the research has more explanatory virtue than a purely quantitative top-down study would have had, and the findings are in this way more pertinent to similar activities in similar post-industrial cities, more representative than an in-depth case study analysis would have been.

Additionally, it can also be noted that this study focused on a slice in time – the present. Many industrial studies, particularly most recently, highlight the value in following the evolution of practices and relationships over time (Gertler 2004). This was not possible as this is a very new technology without much of a history to draw from but, during interviews and through desktop investigation, the beginning of their stories as well as the path since then up to now was explored as much as possible. Given I was aware of this limitation, I asked people about the past, and their understandings of future possibilities relating to the technology, and I gather information about the mechanisms which might produce different future outcomes.

Lastly, it may be suggested that the freedom followed of adopting as many methods as it was deemed necessary and evolving the methods as the research unfolded is in part a strategy derived from how a creative process happens. This should be no surprise, given my background is in Architecture and not in social or physical sciences. Perhaps, as in post-Fordism profound transformations in the context of industrial studies triggered expanded scopes and methods, so does the current context - with its comparably accelerated technological change - open the door for more unconventional mix of methods, as here used, and for hybrid, fluid and creative approaches to knowledge production in economic geography.

4.10 Conclusions

In this chapter I have outlined this study's methodology as an original approach within the economic geography paradigm of industrial research. Having begun by defining the object of the study – activities which have emerged in connection with 3D printing technology - I noted how complex it was to grasp, due to the novelty of the activities. This novelty was also described as the trigger for my *sui generis* methodological approach. I then outlined where my project was located, in London, defined as per its administrative boundaries. The reasons for this choice were discussed, particularly focussing on London's post-industrial attributes such as the prevalence of creative and knowledge industries, the loss of manufacturing and the aspirations for reviving urban manufacturing.

Then, I introduced my research approach and its design, which is characterised by its cross sectoral, horizontal formulation. This approach was created to deliver insights on the contrasting propositions of a new manufacturing revolution, or sectoral diversification through the revival of manufacturing – which could only be assessed if I followed the outcomes of a technology adoption across multiple applications. However, this means I have adopted a technology-led approach, in which I also differ from most economic geography studies focussing on an industry, sector or case study. In this approach, I border on a neo-Schumpeterian theoretical framework, which was applied in analyses of post-Fordism to explain historical industrial revolutions and production changes, because of my starting point being a technology, which links together everything I will analyse about work, activities, location, etc. This approach was appropriate as a methodological practice, although I never assumed *a priori* that technology would be the sole reason for the findings, and I always aimed to find out the hidden stories, the places and people's narratives.

Following this, I focused on the methods employed in this research, which are a mix of qualitative and quantitative. I explained which actions and steps I carried out to conduct my research, and I reflected on how this research stretches the recent trend within human geography to adopt a mix of methods: sometimes the subject of my study was concise and the methods were more top-down such as in statistical analysis, whilst at other times I was immersed in the investigation, for example when participating in forums.

I then explained, as part of my methodology, how I aimed to answer the research questions, which were divided into sub-questions and attributed to specific methods used to gather the necessary information. I explained through the remaining sections of the chapter how exactly my research progressed, including the way I constructed the complete list of entities which I analysed, and how a small number of activities were selected for detailed investigation. This was also not a linear process, as some people were not available for interviews, and some activities were in the process of closing down and had to be replaced in the sample. The sampling process was also *sui generis*, as it comprised initially of typical sampling, but evolved to include replacements and occasional additions so I could get more and better information. It was yet another example of my hybrid epistemological approach to my research subject, and of my mixed research practice. Further, I explained how each method was used in detail throughout my study.

Following this, I argued that my study is effectively *a kind of industrial study*, as it is in scope and method a study in economic geography. My object of study, its theoretical framing, and the research questions are conventional areas of the discipline's focus. But my methods mixed more traditional ways of studying industries in long standing industrial studies such as surveys, statistical analysis and mapping, with less orthodox and more ethnographical and detailed ways of studying economic activities, like participatory methods. My research practice is not a politically framed one, nor a participatory constructivist one, but also not a pure scientific positivist analysis either. Its merit, I believe, is in borrowing from various paradigms of knowledge production and using their methods as needed. In the process I have also sometimes freed myself from some of the constraints of the original research design and allowed myself to follow clues and opportunities to gather more information.

The themes that emerged from analysing all the data collected form the basis of my answers to the research questions and construct an evidence-based theorization of the process of innovation in relation to emergent manufacturing technologies in a post-industrial urban context. The findings are grouped and presented in the three empirical chapters that follow. First, I present what activities are emerging in connection with 3D printing, how they are structured and how they work, including with what other organisations they connect (Chapter Five); second, I analyse the findings on the location and premises of the activities, plus reasons for those findings (Chapter Six); and third, I elaborate on how the 3D printing technology contributes to growth and competitive advantage in a post-industrial urban context (Chapter Seven).

Chapter Five

Characterization of Activities: Production, Sectors and People

42.7% do not 3D Print at all...

(Finding, my research)

5.1 Introduction

This chapter analyses the nature of the activities which have emerged in London in association with 3D printing technology. It answers the first research question, '*What activities have emerged in London associated with 3D printing?* and presents the evidence for my first argument. This is that the primary role of material production in post-industrial urban economies is to support abstract tasks, work processes and outputs of the creative and knowledge sectors. This argument is supported by evidence concerning first the types of work and the sectors of operation I found in London, second the structure of the activities and the people engaged, and third the links with other organisations.

Section 5.2 introduces the businesses where detailed interviews and visits were conducted. This offers some context and background to orient the reader in relation to the empirical analysis which follows, before embarking on more detailed analytical discussions. More comprehensive information on the cases can be found in Appendix A.

The next sections present the three sets of findings to support my argument: section 5.3 analyses data about the types of work conducted and the sectors of operation. I also discuss the notion of identifying 'sectors' and classification divisions within the activities which emerged in association with the 3D printing technology. The chapter then describes the organizations structure and size, and the background/educational status of founders, owners and employees (section 54.4); and

Section 5.5 analyses the links between these activities and other firms, their clients and research organisations.

The findings of these sections reveal that the activities, their types of work and their connections with others in the production chain are more characteristic of knowledge, creative and services sectors than of manufacturing. Work is clearly focused on early stages of products and production chains are expanded and networked as in those sectors already characteristic of post-industrial urban economies (Hamnett 2004; Hamnett and Whitelegg 2007; Castells 1996; Scott 2007 and 2008). The 3D printing technology expands what people do, allowing for new design possibilities, new software creation, faster ways to prototype. These processes were applied across many sub-sectors of knowledge, and innovation is thus found to be about work processes in abstract (conceptual and design) tasks, not about material outputs. Further, the research revealed that activities are well connected with other firms and institutions, forming part of the production networks of creative industries.

The chapter concludes (section 5.6) that 3D printing technology, despite enabling material production outputs, has not triggered small manufacturing activities or manufacturing revival, nor more direct production chains. Instead, it has enabled more and new activities, and expanded networks with existing activities - particularly innovative, creative and knowledge sectors - in London.

5.2 Overview of the Detailed Cases

As described in Section 4.2, the 3D printing activities in London include various kinds of entities such as private firms (of varying sizes), sole traders, not for profit organisations, industry trade associations, studios within educational departments, marketplaces, online communities focussed on this technology, and industry-specific press. All these can be grouped under the 'umbrella' of the activities which emerged in London in association with 3D printing, with the organisations undertaking these designated here as 'entities'.

As explained in the methodology, some cases were followed in greater detail with interviews, email exchanges, group participations and site visits[27]. These cases are

[27] Refer to sections 4.6 to 4.8 for the selection process and classifications.

introduced in this section, and mentioned many times throughout the empirical chapters. Table 5.1 summarises these cases for ease of reference.

Table 5.1 Overview of the 18 Detailed Cases + Romford Makers[28]

Entity	*Brief description*	*Key person (s)*
BrownBear	Online open-source community	N/a
Eszilook	3D printed hardware, virtual reality devices, visualisations	Slavis T. Prioli, Co-Founder
Paul's Hub	Sole trader, 3D printing hub	Paul Lewis, Founder
Medical Prints 3D	3D technology solutions, prints and research for the medical sector	Peter Griffiths and Harry Pinfield, Co-Founders
City Fab Lab	Shared workspace and fabrication laboratory for members	N/a
Heterotopia	Software creator for design of construction elements intended for 3D printing	Paula Gina, Founder
Fantazy Moss	Online marketplace for 3D printed jewellery and fashion accessories	Maria Bernardi and Richard Schuhmann, Co-Founders
Patricio Frater	Sole trader, product and fashion designer	Patricio Frater, Founder
Print Point 3D	Global online 3D printing hub platform	Martina Ricci Calabria, Global Community Manager
Models & Gadgets (M & G)	Printing bureau, product development, design, virtual and physical modelling	Aleksander Demus, CAD Production Manager; Charles Kavanagh, Founder
City Hackspace	Membership association for shared workspace and fabrication tools; Location of meetups	Paul Lewis, Board Director and Meetup organiser
SB Hub (changed to AFMG during research)	Creator of automation software for industrial 3D printing	Mirek Iliescu, Founder
Micro Tech	Design and modelling of parts to optimise metal-based additive	Rajiv Agrawal, Founder

[28] All firms, organisations and / or individuals have been attributed pseudonyms to protect their identities and ensure confidentiality of information. These were however created in ways that maintain the nature of the original name in terms of language, wording, format and length to still convey the character to the reader.

	manufacturing in other industries; patented geometries	
Atelier León	Design and print of decoration products for 3D printing	Jean-Antoine David and Marguerite Moreau, Co-Founders
3D Masters Shoreditch	Consultancy in product development and prototyping	Santiago Sebastian, Co-Founder
Story Lab	Product design and prototyping and for engineering sectors including mechanical and construction	Mike Haussmann, Founder
CUCKOOZ	Professional institution for mechanical engineering, with database and research in 3D printing technology	Chris Lansbury, Information Officer
The Werewolf	Consultancy and product development in gadgets and entertainment sectors for 3D printing	Ronald Nicosia, Founder
Romford Makers	Volunteer group aiming to set up a makerspace in Romford	N/a

5.3 Types of Work and Sectors of Production

This section presents a thorough description of the distinct types of work that the entities surveyed engage in, including all their main and auxiliary tasks, followed by the sectors of their operations. These are key findings to support my argument that material production with advanced fabrication technology (such as 3D printing), in an urban post-industrial economy (such as London), primarily supports the conceptual and design tasks of knowledge, creative and services industries. I show that the activities which emerged in London in connection with 3D printing are part of those leading sectors, as the work carried out is either 3D printing as a task or service to other activities or enabler to creative tasks, such as prototyping, design, etc. Furthermore, there are a large number of entities (42.7% of my sample) which do not print, and instead just work in consultancy, design, software creation, online marketplaces, etc.

Drawing on all sources of information (desktop categorisation of entities, surveys and interviews) this research finds that the most prevalent type of work in London is the provision of services. Services include 3D printing, marketplaces, software providers, consultancy, design, directory, 3D digital modelling, 3D printing, delivery of 3D prints, education, research, associations, open-source communities, media, and event and networking organisers. The least prevalent type of work is fabricator/ supplier of hardware which includes manufacturer of 3D printers, parts supplier, materials and accessories fabricator and/or supplier[29]. There is thus a sharp imbalance: service providers constitute 89% of the entities and hardware fabricators/ suppliers only 11%, as illustrated in Figure 5.1.

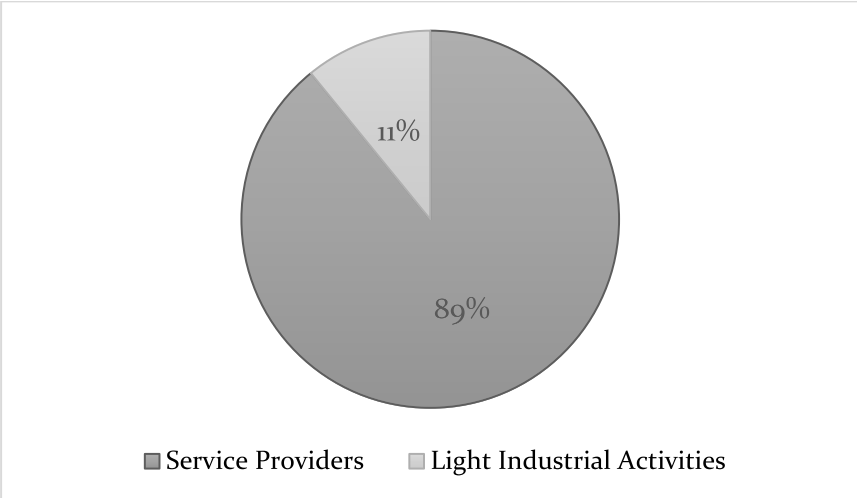

Figure 5.1 Types of work: Proportion of service providers and hardware fabricators/ suppliers in London (According to total list of entities from desktop study)

The most common task conducted by the service providers (89% of total) was 3D printing, followed by 3D digital modelling, design and consultancy. This highlights the strong knowledge-based and creative nature of these activities in London. These are findings based on the classification of the comprehensive list of entities, as Figure 5.1 shows.

[29] Refer to Figure 4.3 for classification of entities (provided in Section 4.6)

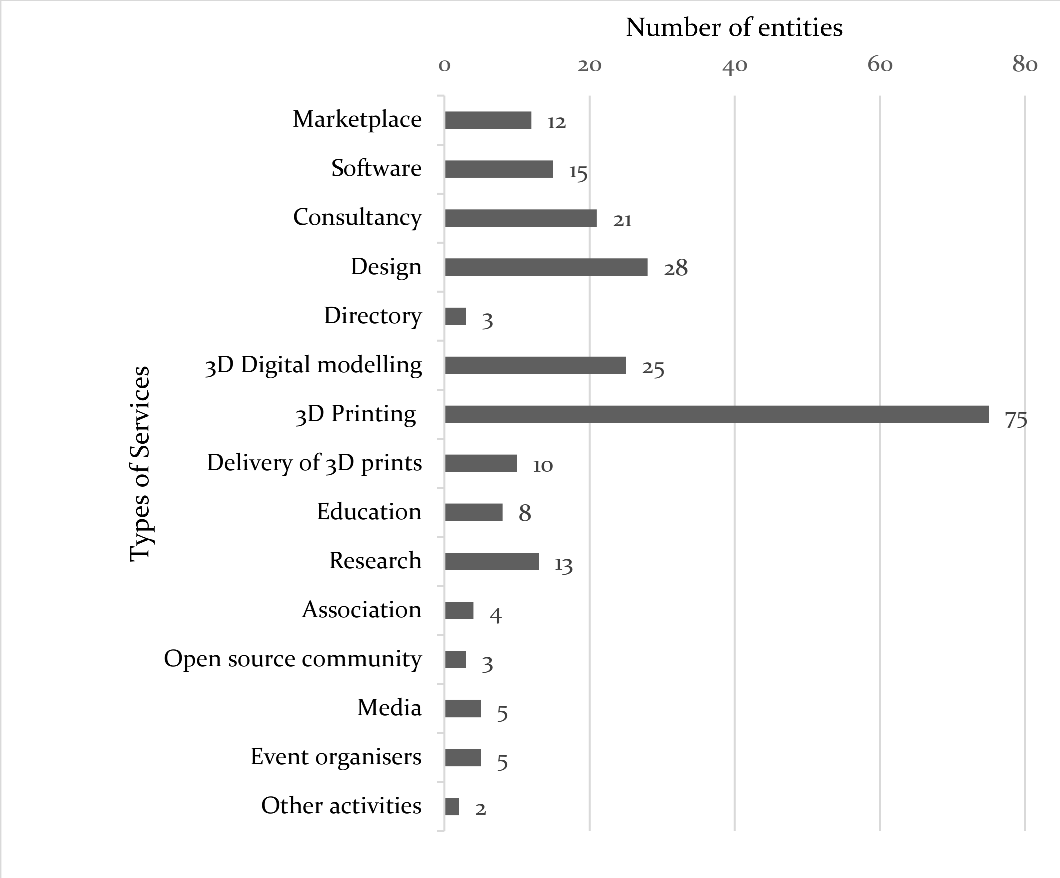

Figure 5.2 Types of services within the service providers (According to total list of entities from desktop study) [30]

A closer analysis was undertaken of the 75 entities (57.3% of the total 131 activities) which use 3D printing technology to make 3D printed *things* (other than just 3D printer machines or machine parts). 3D printing is, as expected, the most common service, but it is rarely the sole service, and is most often combined with other services. Many of these are of creative and knowledge nature, including design, digital modelling, consultancy, research, software creation, marketplace, etc. Further to this, there is a remarkably high number of entities who do not actually 3D print at all: 42.7% of the complete list of 131 entities in London according to desktop investigation of all firms and the services they offer through their adverts, webpages, phone calls, presence in trade fairs, industry databases and industry-wide websites. This finding emphasizes

[30] In this chart the total number of activities adds up to more than the total number of entities, as to each activity a value of 1 was attributed. For example, if an entity has two activities it logs 1 point on each activity.

that these 3D printing related activities do not constitute a technologically led manufacturing revival in London.

Table 5.2 3D printing work within the activities (According to the total list of entities from desktop study)

Activities	*No. of entities*	*%*
Entities which DO NOT 3D Print	56	42.7
Entities which JUST 3D Print	43	32.8
Entities which 3D Print in conjunction with other types of work	32	24.4
Total	131	100

The work of the entities which do not print at all (sometimes outsourcing printing or sometimes not printing at all) includes a very wide range of services, often unique services tailored to specific projects or clients, with many being of a creative nature. These activities are linked to other firms which print for them, or who will then be the users of 3D printing machines. Or they are instead consulting about production processes of other industries, product designing or creating new software. So, despite their work not involving 3D printing, they still included themselves in databases of the 3D printing technology, and certainly most of their work would not exist if it were not for this technology. Even if they do not 3D print.

Having arrived at these findings from desktop analysis of information on the total list of entities – arguably a bird's eye view - it is worth noting that this is also reflected in how participants understood themselves, an insider's perspective. These findings are consistent with the way the survey participants described their own organisation, meaning that the people involved in this study were themselves aware that their focus was not *making things*, but more as creative industries, digital (tech) start-ups, consultancies. They saw their printing work as combined or part of product development and design. Table 5.3 summarises how the respondent organisations described themselves. Only two fifths of respondents described their organisation as printer/ maker, showing that the activities are characterised by many other services and creative or knowledge types of work other than 3D printing. The remaining three fifths of respondents described themselves as designers, software developers, hardware or materials suppliers, consultants, marketplaces, or educational activities.

Table 5.3 What best describes your organisation? (According to survey evidence)

Description	*No. of responses*	*%*
Printer/ Maker	13	39.4
Designer	5	15.2
Software developer	3	9.1
Hardware or materials supplier	2	6.1
Education	2	6.1
Consultant	1	3.0
Marketplace	1	3.0
Maker's cafe	1	3.0
Association	1	3.0
Data provider	1	3.0
Crowd manufacturing	1	3.0
Model making	1	3.0
Other	1	3.0
Total	33	100

In surveys and conversations, participants downplayed the role of 3D printing in their tasks: Idea or product development, as well as design, are as prevalent a response to this question as 3D printing. Prototyping and digital modelling are also amongst the common types of work they reported doing. Figure 5.3 illustrates the most common tasks reported by participants. It can be clearly seen that the use of the actual 3D machine technology is not the most common task.

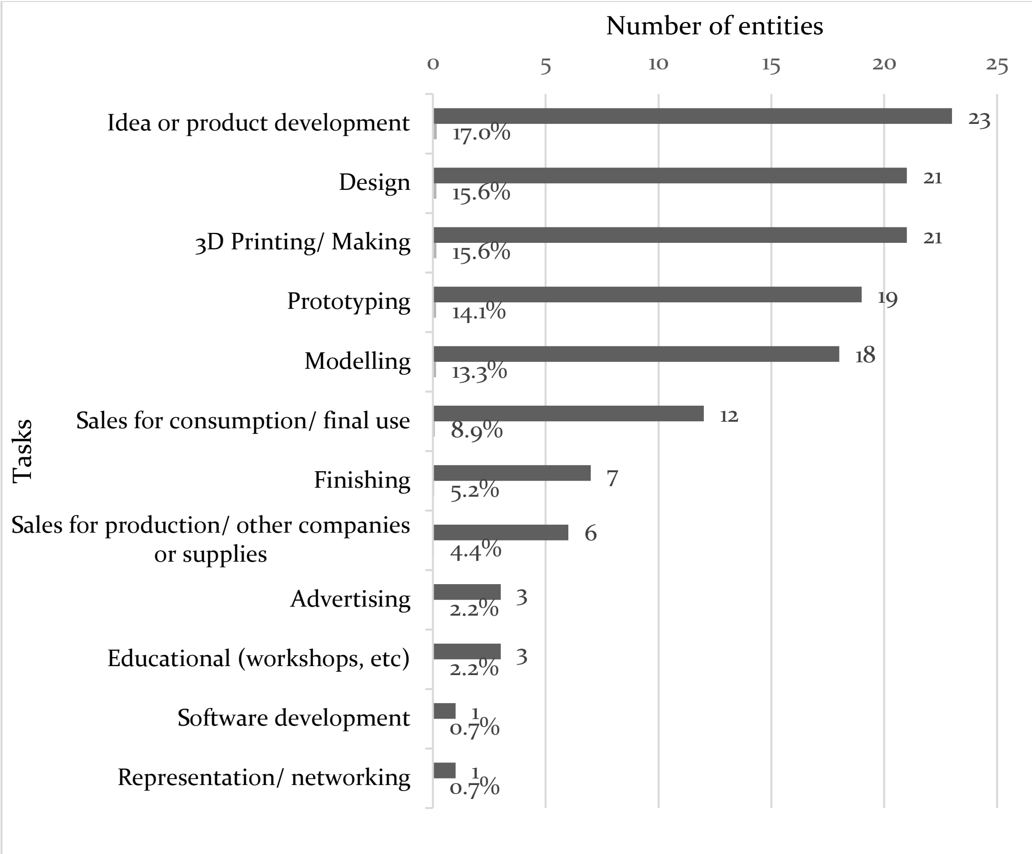

Figure 5.3 Most common tasks reported by participants (According to survey evidence)[31]

Many of these companies provide tailored or personalised services to clients, who range from large corporate manufacturing industries to individuals. For example, Micro Tech sells application licences to add precision and capabilities to existing CAD/ CAM software. They focus on enabling industrial production with 3D printing technology and offer product development services to their large manufacturing clients. They do not 3D print anything themselves, but their clients do with the use of their software. SB Hub, a similar type of entity, develops software solutions that automate processes for large scale additive manufacturing industrial clients. They do not 3D print and they do not have any machines, as they only work on the software. Eszilook, another example, develops personalised Virtual Reality (VR) headsets for mobile phones based on an algorithm that combines an individual's phone model characteristics and personal needs in terms of lens specifications and headset design.

31 In this Figure the total number of tasks adds up to more than the total number of surveyed entities, as the respondents were asked to tick all that apply.

The headset is custom made; thus, 3D printing is the appropriate technology used to manufacture them because the outputs are unique items. The client can either print themselves or send it to be printed elsewhere.

Micro Tech, SB Hub and Eszilook would all be better framed as technology companies rather than manufacturing companies in the traditional sense. They are good examples of the types of activities which emerged in London in association with 3D printing, which do not print but work on technology-related tasks. Innovation triggered by the 3D printing technology in this urban context is thus not about material outputs, but about faster and more flexible work processes.

For the most part, specialisation happens in the type of work or task undertaken, not in a sector of activity. In the most common cases, this research finds that the organisations are specialised in one or two tasks only, or in a material, a geometry, etc. so they optimise the processes of what they do. They then apply those specific tasks or processes to as many sectors as possible, expanding the client base.

In sum, most entities are service providers, about half of which do 3D printing for testing designs, prototyping, or to service other entities in their creative processes, and half of which do not produce anything material as such. There is thus no evidence of an urban manufacturing renaissance based on this technology. Below I will discuss my findings on how the tasks and types of work undertaken are linked to a wide range of sectors of economic activity.

Sectors and Sub-sectors of Production

This section analyses the sectors within which the entities work. Most entities operate in multiple sub-sectors of the Knowledge sector, not within Manufacturing, and that most operate across different sectors, without specialising in a sub-sector at all. However, there is one exception, those working within the medical sector. Considering how cross sectoral these activities are found to be, this section will reflect, as an added point, on the difficulty of using the traditional notions of sector as expressed by Standard Industrial Classification (SIC) to classify these entities, a point which was raised in the methodology chapter.

The data in Figure 5.4 shows clearly that most entities offer services which are not specific to a sector. Most entities work within product design, architecture, entertainment, engineering, etc. – all sub-sectors of Knowledge and Services Sector, not Manufacturing. And, amongst those entities which operate in certain sub-sectors only, product design and prototyping is the most popular, followed by architecture, which is consistent with design tasks being the second most common type of work, just after 3D printing, as described before. The creative industry is the focus of these activities.

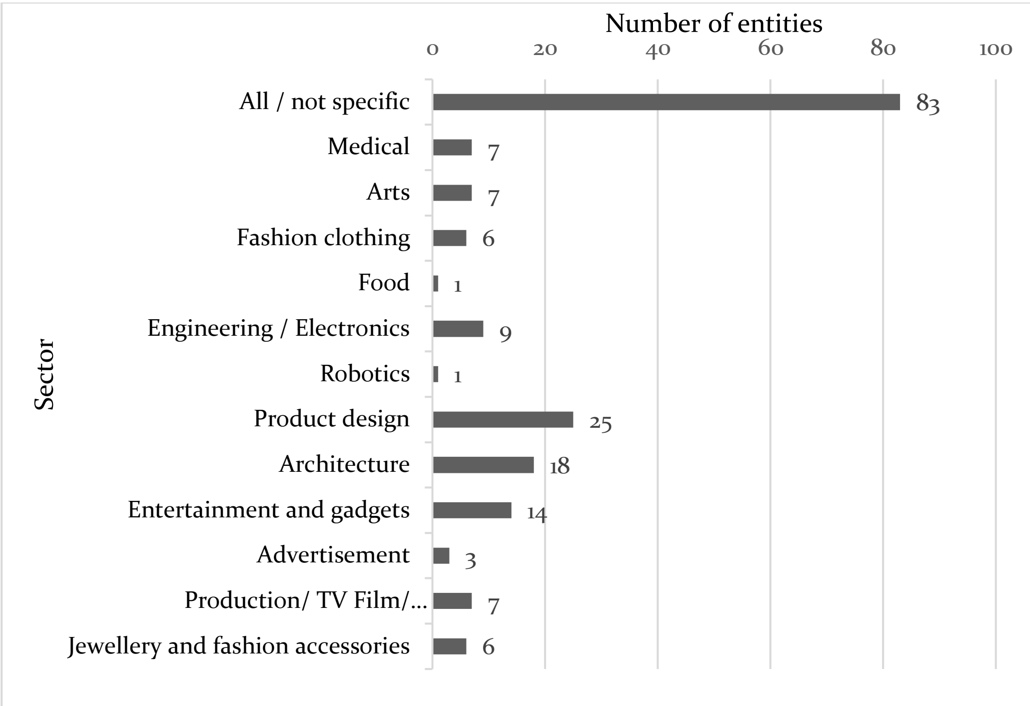

Figure 5.4 Sectors of operations (According to total list of entities from desktop study)[32]

Some of the cases studied in greater depth allow for a closer understanding of how this nonspecific sectoral way of working came into being and how it currently functions in practice: a specialised medical sector firm (Medical Prints 3D) is contrasted with a cross-sectoral firm (Models & Gadgets).

As a result of my sampling process, Medical Prints 3D is the only case I studied in greater detail which is in the medical sector only and it represents the best example

[32] In this figure the total number of sectors adds up to more than the total number of entities, as to each sector a value of 1 was attributed. For example, if an entity operates across multiple sectors, it logs 1 point for each sector.

of exceptions to the cross-sectoral general trend in the cases assembled for this study. It has three fields of work all within the medical sector: (1) 3D printed anatomical models to assist in planning and preparation for surgical procedures and for education, (2) 3D printed prosthetics, and (3) research in the medical field. It has both commercial and humanitarian objectives. The high level of precision, specialisation of materials and knowledge involved in the work explain why there is a focus on medicine and less cross-sectoral activity. For example, at Medical Prints 3D, the surgical use of 3D printed models' parts is accurate to the patient's specific data and the models for 3D printing are created from the patients' MRI and CT scans and 3D printed later. The materials used in printing are close matches to the real body matter that surgeons will operate on, ranging from soft tissue to hard-bone and micro-structures but these materials are not applicable to any other sector. The language is also very specialised and tailored to medical professionals. Figure 4.5 illustrates the specialised work carried out by Medical Prints 3D.

[redacted]

Figure 5.5 Medical Prints 3D: Extract of case studies of surgical pre-planning with 3D printed models: Spine model used before and during an operation and pulmonary artery used in procedures testing, source: http://www.3dlifeprints.com/, accessed 22nd December 2016

In contrast, Models & Gadgets (M & G), is not specific to any sub-sector. Coincidentally, it began in the medical sector and spilled over to all other sectors, but then sub-divided into sister companies to maintain medical as a separate specialism and agglomerate all other possible applications of their work processes and resources in a separate company. M & G thus offer primarily 3D printing services and complementary digital modelling to all sectors, except medical, which is covered by its sister companies each specialising further in a particular sub-sector of medicine. The other three sister companies have different names and are: *Imaging* focused on CT Scanning, X-rays, 3D Scanning and modelling for medical parts, *Implants* which 3D prints medical implants, and *Dentistry* which is focused on printing dental parts. The four companies share parts of the same equipment. M & G's most common sub-sectors were reported to be architecture and product homeware design, amongst all sectors it serves. It is an organisation with significant presence and weight in the field in London, with the largest printing technology capacity of all detailed cases. M & G is well known in the field for their extensive capacities, including printing in nylon, powder, wax, transparent, flexible materials, castable and 3D scanning.

The way M & G is organised shows the clear preference for working across sub-sectors, expanding the use of their machinery and their processes, common in most entities. This preference for non-specialist production is typical of activities working on early stages of products, more akin to the creative and knowledge sectors, whose innovative processes are part of fragmented and flexible production (Storper 1989; Scott 1988a, 2007 and 2008), apart from the medical sector which is the exception for stated reasons of specialism of professionals involved, materials and language.

Added Comment on SIC Sectors

The common way to classify, study and fund industries, the Standard Industrial Classification (SIC) of economic activities is unhelpful to capture the work and to study entities emerging in connection with 3D printing technology. This is because of their lack of specificity, their shared resources and their innovative work, as well as possibly some misclassifications when firms register at Companies House. Here I reflect briefly on the difficulties encountered through some examples:

- M & G is registered as '<u>Other business support service activities N.E.C. (code 82990)</u>', while the other sister medical companies are registered under '<u>Other human health activities (code 86900)</u>'. Further to this, Medical Prints 3D is registered under '<u>Other personal service activities N.E.C. (code 96090)</u>'. There is an inconsistency in these classifications, even within the medical sub-sector, and more even when they share resources.
- Micro Tech and SB Hub are entities which do not own 3D printers, and which provide their supporting technologies to clients who 3D print themselves across multiple sectors. The former provides technology to resolve the modelling complexity of geometries for printing and the later develops software solutions that automate processes for large scale additive manufacturing. Since their operations include software licences and applications support, within SIC division they would fall within Sector J Information and Communication. RP Platform is classified as 'Specialised design activities (code 74100)' whilst SB Hub is classified as 'Business and domestic software development (code 62012)' thus not within Sector J, but within Sector M Professional, scientific and technical activities.
- Heterotopia is a cloud-based platform supporting construction projects. The platform includes a virtual design and engineering BIM[33]-compatible software, tools for parametric design and materials fabrication, regulation compatibility analysis plus construction project management integration software. Heterotopia's software serves the construction sector across multiple stages and types of construction, including different disciplines such as design, engineering, project management and architecture. Interestingly, it is listed with three classifications '<u>Manufacture of other special-purpose machinery N.E.C. (code 28990)</u>', '<u>Development of building projects (code 41100)</u>', and '<u>Other engineering</u>

33 Building Information Modelling

activities (not including engineering design for industrial process and production or engineering related scientific and technical consulting activities) (71129)'.

- Fantazy Moss, another detailed case study, is an online, on-demand marketplace for 3D printed jewellery and other fashion accessories, created by designers and architects from around the world. Customers order online and items are 3D printed to order in a manufacturing hub located near the customer's house, and then delivered. Customization is key in this process, and circa 80% of the orders request some personalised addition to the design (Lomas 2014). The objects can be printed in nylon and plastics as well as metals, including gold and titanium, and the use of this technology allows for augmented geometric freedom compared to traditional methods at a lower production cost, resulting in unusual forms and designs. They do not 3D print the items, and instead send it to some hubs, and manage the process until it is delivered to the client. This activity would also cross SIC classifications, even if restricted to Fashion. It appears classified as 'Manufacture of other wearing apparel and accessories N.E.C. (14190)', not as design services as it could have been expected.

In sum, as it has been found that most entities in my sample work across various sub-sectors, except for medical firms, SIC classifications do not capture the activities correctly, which prevents their study through traditional methods. Working across sectors means that organisations stretch their resources – both machines and people - across different projects as diverse as the clients they are approached by, and that they apply the tasks and type of work they do across various sectors. This characteristic of this type of innovation is thus not well aligned with traditional SIC classifications, largely divided by sector or by output. As such, firms which do very similar work can be found in different SIC divisions, and codes are so spread across the SIC system that it is nearly impossible to have a meaningful group of these activities.

A code could be created for 3D printing services (without a material identified) which could cover all types of 3D print activity, which would capture entities which 3D print. But this would still not be sufficient to include those which do not print at all but still work around the technology. This justifies the use of other methods to study and fully capture these activities, which I have developed here.

5.4 Structure of Activities and Employment

I have found that the activities in study have a lot in common with creative and knowledge industries, in terms of their size and the qualifications of the people involved.

According to survey responses, most entities have been formally constituted as a limited company by shares (LTD), by guarantee (LTD) or publicly limited (PLC) (66%). The remainder are either sole traders (21%), ordinary business partnerships, limited partnerships or limited liability partnerships (9%), and not for profit or social enterprises (4%). The majority of entities are very small operations, as shown on Table 5.4.

Table 5.4 People employed in the entity (According to survey evidence)

Description	*No. of responses*	*%*
1 only	8	24.2
2 to 3 employees	11	33.3
4 to 5 employees	5	15.2
6 to 10 employees	5	15.2
11 to 20 employees	1	3.0
21 to 50 employees	3	9.1
Over 51 employees	0	0
Total	33	100

The size of entities shows that more than half of respondent entities employ under four people, and 87.9% employ less than 10 people, making these largely microbusinesses or microenterprises[34] (Gov.uk 2020). This compares with 95% of businesses in the creative sectors in the UK which employ less than 10 people (Creative Industries Federation 2020).

[34] Businesses employing less than ten people

As expected for small firms, there were no complex team arrangements or extended organisational hierarchies in the detailed case studies. The organisations were very fluid in their internal administration and in the way they worked. For example, in the participant detailed cases, it was common to find people, often the founders/ owners, doing all the necessary tasks, including even support tasks such as administration and stock ordering. This is common in start-up firms and small enterprises.

Through survey data, it has been asserted that organisations are operated by highly educated people, including both owners and employees. This involves people with a mix of academic backgrounds including undergraduate and higher degrees as well as highly skilled and technical people with creative competencies. This is consistent with a London trend where workers have at least a degree level or higher degree level of education. In the creative industries in London more than half of employees have degree or higher degree level education (Togni 2015).

The most common educational background of employees in 3D printing activities is by far Product and Industrial Design. The second most common field of education is Engineering and Electronics, followed by Manufacturing Technology. These three fields of education are generally so common that all operations studied have at least one employee with one of these backgrounds.

The exceptions to this finding are the medical sector entities which also employ staff with medical degrees in addition to at least one of the above. Medical Prints 3D for example includes doctors in addition to manufacturing specialists, technologists, social entrepreneurs, and logistics professionals. The medical arm of M & G, another example, includes dentists and a surgeon in addition to a product engineer, two digital fabricators/ technicians, an architect, a photographer, two model makers, a product designer, an app software writer, and a jeweller administrative.

Other less common backgrounds are, in decreasing order, Architecture, other creative training with transferable design skills (like stage or fashion design for example), which were found in the detailed participant cases Eszilook, M & G and Atelier León, followed by Software and Computing, Photography, Logistics and Product Management.

As many people in the activities were hobbyists, attending meetups at City Hackspace and Romford Makers provided an insight into the background and types of people engaging in these activities at the non-professional level. Attendees at the City Hackspace meetup included artists, post-graduate students, hardware and electronics engineers, an NHS hospital employee, an unemployed business consultant and a sole trader of 3D printing materials who sells to other businesses. Participants at the Romford meetup were from more diverse backgrounds such as council employees, retired professors, retired military, unemployed, teachers, architects, model makers, university technicians, students and retail employees plus some working professionally on or with 3D printing.

In conclusion, the findings reveal that activities are privately owned by one or two founders in the manner of a start-up or creative industry. They are operated by university or college educated, high-tech and creative professionals. These findings highlight that employment in these activities conforms to the wider trend that the premium of technological innovation in urban metropolitan areas is captured by the most skilled labour (Scott 2007; Sassen 2011; Autor 2019). The type of employment which is generated by 3D printing technology is unlikely to be for the socio-demographic group most affected by de-industrialisation (Tym and Lang La Salle 2011), the low-skilled, industrially or artisanal-trained personnel that would be 'making things' in urban units (Cities of Making 2018; Rifkin 2016). It is also a step away from the manufacturing revival possibilities of employment for the medium-skilled jobs disappearing in the current so-called hourglass[35] workforce composition (Sissons 2011a).

5.5 Clients and Links with Other Organisations

One of the more ambitious claims of the new Industrial Revolution is that there would be a significant shift in the organisation of production with more things being locally produced, thus allowing for simpler production chains and reducing intermediaries (Marsh 2012; Anderson 2013). This would happen because professionals

[35] Hourglass labour market composition refers to the prevalence of high wage jobs for highly educated people working in abstract, non-routine and creative tasks, plus the expansion of jobs for very low skilled people working in support and manual, often low paid, tasks. In parallel there has been a significant reduction of in-between jobs for people with medium level training (Hackett et al. 2012).

would become *makers* again and 3D printing would allow for on demand production. For example, an optician or a dentist would be able to make the product they sell as well as offer their expert services. Final consumers would also be able to download parts directly from a designer's website or a marketplace and 3D print them when and where necessary, without the need for large factories producing large batches, in turn requiring storage facilities. This would be applied even to products which are not at the early stage of development, but possibly to all objects, thus modifying what has happened over the last decades in industrial growth, whereby factories became larger and detached from most design services, and many times outsourced across the globe in magnified production chains and links, intermediaries, storage and distribution facilities. Consequently, production chains and transport services could be drastically reduced.

My findings on the activities emerging in connection with the 3D printing technology are that, despite the possibility of shrinking production chains due to capacities for printing on-demand, entities are not focussed on producing final goods, and they are not self-contained enterprises. Rather, they tend to have multiple links with other firms in the production process, plus links with research institutions and 3D printing-related communities. Organisations are mostly occupied with early stages of products, perfecting and expanding methods of work, and performing tasks such as product design and prototyping. Further, in this research I have not found that the clients are necessarily final consumers of the final product.

Most links to other firms are local, although not exclusively. They cross the private, public and not–for-profit sectors as well as involving friends and acquaintances. There are many firm-to-firm services, and the links include other firms as clients or as associates in the production process directly or indirectly, for economic or for creative and exploratory reasons. These findings support the view that these entities are not the beginning of an urban manufacturing revival but rather part of the evolution of knowledge and creative industries to include technologically aided material production – such as 3D printing. Further to this, these activities' multiple links with other creative firms show how these activities are part of the extended production chain which characterises early product development and cognitive outputs of post-industrial urban economies, such as those of the creative industries (Sabel 1989; Storper 1989). These findings are elaborated in the next sub-sections.

The Clients

The results of the survey show that most 3D printing-related entities in London (72.7%) sell to clients which are other firms, and not to final consumers thus not yet meeting the (aspirational) view that with 3D printing products could be more directly produced. There are mixed cases in terms of client relations: about half of the entities focused on a few clients only, while the other half of the responding entities tended to diversify to as many clients as possibly. For example, according to a survey participant:

> 'Basically, my clients are so diverse. I have printed for the V&A museum, for numerous individuals new to 3D printing, design/engineering students as well as private companies (some very well known in the creative space). (...) one of those had an IN-HOUSE 3D printer but outsourced to me and got rid of their in-house 3D printing department' (Duncan Finn, 3D Printing Mayors, Peckham Heights, survey response).

The full findings in terms of types of clients is shown in Table 5.5.

Table 5.5 Types of clients[36] (According to survey evidence)

Choice	*No. of responses*	*%*
Private organisations in the creative sector	22	20.0
Individuals or families	16	14.5
Private organisations in non-creative sectors	16	14.5
Other organisations within the 3D printing industry	15	13.6
Students	14	12.7
Education institutions	13	11.8
Government organisations, i.e. local councils or museums	9	8.1
Not for profit institutions	3	2.7
Other manufacturers	2	1.8
Total	33	100

[36] Note that entities have more than one type of client, so the total of responses is more than the total number of entities. In other words, respondents ticked all types of clients that applied to their case.

Interview data also confirms that most clients of medium and large size organisations are other firms in specialist fields. Some participants also reported that their clients were personal acquaintances, which is a benefit of the agglomerated environment in London and of the common educational backgrounds and interests amongst people. Additionally, participants also referred to students as frequent clients. This was for example the case of Eszilook who reported some clients in the film industries located in Soho, who are the founders' main contacts from when they had worked in the area earlier before setting up this business. Their clients for the 3D printed headsets are primarily creative practitioners who work in architecture, games and virtual reality, plus students. The consultancy and content department has both individuals and businesses as clients, such as for example large architecture firms as Foster & Partners[37] who are hire them for many services, also including animation and VR content.

The location of the clients varies, as some activities reported selling to other firms in London, whilst others reported selling services to other parts of the country and internationally. For example, SB Hub stated that their clients are exclusively other businesses, which are large companies operating in additive manufacturing at large scale, which is still a very niche market. These clients are not based in London, but primarily elsewhere in the U.K., Germany and in other European countries, Mexico and South Africa. This expanded geographic catchment was more common for technology-related activities such as 3D printing software creators and for large and medium sized organisations.

Analysis of the detailed cases suggests that the smaller the entities, the more they tend to have individual or niche clients. But even these clients are mostly not the final consumers. Most clients of smaller entities are in London, and small entities maintain extensive networks of contacts across the city, some of which are personal friends. Even firms which mostly 3D print provide these services to people who are designing and prototyping, more than supplying final products to final consumers. For example, Paul Lewis's clients are mostly individuals, such as students and other people who want to prototype an idea; Circa 80% of Atelier León's clients are private individuals who order

[37] Forster and Partners is the largest architecture firm in the U.K. and within the ten largest in the world.

objects via their website. Small organisations have fewer large firms as their clients, although that happens occasionally. For example, the same Atelier León met with John Lewis a few days before my interview to discuss possible larger orders because the department store contacted them after they won the Etsy Awards and showed 3D printed works at the London Design Festival. This still follows the general trend of clients being other firms more than final consumers.

Outsourcing 3D printing is widespread practice, and this also extends the links in the production chain. Story Lab, for example, use outsourced 3D printing services on a weekly basis. They have built up a trusted network of suppliers which is more than just placing 3D printing orders, as they can rely on the others to advise on materials and surface finishes to achieve whatever they are aiming for with prototypes. This is a common arrangement. Patricio Frater, another example, sometimes receives orders for printing and hires other people within his network to do the printed output, as he does not have time nor sometimes the exact skill set or materials and prefers to spend his time designing. Frater is part of a network of people related to the creative 3D printing design and fashion in London, who frequently exchange work as they receive orders. In addition, he also mentioned his important links with the materials and printer parts supplier companies with who he maintains a friendly relationship.

Through these examples it can be seen that the activities emerging in London in connection with 3D printing are part of a networked system of other creative firms and individuals, some which are the clients. People associate with their network as needed, according to projects or ad-hoc sometimes depending on personal relationships. This fragmented creative production network supports my primary argument that innovative fabrication technology activities are supporting, or are part of, established knowledge and creative sectors in today's post-industrial urban context.

Other Links to Research and Academic Institutions

Besides links with other firms, participants also described multiple connections with government-funded research and education institutions, plus with friends or former colleagues who are key to their production processes. This is typical of creative industries in spatial clusters, where they tend to establish links with local institutions forming local production systems (Scott 2005; Cooke and Lazzeretti 2008). And, as many activities require research, alliances with other firms for research are also common. Below are some selected examples from the detailed cases to illustrate the multitude of these connections:

- Eszilook, a small start-up, maintains links with larger businesses in 3D printing technology such as Ultimaker, Print Point 3D and Form Lab with who they have developed projects, and with magazines including *3D Printing Industry*, *Gizmodo* and *Mashable*.
- The Romford Makers, only in its inception stage and yet to be formally constituted as an organisation, already has links to higher education institutions, such as with the University of East London, including a key member of the University's fabrication laboratory joining the group.
- For research purposes M & G is now connected with a government body, Knowledge Transfer Network (KTN). They also maintain connections to universities for research, as well as commercial reasons, across London. They engage with the departments of architecture, product design, jewellery, arts, design etc.
- SB Hub are connected to universities in the U.K. and abroad, either through research projects or as speakers.
- Micro Tech currently maintains links with UCL and with Imperial College via previous contacts there, providing them with access to their technologies. The company intended to sponsor a doctoral degree at UCL, and frequently engage with other activities linked to the 3D printing technology in London for joint research.

Links with secondary education institutions or community groups have been reported too, as many individuals engage in teaching or mentoring young people. For example, Paul Lewis works with a youth group in Soho, the Dragon Ball, to introduce tech to youngsters, and Jean-Antoine from Atelier León participates in the Mile End Community Project, a local youth and community organisation.

Lastly, the links with other makers and maker spaces were very common in the activities followed in this research in London. This will be discussed in Chapter Seven. Some networks develop across online forums, whereas others happen in person in organised meetings across London's 3D printing and makers-related facilities. For example, Eszilook's founders value the firm's link with the makers movement to the extent that, although their new product (yet to be launched) is a consumer electronics for mass production in Romania or China, they are developing ways to produce a 3D printed version to retain the links with the makers in London with whom they have been growing since the beginning.

Similar strong connections with other makers were discussed by Paul Lewis from Paul's Hub, and by Jean-Antoine from Atelier León. Some connections were identified through the course of this research, as I independently met people who worked together, and they cross-referenced each other In many ways, it felt as if it was a very small world. For example, Paul participates in many 3D printing and maker groups, such as the City Hackspace and the Romford Makers, other cases in this research. The Romford Makers group also has two other people from the City Hackspace. Atelier León's Jean-Antoine and Marguerite are usual visitors of Machines Room, a large workshop in Vyner Street, also used by Patricio Frater.

These findings show that the people involved in the activities emerging in connection with 3D printing are strongly connected in numerous ways with other firms, individuals and institutions across London. They tended to be outgoing and willing to maximise their contacts and networks. Although shrinking production chains, with more simplified and integrated workflows, would be expected as a consequence of new urban manufacturing revival (Marsh 2012; Anderson 2013), the evidence from this research shows that the 3D printing related activities in London exhibit networked tendencies, more like knowledge and creative industries in post-industrial cities observed over recent decades (Storper 1989; Scott 1988a, 2007 and 2008). Further to this, firms trade more with one another than with final consumers, and practitioners reach out to others as much as possible expanding their research and creative relationships.

5.6 Conclusions

This chapter has introduced the detailed case studies and analysed the findings of desktop analysis, survey and interview data to document what types of activities have emerged in London associated with 3D printing, what type of work enterprises do, and their sectors of operation. It has also provided the analysis of research findings about the activities' structure and employment, and their external links, including clients and networks of collaborators.

These sections provided evidence to support my disbelief in an urban manufacturing revival enabled by new fabrication technology – let alone as a trigger to a new post-industrial phase of capitalist production and accumulation, or a new Kondratieff wave, or a new Schumpeterian cycle. Instead, I argue that the role of innovative material production, and new fabrication technology (such as 3D printing), in a post-industrial urban economy (such as London) is to support abstract tasks of knowledge and creative sectors, which have been typical of these cities in recent decades. I argue that the activities that emerged in London in connection with 3D printing are themselves not urban manufacturing units, but part of creative and knowledge industries. And these findings challenge the argument of economic diversification through manufacturing revival in a context such as London, particularly as literature and policy has pointed towards 3D printing being one of those examples (Marsh 2012; Sissons and Thompson 2012; Anderson 2013; BIS, 2012). The key findings supporting my argument are summarised below.

The first key finding is the nature of the work of the entities. It extends well beyond making or fabrication, and includes consultancy, design, software creation, prototyping, etc. And almost half of the firms do not 3D print at all. Even those which 'make' something using this technology do it as part of a creative process, for example, and offer many other services. Or some of those which 3D print are sole traders operating as a hub online to use spare printer capacity, for example, while they design. They are less like light manufacturing and even less like traditional small manufacturing. Further to this, supporting my argument, is the reported tendency to specialise in certain tasks, processes, geometries, etc and then apply that to as many sectors as possible. This shows that 3D printing technology has allowed existing types of work and existing processes in already successful sectors in London to expand and new organisations to emerge from that. But these are sub-sectors of Knowledge, not of Manufacturing, despite the difficulties in asserting SIC classifications in relation to these activities.

The second key finding relates to the structure of activities and employment. It emerged that these are small organisations, founded and employing highly educated people - the same type of people employed in the leading sectors anyway. And not the medium to low-skilled manufacturing or artisanal trainees, as hoped for by some authors anticipating an urban manufacturing revival (Tym and Lang La Salle 2011).

Lastly, my third piece of evidence is the networked nature of the activities, akin to creative industries in creative clusters. As characteristic of many innovative sectors (Duranton and Puga, 2001), the entities were found to be well linked to academic institutions, to other firms in similar sectors, and to the makers communities and maker spaces, all of which are concentrated in an agglomeration like London. These highly networked activities were, for the most part, producing for other firms in similar sectors as part of a networked creative process, and not at the tail end of production even though the technology could have allowed for it. I have found that material production or supplying final products to final consumers and the subsequent reduction of production chains was not prevalent.

In sum, findings presented in this chapter highlight that material production with advanced fabrication technology in an urban post-industrial context is not just about material outputs as final product, but about using new technology – which happens to have a material output - to advance, expand and speed up many other types of work. Findings also suggest that these dynamics are framed by networked relationships between actors, facilitated by the clustering and proximity of activities.

Questions of proximity and clustering emerged as a distinctive feature of the activities reviewed in this chapter. The next chapter will analyse in greater depth findings about the locational dynamics of the activities. It will elaborate further on the factors determining location choices and advantages, and on how the 3D printing technology influenced firm location.

Chapter Six

Location of Activities: Spatial Distribution and Factors

He transports his printer and key tools around with him, normally in his car boot or simply in a bag. He sets up the printer quickly and he starts to 3D print a piece wherever he is…

(Research notes, Paul's Hub)

6.1 Introduction

This chapter examines evidence on spatial and locational trends in 3D printing related activities in London and examines the reasons for locational choices, addressing the research question: *'How is the location of the emergent activities associated with 3D printing related to the urban context of London and its agglomeration economies?'*. This chapter can be summarised as the *where?* of the entities, from which follows the questions, *why there?* and *why not elsewhere?*

Findings presented in this chapter support the second argument of this thesis, which is that innovative material producing technology does not change the geography of production in post-Fordism, particularly the geography of innovation, which is focussed in central city areas (Hutton 2008) where most early stages of product development take place (Duranton and Puga 2001). This has been attributed to more flexible yet specialised ways of working with information and communication technologies (Castells 1996; Tomaney 1994; Scott 1988a and 2007; Storper 1989; Amin 1994); to labour availability (Florida 2002; Kemeny and Storper 2020); to agglomeration of related economic activities (Jacobs 1969; Porter 1990); and to socio-cultural and institutional proximity (Storper and Venables 2002).

Innovation related to 3D printing technology, I find, flourishes in agglomerated settings where there is a particular socio-cultural identity associated with the location, the right people, and good accessibility. These locational trends reinforce the conclusion that advanced manufacturing technology like 3D printing is not reinstating production of final products for consumption in inner London - not even in outer London. It is instead supporting knowledge and creative activities such as design, prototyping etc. Regardless of how easy it would have been to locate new activities anywhere in the city, either because 3D printing is flexible - i.e., does not require big equipment for the most part, is easy to transport and can be used on demand - or because activities do not 3D print, the location of activities is independent of the technology. Rather, material production technology is supporting abstract tasks of creative, technical and knowledge sectors, as argued in Chapter Five, thus the location choices of activities largely overlap with location of those sectors too.

In this chapter I present the evidence which supports this argument. This evidence is comprised of four sets of information, which structure the chapter. First, I present an overview of the entities' geographical distribution in the London metropolitan area (section 6.2). Here I show that activities are overwhelmingly located in the centre of London irrespective of material or abstract outputs. I include a series of maps of London revealing the location of organisations and single practitioners for which I was able to obtain address data. Second, I provide an analysis of the types of premises where organisations and sole practitioners in this field work, some of which I was able to visit during this research (section 6.3). Findings of these two sections make clear that the location of these innovative activities coincides with the location of other London knowledge, services, and creative sector industries – despite rents and small premises, thus not influenced by the technological possibilities of flexible location and single batch, on-demand production of 3D printing technology.

Section 6.4 presents the third set of evidence in support of the argument: factors influencing enterprise owners' choices of location and premises, none of which relate to the 3D printing technology as such. Each key location factor is explored individually. First, the socio-cultural characteristics of the chosen area: areas which have attracted 3D printing activities often already have (or historically had) related activities, including other creative industries, and a strong creative or digital identity from which agglomeration and spill-over benefits can be derived. Second, hiring talent is often key to location choices. This was frequently brought up as decisive, particularly during interviews with the most successful businesses; Third, connectivity, a consideration for these firms, is seen by participants as a means to respond to other concerns such as attracting talent and allowing for extended working hours. As part of the analysis of location choices, I report on how central (and frequently less affordable) location choices of the activities overcome viability challenges. Ironically, this research finds that staying in more central locations with small premises reduces travel time to home and to work, thus allowing for multiple jobs to support self-funding of activities (also called bootstrapping). Challenges to achieving these locational choices remain, but interviews reveal the strength of the central location preference, regardless of difficulties in securing the right type of premises and affordability, and irrespective of the flexibility of the technology which could allow firms to set up elsewhere.

Section 6.5 presents the fourth piece of evidence in support of my argument. It considers how the location of the activities in London is sustained through relationships with activities beyond the city. Here I report findings on the links my participants' activities have beyond London and the nature of those links, including locations of satellite offices and clients. This analysis finds that the activities are better connected globally than regionally, as for example other European capitals are preferred as locations for satellite offices to other English regions. This is a characteristic of contemporary knowledge and creative sector activities in post-industrialism (Crescenzi et al. 2020). Significantly, this analysis finds that activities send more repetitive tasks like 3D printing of final items to premises outside their London main studio, or to other firms. These findings point to a continuation of the separation of production across geographies in post-Fordism, where creative and knowledge tasks are mainly carried out in city centres, and more repetitive tasks are deployed elsewhere (Hirst and Zeitlin 1991; Storper 1989; Duranton and Puga 2001), irrespective of the possibility for direct material production with 3D printing technology.

In conclusion, section 6.6 synthesizes the findings and reflects on how the location of innovation around material production in London is not a technology-driven narrative, but a result of socio-cultural factors which are fundamental to post-Fordist abstract, creative and non-routine activities. And the findings emphasise that material production with advanced technologies can become embedded in (not disrupting, but evolving) the post-industrial geographies of production, which are fragmented across regions, with some cities - like London - leading knowledge and creative production.

6.2 Mapping Locations

This section presents a series of maps and statistical analysis showing where activities linked to 3D printing technologies have been found in London, whilst breaking down location of activities by type. A spatial overlay of activities with the employment distribution of other sectors in London is also presented to discuss co-location relationships.

These location findings are my first set of evidence to argue that new material producing technology like 3D printing does not change the geography of innovation nor the post-Fordist separation of production tasks across geographies (Scott 1988b; Moulaert and Swyngedouw 1989; Duranton and Puga 2001; Hutton 2008; Storper and Venables 2002; Jacobs 1969). My findings highlight that the activities emerging in London in connection with 3D printing are very centrally located and concentrated within six inner London boroughs. Their location overlaps with the central location of services, professional, scientific, technical, educational, and creative sector activities, regardless of higher rent levels in these areas. Further to this, whether activities 3D print or not, their location is as central and clustered as other innovative activities in post-industrial cities.

The spatial data collected, the maps presented, and the subsequent conclusions refer to the location of all 3D printing related activities found in London which could be mapped at the time of this study's empirical data gathering. These are maps of all entities which have a public address plus those which could be contacted and participated by giving their address for the purpose of this research. These are in total 80 entities of the 131 long list, which means that these maps are effectively an analysis of location of 61% of the total. It is important to note that there are thus 51 other entities, 39% of the total, that also form part of this research through desktop studies, but which could not be mapped as no address could be found or provided. These were either not available to be contacted, did not respond to phone calls or emails, did not wish to provide accurate location information, or did not have a fixed location at all. But, since they list themselves as based in London in databases and trade fair lists, their activities were used as part of statistical analysis, but not in mapping analysis. These will be referred to as 'entities which could not be mapped'[38]. Although it is common in industrial studies to analyse spatial distribution over time (Hall 1962; Pratt 1994), the activities in this study are very new - most entities were created less than six years before the fieldwork - therefore a longitudinal analysis could not be conducted. What is presented in this section therefore represents a snapshot in time and provides a good indication of the initial distribution pattern of entities emerging in London related to 3D printing technologies.

Location of Entities with Address

According to the maps produced from the data, there is a clear tendency for concentration of 3D printing entities in the most central areas of London. This is the case for all types of entities mapped. From an analysis of the address data, it was found that 85% of the mapped cases were in inner London boroughs (a total of 68 entities) and 15% were located in outer London boroughs (a total of 12 entities).

A detailed breakdown of the distribution across the different inner and outer boroughs is illustrated in Figure 5.1 below. It shows the exact number of entities located in each London borough. The six boroughs where most entities are located are, in descending order: Camden, Tower Hamlets, Westminster, Hackney, Islington and the City of London. These boroughs accommodate 62.5% of the entities which could be mapped. This is a high concentration of activities in just six of the most central inner London boroughs, all north of the Thames, and all adjacent.

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[38] 39% of the full list of entities considered in this study did not provide an exact address and therefore could not be mapped. The majority of these operate online only, for example through Print Point 3D, or they are listed in 3D printing business directories as being based in London, but provide no physical address. Of those who were contacted and responded by giving their address to be included in the mapping analysis, the locations maintained the general tendency of those with public addresses for more central areas. Questioning the Print Point 3D database and the platform's representative in interview about the general location of the hubs without physical address, it was confirmed that most hubs are located in the more central areas even if their location is not made public. Providing an address is, for many of these businesses, not considered necessary as either everything is communicated online, or there was a need to maintain the privacy of the hub provider, as some operate from home or even from offices where they have other jobs. For some sole traders, maintaining privacy about the actual location of operations was part of a marketing tactic, presenting a more professional image, which a domestic address could undermine.

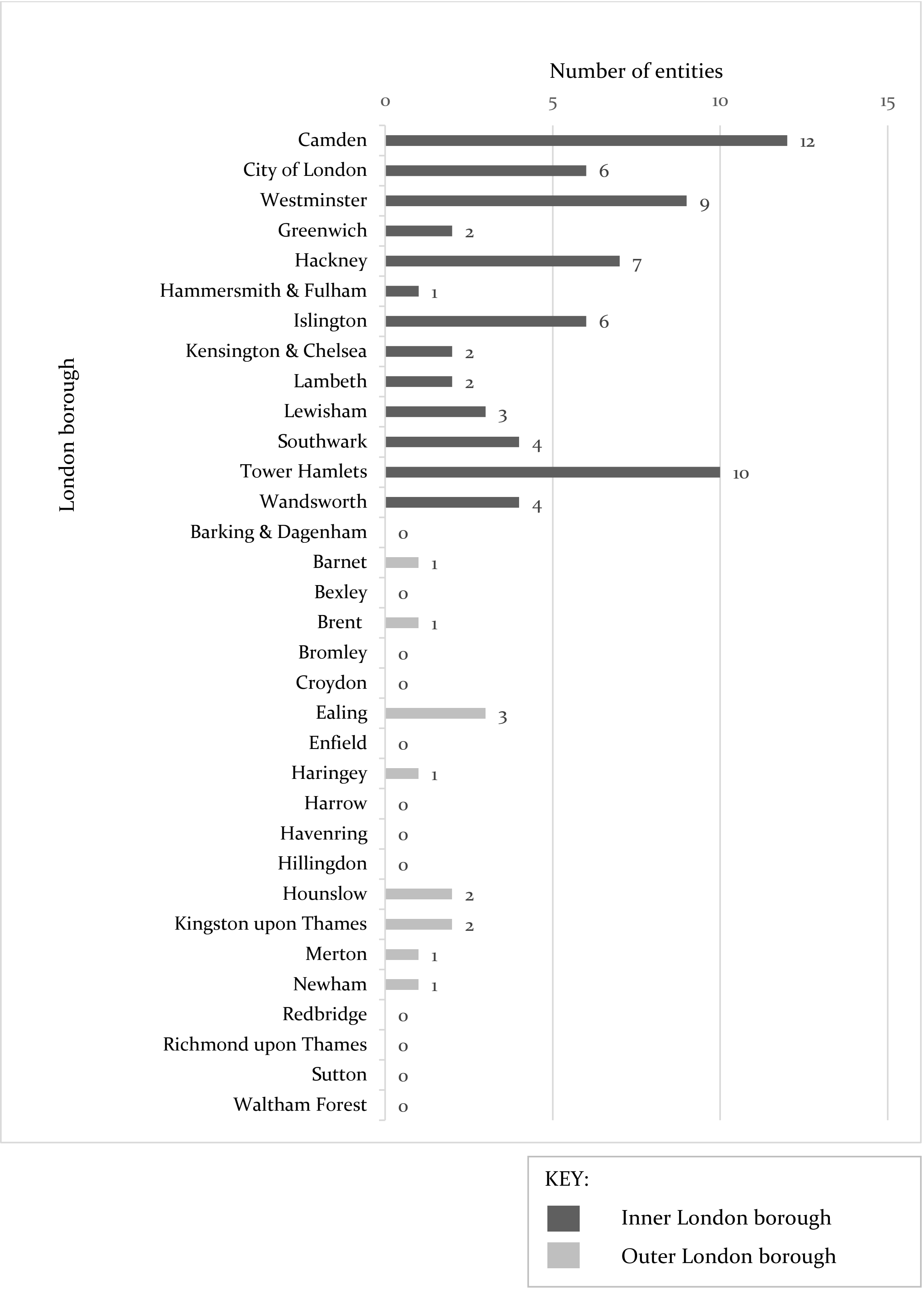

Figure 6.1 Number of mapped entities linked to 3D printing technology located in each London borough (According to desktop studies, direct contact and survey evidence)

When plotting these locations on a map (Figures 6.2, 5.3 and 6.4), it is clear that most entities are located in the inner boroughs of London. Figure 6.2 shows all entities, and Figures 6.3 and 6.4 highlight respectively the most common boroughs and the outer boroughs. It appears that the closer to the centre, the more concentrated and more closely grouped entities are, as shown on the inset of Figure 6.3. It can also be seen that north of the river and inner eastern boroughs are more popular than south of the river and western inner ones.

This trend of distribution of the activities aligns with described trends of concentration of innovation activities in core areas of metropolitan centres with global links (Ernest and Kim 2002; Crescenzi et al. 2020). These trends started and accentuated since the 1980s, when the rise of information and communication technologies primarily have been redefining the geographies of production into the current clusters.

Based on my site visits, I verified that most activities located in inner boroughs were based in zones of employment, within proximity of retail, and in mixed-use blocks. Many were in busy and noisy routes (arguably less suitable for residential uses), including primary, secondary and tertiary roads and even enclaves of the main roads. There were many business centres, office blocks, a few studios and live-work units and no private homes or residential only areas, although some blocks had mixed-uses, including residential above.

Figure 6.2 Location of all mapped activities linked to 3D printing technology in London plotted with London borough boundaries

Overall, the outer London boroughs are much less popular locations. In contrast to the concentrated presence of entities found in inner boroughs, there is a dispersed presence of activities in the outer boroughs of metropolitan London: a total of twelve entities (15 % of the total) are scattered across just 8 (of 20) outer London boroughs. On closer inspection, some of these are located in industrial or business parks; for example, three of the twelve form a small hub in the Park Royal strategic industrial area, and a further two are in low value warehouse-type buildings in Brent and Barnet. Two entities in Newham and Haringey are found within the tail end of the local high street, and another two entities are associated with Kingston University in Southwest London. The remaining three outer London entities are hubs operating from private homes.

Figure 6.3 Location of all mapped activities linked to 3D printing technology with highlighted six most common boroughs and inset showing the area with higher concentration of entities

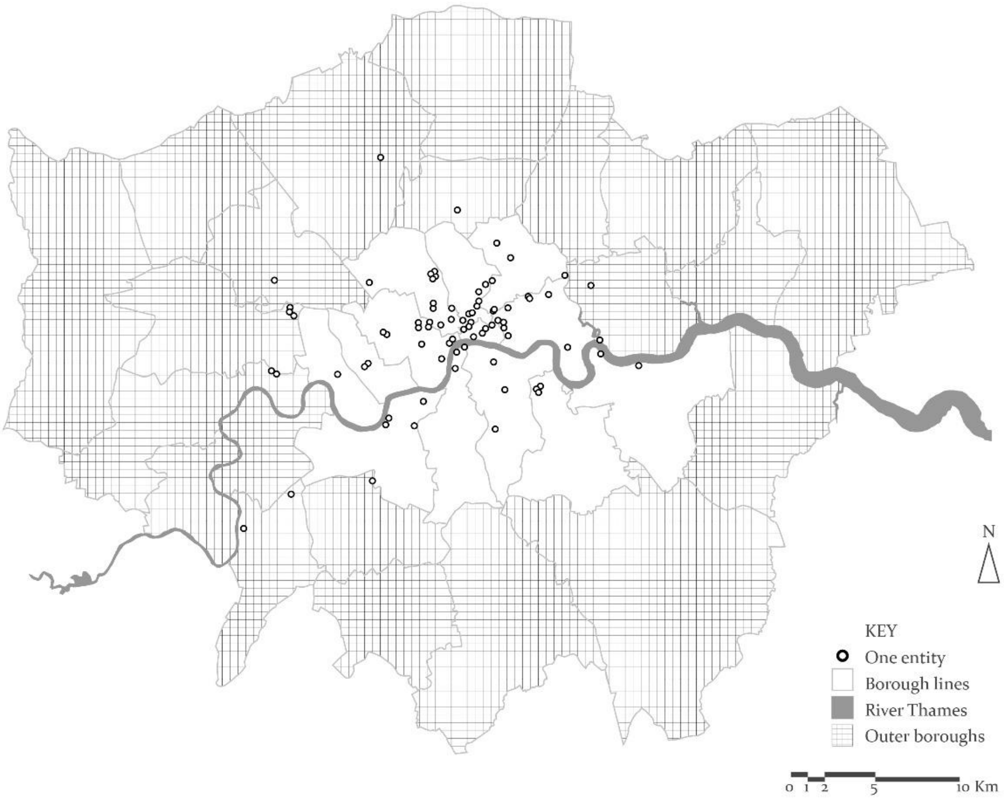

Figure 6.4 Location of all mapped activities linked to 3D printing technology with highlighted outer London boroughs

This urban, central and concentrated location of the activities mapped is characteristic of other innovative industries in post-industrialism. The geography of innovation related to new manufacturing technology continues spatial trends of innovation which have been linked to agglomerated and centralised environments by scholars (Duranton and Puga 2001; Hutton 2008; Storper and Venables 2002) for reasons associated with benefits from localised economies (Porter 1990) and socio-cultural proximity (Glaeser et al. 1992; Hall 1998). The types of activities found in connection with the 3D printing technology appear, from their location within London, to trend less like manufacturing activities of material outputs destined to final consumption as those in peripheral areas (Prothero 2007; Tym and Lang LaSalle 2011; Van Winden et al. 2011). Furthermore, they do not appear to be in areas of lower labour and rental costs as some have argued would be facilitated by the technology (Bryson et al. 2017; Marsh 2012). This can be explained by the types of work the entities do – largely knowledge and creative focused, with abstract outputs intended for other firms, and in support of product development tasks rather than for final consumption - findings presented in the previous chapter.

After this overview, the data allows this analysis to be more specific and to breakdown mapping of locations by types of activity. These findings, as follows, reinforce the conclusion that locational choices follow those of the creative and knowledge sectors. This holds true for all types of mapped activities, particularly those which provide services (as opposed to distribution of parts and materials), irrespective of whether they undertake 3D printing or not.

Mapping Activity Types

Considering the spatial distribution of activities in relation to the nature of their work, when mapping services providers separately from hardware fabrication and/or supplier activities[39], it is noticeable (a) that there are more service providers and (b) that they tend to be more concentrated in the inner London boroughs. Hardware fabricators and/or suppliers tend to be less concentrated, not forming clusters amongst themselves, and there are fewer of them in total. It is worth noticing that the entities in Park Royal, the only group in closer association in outer London, all trade hardware fabrication or supplies only, and sale of 3D printers and of printer parts. They are located in an area historically associated with distribution and with good connection infrastructure. Figures 6.5 to 6.8 show locations by type of activity. It should be noted that this breakdown by activity type does not have to do with the types or sizes of spaces required as there are service providers which require larger spaces in inner boroughs (for example maker spaces), as well as small spaces in outer boroughs (such as a parts or materials supplier).

[39] Refer to Figure 4.3 for classification of entities provided in Section 4.6

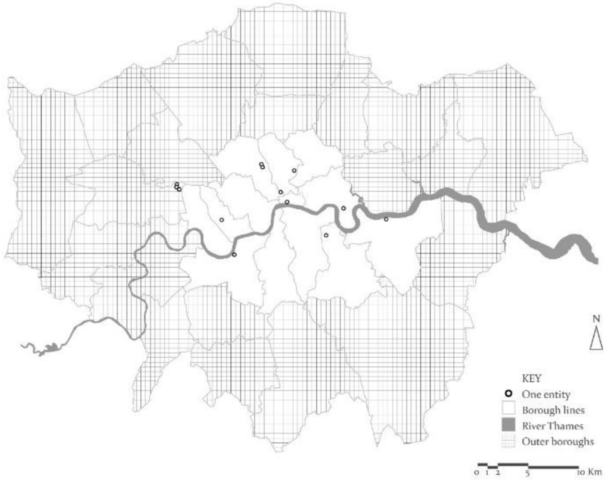

Figure 6.5 Location of activities including hardware fabrication and/or supply of printers, parts, materials and accessories (may also offer complementary services such as consultancy) which could be mapped

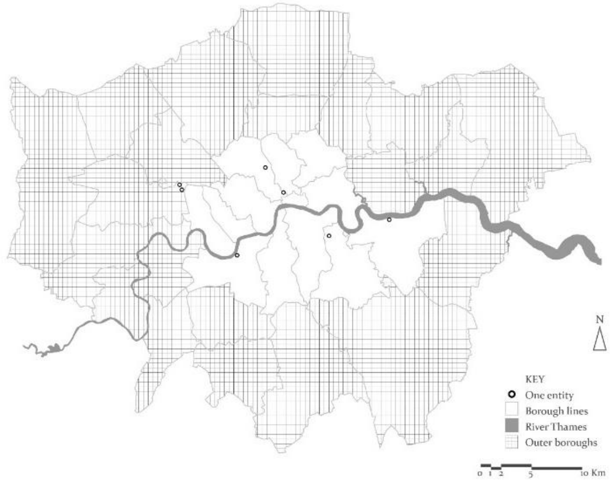

Figure 6.6 Location of activities which are only hardware fabricators and/or suppliers of printers, parts, materials and accessories (do not provide any additional services) and could be mapped

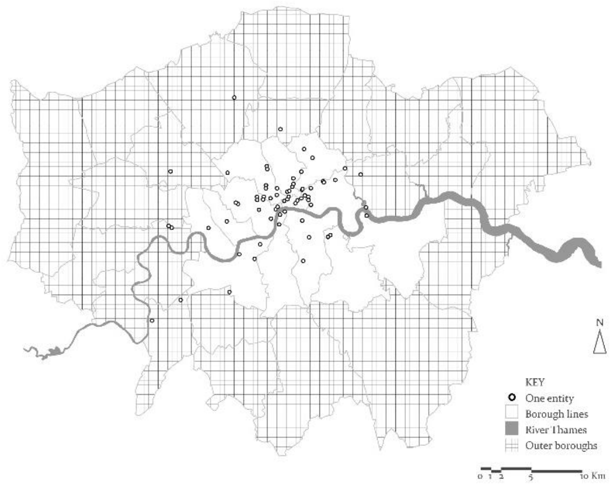

Figure 6.7 Location of activities which are only services providers (do not fabricate and/or supply any hardware printers, parts, materials, or accessories) and could be mapped.

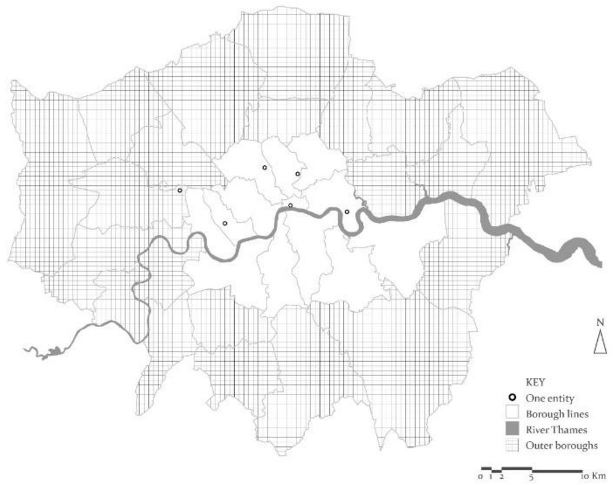

Figure 6.8 Location of service providers which are also hardware fabricators and/or suppliers of printers, parts, materials and accessories which could be mapped

When mapping separately the service providers which 3D print – regardless of purpose (i.e. as part of a design process for internal use only) – to compare this with those which do not print (Figures 6.9 and 6.10), it can be seen that the spatial distributions appear almost identical, except there are a few more printing entities south of the river. This data suggests that, regardless of whether activities produce material or abstract outputs, their spatial distribution tendencies, centrally located and clustered, are similar.

Furthermore, 3D printing entities which 3D print do not appear to strongly follow the location preferences of traditional manufacturers in post-industrial cities which tend to move out or locate on larger parcels of industrial land. These findings indicate that having a material output or not does not determine the location preferences of these activities. This can be explained with the findings presented in Chapter Five, where it was shown that even activities which print, do not print for final consumption, but for themselves or to input to other creative firms as part of creative, prototyping or design processes. Regardless of type, most activities related to 3D printing follow location trends established in the literature for other innovative activities in post-industrialism (see for example Scott 1988a and 2007; Duranton and Puga 2001; Storper and Venables 2002; Hutton 2008; Foord 2012).

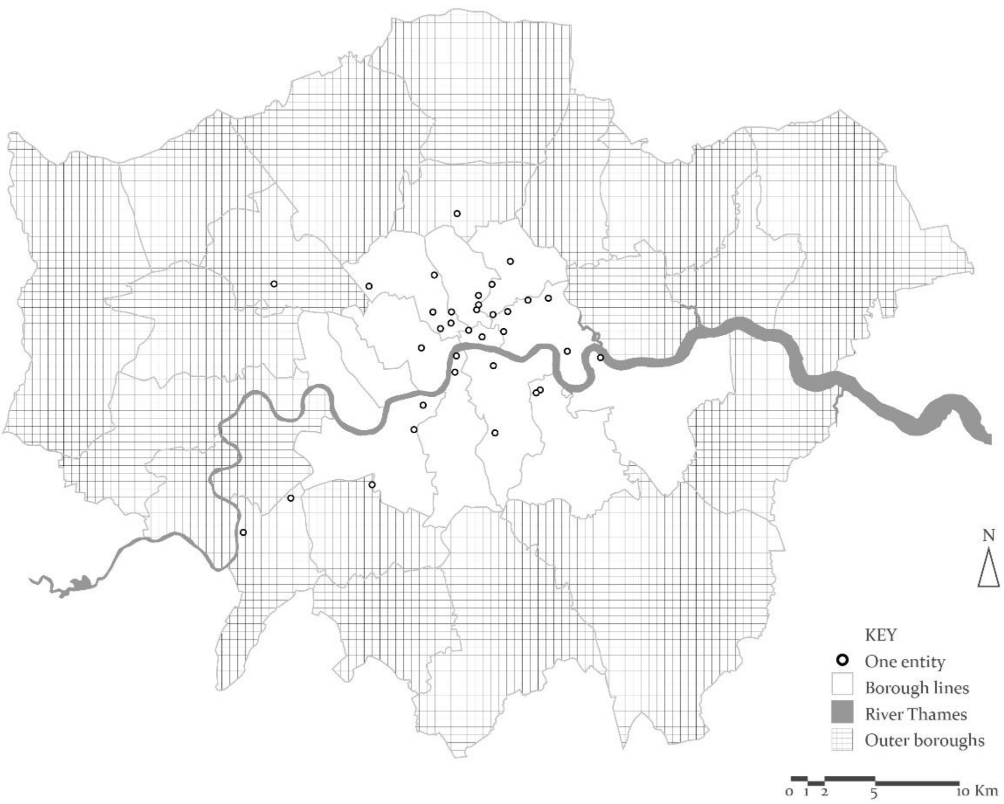

Figure 6.9 Location of service provider activities which 3D print and could be mapped

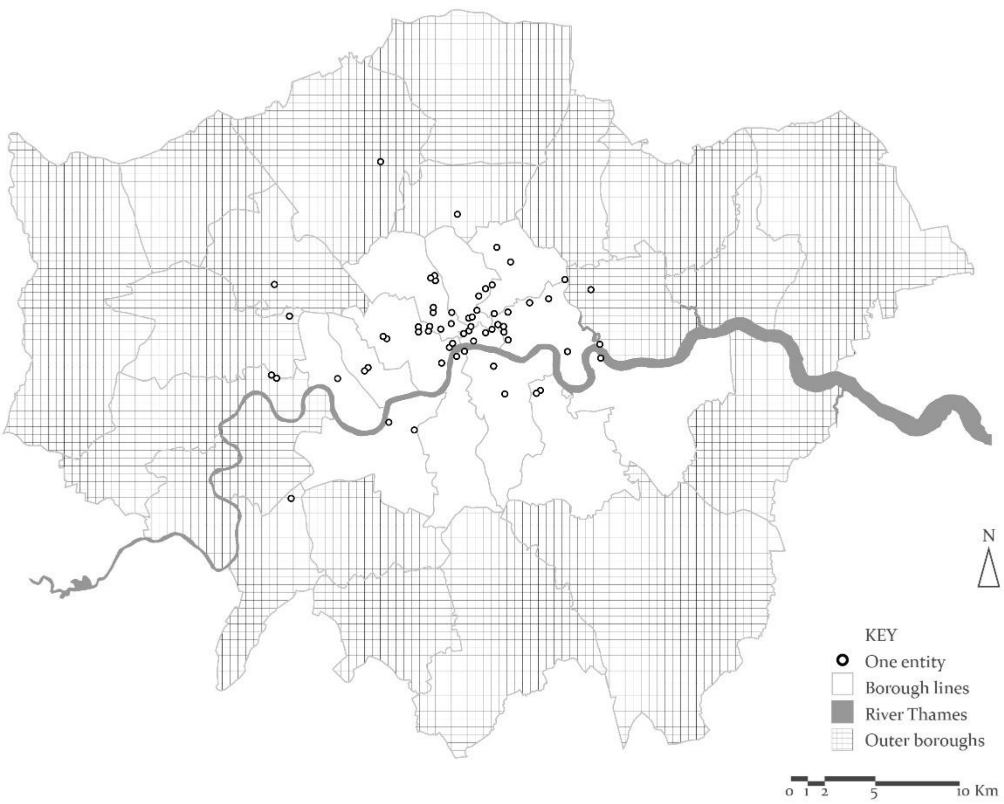

Figure 6.10 Location of service provider activities which do not 3D print at all and could be mapped

Further to mapping per types of activities and outputs, my data also allows for additional plotting according to type of sector. Figures 6.11 to 6.13 compare the spatial distribution of entities associated with 3D printing technology that are working in creative sectors[40] (Figure 6.11), non-creative sectors[41] (Figure 6.12), as well as those working across a number of different sectors (Figure 6.13). This comparison reveals first that there are more entities working in creative sectors than not. Second, the figures show that creative activities have a greater tendency to cluster in inner areas, whereas non-creative activities are more dispersed. There are however some activities working in creative sectors in the outer boroughs of London. These findings coincide with the recent trends for creative industries in London to concentrate and cluster in inner boroughs to derive agglomeration and spill-over benefits (Togni 2015). The creative activities associated with 3D printing technology are mostly located in the inner London boroughs of Islington, Camden, Tower Hamlets and Hackney. These are also the boroughs with more creative industries in London and some with the highest rates of creative company formation (Togni 2015: 50-51). Further, in London clusters with a specific creative focus have been observed such as: Hackney associated with Tech City; Soho focused in the film industry; Islington, Westminster and Camden for various creative industries as architecture and design (Mateos-Garcia et al. 2014). These clusters coincide with the focus of some 3D printing related activities, particularly activities working in digital products centered which are around Old Street Tech City (such as case studies Eszilook and SB Hub), and those located in Hackney and Camden more akin to architecture and design (such as Patricio Frater, The Werewolf, 3D Masters Schoreditch plus Atelier Leon). Patterns of location thus follow distributions already identified in London for the creative industries.

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[40] Refer to Figure 4.3 for classification of entities provided in Section 4.6. The activities mapped as creative sector are: arts, fashion clothing, product design and prototyping, architecture, entertainment and gadgets, advertisement, television production and visuals, and fashion accessories and jewellery. It includes only services, thus excluding hardware fabricators or suppliers.

[41] Refer to Figure 4.3 for classification of entities provided in Section 4.6. The activities mapped as non-creative sector are: medical, food, engineering, electronics/ robotics. It includes only services, thus excluding hardware fabricators or suppliers.

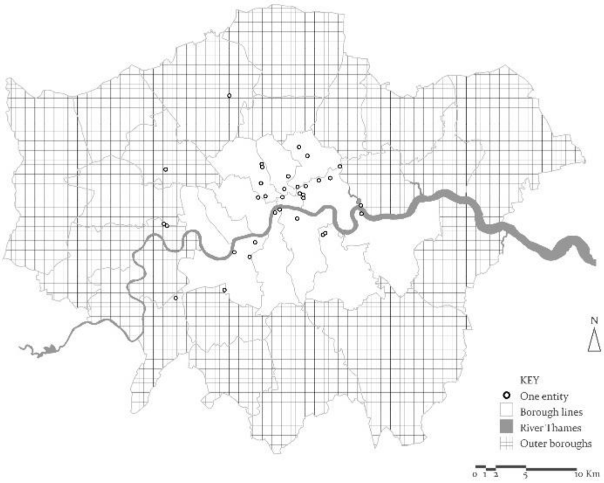

Figure 6.11 Location of activities working in creative sectors/ creative industries which could be mapped

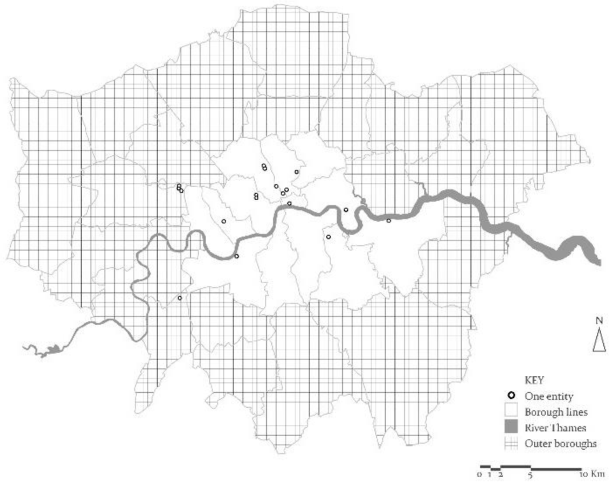

Figure 6.12 Location of activities working in other sectors/ non-creative industries which could be mapped

Figure 6.13 Location of activities working without specific sector focus or across all sectors which could be mapped

Mapping of all activities emerging in London in connection with 3D printing technology with address per activity type supports the conclusion that these activities have a tendency to locate within inner London irrespective of material outputs. They broadly follow tendencies to centralise and cluster in similar ways to other creative activities in London. It has been seen that the geographical location of activities is thus not dissimilar to what we know from literature (Scott 1988b; Moulaert and Swyngedouw 1989; Duranton and Puga 2001; Hutton 2008; Storper and Venables 2002) on the location of other kinds of innovation in post-industrialism – urban, central and clustered, regardless of the possibilities of the technology and of its material outputs.

The analysis now turns to the locational relationship between activities associated with 3D printing and other London economic activities in order to develop a better understanding of the locational overlaps, similarities and differences between them.

Co-Location of 3D Printing Activities and Other Economic Activities

I have overlaid maps of the activities emerging in connection with 3D printing onto those of various other sectors and types of employment within London. I have found that the location of 3D printing activities is consistent with the location of employment in sectors of knowledge, creative and services within London – despite rents and small premises. These findings continue to support the argument that these industries are part of the typical post-industrial economy of London, supporting abstract tasks of production and development of products and ideas at early stages, as part of the London's agglomerated economy. Below I present the various maps and their analysis.

I start with overlaying the activities identified in this study with the Central Activities Zone (CAZ) and Northern Isle of Dogs (NIoD). Analysis by the GLA economics (Mayor of London 2016) shows that, in London, there is a sharp tendency for agglomeration of jobs (in Financial, Insurance, Professional, Scientific and Technical sectors) in the CAZ and in the NIoD, combined with clusters in outer London hubs. These zones register the highest employment density measured in jobs per Sq Km in the Economic Evidence Base for London (2016). With the exception of the Isle of Dogs, which is mainly a financial hub, it is noticeable that there is an overlap between the concentration of dominant sectors and the location of activities emerging in connection with 3D printing technology. Figure 6.14 shows an overlap between the CAZ and all activities which could be mapped, where it can be seen that 50% of activities are located within CAZ, more specifically in the north east part of CAZ.

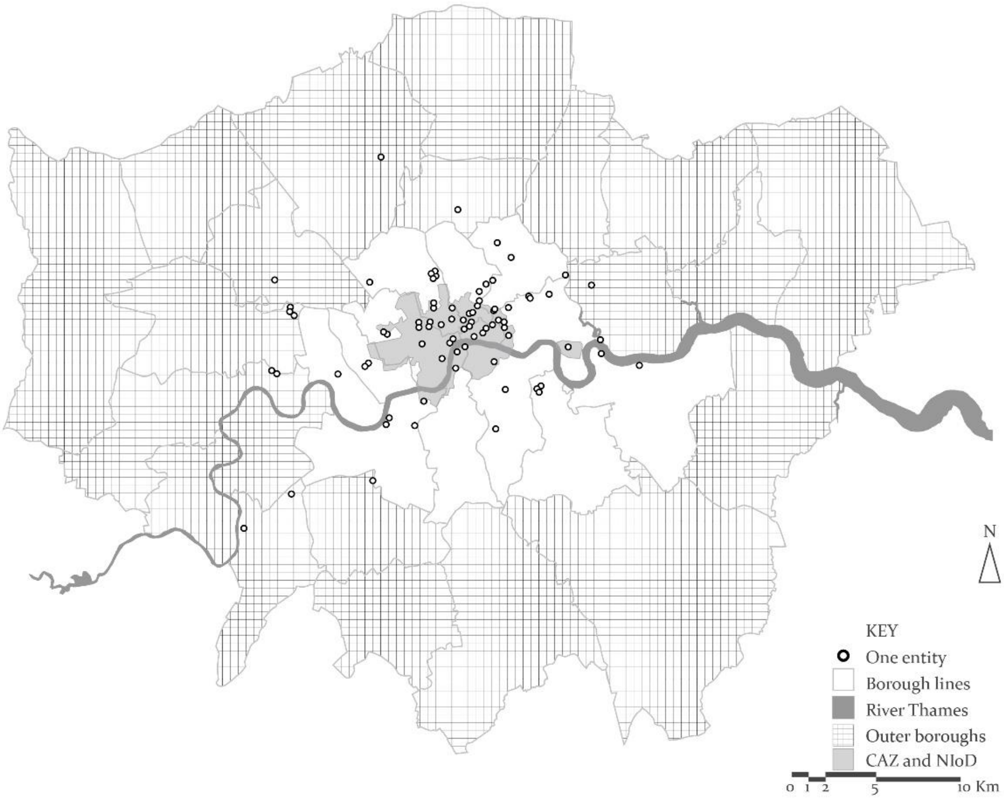

Figure 6.14 Location of all activities which could be mapped and overlay of the Central Activities Zone (CAZ) and Northern Isle of Dogs (NIoD), source: MAYOR OF LONDON (2016) *Economic Evidence Base for London 2016,* London: Greater London Authority

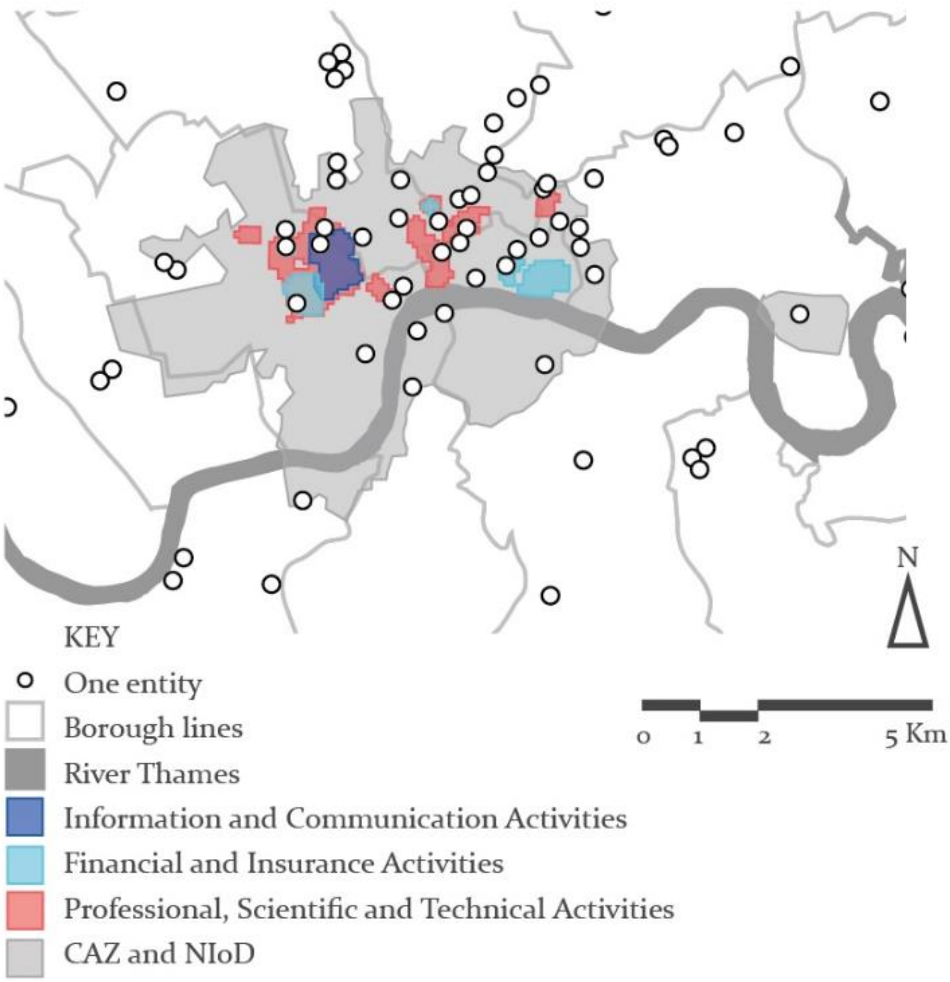

Figure 6.15 Location of all activities which could be mapped overlaid onto heat map of co-locating firms in selected sectors in the of the Central Activities Zone (CAZ) and Northern Isle of Dogs (NIoD) (2013), source: Map 2.9, MAYOR OF LONDON (2016) *Economic Evidence Base for London 2016,* London: Greater London Authority

Looking more closely within the CAZ, I mapped its three most common types of activities co-locating together and overlayed the activities emerging in connection with 3D printing (Figure 6.15). It can be seen that many 3D printing activities also co-locate with the three professional, scientic and technical activities hubs. This finding supports the idea that these activities are part of the network of firms working in those sectors. Further, they contribute to the strength of the hubs, aglomerated environments where sharing resources and transfering knowledge accelerates innovation (Glaeser 1998; Boschma et al. 2009; Essletzbichler 2013).

The activities emerging in connection with 3D printing with employee[42] and self-employed[43] jobs in London, can be further considered in relation to the distribution of different sectors of employment across the city. This highlights whether these activities are more concentrated in association with a particular type of London employment by borough.

When plotting the spatial distribution of the activities which emerged in London in relation to 3D printing technology with the spatial distribution of the relative share of London's employee jobs[44] by borough, it can be seen that, with exception of Hackney, the boroughs with more employee jobs also overlap with most entities mapped. It can also be seen that, when breaking down employee jobs per sector, the activities in this study are located in areas with more employee jobs in Professional Services and Real Estate sectors[45] rather than in Manufacturing. Further, London's relative share of manufacturing employee jobs by borough is higher in outer boroughs which were not found to have activities emerging in connection with 3D printing technology at all such as Hillingdon, Enfield, Barking & Dagenham and Bexley. Figures 6.16 to 6.18 show an overlap of the entities from this study with the GLA economics published data.[46] This shows, yet again, that the location characteristics of activities

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[42] London's relative share of employee jobs by borough is sourced from the GLA Economics, and this data has been mapped by the source.

[43] London's percentages of self-employed jobs have been collected as a spreadsheet only and, as there were no maps available at the source, maps have been produced for this research.

[44] London's relative share of employee jobs by borough is from 2015 according to the GLA Economics, and the 3D printing activities mapped are from 2016/ 2017.

[45] 'The London Labour Market Projections 2016 reports that the London economy has become more specialised in a relatively small number of sectors: Financial services; Information and communication technologies; and, Professional and real estate services. These sectors accounted for 53% of London's output in 2014, up from 42% in 1997. These are also sectors which have a disproportionate share of UK jobs in London.' (Hope 2017: 25)

[46] The definition of an employee job for the GLA London Jobs series follows that used in the ONS Workforce Jobs series, where Workforce jobs = employee jobs + self-employed jobs + HM Forces + Government supported trainees. In London, employee and self-employed jobs account for over 99% of the total Workforce Jobs. Workforce jobs in the GLA analysis relate to the number of jobs in London, whether or not they are taken by London residents. GLA also distinguishes jobs from people, as some people may have more than one job. Jobs are recorded per registered business address. (source: HOPE, M. (2017) *London's boroughs: borough by sector jobs, data and methodology*, Working Paper 92, GLA Economics,

which emerged in connection with 3D printing and the predominant economic activities in London are similar in nature.

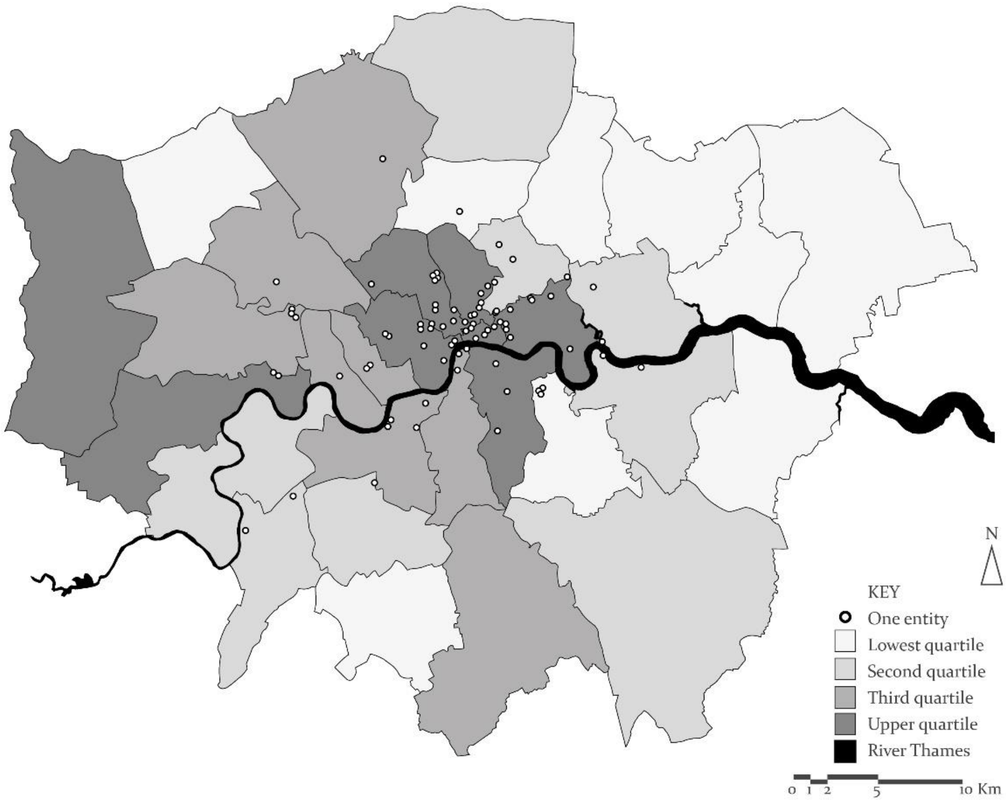

Figure 6.16 Location of all activities which could be mapped (2016-2017) overlaid on share of all London's employee jobs (2015) by quartile, source: HOPE, M. (2017) *London's boroughs: borough by sector jobs, data and methodology*, Working Paper 92, GLA Economics, London: Greater London Authority, available from http://www.london.gov.uk/gla-economics-publications, accessed 24th August 2018

London: Greater London Authority, available from http://www.london.gov.uk/gla-economics-publications, downloaded 24th August 2018).

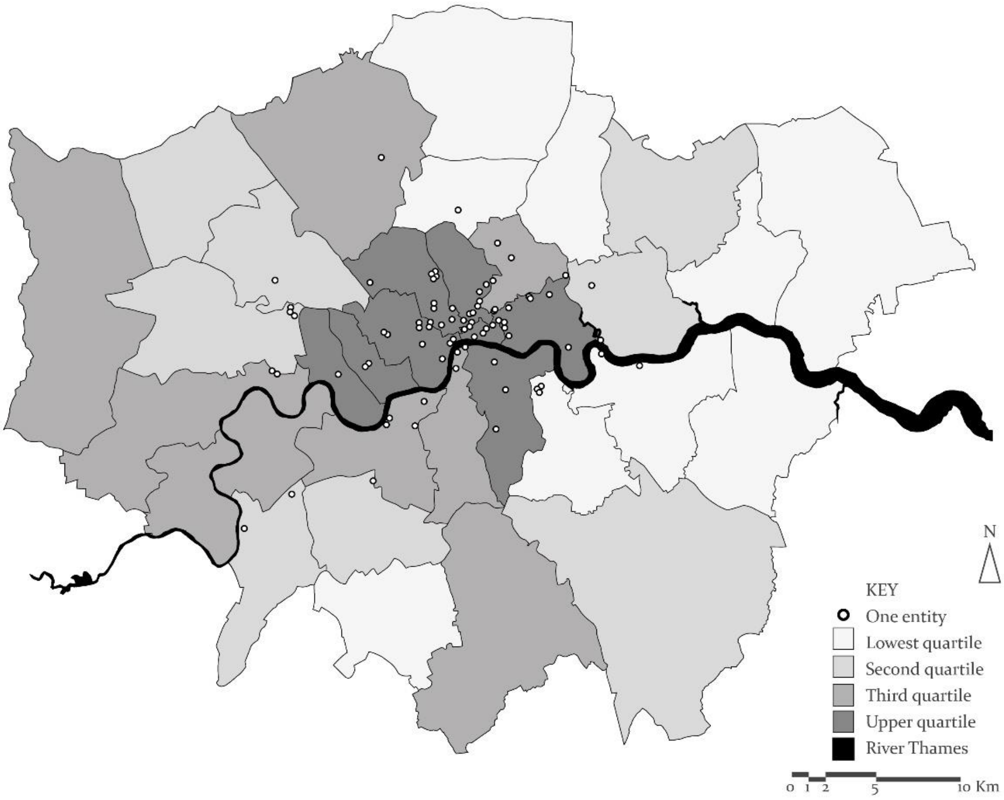

Figure 6.17 Location of all activities which could be mapped (2016-2017) overlaid on share of London's Professional and Real Estate Services employee jobs (2015) by quartile, source: HOPE, M. (2017) *London's boroughs: borough by sector jobs, data and methodology*, Working Paper 92, GLA Economics, London: Greater London Authority, available from http://www.london.gov.uk/gla-economics-publications, accessed 24th August 2018

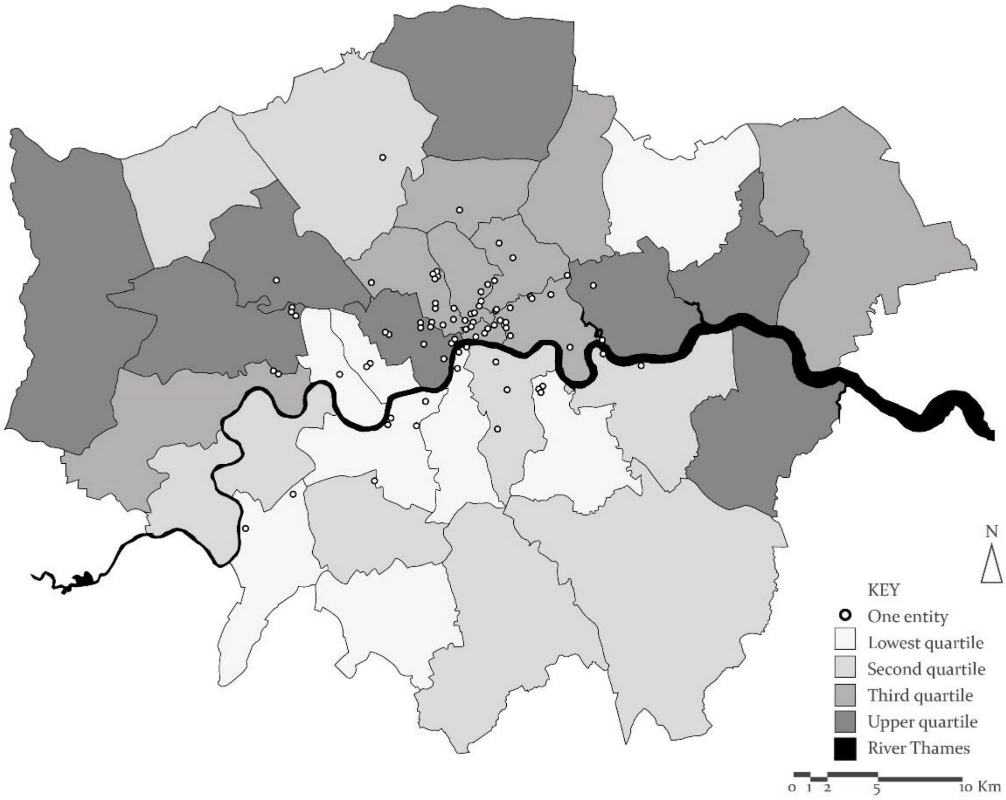

Figure 6.18 Location of all activities which could be mapped (2016-2017) overlaid on share of London's Manufacturing employee jobs (2015) by quartile, source: HOPE, M. (2017) *London's boroughs: borough by sector jobs, data and methodology*, Working Paper 92, GLA Economics, London: Greater London Authority, available from http://www.london.gov.uk/gla-economics-publications, accessed 24th August 2018

Having looked at co-locations in inner areas of London and across London as a whole, I turn now to the analysis of co-locations of activities specifically located in peripheral areas. The general London trends point to prevalence of Transportation and Communication sector activities in outer London employment clusters, regardless of their detailed and localised differences (see GLA's Economic Evidence, Mayor of London 2016):

> 'Distinct clusters of sectors by employment are seen within London with Financial and insurance activities, and Professional, scientific and technical activities being of importance in Inner London; while employment in the Transportation and communication sector is generally more significant in Outer London.' (Mayor of London 2016: 48).

But scholars have also noted not just differences between various outer London employment locations, but also the diversity of activities within each peripheral employment area. They have highlighted that those hubs are not used exclusively as transportation and logistics centres but also as services, including with a degree of innovation which is often neglected by local authorities (see Ferm 2016; Ferm and Jones 2014; Giloth 2012). This also applies to outer London activities related to 3D printing. Only Park Royal, in the outer London borough of Ealing, had activities related to transportation and logistics operating as of 3D printers, material and/or parts. This activity is supported by the good local road infrastructure and the connectivity of the area. But other activities related to 3D printing in other business parks in outer boroughs are not involved in transportation or communications. Examples include Nest-networks, located in Newham's Burford Road business park which provides consultancy in technology, and Story Lab, a participant case of the detailed sample located in a hub in Chiswick, outer London borough of Hounslow, working in consultancy for product design, prototyping and engineering. Both have a comparable quality, innovation and outreach to activities found in central London. Additionally, I also found that some outer London entities are 3D printing bureaus in high streets and associated with local education institutions, plus some activities operating from home. Equally, they do not fall within the general description of transportation and communications.

It can be thus noted that, in the activities included in this study, innovation is not only found in the most central areas of London, and that some activities innovating in relation to 3D printing technology are also for example near an outer London university or mixed with transportation and logistics in outer London's business parks. Regardless of this (important) observation, which backs scholars' work on the nature of outer London employment being unnoticed because of generic classifications of transportation and logistics, most emerging activities related to 3D printing concentrate in the centre of London, within a few inner boroughs, and half are located within the CAZ alone. They overlap with the locations of most creative industries in London (Togni 2015; Evans 2009), more than with manufacturing, near other professional, scientific and technical activities.

Lastly, I overlay the activities in the study with the locations of incubators, accelerators, co-working spaces[47], artist studios and 'maker spaces'[48] in London (Figure 6.19). The London Enterprise Panel found that those spaces, a mix of offices, workshops and laboratories, are also concentrated in the CAZ and CAZ fringe boroughs. They identified clusters in the inner East London area in the boroughs of Islington and Hackney (around Old Street roundabout and extending across the Shoreditch area to Farringdon), in Camden (around Bedford Square) and in the City of Westminster (mainly around Soho). Some of these locations overlap with the location of activities emerging in connection with 3D printing, particularly Islington, Camden, Clerkenwell, Shoreditch. They are also the most common locations for creative industries in London (Togni 2015).

According to the GLA, incubators, accelerators, co-working spaces, artist studios and maker spaces 'tend to correlate with high concentrations of businesses in digital technology, communication, and creative sectors, which have a higher incidence of start-up activity. The concentration in central areas is evident while coverage in outer London is much thinner and tends to include facilities with a social focus operating in partnership with local authorities, charities, or housing associations' (Mayor of London 2016: 256-257). This same pattern of location is verified for the 3D printing related activities in this study according to the mapping analysis presented. Another parallel can thus be drawn between the activities in my study and these types of activities, once again pointing to locational patterns characteristic of creative and knowledge sectors, less akin to that of light manufacturing, despite the location flexibility of the 3D printing technology.

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[47] According to the London Enterprise Panel, definitions are: Incubator space is typically space designed to support the growth of start-ups or businesses in their early stages with associated business support facilities; Accelerator space refers to space for start-ups or existing businesses with high growth potential with support services provided by investors who may then seek an equity stake or some other financial return; Co-working spaces provide a combination of workplace and support facilities at affordable rates on ad hoc or short-term bases with access to meeting rooms or other shared facilities. (MAYOR OF LONDON (2016) *Economic Evidence Base for London 2016,* London: Greater London Authority)

[48] Maker spaces are shared workshops with shared tools, machinery, and desk space where people can fabricate things.

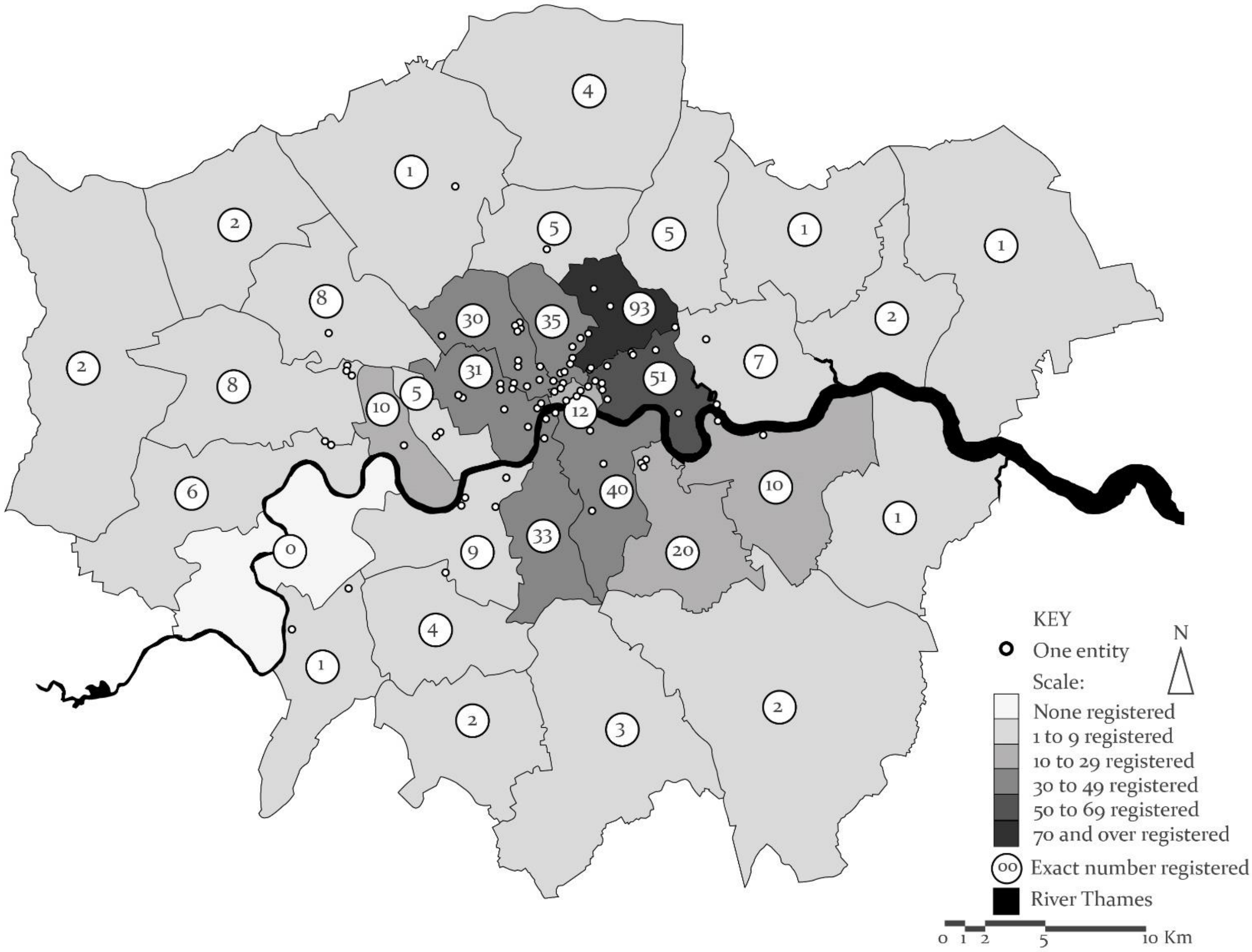

Figure 6.19 Location of all activities which could be mapped (2016) plotted with number of incubators, accelerators, co-working spaces, artist studios and 'maker spaces' by borough (2016), source: Map 6.1, MAYOR OF LONDON (2016) *Economic Evidence Base for London 2016,* London: Greater London Authority

The concentration and co-locations found through the mapping exercise point to activities related to 3D printing being no exception to the well-studied post-Fordist agglomeration economies where leading firms, sub-contracted firms, employees and customers benefit from co-presence and synergies between same and across sectors (Duranton and Puga 2001; Scott and Storper 2003). These kinds of co-location have been found to be prevalent specially within contemporary dominant centres of innovation (Crescenzi et al. 2020), so that leading agglomerations are increasingly more specialised in the abstract, cognitive and conceptual tasks. By contrast, fewer co-locations are found between firms of sectors of manual and routine tasks (Duranton and Puga 2004). My findings from mapping and overlaying locations point to 3D printing related activities forming part of the city's abstract, cognitive and conceptual innovation core, despite being associated with a technology for material production.

Given the observation that there is a strong concentration of 3D related activities in central London, and that rents in these locations are significantly higher than elsewhere in the city, the following section explores the types of premises occupied by these activities. These findings explain how it is that, despite these affordability challenges, these activities, often start-ups, manage to secure a central location.

6.3 Types of Premises

This section presents the findings on the types of premises occupied by the activities identified in this study, gathered through surveys, photography and visits to businesses for face-to-face interviews. Overall, it can be reported that most premises occupied by activities are small and informal, which is arguably expected given most are centrally located and most are microbusinesses. The exception, in terms of size, are makerspaces which require much larger sites than other activities, as they are essentially shared workshops with large equipment and tools.

Table 6.1 shows that studios, warehouse conversions, flats and high specification offices are the most common types of premises. If we group flats and terraced houses (likely to be the owner's homes) then this is the second most popular type of premise, alongside warehouse conversions. This is explained by the considerable number of sole traders and people whose 3D printing activity is not their only occupation and source of income. The high presence of office and studio spaces can be related to the predominant central London location, as well as to the common types of activities and types of work within professional, creative and knowledge sectors.

Table 6.1 Description of the organisation's premises (According to survey evidence)

Type of Premise	*No. of responses*	*%*
Studio	7	20.6
Warehouse conversion	6	17.6
Flat	5	14.7
High-specification office	5	14.7
Medium-specification office	3	8.8
Makerspace	2	5.9
Terraced house	1	2.9
Public building	0	0
Other	5	14.7
Total	34	100

Regardless of type, most entities (19 of 33) operate from very small spaces of 5 to 10 m², equivalent to one or two desks, as evidenced by the survey responses and by the places visited (see Table 6.2). This corresponds to the majority of premises which are shared flexible desks in co-working spaces, small studios or owner's homes. For one respondent this was 'The space under my stairs...!' (3D Amigos.Net, survey response)

Table 6.2 Amount of space allocated for activities related to 3D printing and/ or 3D printing itself (According to survey evidence)

Amount of space allocated to 3D printing or related activities	*No. of responses*	*%*
5 to 10 m² (approx. 1 to 2 desk spaces)	19	57.6
10 to 20 m² (approx. 1 small room)	8	24.2
20 to 40 m² (approx. 1 large room)	2	6.1
40 to 100 m² (approx. 1 small office)	1	3.0

over 100 m^2 (approx. 1 large office or makerspace)	3	9.1
Total	33	100

Visiting some of these organisations during my research helped me understand how these activities could operate from such small spaces: This is possible because many activities require just computers and meeting space which can be very informal – as some do not have any making tools or machinery at all, or because the types of 3D printers used by those who print are small machines, or even portable ones[49]. This reflects the London location - as participants suggested that large bulk 3D printers are more common in heavy industry which is not located in London. In any case, no printers at all or smaller printers allow for a small space which is convenient for microbusinesses in London. Although this does not mean that their printing capabilities, quality of outputs and accuracy have been reduced. On the contrary,

[49] There are many different types of 3D printing machines, ranging from small which are approximately the size of a tall 2D desktop printer to very large ones which are the size of small rooms. The smaller types are easily accessible, relatively easy, and flexible to use. The larger types are more expensive, normally customised to users or products and mostly used in heavy manufacturing and research.

[redacted]

Figure 6.20 Examples of typical small and large 3D printing machines: Eleggo Neptune 2S FDM (Print volume 0.0121 m^3 / 0.43 Ft^3)and ExOne Exerial 3D printing system for industrial use (Print volume 3.696 m^3/ 130.52 Ft^3), sources: https://www.3djake.uk/elegoo/neptune-2s, accessed 24th November 2021; https://cdn-3d.niceshops.com/upload/file/Neptune_2_Neptune_2S_User_Guide.pdf, accessed 24th November 2021 and SHER, D. (2015) The top 10 Biggest 3D printers, *3dprintingindustry.com*, available from https://3dprintingindustry.com/news/top-10-largest-3d-printers-54377/, accessed 15th November 2020 smaller 3D printers are highly precise yet flexible printing machines as this technology allows for that.

Some of my participant cases, visited during research, are good examples which demonstrate the character and nature of premises of activities emerging in London in connection with 3D printing. They show similarities to the London premises typical of microbusinesses in creative sectors in their infancy. For example, Atelier León, was initially set up in the founders' living room. Later the landlord had a storage space in the hallway, and they asked if they could rent that hallway space and that is where the studio is now located. It is circa 3 m^2, fully utilised from floor to ceiling with design pieces, printing supplies, drawing zone, laptops, tools and 3D printing machines and CNC cutter. To perform some tasks, tools and objects must be moved around to make space. To use a good example on informality of premises, Paul's 3D printing hub activities operate from multiple locations as needed, such as the City Hackspace in Hackney, his home in Romford, his office in central London where he has a full-time job, and from elsewhere if he goes to visit someone. He transports his printer and key tools around with him, normally in his car or simply in a bag. He sets up the printer quickly (it took him about 10 minutes to set up his 3D printer when he arrived at the interview for this research), and he starts to print a piece wherever he is. Paul knows the time pieces will take to print, and he manages it, so they can be done during the time he is in a certain location. While we talked about his activities at the City Hackspace, he started and finished a 3D printed part of a vacuum cleaner.

By contrast, a particular type of activity was found to require a large space – the makerspaces. City Hackspace and City Fab Lab are examples within my participant cases. They are essentially large, shared workshops with shared tools and machines, where people can work on demand. These spaces have at least 300 m^2 and are set out as workshops.

Overall, regardless of differences in size, most premises visited showed an informal and relaxed atmosphere, with characteristics similar to that of artist's studios, or of low-cost shared offices and workshops. It was frequent to see adapted desks, laptops instead of desktop computers, non-matching chairs, tools and papers mixed, 3D printers and others machinery, design objects and books. And generally, premises were full of things, with other people around from other firms and activities, showing how space is creatively optimised, shared, and maximised.

Examples of premises similar to artists' studios are Models & Gadgets, Micro Tech, 3D Masters Shoreditch and Patricio Frater. The first two are in former industrial buildings, partially altered and refurbished, but maintaining most of the previous character with exposed brick and rough finishes. The third is in a small creative complex of other workshops and studios. Their space is on one single level, shared with other studios. It is all open plan, and it has a second small 10 m^2 room with the 3D printers and other fabrication machines, accessed via a rear courtyard. The last is also located in a two-storey former industrial building, and it is shared with a friend's studio too. In this studio they work and organise shared parties, networking events and classes. The studio acts as a professional meeting place, but also caters to the wider fashion designers' community, and it occasionally hosts artistic events and activities for even larger groups.

Examples of premises more akin to offices are SB Hub and Eszilook, both activities working in digital outputs. These activities use co-working desk spaces, rented as needed, where office facilities such as meeting rooms, bathrooms and coffee points are shared. They shared the office with other businesses of various industries such as technology, advertising, design, accounting, etc. Comparing with the previous examples, these shared offices were slightly less informal than those which resembled artists' studios. But equally, these organisations shared space resources and people talked to others around if they need help or were interested in other's work.

In addition, other places from the complete list were randomly visited without contacting people or interviewing, simply by following the activity's address. Some were accessed if they were publicly accessible – i.e. as a client or photographed from the outside. The characteristics match the other more detailed evidence findings: generally small (sometimes tiny) spaces, former small industrial buildings, with a frequent presence at ground floor, an informal character and similar to either artists' studios or co-work offices. A small number of additional sporadic visits to collected addresses led to houses or residential buildings, suggesting some activities operating from owner's homes.

These findings on types of premises complement the findings from mapping locations of the activities which emerged in connection with 3D printing technology in London. While findings from mapping highlighted how central the 3D printing activities are, and how they mix with services, professional, scientific, technical, educational, and creative sector activities, evidence concerning the types of premises they occupy show how these are akin to those of these same types of activities - small and informal like artists' studios or co-work desk spaces of digital start-ups, unlike manufacturing, regardless of high rent levels in central locations. The next section will now focus on the reasons for the location choices and types of premises used.

6.4 Location Factors

This section presents evidence concerning how factors, other than technology, contribute to the location of 3D related activities in London. I elaborate on each of the factors for choices of location and premises identified in my study, based on interviews, observations and surveys. I first present the identity of an area, a socio-cultural factor, as the most important reason for an activity's choice of place. It means to be near similar activities, near established clusters such as Tech City and cultural-creative industry hubs to benefit from opportunities for knowledge exchange while projecting an external image which helps with marketing to clients and to potential investors. Second, I describe the next most mentioned reason for the location of a new activity, the availability or the ability to attract employees of the right type. And third, I present the connectivity factor, which was seen as important to attracting employees and to reaching out to customers. Noting that none of them has to do with the technological possibilities of 3D printing, I reflect on how resilient these factors really are. Having realised the absurdity of very small spaces in central, expensive locations for doing work which theoretically can be done anywhere, I discussed the choices of location with the participants. I questioned their rational for choosing central locations over more affordable ones elsewhere in London and I provocatively suggested outer London borough locations. I found that neither the flexibility of the technology nor the ease of communication and transport in London, nor the type of work involved would change their choices.

6.4.1 Area Identity

In this research I have found that an area's identity, culture and history is the most important factor for the location and choice of premises of 3D printing related activities in London. Many activities are in inner London boroughs, in very central areas with expensive rents, but more specifically in areas known for the strong presence of digital start-ups, professional and scientific services, and cultural-creative industries, such as Shoreditch, Islington, Clerkenwell, Westminster, Hackney, Camden. In addition, a manufacturing past of small-scale units and culturally valued industrial built heritage contributes to the identity of the area and helps to attract new talent, another factor treated separately in the next sub-section.

The identity of an area was found to play a key role in the activities and founders' aspirations – and inspirations- in their marketing as a newly formed entity, and in their ability to create a profile which attracts funding. Further to this, the area's identity is found to contribute to sporadic collaborations, knowledge exchange and spillovers – usually treated in literature as benefits of clustering, which is more effective when there is a degree of relatedness (Essletzbichler 2013; Boschma and Frenken 2011; Boschma et al. 2009; Rigby 2013), and which the founders seemed to be aware of.

The most sought-after identities for locating activities are either Tech City, which is near many digital firms and supporting services such as incubators, or near a cultural-creative cluster which means the presence of artists and art-related spaces or design studios, with local events which relate to cultural and artistic activities. These identities correspond to clusters of creative industries in London (Togni 2015; Mateos-Garcia et al. 2014), for example cultural and design industries in Shoreditch and in Hackney, and Tech City in Old Street. Some activities had even chosen their location to be associated with both digital and cultural-creative clusters. Being innovative new organisations, they were keen to be associated with these area's identities as a way to establish and externally project their own organisational identity.

For example, Eszilook's founder referred several times during the interview to the Old Street area as 'the famous Tech City'. Although some of his 3D printed headsets had been made in a home studio in East London, he preferred to identify the firm with the head office location in Tech City. Even if they do not actually need a physical presence there as a lot of business is generated through the internet, the reality is that proximity to other start-ups (not necessarily within the 3D printing technology, but digital) is important to place them in the market as a digital start-up company. So, what is it in the Tech City character that brings the right people and more business? When queried directly about the option of moving out to a more affordable office location than Old Street and continuing to do most business over the internet, Eszilook's founder thought that the proximity brought other benefits from a creative point of view. Even if the business could be all cloud based, and located elsewhere less expensive, if the activity had to move, it would still move within Tech City to ensure it stayed near other digital start-ups, as described in his words:

> 'At the end of the day a start-up is made with people, not robots so we still need to be near others even if it costs more' (Slavis T. Prioli, Eszilook, interview)

The cultural-creative character of an area also emerged as one of the most sought-after identities determining the location of activities related to 3D printing technology, particularly those working in design, architecture and prototyping. This was found to be such a strong definer for a business identity in this field, that popular clusters were sought-after from beyond London and even from outside the country. For example, Atelier León's founders wanted to be based in East London, which they recognised is an area famously known in Brussels, where they came from, as the 'creative area of London'. They knew this is an area in Europe where people can develop these kinds of ideas – a making and design studio as they set out to do. So, they chose to move in, arrived in London and found a flat in Bow, and started the business from there. Another example, Patricio Frater, is also based in East London because, he observed, there is a good community of artists and designers there. He has had this studio in Hackney since 2013. He initially chose to come to Hackney when he moved from Italy because he knew about East London and Hackney through his friends and artists' communities, and about art galleries and creative markets in East London. In his words: 'There are always people around with who to develop ideas' (Patricio Frater, interview).

The benefit of the creative context is given by the presence of other firms with which the activities have commonalities - a degree of relatedness, allowing for exchange of knowledge, resources and spillovers. This is well illustrated by the mix of businesses found at the Sunbury Workshops, Shoreditch, where 3D Masters Shoreditch is based. The main space is shared with four other business activities: a domestic and industrial products and jewellery designer, a music video creator, and a two people start-up involving coding, electrical engineering and CAD work. Santiago, founder at 3D Masters Shoreditch, considers it useful to share the space with these other activities, as sometimes there may be tips in conversation that can save hours of work, or sometimes they can get help from others. There are overlaps between the activities, informal opportunities of collaboration. He noted that while 3D printing as a service on its own does not need to be in a specific location, all the other activities that go with it such as product design, prototyping etc. benefit from being in such a cultural and creative environment as Shoreditch. The same benefit of multiple and co-related types of activities was observed at the City Hackspace in Hackney, as it holds other groups besides the 3D printing one, which meet for related themes such as micro processing, programming, woodworking, metalworking, robotics, etc.

Models & Gadgets (M & G) are located in Camden, another well-known cultural-creative cluster of London. They started in Marylebone, West London, originally in the dentistry sector where the firm still has a dentistry-focused office, but when they started expanding beyond the original medical sector, the first client was Ron Arad (artist and architect) who is based in Chalk Farm. The founder realised that Camden has a concentration of architects, engineers and product designers and searched for property in the area, specifically a former warehouse or industrial-character building. Currently they have the head office in Camden to be close to these types of clients and be part of the cultural-creative scene of the area.

Being in an area associated with certain types of activities was also found to have important funding implications. Founders were aware of this, and of the need to thus locate in areas with identities that suited how they wished to be seen by investors. In other words, choosing to locate in an area with a certain identity helped to ensure investors that they were the same type of business as their neighbour firms and facilitated funding. Participants perceived Tech City as one of those good locations to be in due to access to programmes and events involving venture capitalists and incubator or accelerator funding for other technology start-ups. Some activities chose to locate there despite high rent areas. Eszilook made this deliberate choice to be able to receive crowdfunding from Kickstarter (a crowd funding platform for technology projects) as with the Tech City location it could present itself as a digital type of business, although the founder noted that they were not financially entitled to tax benefits from the location as they were not a 'truly' digital business. Additionally, he reported that they also benefited from the proximity with Seedcamp, a source of private venture capital funding and an accelerator for tech companies in Europe available in Tech City.

Other locations mattered too for the creation of a business case to investors. Micro Tech's founder mentioned he had to construct his business case for external funding around a digital identity and location mattered to this profile, so they stayed in Camden. Equally, SB Hub's founder mentioned that his location in Clerkenwell, where other technology businesses are, is good to set up an innovative business due to a good network of investors nearby who really can help to grow the business. And BrownBear had started originally in Amsterdam and applied and got accepted to a start-up accelerator programme in London, the Bethnal Green Ventures and subsequently relocated to central London, setting up a new office at Makerversity, Holborn.

The character and identity of the area was found to be the primary factor for the choice of location for 3D printing related activities, even for those trying to set up in the outskirts of London. This is the case of Romford Makers, which was in its early stages when I joined the group as an observer. I attended meetings by a local community group trying to set up the local Makerspace as a not-for-profit space. The possible locations being considered by the group for their local makers space were the Quadrum, the Brewery unit or the Retailery, all very central locations within Romford and all places associated with creative activities in the area. The Quadrum is a local pop-up for creative people, artists. The Brewery unit had a vacant space and was regularly visited by students and artists. The Retailery was an existing space within a shopping centre in the town centre which has start-up business support, retailers, makers and food outlets with local community focus and outreach. Sessions include a range of programmes for all kinds of businesses such as: how to set up a business plan, choosing a structure for a business, explaining tax and insurance, marketing, how to set up a website, corporate social responsibility, business spaces and lettings, and inspirational talks by local business founders. The Retailery also has affordable hiring desk and retail space for the community and as well as an area to gather, eat and shop with frequently organised events. These three spaces were considered by the organising group regardless of more affordable locations around or outside Romford, due to their association with creative activities. To avoid paying rent, the group considered a temporary pop-up, or very small premises initially, a strategy also used by the activities in central London. For them, the success of the space would depend on being in the right character setting, even if it meant a smaller facility, and being very centrally located in the town.

The previous manufacturing history of an area, its former industrial past, was also an essential element of the definition of an area's identity for many activities associated with 3D printing technology, particularly those who were drawn to the Tech city and the cultural-creative identities. It encompassed two aspects – the built environment and the people. Regarding the built environment, the attractiveness of former industrial elements, some with heritage value, was referenced by some participants and observed in many premises visited during this research. It was found to be a key contributor to the definition of character and identity of an area as presently related to creative industries and to innovation.

The contribution of former industrial identity to the current creative character of an area also points to the evolutionary nature of economic activities in places (Boschma and Frenken 2011; Neffke et al. 2017) through fostering links amongst people and enterprises. For example, Patricio Frater, a shoe designer, notes that near where he is based there were also many leather shoemakers since the 1970s. Now, Frater has been speaking with them about his own shoe designs, sometimes getting the 3D printed prototype to be made in leather as well, which has then opened up opportunities for other design developments to also be 3D printed. An old-established leather shop is on the ground floor where his studio is, and there are others in the same street and in other parts of East London with whom Frater now has established contacts, as he describes:

> 'It is interesting to use the same area to start the same type of business, but with a different technology, when it is still possible to learn from their experience in shoe making from the past. Sometimes I can talk to people when I go to a leather shop and hear about how the shoe industry was here in the 70s. They have also been making shoes from 30 years, so I may get to learn from their experience too. This happens in East London, just walking around and talking to people' (Patricio Frater, interview).

In conclusion, it can be said that the 3D printing related activities found in London are located in concentration in central areas and in small, sometimes shared spaces, not necessarily in the most affordable locations, but where they can borrow identities given to those same areas by other activities, particularly by other digital and cultural-creative businesses. Area identity was found to be the crucial factor in choosing a location and premises. This identity of an area has been defined by many aspects such as a degree of socio-cultural proximity between the activities' founders and other local activities and locally employed people, and even built environment and economic history. These were acknowledged by founders when selecting locations, conscious location choices sometimes with funding implications.

In embedding themselves in the area through the deliberate choice of location, the activities in this study intended to benefit from the area's characteristics, particularly from skilled knowledge and even former existing knowledge such as that from local artisans, as well as an increased ability to hire the right people. This last aspect will be further analysed in the section that follows.

6.4.2 Hiring Talent

Attracting people to work in an enterprise was the second most important factor in the choices of location and premises for the activities. This is because the ability of these innovative businesses to attract and hire the right people was found to be extremely challenging due to a positive economic environment at the time of this research. In the years the field study was conducted (2016-2017), the job market was good and unemployment in London was low. For this reason, people who had the necessary skills to be employed in these activities, particularly young people, were able to choose which jobs they wanted to apply for, thus businesses had to compete to hire the right people.

As acknowledged by founders interviewed, people with the qualifications or experience to be employed in these activities favoured more central locations to work, which are well connected, offer good leisure and retail facilities, with attractive urban qualities, and that embody the right '*spirit*'. This spirit was described as about being in an area where other people also work in similarly creative, knowledge and cultural activities. In order then to attract the right people, founders believed that they needed to locate centrally and preferably in areas of certain job clusters, like those of creative and digital industries.

This location factor highlights the role that urban environment quality, mixed uses and social relationships have in labour availability and supply in an area. If in the previous section the character of the area was identified by founders as key to the activities' choice of location for funding and knowledge exchange reasons, in this section the point is that this same area character determines the attractiveness to potential job candidates. The fact that the first and second most important location factors are hence related and imply (in different ways) the role of social proximity, has been discussed in literature by scholars of relational geography who have argued that ultimately all economic processes are embedded in social relations (Granovetter 1985; Thrift 2009; Grabher and Ibert 2013).

Micro Tech and SB Hub are good examples from this study's detailed cases with regard to location being determined by the ability to hire talent. Micro Tech was located in Bow, East London, where it moved from Camden. The whole team was based there, even though clients were all located outside London. London, particularly the East, is a convenient location due to the people they need to hire, which tend to be people attracted to creative areas, as mentioned by the founder during interview. The same case is described by Mirek, founder at SB Hub as equally all of SB Hub's clients are located outside London, but central London is still the most attractive location for the firm due to the need to hire highly qualified talent, normally associated with technology and start-ups. When queried about the option of an outer London borough location, where rent levels would be more affordable and where they would be closer to the clients, Mirek responded that if located outside central London it would be very difficult to attract the right talent with the skill set he needs, and SB Hub might have to leave the country. In his words: 'This has already proven difficult, and the more central location the more attractive to new talent. If outside Zone 1, then one would lose the benefit of London' (Mirek Iliescu, SB Hub, interview).

In conclusion, the ability to attract necessary skilled labour also determined the central location of activities emerging in London connected to 3D printing technology, regardless of technological flexibility and easy communications. This pursuit of a central location, particularly in certain established digital and cultural-creative employment clusters, even with higher rents, highlights that innovation follows people. My findings for the activities related to 3D printing in London add to the empirical evidence pointing to the significance of the people factor for innovation and growth (Kemeny and Storper 2020; Florida 2002). My case study particularly indicates that this type of job, creative and abstract for the most part, as discussed in the argument of Chapter Four, follows people with high educational attainment, and that in turn those people are drawn to places with other creative jobs. This has been described as a circular causation in literature concerned with whether jobs follow people or people follow jobs (Ostbye et al. 2017).

Below I consider the third factor identified as important for the choice of location and premises – connectivity, which is also key in arguing that cutting-edge material producing technology does not change the location of innovation nor the spatial separation of production in post-Fordism, regardless of its flexible location and on-demand production possibilities.

6.4.3 Connectivity

Connectivity of an area, expressed in London as accessibility by public transport, was found to be the third factor determining activities' choice of location and premises. As gathered in interviews and surveys connectivity has been related to access for potential employees, to the mobility of the owners who many times needed to travel to other employment or to clients outside London, and their need to reach home quickly given the extra hours of work many of them did in their self-funded activities.

For example, good accessibility from their chosen location contributes to SB Hub's ability to find much needed talent, but it is talent which determines its current location. According to the CEO, it would not make a difference if it had started in Old Street or Marylebone, as long as it is located in central London, so people can travel easily to the area, as he struggles to find the right people to join the firm. It is also easy to reach out to clients elsewhere in the country or abroad from central London, but again he would not locate closer to the clients, as that would make it even harder to hire new staff.

Regarding reduced travel time between activities, jobs, and home to support the activities, three good examples from my participant cases are 3D Masters Shoreditch, Atelier León and Patricio Frater. They chose to locate activities and live in areas of creative industry clusters, respectively in Shoreditch and in Hackney, near public transport nodes. They located their 3D printing activity near their home in the same area too as founders have other jobs and need to travel back and forth quickly, sometimes at odd hours. For Atelier León, one of the difficulties was the overhead cost of a space, so the (originally) storage room near the flat rented from the same landlord, a very small and affordable space, was ideal. Furthermore, being just outside their flat, they could save travel time and print more often as needed to test designs, and quickly travel to their other job in Whitechapel. For 3D Masters Shoreditch, similar reasons determined location. When they expanded from their original home set up to finding a workshop, they knew they wanted to stay in North London due to their homes and their other jobs. And they did not want to be too far from the city centre, as they need to be able to access the workshop easily and start printing early and monitor the process. Their chosen location in Shoreditch is relatively close to their homes, and well connected to their other jobs, which for them was especially important since they maintained the business frequently after their normal work hours. Patricio Frater, a sole trader based in London Fields Hackney, where he also lives, noted that this location choice for his studio was based on his lifestyle preferences as a creative designer, pointing to the area's identity above everything. But there was the more practical issue of reducing his travel time overall as in parallel with his design activities for 3D printing, he maintains another job in the design sector located in central east London, to which he travels every day from home. His studio is very close to where he lives, so he can easily access and monitor the printer at various odd times of the day and night if needed. Sometimes he works on his designs from home, then he goes to the studio as the 3D printer is there.

To use another example, it can be said that connectivity in conjunction with the character of the area, is one of the main factors for the popularity of the City Hackspace which was found to be a great focus of networking in the maker's community, previously located in Hoxton, now in Hackney[50]. The premises in this location had a good catchment for Central and East London given the relative proximity to Bethnal Green and Cambridge Heath stations (followed by a short bus ride), with a very high PTAL ratio of 6a[51]. Paul, interviewed, who is part of the board of directors of the space, referred to this location in interview as quite unique due to its creative and industrial character and still well-connected enough that it could serve people all over London. He comes in from Romford and knows of people coming in from other parts of London. At the meetup I attended in the City Hackspace, there were people from West, Central and South London. They all pointed to relative connectivity and easy access to this space, but mostly to the extended opening hours and to the known members and makers community as the reasons for attending this meeting and using the Hackspace

[50] The City Hackspace closed activities during this research for a period of time, having re-opened later in Wembley due to real estate pressure.

[51] Public Transport Accessibility Level (PTAL) ratios are defined by Transport for London (TfL) to measure connectivity from any London address. It varies from 0 (less connected) up to 6b (best connected locations).

in this location. Further to this, the need for bigger premises does not override the need for central locations and good connectivity. Another participant case, City Fab Lab[52], chose to locate in the City of London as the founding partners recognised from the outset that ensuring accessibility was key to its viability.

In conclusion, it has been found that good connectivity is one important driver for location and premises choice for activities emerging in connection with the 3D printing technology. This factor is associated with the other factors presented, since an area's identity in conjunction with good access was found to be key in attracting the right people to work. Connectivity was also found to be important in reaching out to clients – some were outside London and abroad, and travelling quickly between home, this activity, and other jobs as founders did not work exclusively on these activities for financial reasons. This meant that very central, smaller spaces in higher rent locations near public transport nodes were preferred to more affordable ones outside the centre for most activities. However, makerspaces were found to be the exception, as they needed larger premises to store machines, tools and for workshop area. They also depended on connectivity, which had determined their original central and accessible location.

I have presented the three key factors for location and premises choice which this study found– area's identity and socio-economic culture, ability to attract the right employees plus connectivity. All of them relate to the creative, knowledge and abstract nature of these activities and their inherent dependency on social relations amongst people of high education attainment and with other related activities which they support and cluster around. None of these factors was radically different from what we know about the location of innovation particularly at early stages of products and in creative industries, nor what characterizes the post-Fordist fragmented geographies of production (Scott 1988b; Moulaert and Swyngedouw 1989; Duranton and Puga 2001; Hutton 2008; Storper and Venables 2002), regardless of the location possibilities which in principle arise from a technology like 3D printing.

In the next sub-section, I will discuss the strength of the location and premises choices, through interview data designed to assess the extent to which activities in this

[52] The City Fab Lab closed activities during this research due to real estate pressure.

study depended on central, characterful and accessible locations in relation to other options.

6.4.4 Probing Location Choices

During the evidence gathering, the strength activities' location choices were probed with direct questions in the survey and in the interviews. The intention was to find out how strong the current location preferences are, how likely or how easy they were to change, and the resilience of each locational factor.

It was found that, despite some affordability challenges and a high level of bootstrapping and duplication of jobs, the majority of entities interviewed and surveyed (55%) were not considering moving to another location, as shown in Table 6.3.

Table 6.3 Intent of Location change – Is this organisation considering moving to another location? (According to survey evidence)

Choice	*No. of responses*	*%*
No	18	54.5
Yes	12	36.4
Don't Know	3	9.1
Total	33	100

As shown in Table 6.4, rent increases emerged as the top reason which could trigger the need for a potential (although difficult) change of location. However, during the interviews it was discussed at length that moving to outer boroughs or less central locations was not the first or preferred option to address viability if rents increased. Owners mentioned they would still prefer to continue where they are in smaller premises and continue bootstrapping and working on other jobs for longer.

Table 6.4 Possible triggers for location change. What would make this organisation move to another location? (According to survey evidence)

Choice	*No. of responses*	%
Rent/ Cost per Sq. Ft.	12	35.3
Type of Space	6	17.6
Other	6	17.6
Proximity to collaborating firms	4	11.8
Proximity to clients	3	8.8
Proximity to owner's personal address	2	5.9
Proximity to employees' homes	1	2.9
General character of the area	0	0
Proximity to competitors	0	0
Proximity to College or University	0	0
Proximity to public transport	0	0
Total	33	100

Considering particularly the small premises and the high level of bootstrapping, interviewees were asked (rather insistently) whether a less expensive, potentially less central location, could be a consideration if the current location were to become unavailable soon. Given how small some of the spaces were, they were also queried about possible expansion into a bigger space, which would be easier to secure elsewhere. The findings confirmed that interviewees indeed valued their current location, as shown in the examples below.

Patricio Frater maintained that, if he had to move, he would still prefer to remain in East London, possibly in the same area of London Fields or in Hackney Wick at the furthest (circa 10 minutes away from where he is currently based). He noted that if his design business grows, he may need bigger premises, and he would prefer a warehouse type of building which are a type of building stock available in those areas. But a similar space as his current premises would still be 'made to work'.

Atelier León's expansion plan included renting a bigger shared space in a railway arch in East London, as they were growing and had a really small space. Vaissiere, co-founder, mentioned that arch spaces tend to be cheap, as they are classified as light industrial and cannot be developed to residential uses, so they were searching for one. They also liked the idea of a shopfront where people could walk past and see 3D prints, which is currently not possible in their space. The founder was hoping to find a shared arch, so it would be more affordable, and noted that if sharing with people from related fields that would bring valuable knowledge exchange opportunities. He argued that a space like this would be easier to find in East London anyway, and therefore they did not consider moving much further from Hackney Wick, their location.

Mirek, founder at SB Hub, mentioned that only labour access would influence a decision to move outside the current location in Clerkenwell. In that case, he noted, relocation would probably be to the centre of another city such as Cambridge, Sheffield or Nottingham (if in England), due to highly qualified people or an industrial base.

Santiago, founder at 3D Masters Shoreditch, pointed out that given his need to maintain another job, a less central location would not work for the activity, and that his clients were in central London. If the enterprise was based outside central London to reduce rent costs, there would be a constant need to travel and meet clients in the centre, which would not be feasible.

In one particular case, the City Hackspace, a move was inevitable in the near future due to the landlord's redevelopment plans for the area. At the time of the fieldwork, the Hackspace was due to move from their location (by April 2018) when the lease was due to expire, and the landlord had already almost doubled the rent at the time of evidence gathering. If they could, they would find another similar space in the vicinity, according to Paul board director, but after that date in April, the organisation:

> '...will probably break apart as it is difficult now to find another space like this in the area due to rent. The solution of moving activities further out is not accepted by our board of directors, and instead closure is more likely' (Paul Lewis, Hackspace, interview).

During the course of this research, the City Hackspace effectively ceased activities for a period of time after having to vacate the building in Hackney. It has however re-opened in Wembley in the same community-run format some time afterwards, during the writing up of this thesis. As this was an interesting move that could put into question my claims - these activities' central location trends and the importance of an area's character and existing economic clusters for new enterprises - I joined an online chat at the City Hackspace in 2022 to find out more about the new location. I learned that with this relocation membership levels have declined, as the new location is not near crafty or design businesses as the previous Hackney address. Furthermore, one chat respondent indicated that gentrification pressure rendered impossible a return to Hackney in the near future, but that connectivity – this research's third most important locational factor - was the key to this new Wembley location. The new address is as well connected as the previous Hackney one, with PTAL ratio of 6a[53] (located at circa five minutes' walk from Wembley Central or from Wembley Stadium stations, with access to Bakerloo Overground and Railway lines, buses, and on-site parking). Due to similar real estate pressure, the City Fab Lab, another large workshop, closed activities during this research and did not reopen. City Hackspace and Fab Lab London had in common the need for large premises.

The key factors influencing choices of location and premises remained crucial to these entities when the key decision makers were repeatedly questioned about alternative location options in the interviews. In all cases, provocative suggestions about finding a less expensive location and more space in outer London boroughs like Enfield or Bexley, even if close to stations and high streets, or in second-tier cities, were strongly counter argued by the participants. A central London location was presented as a necessary condition for their operations, and some expressed their views on how current policy could help them to secure their locations for longer.

This section, location factors, presented the third set of findings in support of this thesis' second argument that 3D printing technology is not changing the geography of production in post-industrialism, which has been described as separated across geographies (Duranton and Puga 2001; Scott 1988b) according to stages of production and types of activities. More specifically, early stages of production and innovation tend to be located in city centres due to the benefits of concentration of people and businesses facilitating knowledge exchanges and new businesses emerging, whereas final production or mass production is deployed to outer regions. Even though this

[53] Refer to note 49

technology could have assisted new businesses locating in less central areas, or final production be located near the early stages and on-demand, this research found that the location of emerging 3D printing activities was not motivated by technological possibilities, it was not a technology-driven narrative. The character of an area, the ability to attract the right people, and an area's connectivity were found to be the most important factors defining the location of the activities in study. These factors determined that central and clustered locations were even more important than having bigger premises, so much that even activities requiring larger spaces- as makerspaces, close down if they cannot retain their central connected locations.

This chapter proceeds with the fourth and last set of findings in support of the argument that 3D printing technology has not altered the post-Fordist separation of production activities across regions. It considers the connections and the relationships that the case studies had with other activities beyond London (within their own organisation and with other enterprises). It shows that innovation and key operations remain in London, whereas final or repetitive tasks are deployed elsewhere, including 3D printing.

6.5 Beyond London

Many activities related to the 3D printing technology in this study reported virtual and practical connections to locations outside London, both within England and abroad. These connections can be grouped in three types: connections with clients located outside London; connections within the organisation/ intra-firm; and extra-firm connections, particularly outsourcing 3D printing.

These connections demonstrate the separation of production across various locations, where London activities are more focused on product development and on controlling the production process, while the relationships beyond London point to secondary and complementary tasks as well as more repetitive 3D printing. Regarding clients outside London, participant cases reported internet orders for one-off items which they then to be printed and posted anywhere in the world (e.g., Eszilook's VR headsets), or repeat clients located in the north of England (e.g. Micro Tech and SB Hub develop software applications for clients that use 3D printing). Looking particularly at this group of clients, they are larger industrial corporates who used 3D printing as part of complex industrial processes and used the software and applications developed for them in London by this research's participants. This exemplifies a breakdown of the types and nature of production activities per region, characteristic of post-Fordism. 3D printing technology does not seem to change this well-established separation between knowledge, creative microbusiness activities in London and large producing corporate industries in outer regions. Furthermore, when I queried my participants Micro Tech and SB Hub about relocating beyond London to be near these clients or even to other regions in England where similar client industries could be found to expand their client base, interviewed founders expressed scepticism and lack of interest in those places as potential locations for their activities due to need for labour pools and talent. The founders of these two participant cases were only modestly interested in moving to places such as Cambridge or Nottingham where they could contract highly educated people while being closer to their industrial clients.

Considering connections beyond London within the organisation - when part of work was done from a satellite studio outside the core London studio or looking at organisations' future expansion plans, findings continue to highlight that there is a separation of different kinds of activities across geographies. In this separation, London maintains the control tasks and the key development functions, whereas other locations support London, or work on the final stage of production. For instance, an additional project may be done from elsewhere, or many items may be 3D printed outside London if many final objects/ outputs are needed.

Firms' expansion plans beyond London showed this type of fragmented production relationship across various countries too. Noting however that my empirical research was conducted before Brexit was finalised, this analysis found that expansion beyond London within organisations was focused almost exclusively on mainland Europe, and preferentially to Eastern European metropolitan areas. Reasons presented were the comparatively lower salaries and highly qualified workforce available. International expansion to Europe was found to be preferred to national expansion to the English hinterland, particularly in participant cases with founders originally from outside the U.K. The founders of these organisations were international highly qualified professionals, a type of very mobile population who find expansion to other capital cities easier to contemplate than to second-tier cities or suburbs in England. Eszilook, for example, were in the process of opening a new office in Bucharest, Romania for large-scale 3D printing of VR headsets and if that did not work the founder said they intend to 'try it in China too' (Slavis T. Prioli, Eszilook, interview). The head office would however remain in Tech City, Old Street, London from where there is no intention to move. Mirek, from SB Hub, also envisaged continued growth with geographic expansion planned to take place in Kyiv, Ukraine, where he intended to open a satellite office to work collaboratively with London under London's supervision.

Third and last, I observed a tendency to be better linked across global geographies to other metropolitan areas than to the immediate hinterland of London for knowledge sharing and innovation projects co-produced with other organisations located outside London. This is a recognised trend of current innovation (Crescenzi et al. 2020). By contrast, relationships to 3D activities in suburban, rural or in second-tier city regions involved for instance large parts to be 3D printed– if larger than London's machines, or many items to be 3D printed, or delivery in a short period of time; outside London there was more 3D printing capacity, more firms focused on 3D printing at scale and 3D printing services associated with other larger industrial organisations.

And, while this study is limited by not having collected data for activities which emerged as a result of 3D printing technology located outside the London, and only reporting from the London activities perspective, several interviewees referred to outside London locations accommodating large scale printing equipment which requires more space, and more expensive type of 3D printing machines. The Print Point 3D database representative interviewed, Martina Ricci Calabria, confirmed this assessment by the other interviewed participants. There is a very small percentage of 3D printers registered with Print Point 3D database outside large scale metropolitan areas – not just outside London, and those can be larger machines, frequently belonging to large industrial units. As such, some of my interviewed participants used other activities outside London to prototype at quantity, for printing larger items, to test industrial grade quality or for faster turnaround. Participants Frater and Atelier Leon, for example, used a large production service with many machines of industrial quality which 3D prints 24 hours a day located outside metropolitan London in the southeast of England. Frater reported using an external outer London service for faster prototyping of better quality, and Atelier Leon used a similar service for producing the final batch of lamps of a project with many items to 3D print uniquely varying by certain shape parameters.

Further research remains to be done on the wider locational geographies of 3D printing, such as beyond London. Currently there are only a few recent studies for other locations involving other cities or from a country-wide point of view (see Bush et al. (2021) for example for digital urban production including 3D printing and other techniques in four German cities; Muessig (2013) for New York's urban crafts, including some which use 3D printing; Zhang (2014) for one case study in South Carolina relocating to Brooklyn, New York; Birchnell et al. (2018) for workshops with sample firms using 3D printing in China, France, India, Russia, Singapore and the UK discussing intellectual property rights; Laffi and Boschma (2021) for the adoption of advanced manufacturing technologies in traditional large industries across Europe; and Johns (2020) for the same topic analysed through sample interviews to large firms plus research institutions and suppliers across the UK, Germany and the US). As suggested by this research's participants, some outer London activities were aggregated to other larger industries, possibly similar to the cases pursued by Laffi and Boschma (2021) and Johns (2020) so they may present a greater level of specialisation and more 3D printed finished outputs than what was found in London. A comprehensive study on them remains to be done in future research, not this current one.

Within the scope and perspective of my study, the relationships that London activities maintained beyond London, whether with clients, as part of their internal organisation and expansion, or with other enterprises, constitute my fourth set of findings supporting this chapter's argument. The claim is that in the London case, new material producing technology like 3D printing is not altering the geographies of innovation and production in post-Fordism. This is seen here when London activities continue a known trend (Duranton and Puga 2001; Scott 1988b; Florida et al. 2017) of controlling creation and innovation, as the preferred location for entrepreneurship that fuels growth and job creation within knowledge sectors, now focusing on abstract tasks related to new material producing technology, but deploying repetitive tasks, final 3D prints and larger formats to outside London.

6.6 Conclusions

In this chapter I have presented and analysed locational aspects of the activities which emerged in London in connection with 3D printing technology. I analysed where activities are located, what types of premises they occupy, why they are located where they are - and why not elsewhere - plus their work connections beyond the defined London area of this analysis.

This analysis supports my argument that, despite hopes for urban manufacturing revival to emerge from new material producing technologies like 3D printing (Nawratek 2017; Cities of Making 2018; Jakob 2017; Caruso et al. 2015; Sissons and Thompson 2012; BIS 2012), in relation to use of this technology, post-industrial geographies of production remain separated across regions and innovation is concentrated in metropolitan areas like London. Presently, London maintains a role of control centre and knowledge creation in activities associated with 3D printing technology, focused on abstract tasks relating to product development and creative production carried out by clustered activities in central areas. This chapter comprised four sets of findings supporting this argument.

The first set of findings is the location of the activities, found to be centralised, clustered and akin to creative industries and digital microbusinesses. Even though many entities did not provide addresses for their operations, it was possible to map over 60% of entities and, based on that evidence, to identify the most popular boroughs as Camden, Tower Hamlets, Westminster, Hackney, Islington, and the City of London where other knowledge, scientific, creative, and professional activities are clustered. Further to this, half of the activities were located in the CAZ, and they clustered near hubs of creative and digital industries, for instance Tech City in Old Street, more than near manufacturing or light industrial activities. This analysis also finds that the location of both those activities which 3D print and those which do not, regardless of the purpose of that output, is broadly similar. These findings are aligned with arguments on the advantages of agglomeration in central urban areas for innovation activities, especially those working on earlier stages of products by scholars like Duranton and Puga (2001), Glaeser (1992), Glaeser and Kerr (2009). These advantages occasionally extend to outer London industrial parks, which can also house a small number of innovative activities including consultancy, knowledge and prototyping alongside activities focussed on distribution and hardware supplies.

The second set of findings this research found were the very small, shared and informal types of premises from where most emerging activities in connection with 3D printing operate. With exception of the activities which are similar to workshops and thus required larger premises (makers' spaces, hackerspaces and fab labs), most enterprises occupied spaces with characteristics similar to that of artist's studios, or low-cost shared offices and co-work desk spaces.

The third set of findings concerns the reasons for location and premise choices, which do not relate to the new technological possibilities of 3D printing. Firstly, the main reason for the centralised and clustered spatial distribution is the chosen area's socio-economic identity and history. New activities chose to establish themselves in proximity to other activities, such as information technology or cultural-creative, with whom they wished to associate for knowledge exchange, for funding access and for attracting the right type of employees. Tapping into the area's established economic activities and its dominant sectors improved the perception of these new firms by investors and helped capture external funding, whilst defining a better local and global market position for these new organisations. The chosen locations also offered the economic and cultural value that was attractive to the owners, particularly the types of premises they searched for such as the co-working spaces found in the centre, and buildings of industrial architectural heritage. In some of the more design/ creative sector case studies, a local link with expertise stemming from an industrial past of craft industries was reported as a positive contribution to the organisation's innovation and an additional reason for the choice of location. Secondly, location choices were found to be strongly influenced by the area's appeal to new talent, fundamental to securing the needed workforce. This factor was based on both lifestyle choices and the urban character of the area to attract young people well-trained in technologies and design who search for 'cool' areas to live and work according to the participants. And, thirdly, the locations found in this study were well-connected areas, a factor shown to attract the right people too, and to facilitate access to clients outside London, as well as to allow the founders to travel quickly across the city to other jobs or to their homes. This was particularly key given the level of bootstrapping uncovered, and how they accumulated jobs and needed to divide their day amongst multiple activities. These findings confirm the evolutionary nature of innovation (Tomaney 1994; Neffke et al. 2011), notably a spatial dependency on other more established activities in the locality with which they have some commonalities (Boschma et al. 2005). Even in the case of a potentially breakthrough technology such as 3D printing, which had been suggested (Anderson 2013; Jakob 2017) could disrupt geographies of production, innovative activities were shown to be shaped by and dependent on a place's established economic and socio-cultural attributes.

Further to this, my fourth set of findings relate to the nature of relationships my participant activities maintained with other regions, in support of the argument that production location dynamics are independent of technology. I find evidence for repetitive activities, multiple items, larger orders of final stages of production and support projects being conducted beyond London. I also found that if expanding activities, founders preferred to establish satellite studios in other (mostly European) capitals, rather than in the country's hinterlands, a common trait of contemporary knowledge activities set in a post-Fordist global system of production (Crescenzi et al. 2020). This was to capture the value and quality of labour in those locations and to benefit from the concentration of other activities in those metropolitan centres, whilst maintaining the control functions in London. Thus, connections to outer London, to country hinterlands and to global locations reinforce the strength of metropolitan locations for innovation, an association consistent with findings that post-industrial global cities have retained the early stages of product creation and value-added functions (Duranton and Puga, 2001; Storper and Venables, 2002). This new mobile technology did not change that strong association.

These sets of findings reveal thus a gap between urban manufacturing revival hopes, some even in policy, and the reality of a case study in a specific context. These findings are important because understanding that the activities emerging in London in connection with 3D printing are supporting abstract tasks of knowledge and creative sectors (as seen in Chapter Five), and that most are in central London in clusters of other related activities because they derive value and attract people by choosing those locations (as seen in this chapter), can help policymakers develop policies which are directed at the reality of innovation around making technologies - like 3D printing technology - and not based on assumptions made about urban manufacturing revival units locating in city centres or that innovation can spread anywhere easily because of a certain technology. Realising this disconnection between policy assumptions and the findings of this research, leads then to a series of questions for policymakers: are there any reasons for supporting new material technology in a context like London, and what might those be, so that appropriate policy can be designed. My next chapter will focus on these considerations, presenting findings from my research which support the argument that there are good reasons to support these technologies in a context like London. These would not involve supporting a putative manufacturing revival, but would be related to recognising the range of potential applications of this technology and appreciating its significance for innovation in key sectors of a post-industrial urban economy. Further to this, the collaborative ways in which people work while experimenting with this technology are facilitated by agglomerated contexts like that of London and create more opportunities for knowledge exchange and for the creation of new enterprises. Chapter Seven establishes the empirical basis for nuanced policy support for innovative activities in London based on 3D printing technology.

Chapter Seven

Growth and Competitive Advantages: Technology Applications, Activity Paths and Collaborative Practices

Innovation matters and the process of creating new knowledge that can be translated into innovations drives the competitiveness of firms, industries and places. (De Propris and Bailey 2020: 1)

7.1 Introduction

Chapter Five argued that the activities emerging in association with 3D printing in London have not significantly diversified the existing predominant economic sectors of services, knowledge, and creative industries. Despite the material output possibility of the technology, the tasks associated with it in London have been found to be abstract, conceptual, and cognitive, as in these sectors, and are not directed at final consumption. It has thus been reasoned that this new fabrication technology has not triggered a process of urban manufacturing revival, nor has it triggered a new economic cycle. It has also been shown in Chapter Six that most of these innovative activities are located in the central areas of London and agglomerated with other existing creative and knowledge activities – either due to sharing and attracting skilled people, transport connectivity, or the benefits they derive from the local area's identity.

A key question flows from these findings: is there consequently any competitive advantage and growth to be captured from a new fabrication technology - like 3D printing - in an urban post-industrial context like London? In other words, my third research question: '*How has the process of adoption of 3D printing technology contributed to innovation in activities across different sectors in London, and what advantage is it creating in this context?*'. Crucially, this chapter considers the policy implications of an answer to this question.

My evidence suggests that the adoption and exploration of this new technology in the London context is creating new knowledge, innovation and growth, although this is not through the production of final consumables - this has largely moved to other locations in decades of de-industrialisation, and it is hard to argue from the evidence that any reshoring of material production is indeed occurring in London. This new technology also does not hold employment possibilities for low and medium skilled labour, as literature and policy promoting the expansion of fabrication technologies has suggested (Sissons 2011a; Sissons and Thompson 2012; The Economist 2012; BIS 2012; Tym and Lang La Salle 2011; Martinez-Fernandez et al. 2007; Cities of Making 2018; Marsh 2012; Rifkin 2011 and 2016; Thomas 2019). Rather, this chapter demonstrates that the competitive advantages and growth brought by 3D printing technology to the London context are threefold: first, this new fabrication technology facilitates early stages of product development and the kinds of new activities and work processes which are characteristic of the post-industrial London economy – like creative industries, design, research, etc; second, this technology helps inception of new activities which evidence suggests sustain good profit, turnover and jobs because it is flexible affordable and fast; and third, work processes around this innovative technology rely on intensive collaborations, including both organised and spontaneous, in-person and online, which are facilitated by the agglomeration of a context like London and by a common culture which generates new knowledge and continues a cycle of further innovation.

Regarding structure and contents of this chapter, I start in section 7.2 showing how 3D printing technology has been applied by the case study activities in the generation of ideas, concepts and prototyping to improve speed and accuracy of work at early stages of product development. Technological possibilities of 3D printing were successfully applied in familiar tasks of products' early stages by newly formed activities. This shows that a disruptive technology can contribute to growth as it gets integrated in productive processes already well established in the local economy.

In section 7.3 I present the findings on how these new activities emerged and evolved, including their funding strategies and their overall performance. Even though these activities are new, and their history of business development is thus relatively short, my findings are of a positive performance overall. There is then arguably growth to be gained through innovation with advanced fabrication technologies like 3D printing in post-industrial regions like London. Their business foundation stories and progression also shows that the creation of new businesses is helped by the existing cluster structures and by other (more credible) nearby activities to, for example, gain finance. The agglomerated location de-risks the process of innovation, particularly in the aspects related to the unknown aspects of the technology and associated new ways of doing things.

In section 7.4 I consider the collaborative practices which are facilitating more innovation around this technology, the creation of new activities and the survival of new businesses and entrepreneurial activities. These are enabled by the agglomerated context of London and include a range of personal encounters and a common culture and communication style amongst (self-defined) makers. Shared spaces and shared materials, informal and arranged meetings, as well as online forums, help to incubate new activities and new projects. In this section, evidence highlights that the knowledge exchange story is more nuanced than purely physical proximity, and include both in-person and virtual communication, made possible with social proximity and matching of interests. The social proximity which facilitates communication is in turn helped by the experiences of a common region and is often continued through in-person formal and informal meetings.

Even though this study concludes that a fabrication technology like 3D printing can contribute to growth through innovation linked to knowledge, creative and service industries in a post-industrial context, during this study I gathered information on aspects that may hold back the innovation process particularly related to the 3D printing case study. These include specific challenges and obstacles in adopting the technology such as a weak legal framework, the lack of support and financing for these new activities, plus real estate pressures. I thus present a summary of this material in section 7.5.

Final remarks are provided in section 7.6 where I conclude that 3D printing technology contributes to innovation, growth and the creation of value through new but related activities in London. These in turn continue to enrich the localised portfolio of knowledge, services and creative activities thus strengthening the agglomeration and its local economy. The technology is thus being absorbed within the evolution of the post-industrial knowledge production, enabling new knowledge to act upon established knowledge (Castells 1996) through social networks of an agglomerated region more than the re-shoring of material goods production. This sustains the view that there is competitive advantage in adopting and experimenting with fabrication technologies within a post-industrial urban region without a profound alteration of the economic nature of that region.

7.2 3D Printing Technology and Early Stages of Production

This section explains my findings on the advantages of using 3D printing technology in businesses related to the creation and development of early stages of products typically carried out in post-industrial regions like London: generation of ideas, concepts, market research and prototyping. For example, this research finds that the technology of 3D printing is used to improve speed and accuracy of concept design work, to expand the types of solutions and products possible - particularly geometry and material economy of designs and prototypes - and to address market requirements such as creating personalisation. These possibilities are most relevant for knowledge intensive sectors of the kinds that thrive in London, such as design, fashion, architecture, engineering or research activities. Even firms that do not print, but whose work is centred on the technology, such as design industries for 3D printables or software creators, tend to focus on early stages of production and benefit from the same technological advantages. This set of findings shows why this technology has great potential to enhance existing activities in a context like London and that the types of innovation stemming from this technology are intricately linked to the knowledge, service and creative sectors of London.

This section starts with a brief explanation of the typical product development stages in comparison with the possibilities arising from 3D printing technology for the reader’s information. It then moves on to the presentation of the findings - the advantages brought by this technology to the early stages of production.

Product Development Stages and 3D Printing Technology

This sub-section provides an overview of product development stages. It briefly contrasts typical stages and their typical location with possible changes to the production sequence as a result of the flexibility created by 3D printing technology. This sub-section is a preamble to the findings on advantages from the technology realised at early stages of production, as product stages will be mentioned throughout in relation to findings.

A typical product development process comprises several stages succeeding one another in a linear and temporal manner. Sometimes, progress may be set back, and stages are repeated until the end. As illustrated in Figure 7.1, these stages are, most typically, in order: idea generation, idea screening, market research, concept testing and development, prototyping, business analysis, design development, and deploying to manufacture and commercialisation.

There is an association between product development stages and the locations where those stages take place, which has evolved over time. Different tasks involved in completing the various stages started to be separated in Fordism, as production techniques became more complex, and production lines became standardised within the same firm. But since the 1970s, product development has progressively been reorganised into more flexible and specialised ways of working, with different stages being further separated across both local and global geographies and multiple collaborating firms (Hirst and Zeitlin 1991; Storper 1989). As information technology became more widely available and transport costs decreased, early stages of production (conception and product development) became detached from their manufacture. The process of early stages production became more networked (Storper 1989; Scott 1988a, 2007 and 2008; Piore and Sabel 1984; Massey 1984), based around city centres or innovation districts. At the same time, de-industrialisation progressed in those same cities, with mass manufacturing taking place in regions with lower labour and land costs, and finished products transported to places of consumption.

One of the most interesting claims associated with the arguments for promoting material production with 3D printing technology in a post-Fordist context such as London, has been that it can significantly change the way products are conceived and manufactured, because it can amalgamate and disrupt all stages of product development (Jakob 2017; Anderson 2013) and 'can alter the way production is organized across time and space' (Rehnberg and Ponte 2018: 57), including both early conceptual stages and manufacturing.

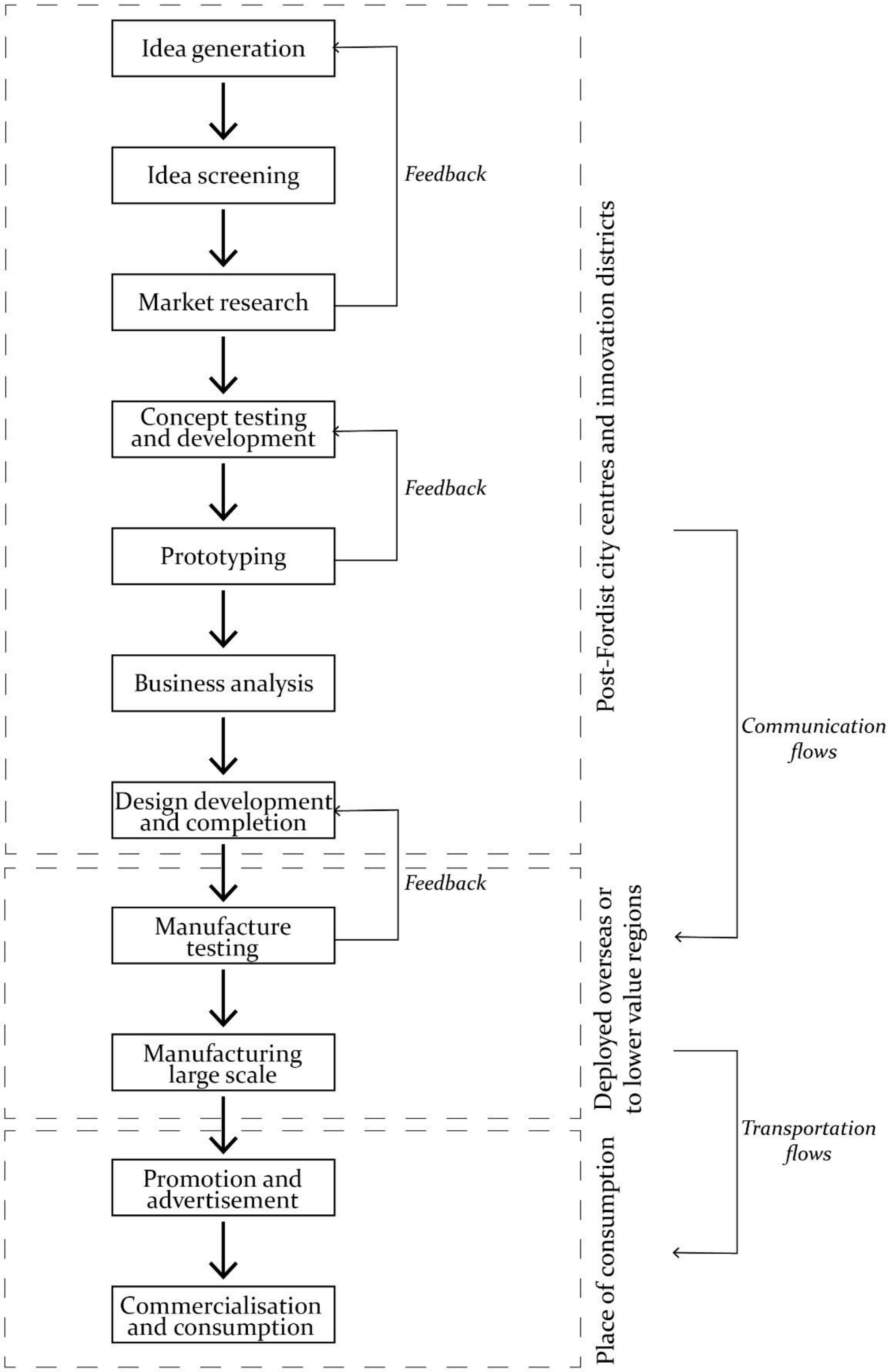

Figure 7.1 Typical production stages

During initial stages of product development, the changes to production resulting from 3D printing can include influencing the original ideas and design briefs due to a greater level of control over the design process, and providing a more efficient process of prototyping due to an expansion of the number of iterations possible. Theoretically, and technologically, with the use of 3D printing technology and with its wider availability, early stages of production can be quicker and can have better outcomes. In manufacturing stages, the changes in production process that could result from 3D printing technology include replacing large scale manufacturing deployed overseas with local manufacturing, as users can print objects on demand at home or in high streets. These changes and the resulting product development process have been represented in Figure 7.2.

The possibility of a new sequence of production challenges the ways that stages of production have been separated and linked linearly within and across organisations since Fordism. It also challenges the geographies of production in post-Fordism particularly regarding the geographical separation between early stages and manufacturing – an issue which gave rise to this study in the first place. These possibilities could mean a 'new way' of developing products because of integration and shortening of stages, plus unique products, or very small batches of on demand production, more similar to artisanal and craft production. However, it has been shown in previous chapters that the activities related to 3D printing emerging in London are not involved in material production at scale and are instead focused on the early stages of production in creative, knowledge and technical sectors with material outputs such as prototypes or no material outputs at all. Thus, the next presentation of findings is how exactly this potentially disruptive technology has been integrated in the work people do.

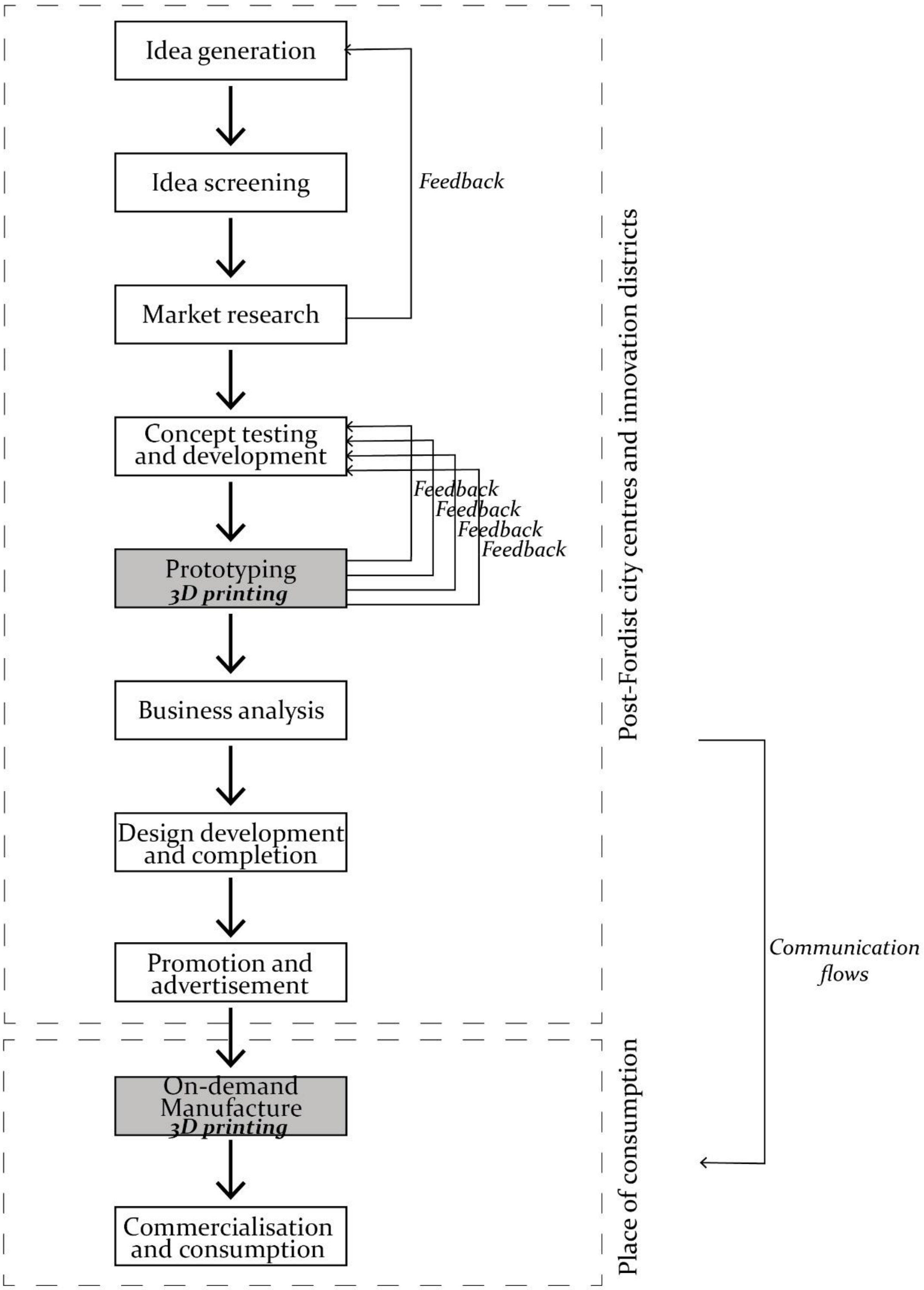

Figure 7.2 3D printing potential changed production stages

Integration of 3D Printing in Early Stages of Production

This sub-section presents my findings on how the 3D printing technology has been used at the early product development stages with significant advantages for the London's newly formed businesses or individuals that this research followed. This reveals how this technology has the potential to generate growth through innovation in a post-industrial context, as innovation happens by integrating the disruptive technological element in tasks of the early stages of product creation. Further to this, the 3D printing technology is particularly well suited to these early product development stages.

The first advantage of the technology for early stages of production is the low cost of low volume of production (directly from the computer to the printer/ direct link from design to production). This allows for more output of higher value products in some high value sectors – as jewellery for example, as well as for more experimentation tests in all sectors regardless of value. This is important to designers and engineers as they work on a prototype and can iterate more for the same cost. Below are examples from my participants which show how exactly this process takes place with this technology.

For Santiago at 3D Masters Shoreditch, for example, the value added by this technology to a design process lies in having the prototype quite quickly, testing ideas as part of product design process. When developing a product, a designer is working in a digital environment, therefore there is always information missing which can be better evaluated when the product has materialised. The 3D virtual model is not sufficient, and the physical printed object gives more information in the process of product development, as 'it becomes a different, real design experience' (Santiago, 3D Masters Shoreditch, interview). For example, a client hairdresser would approach 3D Masters Shoreditch with an idea for a special comb, but the client has no sketching, digital modelling, or design capability, so they develop the idea and prototype it, using the 3D printers to assess and develop designs at a faster pace than if they had to model the objects in other ways. They show iterations to the client and once it is finalised, it is handed over to the client who will work on the business case, and on the production process for it to be mass produced elsewhere or sold in marketplaces on demand. The work of 3D Masters Shoreditch's is thus typical as it focuses on the product prototype design and development only.

3D printing is an affordable and fast way to prototype (varying according to the precise technology and materials chosen) considering a typical home printer can deliver satisfactory results to effectively test designs, prototype and develop products. Participant Patricio Frater confirmed that using 3D printing technology has been very valuable to his progress as a designer. Within a year of establishing the activity, he was able to get to the final designs much quicker than when he started, as described:

> 'You've got the machine next to your computer and you can just test out stuff very quickly, and make changes, so you can grow very fast' (Patricio Frater, interview).

In his primary activity, Frater uses 3D printing technology to prototype iterations of the designs, specifically in fashion and fashion accessories – his main field of work. These works are conducted under Patricio Frater's 3D printing shoe Design Company, which has its own website and brand. He focuses on design and print of shoes which can be classic or funky and bespoke (see Figure 7.3). The shoes can be purchased from the website and sent to the client or downloaded for free for home printing (Chavez 2014). The innovation in Frater's shoes is the material, which is flexible rather than rigid, thus creating extremely comfortable shoes (Desmond 2014). And, he has other secondary activities. Frater runs a marketplace with objects designed to be 3D printed, commercialised under the MyMiniFactory website. These objects are for example mobile phone covers, other shoes (not his design), toys, doorknobs, decorative objects, tools, screws, etc designed either by himself or by others. All objects are available for viewing in 2D and in 3D on the marketplace and are sold as 3D printable files which can be downloaded. The user can print the files of the purchased file-object, or instead order a printed item which will be sent to a printing service and delivered. And lastly, Frater has also taught classes on 3D printing to students, artists and architects in his studio and has produced videos of the classes which are sold online. It can be noted how all activities of early stages of production are incrementally improved by the application of the new technology, and how more complementary activities are created.

[redacted]

Figure 7.3 Patricio Frater's shoe designs, source: http://www.michelebadia.com/, accessed 2nd December 2016

But, even in this case, it is interesting to note that avoiding printing the final product is advantageous. Patricio Frater noted in interview that, for example, moving the printing of the final shoes to the client creates value by freeing up his time for other activities like design and management, since just printing is not a very profitable activity and not in his interest as a creative professional. Thus, the innovative technology is applied to benefit familiar types of processes – in this case Frater's creative design process - showing how a disruptive technology can be embedded within locally existing production habits even in newly created businesses.

Since we have seen in Chapter Four that many firms do not print at all, it is important to highlight that this cost saving and investing in more iterations being an advantage for designers happens also in firms who choose not to print. A good example of how and why this happens is Story Lab, who do not 3D print, but maintain that 3D printing adds value to their product development process. They mentioned that they were looking at the possibility of getting a cheap desktop printer but the reason they prefer to outsource is that external firms carry all the overhead cost for maintaining machines, offer more material options and compete to have the latest printing technology. Testing designs through 3D printing sometimes is arranged externally to address difficulties arising from the printing process itself, as described in the quote below:

> 'Despite what people think 3D printing is not just plug and play unless you are really in the hobbyist area. Professionally, it requires an understanding of what the materials are capable of and how to orientate the part to get the best results. An example recently is that we have made a load of parts for a virtual reality motion platform installation. Some were machined, some were handmade using traditional model making and some were 3D printed. Each part required an appropriate process' (Mike Haussmann, Story Lab, e-mail)

SB Hub, another detailed case study which do not 3D print, also works on early stages of production, writing software for additive manufacturing to be used by large manufacturers who use 3D printing as part of the process of manufacturing large batch goods, but the manufacturers are located outside London.

Other cost reductions were mentioned by participants in terms of time gains in the process of developing a product. This was highlighted for the medical sector by Medical Prints 3D, where 3D printing technology allows for better preparation and reduction of surgical theatre time, thus achieving better results and at lower price. This meant that prosthesis can be personalised to each patient to increase the success rate. It also reduces the cost of the medical procedure itself compared to a typical process, as the process is 80% quicker (source: http://www.3dlifeprints.com/humanitarian/, accessed 22nd December 2016). Using 3D printing technology reduces costs compared to traditional methods, which is making these types of treatments affordable to developing countries, to where they have now expanded. According to Sher (2015) in 3D printing technology online news, legs and arms can be printed at a cost of circa $50 USD each. These technology advantages have been presented by Harry Pinfield (2016) from Medical Prints 3D while speaking at Innovate UK Conference, where he even argued for a 3D printing hub in NHS hospitals to deliver better services for prosthetics at higher efficiencies and lower costs.

Another advantage of the use of 3D printing technology for early stages of product – including concept and development, is the increased geometric freedom without added production cost. This was noted by my participants, and it has been highlighted by literature as well (Thomas 2019). This technology allows for more disconnection between form, complexity and the amount of matter used due to the additive nature of the process, which can be of use to many products in all sectors but was more immediately used by those operating in fashion, architecture, and furniture

- sectors which typically flourish in London. Geometric freedom allows for more original designs, as for example in the design work of Patricio Frater, in the accessories designed and commercialised by Fantazy Moss, and in the consultancy and prototyping outcomes developed by participants 3D Masters Shoreditch and M & G. An increased part functionality can also be derived from more geometric possibilities, which in time also can contribute to a more sustainable production process by reducing material usage. This is a technology-enabled advantage which requires specific abilities from the designers, which happens for example with Atelier León's shaped lamps. In this example, an order of large quantities - for example, their recent project of fifty uniquely designed lamps for a long corridor as part of the fittings of the space - is done using parametric tools so they are all different. These types of design are only possible to realise because of 3D printing technology, and this has helped their studio progress as innovative designers.

And, a further advantage of using 3D printing technology at early stages of production widely discussed by participants was the product personalisation possibilities. This is often called mass customisation in literature which has been claimed to be a wide-reaching future trend (Marsh 2012; Thomas 2019). It is said to open opportunities for non-standardising items that have always been standard at an added, but still low, cost. Some participants of this study mentioned that the consumer could become more involved in the production process and input, manipulate, and adapt to his/ her preferences, and thus buy more. Case studies like Fantazy Moss relied entirely on this, creating fashion items with parameters manipulated by the client. This is another possibility that can be captured by sectors like fashion for example, a typical London creative activity. The case Eszilook used this personalisation advantage on the actual 3D printed headset they designed and sell, as personalisation added value to the VR product. Since the headset becomes a personalised item, it would have been very expensive to produce it through normal traditional manufacturing processes. And, in addition, the fact that each headset is personalised allows them to charge higher prices to their high-end users. Personalisation of items reduced Eszilook's production costs, but those savings are not always passed on to the consumer's purchase price, thus adding some value to the company.

It can be concluded from the evidence discussed above on how the 3D printing technology is used that there are many advantages and value gained from using this technology in both pre-production/ concept and design development stages. Key advantages identified have been the low cost of low batch production, the speed of testing of designs, the geometric freedom, and the personalisation possibilities. All these gains can be best realised at earlier stages of product development, and in activities of the kinds that succeed in the London context– creative, knowledge, artistic, innovative services, engineering. For this reason, despite not offering a manufacturing revival in post-industrialism and not leading onto many final consumable products made in London, 3D printing technology brings value to a context like this: it can be successfully integrated within many types of activities that usually flourish in the London economy.

Further to this point, the empirical evidence highlights that the activities in study are often linked to other activities in London, part of a networked production of knowledge and creative services. Often the technology, or associated software, or its possibilities described above, help increasing other industries' productivity. For example, Aleksander Demus from M & G noted how quick their modelling services are compared to traditional modelling, due to the speed of the technology, which helps architectural firms spend longer on the design of competitive proposals.

Some of the firms studied described activities more embedded in the creative activities of other firms, across various fields. Participant Slavis T. Prioli described the users of Eszilook's VR technology as ' from the entertainment industry, [they're] working in films, games and so on', whereas the founder of Atelier León described in great detail a specific project with 'an architectural office, they asked us for 15 lamp shades for a health centre (...) and it two weeks we were able to do these 15 lamp shades and in these there were 25 different designs, all parametric. It was a very long corridor in a long building, and as you walk through the corridor you can see the lamp shape changing.' Unlike a fabrication technology that helps producing greater quantity of something, 3D printing technology's possibilities helped create a more striking design.

The links with other industries show how the 3D printing activities in this study are related to other firms in London of similar nature to themselves too. This study's participants are part of a linked network of London activities working at early stages of product design:

> 'I've been working for other firms who need some prototyping. They will be part of the design process with us. (..) As I come from an engineering background, sometimes my clients are engineering firms who come for pure prototyping, like mechanical prototyping - a bit

> of creative sector, but also a lot of professionals in engineering' (Santiago Sebastian, 3D Masters Shoreditch, interview)

Through these examples it can be seen how the suitability of the technology to the early stages of production is used to improve productivity through a networked production chain involving various industries and activities, akin to linkage effects.

The next section will present the second set of findings supporting the argument that advanced fabrication technologies help innovation and growth in agglomerated post-industrial regions like London. The findings below describe the process of creation of the activities emerging in London in connection with 3D printing technology, alongside their financing strategies and business trajectories which are mostly successful. Through these findings, it can be seen that innovation is a process that relies on some attributes of the locality to de-risk the disruptive element part of the process – in this case the experimentation with the technology of 3D printing.

7.3 Paths of Successful Activities

This section details findings concerning how the activities found in London emerged and flourished to show that there is growth from the application of 3D printing technology to typical production of a post-industrial context like London. The section is organised in three sub-sections, reporting first on the inception process of these innovative activities, second on their business trajectories over the brief period of time they have been operating, and third on their financing strategies. These three aspects give a good understanding of how these activities are embedded in the London location and how the success of these activities relies on established aspects of the local economy, like local institutions and funding.

It will be shown first how the foundation of 3D printing related activities is linked to many other activities in London, including other creative firms, research organisations and universities. And that the technology helped new activities starting up, particularly those of design and prototyping. These findings support an evolutionary perspective on innovation occurring through knowledge spillovers between activities with a degree of similarity in an agglomerated context (Rigby 2013; Essletzbichler 2013; Kogler, Rigby and Tucker 2013).

Additionally, it will also be shown in this section that these activities have above average growth rates compared to London's creative industries in terms of number of employees, turnover, and profit. This suggests that innovation emerging from advanced manufacturing technologies can contribute to growth in post-industrial regions, despite not leading on to changes in the organisation of production at the late stages of production. And it will also be described how the location played a crucial role in de-risking the innovation process when funding was obtained by association with co-located activities.

7.3.1 Activity Origins

It has been found that all these organisations are very new, as is the technology of 3D printing itself, and so their stories of formation are very recent and, in some cases, still unfolding. The Figure below shows the age of organisations that responded to the survey in 2017. It can be seen in the Figure 7.4 that most entities (73%) have less than six years of activity[54].

These new activities emerging in connection with 3D printing technology are in fact evolving from within other industries of the London economy. There is a real synergy between the new activities which I follow in this study and the creative, higher education and knowledge sectors established in London, well expressed by the innovation processes which I document below. The stories are of evolution of existing activities, rather than disruptions triggered by a new (even if potentially very radical – see Marsh 2012; BIS 2017; Brown 2015; Anderson 2013; Barnatt 2014) technology. I thus draw on the evolutionary notion that the stories of how organisations came to be what they are cannot be complete without the study of the specific traditions, immediate contexts, and contingent geographies from where they emerge (Tomaney 1994). The path dependency of innovation is seen in the stories of inception of activities, as new activities are only slightly different from their original 'parent' businesses. Further to

[54] The year of information gathered was 2017, so the age of the entities is counted from 2017, not from the year of the thesis submission

this, the examples that follow demonstrate that technology was an essential element that allowed for related innovation, providing the trigger for a further experiment or a new idea. But it was not the only component of innovation as new activities are framed by the founder's related knowledge, hobby interests or work experience.

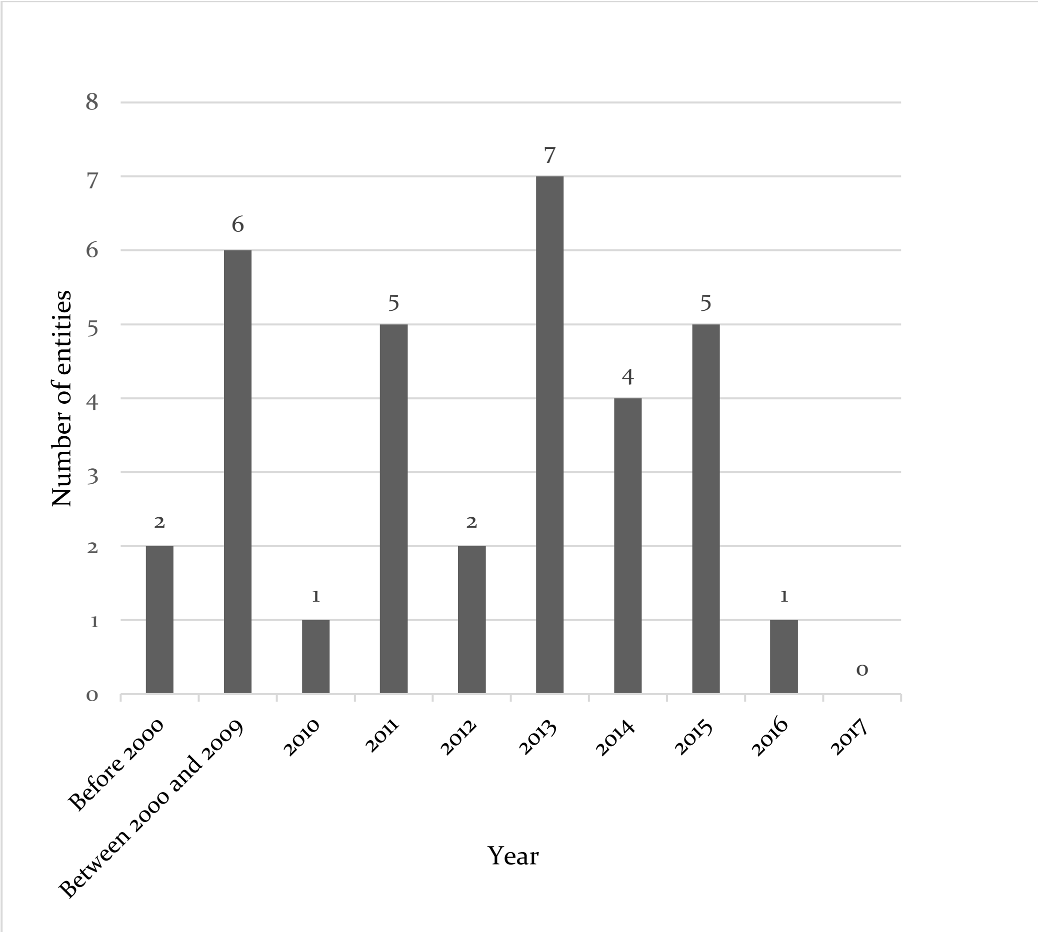

Figure 7.4 Foundation of entities (According to survey evidence)

Below I expand on the three most common kinds of origins I found in my research: the *hobby beginning* (when a hobby or casual interest originates a successful business), the *academic beginning* (when firms are formed following an academic project or thesis, many times maintaining the academic connections) and the *spillover beginning* (when a new entity is formed out of an existing industry operating in a slightly different but sometimes complementary field). All these demonstrate well how this technology facilitated further innovation in continuity with existing economic sectors.

The Hobby Beginning

Paul's Hub is the best example amongst my cases of how a hobby was turned into a firm (sole trader), plus research, talks, and community groups. Paul Lewis's 3D printing activities started at the end of 2012 as a hobby, as he liked to work on robots. But he 'always thought that robots were rather ugly, and he decided to make them look nicer' (Paul's words). He tried initially with Computer Numerical Control (CNC) cutting technology, and heard of 3D printing technology and tried it more successfully. At that point, he received a small inheritance and invested in a 3D printer, still as just as a hobby.

From that point onwards, Paul's Hub grew to a small side business, and expanded further, although the founder maintained his full-time job as a voice engineer for IBM for a while. Paul's activities, having started as a hobby, have expanded considerably and he is now a key person in the London 3D printing scene. He is an active member of the 3D Printing Makers Community in London, and he organises the 3D Printing Meetups at the City Hackspace[55], where he sometimes uses a desk space as well. He also jointly runs the group working to create the Romford Makers (which is also part of this study), plus he is involved with other groups networking to develop the technology across the country. Many of Paul's Hub activities are processed via the Print Point 3D (another detailed case study in this research), which is a shared economy website[56]. Paul's Hub has won contracts for several 3D printing jobs: Printer guide for 2015, 2016 and 2017 as well as the Printer 10 days, which are marks of quality and trust from Print Point 3D. The image below shows a view of Paul's Hub page on the Print Point 3D website.

[55] The City Hackspace in Hackney Road closed about a year after my interviews and my meetings there, and during the time of writing this thesis (from February 2018). It has now re-opened in a different location in Wembley.

[56] Print Point 3D the U. K's largest online platform where people can offer 3D printing services and where customers select a service provider, designated as a 'hub' to 3D print their files. It is a network of hubs, organised by location with global coverage. Hubs have their own page, and customers can select a hub for a job based on quality, price, or speed. In addition, it offers discussion forums and organised events to spread information about the technology.

[redacted]

Figure 7.5 Paul's Hub: Webpage with examples of 3D printed outputs on Print Point 3D platform, source: https://www.3dhubs.com/users/ianadan, accessed 22nd December 2016

Paul's Hub case shows how 3D printing technology enabled a new activity that grew from a hobby to a business, involving reaching out to other people and opening other avenues of research and experimentation. This was possible because 3D printing technology is flexible, affordable and information is freely available and/ or shared.

The Academic Beginning

An academic basis for the beginning of activities was found to be very common, based on the interviews (nine of the 18 cases studied in reported commencing from academia). This way of starting an activity points to why support for this technology offers benefits to a local economy as that of London – because London is a context where there are opportunities to research further in academia and to apply that research, and that can create a positive cycle of continued innovation. The examples of some participant cases below illustrate this point.

Atelier León's activities started during Jean-Antoine (the founder)'s architecture masters when he focused on Digital Fabrication. As a graduate, he researched Fab Labs worldwide – New York, Rotterdam, Amsterdam, London. Jean-Antoine then set up the first Fab Lab in Brussels. Shortly after this Atelier León London was set up (in 2015), after he moved to London with his partner, with the specific intention of starting a small 3D printing and design factory in East London.

3D Masters Shoreditch started when Santiago, the co-founder, was doing his engineering post-graduate degree in Southampton and met a colleague there who was doing a PhD also using 3D printing. He learned more about the technology, and that coincided with the arrival of the typical home printers in the market at lower price. They bought one machine and started experimenting while still studying. They thought there was a business opportunity for this technology, then went on and joined the Print Point 3D website and started prototyping, initially from home. Later they were able to get hold of more projects, and rented their current space at Sunbury Workshops, Shoreditch from where they operate now.

And Patricio Frater's activities started following prototypes in 3D printing he explored while at university where he completed a degree in Industrial Design. Afterwards, he joined a design agency which produces 3D printers and designs objects for the machines, designing mostly toys. At that agency, his name was extensively advertised, and that allowed him to continue designs in his own name as a brand. So, he moved on to set up his own operation in fashion, initially designing only shoes for 3D printing. Recently he has expanded to houseware, kitchenware, and more fashion accessories all to be 3D printed, as well as consulting, courses and running a new marketplace platform for other designers.

Likewise Rajiv, the sole founder at Micro Tech, has been involved in the technology before the firm was founded. His background is engineering and industrial design, and he has a PhD in complex geometrical designs from the UCL. After his degree, he set up Micro Tech and was joined by another director, who has a PhD in Orthopaedic Biomechanics.

The academic connections of many entities tend to continue through projects or products, as some are research and involve untested processes. In addition, expansion of activities often happens also through further academic engagement. This is the case of Medical Prints 3D, a medical organisation which develops low-cost anatomic models from 3D scans of the patient's body which are then further improved with 3D digital modelling technology and 3D printed. The firm engages in various research projects with hospitals and with universities, such as learning models for students, investigating 3D printed prosthetics, studies of micro-cardiac structures and simulation skull and brain through 3D printed models, etc. According to the CEO, interviewed in 2016 at Innovate UK conference (Medical Prints 3D 2016), the firm has started a collaborative research project with Alder Hey Children's Hospital and has now permanent employees working at the hospital's innovation department.

These examples highlight that research related to material producing technology has been applied to the business context successfully in London, and often the links between businesses and academic research are ongoing. This process of research, application and feedback - a cycle of innovation - can contribute to local economic growth.

The Spillover Beginning

A spillover beginning happens when new activities originated from other activities which did not use 3D printing technology. This process has been described in the evolutionary literature as when someone was developing one process in an organisation and then sets up his/ her own new firm and the same process is instead applied to new products or new sub-sectors (Rigby 2013; Essletzbichler 2013; Kogler, Rigby and Tucker 2013; Duranton and Puga 2001). Glaeser et al. (1992) attributed urban economic growth to this process, and they particularly noted that it generates further benefits to the city economy if the spillover happens across different industries. This is precisely the foundation story of some cases I followed in this research. And existing literature has also highlighted how spillovers tends to result in growth when new technologies are part of the process copied across to other industries (Henderson, Kunkoro and Turner 1995; Neffke, Henning and Boschma 2011). The next paragraphs describe how exactly spillovers led to the foundation of some successful cases I followed in detail.

The group of four companies of which M & G is one part originated in the medical sector. The founder is a dentist surgeon who started using 3D printing technology in reconstruction surgeries to achieve more accurate solutions. His capability in 3D printing led to the development of other firms in the medical sector: two additional firms for implants, and one for 3D dental scanning. Later, responding to demand for application of the 3D printing technology to other sectors, he set up M & G (one of my detailed cases), which works as a 3D printing bureau and focuses exclusively on product development and prototyping for non-medical industries. It has its own designoriented digital modellers and project advisers for design, architecture, product development projects.

Eszilook, another spillover example which I followed in detail, was founded when Prioli (co-founder) developed a new device for Virtual Reality (VR) which can be 3D printed, customisable and attached to most mobile phones. He used to work on VR settings at another company within the film and games industries. He used knowledge gained at that company, and using 3D printing technology developed a new device for VR, and with it set up his own firm. The company has since been successful, added more VR and games-related products, and it was incorporated within a year of its foundation.

A third spillover beginning process is well exemplified by the case of Fantazy Moss, a marketplace for 3D printable and customisable fashion accessories. It has evolved from another organisation within high-end fashion, where the founders previously worked. They maintained a similar market approach based on highly customisable items, but now using the 3D printing technology which was not used in the parent company. It shows, once again, how the process of innovation is one of *related* evolution, for example when a new activity which uses a new technology is related with the company from where it originated, a condition for successful innovation which scholars like Rigby (2013) and Essletzbichler (2013) have emphasised.

The two co-founders of Fantazy Moss have a background in fashion design. They created this company with the help of 3D printing technology because this technology is appropriate for the development of their Co-Couture concept, which means personalised high fashion, an idea that opposes mass produced fashion items (De Souza 2013). They had developed this concept and associated ideas previously while working for other, more traditional luxury fashion firms. These ideas were the base of Fantazy Moss's foundation which uses 3D printing technology to maximise personalisation of items, and trades online only. At its inception stage, Fantazy Moss offered 3D printed luxury personalised jewellery and fashion accessories, including the founders' own collection, and a bespoke service by other designers which they just 3D printed. The firm grew steadily, expanding customer base, product ranges and the number of collaborating designers. The co-founders stressed that their success was not only due to the 3D printing technology but also because the designs stood out (Graham 2014), given their fashion background and experience, as they maintained a curatorial input over all designs available for sale (Knowles 2015). This acknowledgment highlights the importance of transferable knowledge in innovation, and how the new technology is integrated into the existing productive culture of the location and contributes to its evolution in the process of spillover.

The three types of beginnings identified in this study – hobby, academic and spillover, show how new activities and innovation are related to the existing agglomerated context in terms of its social and economic production structures, and arguably a disruptive technology like 3D printing technology was integrated and contributed further to the richness of the knowledge and creative sectors in London.

It is clear from these examples that 3D printing technology had an enabling role in the process of innovation. In other words, the possibilities of this technology were a trigger to more new innovative activities. Therefore, it can be noted that the nature of the new activities bears a strong relationship with the parent activities and that together they form a network of related businesses which are not too similar neither too dissimilar, creating a richer environment of related economic diversity (Henning and Boschma 2011), which has been recognised in literature as a good context for more innovation. The overall result is thus a positive continuous cycle of innovation and new business creation in the agglomerated region.

7.3.2 Business Trajectories

As pointed out by Chung, Yang and Cauldwell-French (2018) in research on creative activities, business trajectories do not always follow a linear path, and fluctuate depending on projects they are commissioned to deliver. Regardless of this characteristic and of the short life of these relatively new organisations, I have found that there is a good number of (slightly larger) firms operating in activities relating to technology, computing, engineering, product development with excellent growth rates. I have also found (smaller) activities in fields such as fashion, small 3D printing hubs, as well as maker spaces which are less successful, even closing down.

The data shows that higher growth is linked to the type of innovation, as activities linked to computing and engineering tend to grow more than activities linked to arts and craft. This mixed picture is associated with the types of work that organisations do, their size, business plans and level of innovation in processes and machines. This division of success across size of firms and areas of work is consistent with the London trends for the creative industries, as according to the GLA Economics Research (Togni 2015) the industry sub-group of IT, Software and Computer services was the fastest growing by contrast with the least growing Crafts group. But regardless of this separation, as a whole, the activities emerging in relation to 3D printing do perform better on average than other creative industries in London, which forms evidence to suggest that 3D printing technology adoption adds value to a post-industrial economy.

Overall, according to survey responses, more than half of the entities have grown in their number of employees over the last two years. The average growth in number of jobs is 16.8%, which is particularly good in comparison with the 11.8% average growth of number of jobs in creative industries in London as a whole (Togni 2015). Further to this, for the majority of those which grew, the growth percentages are particularly good for 30% of activities as they grew more than 20% in number of employees over the last two years. All the percentages registered are shown in Table 7.1.

Table 7.1 Growth of number of employees in percentage in the last two years[57] (According to survey evidence)

Description	*No. of responses*	*%*
Has not grown/ Not applicable	16	48.5
1 to 10 %	5	15.2
11 to 20 %	2	6.1
21 to 30 %	3	9.1
31 to 40 %	1	3.0
41 to 50 %	2	6.1
Over 50 %	4	12.1
Total	33	100

[57] Refers to the date of the survey (2017)

Regarding turnover and profits, this study has found that across all documented activities emerging in connection with the 3D printing technology in London, more than half have been growing (although at various rates) which is a good performance indicator. According to the evidence gathered 60.6% have grown in both turnover and profits in the last two years, while 39.4% have not registered any growth in the same period. The average growth rate of the activities is 11%, which is a much higher rate of growth than the average 3.4% of creative industries in London (Togni 2015). Moreover, about half of those which have grown have registered significant growth over 16%. The breakdown of turnover and profit growth is presented in Table 7.2.

Table 7.2 Growth in turnover and profits in percentage (According to survey evidence)

Description	*No. of responses*	*%*
Has not grown/ Not applicable	13	39.4
1 to 2 %	1	3.0
3 to 5 %	5	15.2
6 to 10 %	1	3.0
11 to 15 %	2	6.1
16 to 25 %	2	6.1
Over 20 %	9	27.2
Total	33	100

Through the empirical study it has been found that the entities growing at higher rates are more technology, digital or software-focused, design, product development and prototyping/ engineering. And they are of slightly bigger size - circa five people or over, reaching sometimes twenty people. This growth in activities with largely non-material outputs supports the argument that innovation related with the adoption of 3D printing in the post-industrial context is not about restating or re-shoring the production of goods, but about expanding and growing knowledge and creative industries related to this technology. In those, people think about how to use this technology and design ways to best apply it to other productive industries which are creating the consumable goods, located elsewhere. This is well exemplified by representative cases Micro Tech, Eszilook, SB Hub and M & G whose strategies and reasons for success are explored in greater depth in the next paragraphs.

Micro Tech develops software to large manufacturers located outside London. The firm has always been growing, driven by the development of the software itself which attracted an expanding the number of clients. It started with two people, and quickly it grew to six team members at the time of the interviews. Initially, the founder spent some time developing the business model by carefully considering the needs of large manufacturers – the clients, which he pointed to the key reason for the success.

Eszilook, another 3D printing tech start up based in Old Street, has also been growing in turnover and profits from two to ten people in less than four years, according to the LinkedIn page (accessed 21st December 2016). Its success relies on mixed activities including 3D printing plus consultancy, web marketing and content writing for the web, as well as developing products to be 3D printed elsewhere (if they outsource a batch, or by clients). Eszilook is formed of two separate parts: one is the personalised 3D printed VR headsets for mobile phones, and another is the content production department, which includes Virtual effects, Computer Generated Reality content (CGR), games, PR stands, advertisement, interactive experiences, consultancy, and animations. This part of the business, which does not print anything and is content focused only is the most profitable. And, to remain profitable, they divert their 3D print costs to their clients by promoting the route whereby clients can print their headsets if they have a 3D printer or though Print Point 3D.

SB Hub, a Clerkenwell-based software company, has grown significantly since its inception in 2013 from a single founder to eleven people, and were recruiting a further nine people at the time of the interview. The business' success lies in the innovation of the software product and its applications. It started because additive manufacturing is growing and has enormous potential for goods production, but the processes at large scale are still very inefficient in terms of the workflows and operations. Their software addresses this, supporting the large manufacturing operations, mostly located outside London. During this study SB Hub grew, went for public offer, and rebranded as a larger firm, AFMG. This was widely reported in the 3D printing specialised press:

> 'UK based 3D printing software company SB Hub has re-branded as AFMG. In time with the new look, AFMG has also launched a new artificial intelligence platform to automate additive manufacturing

in production.’ (3dprintingindustry.com/news, accessed 12th July 2018)

M & G is another example of a company that has been growing consistently in both turnover, profits and staff. However, this company 3D prints but not final consumable types of products. It prints in support of other creative activities of London, such as product design and architecture. M & G’s growth is due to acquiring the latest technology and being the first in London offering certain machines, which despite significant upfront capital invested, attracts more customers and is profitable. They do all complementary services to support a successful 3D printing output, including pre-production, design input, digital modelling, and post printing production, as required by clients which is the most profitable part of the business. Some clients approach them with promising ideas and good business skills but without design and printing capabilities or understanding. With these clients, they work on product development. According to the CAD production manager interviewed, the tasks of digital model-making, product development and 3D printing are profitable, whereas the work of printing models finalised by the clients is not. In the design development of products the profit margins are particularly good, highlighting the nature of the business as typically creative and consultancy, more than manufacturing even with a good range of machines.

Micro Tech, Eszilook, SB Hub and M & G are all very well established and leading organisations in the 3D printing technology in London, in their respective sub-fields. Common indications of success include significant innovation and investment, firm size (over five people), and to some extent the sub-sectors of work – such as software creation, product development, as well as the flexible mix of services offered to clients. Other factors positively influencing the success of these firms were the ability to strategize and formalise reliable business plans, and to spot the market gap. These examples, and the overall picture of a positive group of activities and innovation relating to 3D printing technology support my argument for the value of a fabrication technology in post-industrial London because of the multiple knowledge, creative, design, software production opportunities that this technology opens up. This value is captured because of the concentration of creative and knowledge industries already in London, and because of the easy connections to other larger industries outside London.

But, during this study, which lasted nearly two years gathering empirical evidence, some entities also discontinued their activities, as in any case happens in business creation. In the group of 18 cases followed in further detail, five[58] suspended activities during my empirical research. However, the deduced 72.2% survival rate of my sample is still a good survival rate for London. It compares with 39% survival rate of all businesses in five years (ONS 2018) in London. For completeness of this research, the stories of closure will inform this chapter's last section (section 7.5) which considers the key challenges to this type of innovation so that they can be addressed.

Now I move on to explain how these new activities have been financed, a key aspect of the successful performance of the activities which evidence suggests is linked to their specific location.

7.3.3 Funding

Analysing how the new 3D printing related activities acquired funding showed that the co-location of these new activities with more established creative industries is key to new firm set up. A common and agglomerated location de-risked the process of business start-up, and enabled the transformation of innovative ideas, hobbies, academic degrees and experimentations into profit making firms. The creation of new businesses was financially enabled by existing local structures – such as incubators, and by other nearby activities which appeared more credible to investors or to collective funding gathering. Location appeared as a key factor to access funding, thus another finding that brings into question the myth that a flexible technology can generate a successful business anywhere.

This research found that the success of the activities relates to a mix of funding strategies. These include self-funding (also called bootstrapping), non-traditional financing such as crowdfunding (due to the difficulty in reaching out to traditional banking) and public sources.

A significant majority of activities emerging in relation to the 3D printing technology were funded initially solely by the founders' own resources, which is

[58] The five which closed activities are: Heterotopia, Fantazy Moss, City Fab Lab, City Hackspace (which reopened circa half year later in a very different location) and The Werewolf.

common in the early years of businesses in London as 82% of London start-ups use self-funding in some way to finance their business (The Company Warehouse 2016). It was found, however, that the cases of nearly all privately self-funded firms were less successful, and the more successful enterprises combined self-funding with other sources. However, funding opportunities were mostly available in connection with the location of firms. Below I describe how the businesses obtained them, bridging the problem around lack of guarantees to investors and lack of business case, because of the novelty of the technology, through the co-location with innovative firms of other (related) fields.

Early-stage ventures for SME technology businesses and crowdfunding bridged the gap of funding where traditional external funding was not available. But firms relied on nearby addresses and local incubators to access the funds or to construct the narratives to attract donations. For example, Eszilook received crowdfunding from Kickstarter after developing their first VR headset for mobile phones, which allowed them to set up the company because they present themselves to the donating audience as a London tech firm from Old Street.

Many funding opportunities were boosted by a London location. For example, BrownBear, an open-source website and leading platform for the 3D printing technology application in engineering, received a combination of government grants and charitable funding: Creative Industries Fund NL, F-Founders Forum For Good, Nominated Trust and Stichting Doen Nationale Postcode Loterij. The firm started in Amsterdam, and in 2013 the project won the Social Tech, Social Change Award from Nominet Trust and since then it maintains a small team of permanently employed web developers. Through this trust they applied and got accepted to a start-up accelerator programme in London, the Bethnal Green Ventures, whose funding comes from three core funders: Nesta the UK based charitable organisation for technology and innovation, the Nominet Trust which funds tech for social good projects, and the Big Society Capital which is growing social investment in the UK. For this reason, the founders relocated to London, setting up a new office in Somerset House, but the rest of the team remained based in Amsterdam. In this case, charitable and public funding helped to first secure a London location, second support the core online activities of a growing, innovative firm, and third support another activity at the Somerset House hub, resulting in an important London location for the 3D printing research more generally.

This research found that 27% of the activities (according to survey data) received some form of public or charitable funding. There are some cases of external direct European Union funding, of national government-backed grants, non-profit innovation funds and of academic or research scholarships. Public funding was also sometimes accessed because of a London location, particularly as at the time of the empirical research the U.K. had not yet left the European Union. And further to the conclusion of this thesis on the value of 3D printing technology in post-industrial cities arising from its possibilities for the knowledge economy, it can be seen that most grants were obtained through research-related organisations, rather than from manufacturing related funds. For example, during its inception years, M & G had not received any external funding and relied on self-funding and income from sales. However, as they have risen to a leadership position in the industry, they started to be involved in research projects about the 3D printing technology, receiving external funding from mixed sources such as retailer Argos and collaboration and for KTN (Knowledge Transfer Network), a government organisation. Equally, Medical Prints 3D received funding from many international charitable organisations, alongside crowdfunding. And, Atelier León had received funding through the London university attended by the co-founder.

Some cases with EU funding have grown and attracted private external funding. This was the case of SB Hub, one of the study cases reporting highest growth and which went public during the writing of this thesis, which received EU funding in its earlier stages associated with their software product. It has also then been externally privately funded mostly through technology-linked funds to who a London location mattered.

In sum, the mix of funding – self-fund and sales, less traditional private options such as crowdfunding and niche SME funds for technology, plus public sources and grants enabled the beginning and the progression of activities through a path of success. A strong commitment by the founders – either by self-funding, or by reaching out to a variety of funding sources linked to new technologies allowed new activities to start, develop and continue operations. But the London location, and in some cases specific locations like Old Street tech hub, were key to de-risk the new firms to their financing bodies. London does have a competitive advantage when 3D printing technology innovation is concerned.

The next section presents another set of findings in support of the conclusion that there is value and growth to be derived from a fabrication technology like 3D printing in a post-industrial context like London for innovation in connection with creative and knowledge industries. It analyses the ways people collaborated for the success of ideas, products and activities in the process of adoption of this new technology, and how social and physical proximity were part of knowledge exchange.

7.4 Collaborative Practices

This research has revealed a third reason this new technology can contribute to growth and to the creation of value in a post-industrial context such as London. The collaborative practices which characterise the culture of work around the 3D printing technology, and which are facilitated by the agglomerated context, help knowledge exchange which is critical to innovation (Baycan et al. 2017) and to the cognitive-cultural economy. Collaborative practices found amongst the case studies (such as shared spaces, machines, and tools, as well as sporadic and scheduled in-person and virtual meetings) contribute to the creation of new knowledge which can lead on to further innovation and contribute to the competitiveness of London.

I observed a culture of collaboration amongst 'makers', including between firms, sole practitioners and hobbyists, which participants mentioned quite often in conversation, and which has been noted in related literature too (Anderson 2013; Barnatt 2014). The makers' community is defined by a common interest in making things from scratch, inventing and experimenting rather than buying ready-mades (even parts) of the shelf. And this community – although not formally established, has a culture of sharing knowledge about the processes of making things. Fruitful sharing of knowledge happens because there is a common style of communication (meaning certain terms used) and a shared system of meanings, plus a common interest in making things, described in literature as 'matching' (Duranton and Puga 2004) for effective learning in the process of innovation. This is possible because there is proximity of background, motivation and knowledge which makes the collaboration possible and productive (Rigby 2013; Essletzbichler 2013; Kogler, Rigby and Tucker 2013), as well as a degree of clustering amongst businesses. 3D printing, as a technology for material production, has benefitted from this culture of sharing in its development, implementation, and adoption in innovative activities. Innovation, through new projects and new firms have been outcomes from the culture of collaboration.

By contrast with traditional processes in market economies, where competition has been argued as the main driver for innovation around new technologies (Jacobs 1969; Glaeser et al. 1992; Porter 1990), the 'makers' are generally very proud of the benefits of their openly collaborative approach in the development of new ideas and products. In the absence of many established formal systems for codified knowledge sharing (like Science institutions, R&D laboratories, universities, research centres) given the novelty of the technology, less formal opportunities for knowledge sharing emerge through the clustering and physical proximity and through the deliberate actions of individuals and maker communities which allow for tacit knowledge exchange, so that people have opportunities to share their experiences. Literature on innovation has long highlighted the importance of collaboration with external actors, including with other firms and key individuals (Cooke and Morgan 1998) for the creation and survival of SMEs, and for their potential to innovate and overcome barriers such as financing, poor management and marketing skills, lack of skilled labour and misdirected search for information (Freel 2000). The empirical evidence in the case studies of this research is particularly compelling of small firm growth linked to sharing tacit knowledge of doing and experimenting. It can be read for example in some websites that:

> 'Champion 3D started up to solve a manufacturing problem, Josef the founder and his partner wanted to make accurate educational biology models which can cost in excess of a £1,000 to buy ready-made. He decided to purchase a second-hand 3D printer for much less after deciding this was the technology to solve this. "I have since offered my 3D printer locally to makers and creatives wanting to turn their ideas in to physical models. I have slowly grown the small "bedroom" studio to six printers and completed over 1,000 orders. Peckham Levels will now enable me to expand my business further' (Peckham Levels website, Champion 3D Printing, accessed 14th August 2018)
>
> and
>
> 'We made it open source so everyone really could pitch in. And we started to grow' (Ultimaker website, accessed 31st May 2015)

Below the analysis of the specific collaborative practices that this research has found is presented, including how they happen and how they have contributed to the success of the activities. Further to this, it is highlighted that collaboration is strengthened by the agglomerated context of London, and that it is also predicated on a common culture with common terms and behaviours which are part of shared place experiences too. Whilst some of the interactions take place online, the construction of the makers culture relies on a combination of online and presential knowledge exchanges. Physical location facilitates in person formal and informal meetings, as well as the construction of the social proximity which in turn helps efficient knowledge exchanges by all means.

7.4.1 Shared Workspaces and Shared Equipment

As many activities using 3D printing technology in London are self-funded or part funded start-ups set up as individual hubs or small organisations, it was common to find people sharing workspaces, machines, and tools. Space sharing alone would not be unexpected, as it has become common in dense urban areas as London, where space is costly. But with co-working desk places, shared studios or shared labs also came tools and machines for everyone's use, which is less common in traditional shared office environments. The benefits of this were threefold: it helped activities survive without so much investment, it made more and better machines available to more people and created opportunities for informal collaborations.

The participant designers of this study shared spaces and a variety of equipment. For example, Patricio Frater's large studio space in East London, was shared with a friend and had his printers that he shared with other users too. Frater also reported sharing contacts with a large group of 3D printing design and creative industries members in London for the purpose of printing. When he needed to print, he selected from a pool of circa 15 people depending on the order and availability. As a group, they operated as a network who distributed work amongst themselves according to specific skills. Likewise at 3D Masters Shoreditch's main workshop, which was shared with three other small businesses, I saw a common space at the back where all machines – including 3D printing plus other fabrication technologies, materials and tools were available to all resident businesses.

This research also found other types of shared spaces where equipment was rented or shared amongst a larger group of users, and these created many formal and informal collaboration opportunities. For example, the City Hackspace was a type of shared space where members used desks and a good range of tools as needed under the payment of an honour-system membership fee. People who do not have the space for their activity elsewhere came to the City Hackspace, which was organised around the ‘makers’ culture with other complementary services. Although it was not for running businesses permanently as other types of co-working spaces (it could not be given as a sole permanent business address) it served sometimes for example Paul’s Hub which did not have a specified address.

A fabrication laboratory type of space (known in makers’ culture as a Fab Lab) is also a similar type of work environment, where many tools and machines such as 3D printers, laser cutters, CNC, vinyl cutters, etc are shared. But it is more formalised in terms of membership arrangements and user rules than a hackspace. My City Fab Lab, a case this research followed in detail, is a good example. It offered large workshop areas equipped with rapid prototyping machines such as 3D printers, laser cutters, electronics lab, textiles, material supplies, and a tool shed, plus desk space for innovative early-stage companies. In addition, the lab was part of a global network and it provided start-ups with support to develop products and to scale up, including financing, access to a creative community, educational and training events, business partners and help from other experienced professionals.

Sharing tools and machines was useful to support many activities at their inception stage, to reduce the need for investment upfront and to amplify the possibilities of experimentation. Additionally, it provided a background to more cross over between different activities and people, thus providing an excuse for impromptu conversations and more opportunities for tacit knowledge exchange and creation of informal networks of makers. Occasional, everyday share of experiences and work dialogues around projects in the making, machines and tools were opportunities for knowledge exchange. As mentioned during one of the interviews ‘…people occasionally help each other and discuss progress on projects’ (Santiago, 3D Masters Shoreditch, interview). This level of sharing of equipment and its benefits to transfer of information was only possible because of the agglomerated context of London, where there are enough members of a hackspace or of a fabrication laboratory, or because the activities sharing spaces and tools were somehow related.

7.4.2 In-person and Virtual Knowledge Exchange

This research has found organised in-person meetings complemented by online sharing enabled by a common culture, a certain social proximity constructed around the theme of making which facilitated knowledge exchange. Shared spaces and a concentrated and well-connected city centre naturally create collaborative work environments (Storper and Venables 2002) where discussion and exchange of ideas can happen easily and informally. But additionally, the London location facilitated organised meetings about all subjects related to 'making things' and about 3D printing. These were widely held by many firms, not-for-profits and education institutions, because of the novelty of the technology and the challenges that come with experimenting around it. Furthermore, as there were no formalised groups or institutions yet around the 3D printing technology (and other related new technologies) the community of makers was very proactive and self-organised. This research found and participated in organised 'meetups'[59] which were highly popular amongst the makers' community. They were forums for exchange of information and ideas, and easy to organise due to mobile phones and on-the-go communications, and nearly all free. Depending on the organiser, they could be opened to anyone who had an interest and signed up, or available to members only. Some examples below in which I participated aim to show how these meetings contributed to the development of projects or to the creation of new activities.

The meetings at the City Hackspace were organised through an app by Paul Lewis, who was at the City Hackspace every two weeks for 'meetups' on the subject of 3D printing which he led - the 'London 3D-Printer user self-help group'. The meetings were opened to everyone, late in the day and generally very informal and unstructured. I attended these meetups for observation and discussion with the participants. From my observations, people came in with a keen interest in both sharing and getting hold of latest information. They brought in their laptops, 3D printers, sketches or prototype objects and tests. Participants, including people who did not know each other before, talked around the tables about a variety of issues concerning their methods of work, their projects, ideas and products. Mostly people sought advice on printing, modelling or materials for specific problems they faced, and they enjoyed getting to know the

[59] Subject meetings organised online via Meetup, a popular app.

other ‘makers’. Conversations extended well beyond the project which brought them there in the first instance, to anything concerning ‘making stuff’, such as places to go and future events and opportunities. People attending were from a range of backgrounds, ages, and occupation. They simply had in common wanting to ‘make something’ using 3D printing technology. Queried on the best format of these meetings, the value of attending these meetups in person, rather than exchanging e-mails for example was highlighted in comments such as:

> ‘I can explain more things face to face, and there’s a wider range of skills here. More problem-solving. Knowledge comes from all, real problem solving’ (Peter, meetup participant)
>
> ‘The group are very helpful sharing their knowledge. There is a lot of experience in the room and a good chance to absorb knowledge’ (David Tom, meetup participant)
>
> ‘I come here because of the other meetups too, the variety of skills available’ (Farez, meetup participant)

One particular meetup which I have also attended, The Romford group, had a different, more specific purpose: to create a local maker space ideally to open that year (attendance to the meetings took place in 2017). The group, formed by and including people linked to the 3D printing technology as hobbyists or as part of their job, acknowledged the lack of further capacity in the City Hackspace which was the closest makerspace and the need for a new one in Romford. The key discussion during this group’s meeting was how to find space for a pop-up for people to come along and print, start businesses, collaborate and learn, and grow from there to a permanent space. Before I got involved, in December 2016 they had organised a Makers Market in Romford, which was well attended according to the group. Following that, when I participated, the group discussed the local lack of tools and machines for sharing compared to central London, something their project for a local makers’ space would address. They also discussed ways and actions to engage with local developers, local retail, the local arts centres, and the University of East London to better achieve their goal. This group’s activity was very deliberately trying to bring growth and this type of innovation to the local area, and it can be noted how it engaged with other (non-making) activities locally. It exemplifies how the value of the activities emerging around 3D printing technologies in a London context (even in the less central areas) is not restricted to printing or fabrication businesses, but to other services, knowledge and creative activities.

Other cases from this study organised makers' meetings, particularly the larger businesses: Print Point 3D had a system of events to grow interest in the 3D printing technology and organised events in the metropolitan areas where it has hubs - London, New York, Paris, Amsterdam, Milan. They also held smaller community meetings, education groups, and had started a programme of 'Mayors' for each city to look after the local community of 3D printing hubs; M & G regularly hosted seminars, subject-related meetings, other events, and exhibitions in their building in Camden, free and opened to anyone who was interested in making; City Fab Lab held educational and training events for business partners, for members and for experienced professionals; and Patricio Frater had also organised educational events and meetings in his studio, as well as parties for 3D printing designers.

This research found that the range of in-person meetings and forums organised by the community of makers was incredibly significant in the adoption of the 3D printing technology and in the development of projects. This aspect of the collaborative makers' culture was helped by the agglomerated environment of London where very many people concentrate thus creating some critical mass around a subject like 3D printing, and by easy communications – such as the mobile app for meetups. These meetings contributed to knowledge diffusion, new projects, new activities, and the formation of networks, thus opening up opportunities for local growth and innovation directly and indirectly. They are empirical evidence to the importance of informal knowledge exchanges for the formation and survival of SME's as highlighted in literature (Cooke and Morgan 1998).

Collaborative practices employed in the development of 3D printing technology-related projects and activities extended to online sharing of information, such as open innovation/open source and co-creation. These ways of collaborating allowed for many new activities, new projects, and further innovation and complemented the exchanges that took place in-person through consolidation of the social proximity between makers, through diffusion of information about physical encounters and through free exchange of project material.

The use and exchange of free information, known as open-source[60] material, was found to be deeply rooted in the working culture of people using 3D printing

[60] Open source content refers to information which can be freely accessed and downloaded from an online repository location. Software, hardware designs or product designs which are freely shared

technology because, since the early days, the technology evolved through many open-source research projects[61]. Online communities who share files have been key to the progression of the 3D printing technology and related activities in London, whilst also constituting unofficial regulatory forums where the collective authorship, property rights, costs etc are compared and diffused. This research found that some forums for open innovation in the field of 3D printing led on to in-person meetings, which are facilitated by a context like London which is well connected and agglomerated.

Some of the research's representative cases have grown design products fully or in part out of open-source material. This was reported or noticed at Eszilook, Patricio Frater, Paul's Hub and Print Point 3D. The later, besides being a marketspace for 3D print makers, has a domain where free material about anything related with any new fabrication technology is published. BrownBear's core business, another representative case, is a social network site entirely dedicated to open source/open innovation sharing. These processes of share of contents were very fruitful in the subject of 3D printing technology because there is a common culture amongst the makers, characterised by a common style of communication and shared interests amongst members, which facilitated exchange of information.

At BrownBear, a community of related interests in making technology which I joined as part of this research, there were files and information to enable registered

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online are normally traded under a Creative Commons License, rather than protected via authorship and copyright laws, meaning that anyone can legally use or alter the design. An easy and flexible access to shared contents has allowed for innovation particularly in technologies associated with science, medicine, and education (Sher 2015). And in the process of sharing, the originator also normally benefits from contributions and improvements to the original designs from feedback given by the peer community upon testing.

[61] Key projects in the early development of the 3D printing technology were the RepRap in Britain and MakerBot with Thingiverse in the U.S. The first two were research on the 3D printing hardware technology, and their model designs of 3D printers were freely available to download and print in parts so that interested users could build their own machines. Ultimately a machine could and would reproduce itself free of costs, spreading local manufacturing. Thingiverse is an online website with an extensive archive of files of 3D printer parts for download for the printing community. People can upload and share their designs under the legal form named the "Creative Commons License". It is the world's largest 3D printing community for both professionals and non-designers originally created by MakerBot. The MakerBot Industries has been acquired by Stratasys, the largest 3D printing hardware manufacturer corporation.

users to develop technology projects on their own or to develop co-created projects. Access to information was free for subscribers under real names (not usernames). Information ranged from YouTube videos showing the building process, to drawings and diagrams of the relationships between components and fabrication steps, to technical drawings and calculations of complete projects, to descriptions of projects so detailed and structured that anyone with some related knowledge could easily re-use or adapt. The site displayed many projects of great complexity and variety right from the home page. Featured projects included robots, drones, machines, prosthesis, computer parts, experimental cars and other vehicles or just parts, 3D printers, design products like furniture and decoration, renewable energy devices, etc. Furthermore, it was also possible to 'hack' existing projects, meaning to duplicate them with the aim of evolving them collaboratively online or individually on or outside the platform. The company does not claim ownership or rights over any content it makes available.

BrownBear also functioned as a support network to makers by creating a universe of similar experiences to encourage anyone to proceed with his or her own idea. It was therefore easy to feel part of the community, or to find someone else to collaborate and to 'make things' with. Personalised sentences, images of finalised projects or shared experiences by other makers were frequent. The establishment of relational proximity happened without physical or relational proximity, as argued by scholars recently (Grabher and Ibert 2013). BrownBear was a space of knowledge 'no less social, less tacit, less sticky, less negotiated than physical space' (Amin and Cohendet 2005: 470).

The first person (I) was used frequently in descriptions of individual experiences on projects, but mixed with specific vocabulary of the technology and of 'making' to maintain the strong sense of community:

> 'In this project I'll be describing my experiences taking part in the first Bio Hack Academy" (sentence by Gerrit Niezen from the Swansea Hackspace, project Bio factory, who has 46 Followers, of which three are Makers).

The makers communication style was part of these online collaborative practices. At BrownBear it was assumed that people within the community could understand all specific terms, as no explanation was provided for programming language for example. Some are neo-words and others are technical words, such as for example 'hackability' (the ability to hack/ make something), 'e-waste' (electronic waste), 'Arduino', 'Raspberry Pi' (types of control boards), etc.

The screenshots below show typical contents of BrownBear: Figure 7.6 shows an index of projects from where title, name of maker and a key brief description with personalised quotes can be seen. It can also be seen that the project names are part of a common 'makers' language, such as QuadBot V2.0, Hexy, Sparky, Xpider, EXiii-Hackberry, QuadCopter, etc which I had to familiarise myself with in the process of participating in forums. Figures 7.7 and 7.8 show the type of information available for a project: detailed descriptions, videos, files to download, and online talk threads through the project process which is to a high degree of detail and disclosure, beyond what most businesses in other fields would disclose to potential customers or competitors. Figure 7.9 is a sample page of project information downloaded (as an example for this research) with files of parts to build and program a prototype 3D printable electric prosthetic arm created by a Japanese robotics company based in Tokyo. Here the exhaustive detail of available contents can be seen, including even suppliers and availability in different countries for every element down to screws and wires. This example demonstrates well the availability, level of organisation, complexity and extent of the information shared through BrownBear makers' social network platform.

[redacted]

Figure 7.6 BrownBear projects index example, source: https://www.wevolver.com/home/, accessed 21st December 2016

[redacted]

Figure 7.7 BrownBear page inside a project, with video and description, source: https://www.wevolver.com/home/, accessed 21st December 2016

[redacted]

Figure 7.8 BrownBear, inside a dialogue thread page of a project, where people ask and suggest changes to projects in a virtual collaborative work process, source: https://www.wevolver.com/home/, accessed 21st December 2016

[redacted]

Figure 7.9 BrownBear, example of project information for free download, source: https://www.wevolver.com/home/, accessed 21st December 2016

Collaborative practices extended to intentionally leaving part of the project to be finished by someone else, sometimes customers, and sometimes online too. Co-creation, as the joint creation of a project or a design, is very common in the makers community work culture. It is another aspect of the collaborative practices which consolidate social proximity, which enables knowledge to be more effectively shared. It happens either when many parties participate in the production process or when there are parameters which are intentionally left to be manipulated by others, for example customers, to enhance participation in production and personal characteristics of a product. Unlike typical design products whereby the design is finalised for the customer, with 3D printing technology the design could be finalised and personalised by the customer or by other practitioners. This is particularly helpful and more profitable in high end designs, where finalised products can be time consuming and costly for creatives.

Co-creation is used amongst the makers' community for new projects and for ideas generation and development, or to reach out to more clients. It is particularly used in certain sectors which are traditionally successful in London, such as jewellery and product design. Fantazy Moss and Eszilook are two of my detailed London cases which have used co-creation to gain more customers or to deliver a more competitive product: Fantazy Moss created many high-end jewellery items with geometric parameters and material combinations which could be changed by the ordering customer, from a base design created by the original designer (see Figure 7.10); Eszilook's approach to co-creation was to allow for certain elements of their base VR headsets for mobile phones to be finalised by other sellers, registered as 'Eszilook Partners', who received orders themselves to which the parent company charged a fee (see Figure 7.11)

[redacted]

Figure 7.10 Fantazy Moss's jewellery items examples, source: LOMAS, N (2014) WonderLuk Is Using 3D Printing To Power An On-Demand Fashion Accessories Marketplace, *techcrunch.com*, available from https://techcrunch.com/2014/10/16/wonderluk/, downloaded 20th January 2017

[redacted]

Figure 7.11 Eszilook's headsets in multiple combinations of models and colours, source: https://www.altergaze.co/games-and-products/, accessed 21st December 2016

This way of working, typical of the makers culture around technologies like 3D printing, has created new knowledge or new products which contribute to competitiveness and advantages of typical activities of post-industrial London such as fashion, etc. Co-creation, alongside the other collaborative practices associated with the use of 3D printing helped further innovation, set up, survival and growth of activities.

This concludes this chapter's findings in support of the conclusion that despite evidence of fabrication technology not increasing manufacturing activities with final goods outputs in London, this technology can bring growth and contribute to the creation of value in a post-industrial economy like that of London. This value is created through the suitability of the technology itself to early stage of product creation located in centres like London and through the ways this technology helps viability of London's creative and knowledge start-up businesses. Further to this, value is created in a post-industrial region like London because of how technology adoption in post-industrialism is a collaborative process relying on social proximity for effective knowledge exchange. In particular, the makers culture around fabrication technologies and methods was strengthened by the concentration of people and businesses and the good accessibility within London.

I will now move on to a sub-section which summarises issues found in this research relating to the 3D printing technology which may limit adoption and development of the technology, and may set back new innovative activities.

7.5 Issues Which May Slow Innovation and Growth

During this research I have identified several issues which may prevent growth and further innovation resulting from the 3D printing technology to be realised. Some issues relate directly with limitations of the current legal framework, while other issues have to do with how activity owners address their business case and funding strategies – and their under preparedness to manage these. Additionally, there are real estate pressures impacting the locations of activities, particularly those requiring larger premises.

It is worth here reflecting on these, as it would be a missed opportunity not to do so, having collected insider's information on these new activities. And, perhaps, because it would be misleading to paint a picture of an easy route to growth and innovation arising from the technology, knowing from this research that there are significant issues which may prevent this from happening swiftly, and which need consideration.

Insufficient Legal Framework

As many products and software are produced collaboratively and the technology and materials are relatively new, regulation is yet to catch up with practice and some concerns were reported by the participants on matters of authorship and responsibility, plus on quality certification and control of outputs.

Problems with authorship and legal responsibility limitations were reported by the participants and widely discussed in subject magazines and presentations I attended. At the time of this research there were no clear legal definitions to provide practitioners with confidence in terms of who is the author and who should be receiving an award or profit from a design or product, and who is responsible and liable when there are complaints. These issues were more significant in co-creations with parameterizable geometries, and in the use of open-source material.

Participant firm Eszilook, whose VR headsets are customisable from a base design, reported a typical case of this issue: as the headsets are tailored to each customer needs, each one is effectively a unique design every time it is 3D printed. From a legal point of view, there was no way to protect their intellectual property. They resolved the problem by creating a network of authorised sellers to co-design and 3D print each product iteration. But later, other people started using their headsets and their lenses in other products and using non authorised sellers without paying them anything, and they could not claim breach of copyright.

Problems with quality certification and control of outputs were also commonly reported by participants. At the time of empirical information gathering, there were no norms for materials specifically 3D printed, nor for the print processes either and an output quality can vary substantially depending on how it is 3D printed (for example print speed can affect resistance). Some norms can be applied from products manufactured by other processes, but they do not entirely suit the purpose of protecting consumers.

To deal with this problem, Print Point 3D, the largest platform of 3D printing services, developed an internal certification system for the hubs. These include user feedback five start system, indications of whether the hub is a 'Manufacturer Partner' or not, icons for industrial –grade quality, ability to sign Non-disclosure agreements (NDA's) and registered business, etc. In addition, a very extensive system of badges has also been created to reduce complaints. And, for the lack of a better norm, the Print Point 3D certification system is used outside the hub platform across the industry.

Issues of Business Case, Funding Options and Owners' Under-Preparedness

Despite an overall good performance of new activities related to 3D printing, many reported difficulties constructing a business case to support further investment. This difficulty rose due to owners' lack of knowledge and lack of contacts, and due to their focus on the creative or technical aspects of the activity to the detriment of time dedicated to management.

Many participants in this study identified this difficulty clearly. Patricio Frater, who struggled with viability of his multiple activities, acknowledged that he had never tried to apply for funding, despite his continued challenges. He had considered Kick Starter at one point, but admitted, he lacked skills in the 'business side of things [and] was never genuinely interested in preparing a business plan or reaching out for a business loan' (Patricio Frater, interview). In interview, he mentioned that he would not know how to reach out to other kinds of external funding because he wished to spend his time working mostly on the designs, experimenting with printing prototypes, and applying the technology to his creations. He also noted that, as a creative designer, he lacked advertisement skills, and would have had more success if he had employed a marketing specialist from the outset.

The Werewolf, a case investigated in detail, closed due to the founder's unwillingness to grow steadily and his lack of understanding of how to secure long term funding without the need for constant growth. And, as Frater, the founder's focus was on the projects, not on managing the finances. These reasons for closure of the business were well summarised by founder Ronald Nicosia:

> 'I submitted my application for the Start Up Loan scheme, it was rejected twice because it wasn't clear enough and I wasn't justifying the income. I have been approached by a financial service that

> proposed to help me on raising funds to be invested for promotion and upgrading the equipment (...). However, I made a choice to not progress because I wasn't ready to take responsibility for a big investment. It would have meant to take a risk economically (...) This was my first experience as an "entrepreneur" and my idea, when I started, was to open a business with a very low risk (small expenses), doing what I was able to do (I am a product designer, I knew how to use 3D graphic software and 3D modelling, and I knew how to use 3D printing technology) and just earning what I need to live (...). [Plus] I had a lack of experience in several areas of the business, from the financial side to the project management and marketing.' (Ronald Nicosia, The Werewolf, e-mail exchange)

The founder of Paul's Hub also identified a similar set of difficulties, highlighting that it is nearly impossible to find funding or borrow money from investors doing what he does, unless there are customers lined up as a guarantee. This is however not possible when trading through a platform only since work comes on a bid-for-job format. According to Paul, 'a typical maker does not have money, and is at a stage of product development. But they need to continue developing the product to be able to reach the point where it can be taken to market, so there is need to help funding this critical product development stage when people are designing and prototyping.' (Founder, Paul's Hub, interview)

These difficulties in terms of securing external financing, lack of business support and no understanding of where to find it are common in creative enterprises (Chung et al. 2018). These activities emerging from the 3D printing technology are no exception to a problem of recently formed creative businesses. As there is potential for further innovation and growth from activities emerging from 3D printing technology in London, the issue could be addressed via, for example, an incubator service or support programme, just like there was for emerging activities in the digital sector - see for example in the Old Street area the City Growth Programme (2003–2009) created to instigate business-led clustering, training and business support with the aim of preventing decline and retaining presence of new digital activities within the area (Bagwell 2008; Foord 2012).

Real Estate Pressure

Some activities reported being threatened by real estate pressures and plot redevelopment. This challenge has been analysed in planning literature in relation to manufacturing uses conflicting with other land uses in London (Ferm 2011 and 2016; Ferm and Jones 2014 and 2017; Brown 2015; Giloth 2012). And, given one of the arguments of this thesis that technology alone does not explain or change the location of innovation (as socio-cultural factors, accessibility and labour factors do) real estate pressure on central locations best suited for innovation can have a significant impact on the formation and growth of new activities. This issue, probably more than the other issues presented in this section, may hold back this type of innovation and inhibit the creation of an economic context of related diversity.

This research found that this issue affects primarily the maker spaces and fab labs due to their need for large areas in more accessible locations. My case studies City Fab Lab and the City Hackspace closed activity during the research. Their closure, explained in detail below, may have a negative repercussion on the development of 3D printing related activities in London, as they provided access to equipment to people starting new ideas, and served as locations for meetups and knowledge exchange.

City Fab Lab was a 4,000 sq. ft. space that provided 'creative workspace in the City of London for early-stage hardware start-ups' (http://www.fablablondon.org/, accessed 22nd December 2016). It offered workshop areas equipped with rapid prototyping machines such as 3D printers and laser cutters, plus an electronics lab, textiles, material supplies, a tool shed and desk spaces. It was available to registered members on payment of the membership, which varied from basic to tailored arrangements. In addition, the lab was part of a global network and it provided start-ups with support to develop products and to scale up, including financing, access to a creative community, educational and training events, business partners and help from other experienced professionals working in the field. Figure 7.13 illustrates the range of activities at City Fab Lab. City Fab Lab closed after four years in business as the building where it was established went for redevelopment. Its role as an innovation hub in the 3D printing technology development in London has been lost.

[redacted]

Figure 7.12 City Fab Lab: Activities and machines available, including food printing, several 3D printers, materials storage, product design and events, source: http://www.fablablondon.org/ , accessed on the 22nd December 2016

A similar story is the case of City Hackspace, a not-for-profit makerspace located in Hackney Road which offered extended open hours - 24 hours a day/ 7 days a week accessible with the Oyster card for members. The facilities occupied an entire four storey building (circa 10,000 sq. ft. in total) and it had desk space, tools, and a variety of machines for use by the members. It served as a meeting point for meetups too. The organisation had to move out of the building in April 2018 when the lease expired, as the landlord raised the rent to almost double. After this, the organisation closed while looking for new premises. During this thesis writing, the City Hackspace has re-opened in a new location in Wembley, but the Future Manufacturing Meetups remained cancelled.

Both cases were important meeting and networking points, and their closure impacted (at least temporarily) the more established community who met regularly there, and the new entrepreneurs seeking for early contacts and initial help on projects. They were, due to their nature, fairly large spaces because of the variety and quality of the tools and machinery they had, and that made it difficult to continue securing large premises. Also, they needed to be more centrally located to have a better catchment and attract people for membership, as well as to have good transport access due to their extended open hours.

7.6 Conclusions

This chapter has focused on whether and how 3D printing technology can contribute to innovation, value and growth in London. It has provided three sets of evidence-based insights to conclude that there are grounds for this technology to continue to be promoted in policy and even further supported in this context. These are, first, advantages emerging from the technology itself and its suitability for use in early product stages which flourish in London; second, how new activities emerged in relation to other activities typical of the London economy and achieved good performance; and third, the collaborative nature of the technology adoption process which is helped by the agglomerated environment of London. With these findings, I argue that despite evidence of fabrication technology not increasing manufacturing production in London, this technology can bring growth and contribute to a cycle of innovation in London. The evidence showed how new activities and ways of working which find the conditions to evolve from the existing London sectors, strengthen the agglomeration of activities of related diversity (Henning and Boschma, 2011) – as somewhere between specialisation and diversification – a characteristic of regions where more innovation can flourish.

In contrast with perspectives that assume the potential for re-shoring of production of consumables to western cities through the use of new fabrication technologies (Bryson et al 2013; Johns 2022), this research shows that the value created by these technologies in these contexts lies in how they can be associated with very typically post-industrial activities such as design, knowledge, consultancy, software production. They can therefore be characterised as part of an evolutionary process of innovation predicated in knowledge exchange and collaboration supported by physical and social proximity.

On the advantages emerging from the technology itself and its use, I have shown in this chapter how 3D printing technology triggered and facilitated new activities working on early stages of products in knowledge and creative sectors, activities which are typical of a London context. New organisations work on a vast array of projects using 3D printing technology as part of the product development process, but rarely use the technology to produce the final 3D printed item, neither on demand nor for larger batch fabrication. These later stages of production are still being directed elsewhere, prolonging the time and space dislocations of production in post-Fordism that some have suggested this technology could reverse (Marsh 2012; Anderson 2013; Economist 2012; BIS 2012; Rifkin 2016; Barnatt 2014; Thomas 2019). When products are 3D printed by the organisations these are mostly prototypes, and these are extremely useful for creative, design and engineering start-up businesses. And technological possibilities such as geometric freedom and product personalisation which characterise 3D printing technology are advantageous when used at early stages of product development, which can bring a competitive angle to many types of activities in London such as fashion, design, architecture etc.

I presented evidence on how businesses started from previous work in academic institutions or in other related firms, as well as due to individual's own interest and hobbies, and thus are deeply embedded in London's post-industrial economy and evolve from within the local economy. These new activities developed well in terms of job creation, turnover and profit when compared to other creative industries and start-ups in London. The most successful cases were in the digital/ software, design, product development and engineering sub-sectors, and had more people, good business plans, and flexibility in the working processes as well as providing an array of services to clients. Further to these business trajectories, this research found that despite challenges faced in getting funding for a new technology, many founders self-funded their businesses, or accessed government grants and European funding, as well as crowdfunding and using SME venture capital investments tailored to technology or digital businesses instead of more traditional banking support. The London location, and particularly co-location with technology businesses helped funding access.

The last set of findings supporting this chapter's conclusions on the value of fabrication technology in post-industrial urban economies relates to the processes of work and culture generated by the development, research, and experimentation with this new technology. Evidence highlighted several collaborative practices facilitated by the agglomerated environment of London, such as shared spaces, tools and machines, as well a social culture which facilitated knowledge exchange. Innovative activities associated with 3D printing technology in London relate to each other not in competition, but in collaboration, which can be argued to be a defining characteristic of post-industrial technology-related innovation.

These findings support an evolutionary perspective of how innovation happens in cities through existing work that leads on to more work (Jacobs 1969), and through knowledge spillovers across activities with a degree of similarity (Rigby 2013;

Essletzbichler 2013; Kogler, Rigby and Tucker 2013). A new (possibly disruptive) technology has been adopted and is generating growth through an evolution of spatially related activities. Space, both physical and social is critical to innovation in post-industrialism, as it sets the tone of the outcome of innovation through the types of existing economic activities and through the institutions and the cultural norms that help knowledge exchange.

These findings highlight a conclusion that we have not moved beyond post-industrialism, despite new material producing technologies that may have indicated otherwise. There is more knowledge and more creative innovation to be derived from material producing technologies in post-industrial urban economies like London. Economic progression relating to the new fabrication technologies like 3D printing can thus be conceptualised as an integration of disruptive productive techniques and methods – by the technology itself - with an incremental process of activity development. This is set within a post-industrial region's economic context, where the locality plays a role in the types of innovation outcomes when the technology is adopted, and the existing local attributes offer structures and practices that mitigate the risk of the disruption element. These conclusions build on the historic interest of economic geographers in evaluating and explaining the causes and processes of industrial development, and thus this chapter offers a theoretical contribution to both the evolutionary and the cluster literatures. The concluding chapter draws together the overall contributions of this thesis to empirical, theoretical and policy debates.

Chapter Eight

Conclusion

8.1 Introduction

The trigger for this research was the interest in adding resilience to post-industrial urban economies through a strategy of growing the share of manufacturing outputs and manufacturing employment in urban economies where knowledge, creative and financial sectors predominate. This strategy of economic diversification aimed to address persistent issues of post-industrialism and historic decline of manufacturing which are exacerbated during recession periods. These issues are notably the uneven distribution of development at local and regional levels (Martin et al. 2015), the difficulties with initiating innovation and growth in certain post-industrial regions, accentuating inequalities (Kersley and Shaheen 2014; Hackett et al. 2012; Scott 2007), and the creation of lower skilled jobs to replace those lost during deindustrialisation. For decades, these challenges have concerned urban policy makers and driven policy agendas such as creative cities which have been criticised (Pratt 2008, 2009b and 2010; Pratt and Hutton 2013; Hutton 2008 and 2009; Zukin 2010; Markusen 2006) for their inability to tackle (and sometimes even exacerbate) the problems they try to address.

Meanwhile, particular aspects of potential recovery from the effects of de-industrialisation have been a focus of scholarly research in economic geography, such as how urban economies grow generally (Duranton and Puga 1999) or in relation to diversifying their economic portfolio (Neffke et al. 2011). Scholars have also enquired about the nature and limits of diversification for resilience (Boschma and Martin 2007; Martin 2012) plus how and where innovation flourishes (Glaeser and Kerr 2009; Glaeser et al. 1992), even including specifically innovation in manufacturing production (Boschma and Frenken 2011; Neffke et al. 2017).

In this context of scholarly research on one side and previously failed urban economic regeneration policies on the other emerged the visions for an urban manufacturing renaissance in the recession post-2008. These visions became significant, adopted and marketed by policymakers and media (BIS 2012 and 2017; Tym and Lang LaSalle 2011; Cities of Making 2018; Marsh 2012; The Economist 2012; Brown 2015), research organisations (Sisson 2011a; Sissons and Thompson 2012) and a group of scholars (Rifkin 2011 and 2016; Rothkopf 2012; Nawratek 2017; Thomas 2019; Anderson 2013; Baldwin 2016). They were greatly helped by many recent developments in manufacturing technology, including the 3D printing technology which has been the focus of this thesis.

But these visions and policy initiatives remained disconnected from scholarly research in economic geography until very recently (De Propris and Bailey 2020; Laffi and Boschma 2021; Liao et al. 2017; Fraske 2022; Johns 2020 and 2021); not backed by comprehensive case studies, these run the risk of a similar fate to the creative city policies of the early 2000's. There were at least three problems with the proposition that an urban manufacturing renaissance with new technologies was capable of addressing de-industrialisation problems. First, the scale of the ambition and the nostalgic tone of the narratives proposed contrasted with my observations of city transformations, in terms of urban masterplans I am involved in working on professionally, and in terms of the actually emerging activities in London. Hardly any masterplan I have been involved with had any (let alone significant) space suitable for manufacturing, nor had I witnessed interest from developers, promoters or even local authority planners in providing for these activities. Second, there were no empirical studies or evidence to suggest that those strategies would be as successful as envisaged, nor any ideas on how to best guide, support and fund them. Third, there was no synthesis of arguments concerning these assumed (quite significant) production changes in theoretical terms to link either evidence or these visions to the existing analyses and literature on post-Fordism, clusters or evolutionary economic geography. Nor had economic geographers and urbanists developed insights into how to recreate growth and overcome uneven hyper-polarised development across different regions.

My aim in this research was thus to understand, theoretically and empirically, how technologically innovative material production permeates through a post-industrial city's economy and whether it can trigger an urban manufacturing renaissance, leading to economic diversification. For this purpose, I designed a cross-sectoral study of a case study of activities emerging in connection with 3D printing technology, and a sui generis methodology of analysis that could lead me to useful conclusions. I designed a specific combination of quantitative and qualitative methods (ranging from high level statistical business data to participatory methods) to fully understand these activities, and to be able to extract conclusions that could contribute to the scholarly body of knowledge on innovation around the new fabrication technologies and that could grasp meaningfully the processes of innovation I was studying. This aim was framed as three research questions that allowed me to draw supported conclusions: first 'What activities have emerged in London associated with 3D printing?', second 'How is the location of the emergent activities associated with 3D printing related to the urban context of London and its agglomeration economies?', and third 'How has the process of adoption of 3D printing technology contributed to innovation in activities across different sectors in London, and what advantage is it creating in this context?'

A cross sectoral design for the study allowed me to understand how material production, particularly with 3D printing innovation, is generating new types of activities in relation to the most prevalent sectors in London (and without material outputs), and to assess whether this could potentially bring about economic diversification. My findings have supported the conclusion that instead of reviving urban manufacturing, innovative fabrication using 3D printing is supporting abstract tasks, work processes and typical outputs of post-industrial creative and knowledge sectors, and sometimes even providing the trigger for new creative, knowledge activities without generating any material output whatsoever. They have also highlighted the social and economic factors' driving the location and success of innovation in post-industrialism, which my evidence suggests is unaffected by technological flexibility. This has implications for policy objectives directed at the regional dispersion of innovation. Arguably, post-Fordist geographies of production are likely to remain separated across regions with innovation concentrated in metropolitan areas like London, even if manufacturing technologies like 3D printing would facilitate other remote locations of activities. But these conclusions do not render support policies for digital fabrication technologies useless. Without trying to recreate the industrial revolutions of the past, (and discarding hype, utopian visions and jargon in favour of evidence-based intentions) urban policymakers can support innovation which emerges around fabrication technologies like 3D printing in post-industrial metropolitan areas to boost competitive advantages in existing knowledge sectors. My findings indicate that new fabrication technologies can have a positive impact on the city's economic competitive advantage and value creation, as they improve ways of working during the early stages of products, generate new activities with good turnover and above average profit, and encourage collaborative processes and shared spaces. In sum, they help with a particular type of diversification, that which is *related* to knowledge and creative sectors of post-industrialism, and which can contribute to continuing a positive cycle of growth.

In this concluding chapter, I will now reflect in more detail on the key findings discussed in the empirical chapters of this thesis (section 8.2). I then reflect on the theoretical and policy implications of my findings (section 8.3). I continue to present synthesised conclusions and reflections on production changes resulting from innovative manufacturing technologies and the ways in which material production is being more integrated in the predominant sectors of a post-industrial urban context as London (section 8.4). I reflect on why this research matters, and on its originality in section 8.5. Lastly, in section 8.6 I suggest some possible avenues for future research in support of these arguments, including building a wider range of case studies.

8.2 Key Findings

8.2.1 What Activities Have Emerged in London Associated With 3D Printing

My first research question inquired if the new activities emerging in connection with 3D printing technology were in fact atypical of, thus diversifying, the types of activities which emerge and get established in a post-industrial economy like that of London. This question could only be answered through finding out what the activities are and analysing them in relation to the dominant activities in the local economy, which within the post-industrial context is very layered (Ferm 2016; Ferm and Jones 2014).

My findings on the types of activities emerging in connection with 3D printing technology, their work, the structure of firms, clients and their links to other organisations point to activities related to the new fabrication technology of 3D printing forming yet another layer of the cognitive-cultural economy of London. They provide evidence for the first argument of this thesis: that the role of innovative fabrication technology in post-industrialism is to support abstract tasks, work processes and outputs of creative and knowledge sectors. Below is a detailed reflection on how the findings support this conclusion.

The first key finding on the nature of the activities studied (possibly the most surprising finding of all) is that most activities emerging and even listing themselves as 3D printing '*industry*' members are services, consultancies, knowledge and creative firms, whose work extends far beyond material production. Moreover, I found that a large number of those activities did not 3D print anything, and some did not even have a printer, preferring to outsource prints or not needing to print during their operations. This surprising fact revealed that sectoral diversification via manufacturing renaissance is not the outcome of the adoption of new fabrication technology in a post-industrial context. This main outcome emerged as part of my enquiries as to what tasks are the focus of the activities.

I observed a certain specialism in tasks and work processes, meaning that firms were focusing on only a narrow aspect of what they could do with, for or around this technology and perfected that process until it could be applied to as many sectors as possible. Moreover, activities were very cross-sectoral once a work process was established, which made traditional SIC classifications complicated to apply and ultimately unusable to analyse this type of innovation. Overall, what I noticed was that there was an expansion or added speed to what people did because of the 3D printing technology, leading to, for example, a new service or consultancy, a new software, or a new design possibility. All these were emerging in connection with 3D printing technology, but the innovation, in short, was not about material outputs but about work processes, thus knowledge, services, and creative work.

Further to this, when analysing the types of work being done by the entities, I observed that most work was prototyping, early stages of product development or consultancy services such as software design for other firms, design, or marketplaces. In sum, this technology was not about material outputs and final stages of production but from the outset was about advancing other sectors and product possibilities. This finding may however not surprise most academics, given the extensive body of works about how early stages of products are characteristic of post-industrial agglomerated environments like London (Jacobs 1969; Glaeser et al. 1992; Glaeser and Kerr 2009; Neffke et al. 2011; Duranton and Puga 2001). But these findings challenge policy assumptions that a new fabrication technology can trigger a resurgence of an urban manufacturing sector and resumption of goods production (Bryson et al 2013; Johns

2022) with potential to counterbalance downturns in other (typically post-industrial) sectors of a city's economic portfolio.

In getting to know the activities emerging in London in connection with 3D printing, I also found out about the people involved and the other activities with which they are connected. Evidence was once again revealing of similarities to a typical London knowledge and creative sector, as most people involved in these emerging activities had advanced academic qualifications or high technical degrees and maintained links to academia or to other similarly creative firms. Assumptions need to be revisited concerning the 'power' of new fabrication technologies to provide employment to low and medium skilled people who struggle to access the high value jobs and opportunities of knowledge sectors, or who have endured the negative impacts of de-industrialisation. Their skills are arguably less transferable to new activities emerging in connection with fabrication technologies than the industrial revolution visions supposed. Thus, other policy instruments such as training and re-education may be more effective at addressing low skilled unemployment and wage inequalities, rather than relying on creative activities, such as those documented in this study, to employ and train them on the job.

In summary, all key findings on the types of activities which emerged in London in connection with 3D printing support the first argument of this thesis that instead of reviving manufacturing and diversifying post-industrial concentration of services, innovative fabrication technology is supporting abstract tasks, work processes and outputs of creative and knowledge sectors. The characteristics of the activities, the types of tasks and work, the structure of activities and their outward links revealed innovation and emerging businesses not in manufacturing, but in the same sectors which are currently most present in the London context. Below I synthesize the findings on the spatial distribution of these activities across the city, and how they are shaped by and shape the space and the places where they are located.

8.2.2 The Location of Emerging Activities Associated With 3D Printing

Examining the location of emerging activities related to 3D printing technology in London and the reasons for their location choices is a key part of this study. One of the problems leading me to undertake this research was the observation that current city transformations did not always make much space available for new manufacturing units. And, another key motivation for producing this research was to understand the role of location in the new types of material production associated with cutting-edge technology, and how these technologies are changing geographies of production. This is undoubtedly the key contribution that this research brings to the scholarly literature (Liao et al. 2017; Gress and Kalafsky 2015; Laffi and Boschma 2021): that economic geographers need to attend to the analysis of the transformations and implications that these technologies have for geographies of production and for the economy of regions.

Furthermore, finding out about where the activities emerging in connection with 3D printing are located can provide new evidence on the key factors influencing the location of innovation, particularly as the technology which is the focus of my case study allows for greater locational flexibility – whether because it can be installed almost anywhere and is easy to transport and assemble, or because many activities, I found, did not really 3D print at all. So, this technology is a good case to evaluate the importance of location and its defining role in innovation.

With all this in mind, I located all entities I had listed and mapped them according to various groups and categories, and then overlapped them with existing (non-3D printing related) activities in London. I also investigated the reasons why they were located where they were, largely through detailed interviews. I explicitly challenged participants to reflect on their location choices, suggesting for example that participant activities could relocate to an outer borough such as Enfield, where they could rent bigger premises and reduce their current rent burden. However, I invariably obtained '*No*' for an answer.

A number of key findings emerged. First, it was surprising to learn about the considerable number of entities without physical location while, at the same time, those entities which could be mapped and visited were to be found in very central and clustered locations. Second, the socio-cultural identity of an area, its connectivity, and availability of (the right) people were key determinants of location. And, third, the global dimension of the chosen location and its detachment from the country-region geographies was evident.

The first key finding had an intriguing element - the fact that many entities were included in London lists, London databases or London events but did not provide any kind of physical address either in London or elsewhere. The reasons I found for this had to do with privacy, with the overlapping of enterprises with other jobs or other firms, and was also a marketing tactic for businesses which operated online only and where home-like addresses were said to put off clients. But my research was still able to progress and generate sufficient locational data to support reliable findings on physical location choices.

From the entities which could be mapped, I concluded that 3D printing related activities are overwhelmingly located in the central core of the city. They are situated in proximity to other typical post-industrial metropolitan industries belonging to the knowledge, services, financial and creative sectors. The activities here in the study are clustered and agglomerated in areas where business rents are not the most affordable, but where there are agglomeration economies resulting from concentration, particularly linked to people's time. And, I found that one of the strategies adopted by the entities in order to be located where they are is to use extremely small premises.

I have found through the detailed analysis of the locational choices of my case study activities that the main reasons why activities were located so centrally and were so clustered is linked to what they get from their immediate context in terms of cultural identity of the area, connectivity, and ability to attract new employees. The area's identity, such as for example the well-known silicon roundabout zone in Old Street, influences how businesses could position themselves socially and commercially to their clients and to their business partners or funding opportunities. This is crucial in attracting new employees, generally young and highly skilled people who, according to my participants, aspired to be employed in vibrant areas of the city centre for all the leisure, retail, public spaces and occasional meetings which a city centre agglomeration can offer. Connectivity was another key factor in location choices, itself a factor linked to both the identity of the area and the ability to attract people, as well as of course facilitating reaching out to other regions and travelling abroad for business development.

These findings are as expected by most academics analysing the location of innovation and early stages of product development (Jacobs 1969; Duranton and Puga 2001; Henderson et al. 1995; Storper and Venables 2002), which has long been argued to locate in city centres to benefit from the agglomeration of other related activities.

But my findings make an original contribution in showing that even a material producing technology of significant flexibility did not subvert that characteristic, in contrast with some visions and policies which expected this technology to have the power to help innovation flourish in outer or suburban zones, more evenly distributed across geographies. 3D printing technology can be set up anywhere and occupies a relatively small space – only slightly more than a 2D desktop printer in most cases. Many of these activities operated only online, and nearly half did not even print anything or own a printer. But my findings show that they were nonetheless located in the central zones of London, clustered with other creative and knowledge industries.

In line with these results, I can argue that technology alone does not influence or change the geography of innovation - analysed through the case of innovation involving fabrication technology - and that social and economic factors are more significant determinants. The location of innovation is determined by the socio-cultural identity of an agglomerated area, by its ability to attract the right people, and its accessibility factors. This has implications for processes of creating growth in regions and for reversing spatial development inequalities, pointing to investment in those factors alongside any investment in the technology as such.

Lastly, I have found that many activities in this study adopted a global outlook, and that London maintained a knowledge control function in the process of expansion, characteristic of production distribution in the global post-industrial value chains (see for example research by Crescenzi et al. 2020). Frequently activities would outsource repetitive tasks to larger outer London production firms, or expand their creative activities to other metropolitan areas across Europe where highly educated people could be recruited. Conversely, the activities in the study were very disconnected from the outer London 3D printing technology activities, reported to be larger firms, except to deploy larger batches of production. The location of innovation, and the distribution of production across geographies was not a simple technology narrative, but a socio-economic, cultural and an evolutionary one.

These three sets of findings support the arguments that technology alone does not change the geography of innovation. Innovation as a process can be thought of as an outcome of the advantages generated by agglomerated environments of the city centre, defined in many ways by the economy of the present and recent past of that place, despite flexible and portable technologies, online possibilities or not using material outputs of the technologies at all. Prompted to consider changing to an outer

London borough to have more space with more affordable rent, participants who used portable machines maintained that they could not succeed to attract clients, funders, or recruit employees away from the city core's recognised creative, tech or knowledge districts.

These locational findings complement the first argument of this thesis, which is that innovative material-producing technology is part of the knowledge economy, and that new fabrication technology is supporting abstract tasks, work processes and outputs of creative and knowledge sectors, rather than reviving an urban manufacturing sector. The findings about the location of activities in the study reflect that they are characteristic of post-industrial knowledge production. The conclusion points away from a revolution or a new growth wave in a cyclical interpretation of economic progression, as well as away from a substantial reshaping of the spatial expression of production or the distribution of activities unevenly across regions at the strategic and city or local scales. These findings point more towards another layer of post-industrialism where concentration of activities remains key and city centres remain places of the early stages of cognitive production, in connection with offshore areas of late-stage production. A fabrication technology per se does not erode the weight of regional economic history in shaping innovation, but this study finds that it can accelerate evolution.

8.2.3 How 3D Printing Technology Contributes to Growth and Competitive Advantages in London

In addition to enquiring about the types of activities emerging in London in connection with 3D printing technology and their location, I sought to understand how the technology was being explored and adopted within the context of knowledge and creative industries, and if it created any benefits for the economy in London. My research thus expanded to finding out how 3D printing technology helped establish new activities, whether the new activities were successful, how they were established and funded, and what new processes of work they introduced. Plus, it was critical to obtain evidence on what is particular about this technology as an innovation trigger, and if there is a rationale for policy supporting the development of digital manufacturing technologies in a post-industrial context such as London.

As it became clear during the research that the fabrication technology of 3D printing was not generating urban manufacturing or manufacturing renaissance (the starting point of my research), the next logical question became whether and how this technology contributes to the growth and the creation of value in this context. On reflection, this research can have a wider policy impact, if it enhances understanding of how a new fabrication technology aids a local economy in a context like London.

Based on the evidence found, I conclude that the support of manufacturing technologies through research, business and application development in a post-industrial context like London is advantageous as it creates value in a post-industrial urban economy, despite it not creating a manufacturing revival. This is fundamentally because its technological possibilities help in creating an environment of related diversity in London (Henning and Boschma 2011), which is an economic environment where more innovation is facilitated through the meaningful connections between people and businesses which facilitate the exchange of knowledge, and which tend to be economies of greater economic resilience (Martin 2012).

My key findings in support of these conclusions are, first, that this new technology is very suitable for many new activities working in early stages of product development, second, supporting better performance of the emerging activities, and, third, that work practices around material production involve collaboration which is facilitated by an agglomerated context of a city like London that, despite online collaborations, involve a great degree of social proximity. These constitute good reasons why 3D printing technology can contribute to the London economy.

I have found that 3D printing technology generates a range of new activities set around new software, new materials, new products and new work processes, as people experiment with it and develop its applications. For the most part, the activities are centred on early stages of product development, which has already been shown to be most advantageously done in cities centres like that of London (Duranton and Puga 2001). The 3D printing technology presents many characteristics suitable for it to be used at this stage of work such as low cost of low batch production and fast testing of designs which is particularly relevant for creatives in fashion, engineering, product design, etc, plus product personalisation possibilities and geometric freedom. Some of these characteristics of 3D printing helped start-up businesses survive. This was the case for designers and engineers for example, who could have their product options tested quickly and more cost-effectively than using traditional model making, for example.

Having created a new data base of 3-D printing related activities from scratch, I analysed the activities' performance through their inception, their brief evolution, and their financing. I found that, overall, the activities emerging in London in connection with 3D printing have above average job creation, turnover and profit rates when compared to other creative industries in London. I found out that these activities were relatively new (as is the 3D printing technology itself) and generally small organisations whose starting stories involved taking hobbies more seriously, expanding academic projects or spillovers from other activities. And I found in this research that they were agile enough to find a combination of solutions for remaining in business – such as crowdfunding, venture finance and bootstrapping, despite the novelty of the technology. The good performance of the activities compared with other start-ups and with other creative industries is another reason why it can be concluded that 3D printing technology adds value to the London economy.

The last finding supporting the conclusion that there is value to be derived from the promotion of a technology like 3D printing in a post-industrial urban economy is that the adoption and technology development process is collaborative in nature. An emerging technology brought, for example, more situations of collaboration, both physically and virtually, involving spaces and equipment, frequent meetings and online sharing. This can contribute to a region's competitive advantage in a context such as London where collaboration is facilitated by its densified environment, and where social spaces can be constructed physically and virtually. Complementarity amongst activities can make tacit knowledge exchange very fruitful.

In conclusion, findings provide evidence that the promotion of fabrication technologies such as 3D printing in places like London may usefully be incorporated within policy targeting the creation of value and growth through innovation. However, policymakers must be realistic and evidence-backed about the nature of the positive outcomes, as this research finds those to be different from current policy aims. The positive outcomes are that this technology facilitates the creation and growth of activities with good performance, notably activities of the kinds that thrive in this agglomerated environment, including creative, knowledge organisations employing highly educated people who collaborate and share resources in the centre of the city.

In this way, this technology can contribute to London's economic advantage and growth.

8.3 New Fabrication Technologies and Innovation in Late Post-Industrialism

This research investigated innovative material production in the current post-industrial context through the case of activities which emerged in London in connection with the 3D printing technology. The results present several theoretical implications for a contribution to scholarly understanding of innovation dynamics in post-industrial urban economies: the need to move beyond associations between new fabrication technologies and historic manufacturing revolutions; leading onto a different understanding of material production in relation to knowledge and creative production post-industrialism, not defining a standalone major manufacturing sector, but embedded within activities whose outputs are mainly abstract. Acknowledging that these digital fabrication technologies do not involve a move past post-industrialism, but rather that a series of new technologies may be evolving post-industrialism as the geographic distribution of production within local economies, rendering obsolete models of sharp and disruptive pathways to innovation and growth.

These theoretical considerations and the empirical findings of this research, support a justification (and expectation) for why urban policy would be well advised to continue to promote advanced manufacturing technology research and development in post-industrial cities, to add related diversity to the urban economy, as discussed in Chapter Seven. Additionally, these theoretical implications open the door for a new framework for policy, one where a sharp divide between material production associated with manufacturing sectors and their respective sectoral policies, versus abstract production associated with knowledge and creative sectors and their respective policies is not relevant. Rather, a more integrated approach with potential distance from the notion of sectorally-framed policy making may be more effective. This thesis suggests that this historically constructed divide may be replaced by a nuanced approach whereby material outputs, particularly related to innovative fabrication (such as the 3D printing case study), are better conceptualised as embedded in knowledge and creative production of urban post-industrial economies. This in turn can lead onto combined policies allowing, for example, for planning more flexible spaces and premises, overcoming manufacturing prejudice, creating more shared funding opportunities, and ultimately towards even a new logic of classification of economic activities from the point of view of their degree of innovation and their multi- sectoral reach regardless of the nature of outputs.

Considering the clear grounds for the need to move beyond ideas of a New Industrial Revolution as the rebuilding of manufacturing production in the traditional historical sense, even if with new disruptive technologies, this research challenges the arguments of existing literature and policy promoting manufacturing renaissance in urban centres like London. This thesis offers evidence for scepticism about views that fabrication technology is triggering a significant change in the course of industrial capitalism, a new revolution in production (Marsh 2012; Sissons and Thompson 2012; Anderson 2013; Tym and Lang La Salle 2011; Cities of Making 2018; Rifkin 2011 and 2016; Thomas 2019).

This research offers a perspective on post-industrial production which is original and unique: the understanding that material production can be embedded in knowledge and creative production, bridging the divide between goods and services in framing production and sectors. This is because of the possibilities created by new fabrication technologies such as speed, flexibility and geometric freedom. Unlike in the past, when material outputs defined a sector of production on its own – it defined manufacturing, at times the largest productive sector of London - now material outputs can be complementary to knowledge and creative production. This is why it is so difficult to attribute SIC codes to the activities which my study has followed.

This study highlights that innovation in late post-industrialism is based not solely on an innovative technology, but on the existing spatial economic arrangements of an area. Innovation happens in agglomerated contexts and technology enables related innovation, not necessarily in a disruptive manner (even if the technology is considered disruptive due to its technical modus operandi). And, as there is a body of literature in evolutionary economic geography that concerns itself with the degree of relatedness between activities in regions (Rigby 2013; Essletzbichler 2013; Kogler, Rigby and Tucker 2013; Jacobs 1969; Henning and Boschma 2011; Glaeser and Kerr 2009; Boschma and Iammarino 2009; Neffke et al. 2011), this case study provides evidence of the need for a level of relatedness for innovation, even in the presence of a disruptive technology. Technology, such as 3D printing, can be a key element that enables more related innovation and contributes to a fertile environment for a continuous cycle of innovation. Related diversification can (and does now) cross the historic divide between manufacturing and its material outputs, versus knowledge and creative sectors and their abstract outputs.

On the influence of the context and places in innovation, I have added new evidence to literature (Jacobs 1969; Duranton and Puga 2001; Storper 1997; Scott 2000; Foord 2012; Landry 2008; Florida 2002; Schuster 2002) concerning itself with the value of city centres for innovation and of the influence of place identities on the types of innovation flourishing there. My study found an emphasis on the social culture of the area determined by its economic activities plus its building stock and projected culture (i.e. silicon roundabout in Old Street; creative and artistic industries in Hackney) relating to the types of innovation that take off and to activities settling there. In this case study, the location choices of innovative activities were not dependent only on the technology which, in this case, could have been quite mobile and flexible, but on the social and cultural attributes of districts. Neffke et al. (2011) have already argued that innovation emerges in relation to an area's more established activities with which new activities can have some commonalities, and my study adds that if an area has a certain specialism or branding this attracts even more of that co-location and creates more of those benefits. This is more accentuated in a post-industrialist context as people move across distinct but related activities even more in knowledge industries than in routine task industries of the past as discussed in a recent paper by Crescenzi et al. (2020).

This thesis' perspective on the importance of collaboration in contemporary innovation and technology adoption adds to a discussion on the effects of agglomerated environments for positive externalities and growth. Scholars like Porter (1990) and Jacobs (1969) observed that agglomerated environments of smaller firms, as opposed to monopolies of larger firms, have greater ability to generate positive externalities; there is thus some evidence base for spatial policies that promote economic concentration of multiple activities. However, they differ regarding the mix of activities that would most benefit from the agglomeration, as Porter (1990) saw further advantage in specialised clusters of firms within similar sectors, while Jacobs (1969) argued that diversified activities in proximity would be most advantageous for growth. Regardless of this (key) difference, both have argued that competition between firms is the means by which they increase productivity and speed work; in Porter's perspective firms are surrounded by direct competitors, are aware of them and thus adopt technology and innovate, while in Jacob's analysis branching out and outsourcing work in agglomerated environments creates niches of production which triggers further innovation. But in this research, what I have found is that it is through collaboration that innovation continues from within the local economy, to improve and to speed creative production. The challenges of adoption of a new technology such as 3D printing have been many times a catalyst for further and for more open collaboration, as I observed when I joined meet ups for example.

In drawing to a conclusion, given all these points, my research presents an evidence-based theorization of the process of innovation involving new fabrication technologies in a post-industrial context – that material production is embedded in typically post-industrial sectors of abstract outputs working primarily on early stages of products and on intensive services. This cuts across historic divides between manufacturing and services, renders narratives of urban manufacturing revival inaccurate, and calls for more effective combined policies and activity classifications. These economic policies could thus have more wide-reaching effects, across various sub-sectors. In this way, this research contributes to our understanding of the present economic and urban processes of the knowledge and creative sectors, and of the actors involved and their dynamics. Further, this research adds to our knowledge on the role of metropolitan spaces in innovation, which is one of influence over the types of innovation and activities emerging and an enabler of collaborations.

8.4 Dismissing the New Industrial Revolution

For many, there is a great expectation of a Fourth Industrial Revolution or Industry 4.0 accelerating growth whilst reinstating low-skilled jobs and bridging income inequalities (Kersley and Shaheen 2014; Hackett et al. 2012; Scott 2007) and uneven development (Martin et al. 2015; Ernst and Kim 2002) which grew out of de-industrialisation in Western Economies. But what emerges from this thesis and its evidence is that some of the narratives around the digitisation of industrial production are as neo-liberal in ethos as the causes of the problems they aim to address. Often, grey and even scholarly literature (refer to Chapter Two) is nothing more than abstract suggestions and futuristic scenarios around the next popular concept for cities (making good use of eye-catching expressions) that influence policies away from tackling the roots of those problems such as lack of education investment for unemployed adults, unfair taxation and wealth distribution. There is a lack of evidence and an excess of confusing, contradictory, scaled-up imaginaries and visions. This is not dissimilar to what had happened when 'creative cities' were theorised and creative classes were claimed to be the new drivers of growth, often presented as solutions – with public funds - for shrinking metropolia, losing industries and battling unemployment.

This thesis dismisses the theory that a revolution is linked to new production technologies and digital processes of manufacturing production. Unsubstantiated by evidence, most literature presenting a revolution needs to consider the role of space in maintaining the continuity of economic links, social relations and productive cultures. It side-lines evolutionary pathways to growth, favouring a disruptive view of capitalism progression, more akin to a Schumpeterian theorisation of creative destruction in industrial development. But in doing so, it mischaracterises digitalism and information technologies as newer than they really are because they are already factors in knowledge production in post-industrialism. Considering that new manufacturing capitalism will substitute paper capitalism (Mosconi 2015) and manufacturing will increase productivity in Western economies, whereas services and knowledge industries can no longer do so, is a radical theory. It ignores that so many high-growth regions rely on knowledge, finance and services, and fails to acknowledge that new digital productive technologies can also add substantial productivity to services – see, for example, the concept of servitization by Lafuente (2019), which is the expansion of service analytics linked to data on products – the Internet of Things, or this thesis' findings on the nature of the activities related to the 3D printing industry in London – software writers, designers, consultancies.

The idea of a smart factory, for example, as a place of production where automation replaces human labour in large part or entirely (Osterrieder et al. 2020) and which requires extensive use of information technology (de Paula Ferreira et al. 2020) implies that there will be plenty of work in systems, knowledge, services, energy, management, policy, design and engineering to turn that into actual operations. That still means plenty of abstract work, if not more than what factories require now. Production controlled digitally and in real-time (Zheng et al. 2020; Kumar and Lee 2022; Wanner et al. 2023) implies extensive networks, software and communications. As shown by the case study of this thesis, many new activities related to all the technologies necessary for smart factory operations will start to emerge. And they will rely on highly educated labour (Tavassoli et al. 2015) – like the founders and employees in the case study of this thesis - and need to be located in city centres to capture the talent they need. This will require extra training of people and higher education degrees, or what some hype and scholarly literature has already nicknamed Education 4.0 (Grybauskas 2022). If one considers the findings of this thesis, what can be anticipated is the growth of knowledge-intensive, creative and service activities and jobs of abstract outputs as a result of smart factories. The negative perspectives of job disappearance (Acemoglu and Restrepo 2018; Starr-Glass 2019) miss that with the possible digitalisation of value chains (the smart value chains described by Prause and Atari 2017) and the mass customisation of products (Barnatt 2014; Marsh 2012) – which is more realistic to assume for high-value products rather than scale up to everything - will come the increase of knowledge-intensive jobs to set that all up.

Moreover, on contradictions around Industry 4.0 theories, it is hard to imagine why significant material production will relocate to close to cities and consumers in small units or even homes (Bellandi et al. 2020; Perekwa et al. 2016; Bryson et al. 2019) just because the technology is more flexibility and there will be faster communications and more information if it all can be automated as in some descriptions of the future of manufacturing (Osterrieder et al. 2020). Or why would consumers fabricate anything at home? If production can be automated, why would it take up space at home? It is more complicated than that., as shown in the case of 3D printing activities. It has been found that production requires specialised personnel to operate systems or to finish the product to a good quality standard; not all is fully automated – the 'human' tasks are not the fabrication but the control, design and management. In either scenario, if systems become faster and better connected, people may use their time on more leisure or even social networks, and rental pressure may accentuate as a result of more activities needing to locate centrally to attract talent. Knowledge-intensive activities require urban locations (van Winden et al. 2011), but automated factories may be set up elsewhere. Still, the early stages of production, testing, and post-production will be urban. The perspective advanced by Johns et al. (2021) or De Propris and Bailey (2020) of regional supply chains composed of a mix of urban and suburban activities seems thus more plausible, and only in this way, perhaps, may more material production will be in Western economies. When authors describe industrial urbanism (Hatuka and Ben-Joseph 2022), they refer to research, perishable goods and knowledge-intensive activities in cities, which are already quieter, cleaner and need to be near markets.

The theory that because of Industry 4.0 technology, production will be re-shored to Western economies, which will have many material outputs again, is also challenged by this thesis. My findings also point towards very little, if any, material production of final outputs other than material production supporting creative and knowledge tasks. When firms needed to scale up, they approached other regions or countries, and proximity was not a factor. Evidence shows that the location of new activities overlaps with local areas of already great economic strength in the city centre but that those do not focus on final outputs. It should be pointed out that emerging research by other scholars with empirical data on this subject, in both social sciences and management fields, finds similar conclusions to my own and start to dismiss theories of reshoring and breakthrough with post-industrial informationalism – Chiarvesio and Romanello (2019) and Cohen et al. (2018) find that reshoring is not happening as much as technologies are being implemented in offshore locations as well, and growth of western industry is balanced by other relocations and production location decisions processes relate to complex factors other than technological possibilities; and Busch et al. (2021) and Laffi and Boschma (2021) find a strong relationship between Industry 4.0 implementation and knowledge and ICT industries, including co-locations within European regions.

As when creative cities' arguments shaped city policies, it is concerning how this new trend of theories is guiding policy and attracting funds to address spatial imbalances and wage inequality. For example, in Britain, the Levelling Up policies include industrial policy and in Europe, public funding is being directed to these technologies away from reskilling people, for example, or supporting the remaining productive industries, which in some regions face rent threats – see for example how much industrial land has been lost in London boroughs to housing.

A better approach would be a spatially focused industrial policy rather than a technology-focused one, acknowledging and linking regions' firms, institutional structures and characteristics of the local population, their skills and occupational and productive cultures to level up. This research offers good evidence for an alternative justification (and expectation) for policy to promote advanced manufacturing technology in post-industrial cities – not because it will revive urban manufacturing or initiate a new industrial revolution, but because it can contribute to the creation of an environment of related diversity (Henning and Boschma 2011), one which is found to trigger further growth. Material-producing technology, like 3D printing - my case study

- and possibly many other digital technologies that change production processes, can aid the early stages of product development and support knowledge-intensive activities. Further, the emerging activities using this technology in knowledge and creative fields of software, prototyping, design and engineering were found to have higher than average growth - turnover, profit, and jobs.

Policy should thus be regionally tailored – for example, in a global metropolitan area like London, the focus should be on the technologies that best aid knowledge and creative sector industries and research with highly educated labour. This needs to run alongside (and not instead of) support for marginalised and under-recognized productive activities in the metropolis, which are often threatened. In other regions, for example, for levelling up, policies should instead focus on existing, perhaps larger productive industries and digital production applications to benefit those whilst upgrading people's skills to interact with automation. My findings suggest that policies focusing on new innovative material production are not substitutes for policies to upskill people of lower wages who remain detached from knowledge sector opportunities. Furthermore, they are not substitutes for spatial policies directed at counterbalancing market forces through spatially redistributing economic activities to areas outside the city centre.

Promoting technological innovation around material production in post-industrial Western regions should thus reflect how these technologies are used and adopted in evolutionary continuity and related to the region's economic portfolio, workforce composition and productive culture.

8.5 Reflections on the Originality of this Research

This is an original analysis of the nature of innovation in the current context of new production technologies in post-industrial urban settings, and necessary research given the proliferation of speculative views on the possibilities opened by advanced manufacturing technologies. This research is amongst the first comprehensive case studies so far on advanced manufacturing technology adoption within a post-industrial city context from an economic geography point of view.

The originality of this work involves thus many aspects, such as the design and the methods of the research, plus its empirical focus, as well as linking the subject of a new fabrication technology to the theoretical body of work which has contributed to our understanding of post-industrialism. Below I reflect on each of these aspects.

Regarding the research design and the methods used in this research, the originality lies in being a cross-sectoral study which is a result of the proposition on diversification being queried. A horizontal study following a technology rather than a sector or an industry is not a common approach in the range of case studies in the literature on post-industrialism. Further, the way my research adopts many combined methods including a quantitative element with data examined statistically plus a qualitative, more participative, aspect to allow insights on firms and people to emerge in an organic way is also original and uniquely related to this technology case.

This research is also original in its empirical focus – material production with the use of advanced manufacturing technology. This research starts to fill the gap in evidence relating to uptake of advanced manufacturing technology, as there are very few case studies in geography, planning or urban studies literature on activities adopting 3D printing technology (Busch et al. 2021; Laffi and Boschma 2021). With policy and even scholarly literature promoting the idea of a manufacturing renaissance based on these new technologies, this study is thus an original and important contribution to the understanding of the effects of this technology on production and economy. This study thus provides an evidence-based conclusion on how advanced manufacturing technology can contribute to growth and the creation of value.

This work will matter to scholars, and hopefully also to policymakers and media outlets because my main arguments challenge the views that a new industrial revolution is about to unfold. It also brings into question many (I argue ungrounded) views for a return to craft or boutique manufacturing, for a wider urban manufacturing revival or for on demand local production with the aid of new manufacturing technology. For policy makers, the focus of my enquiry provides a clear shift from both the 'hopes' for making and makers to revive manufacturing in post-industrialism, and the justification once again (after many arguably mistargeted Creative City policies) of the continuation of neoliberal agendas with respect to city regeneration. The research contributes instead to a better understanding of the role of material production with advanced technologies – like 3D printing - within post-Fordist urban economies like that of London. Innovative material producing technology like 3D printing is not irrelevant - much the contrary. My research not only challenges widely held views on this topic, but also provides an alternative rational for supporting manufacturing technology in an urban context: because fabrication technology certainly changes and speeds up the way many things are done in knowledge and creative sectors, and aids how work processes and organisations are arranged, but the changes are not as radical as some may have expected. Thus, I propose that policy continues to fund or support the development, research, and implementation of advanced manufacturing technology in order to enhance sectors of abstract outputs such as knowledge, creative, digital and services characteristic of post-industrial economies. Such policies are also recommended because the processes of innovation and of adopting a new technology fostered new collaborations and knowledge exchange opportunities, which are helped by this context where related activities spatially agglomerate.

Lastly, regarding this research's engagement with a theoretical body of work, its originality lies in refocusing the debate in post-industrialism *on the present*, more specifically in continuing to move from a narrative on post-Fordism and the transformation and replacement of manufacturing industries for services, knowledge and creative industries into an understanding of the nature and processes of innovation within the knowledge and creative sectors in association with various emerging digital technologies perpetuating networked and essential very socially-framed ways of increasing growth. The focus is on the most recent changes in ways of innovating within these sectors, with the evolving and emerging information and communication technologies *plus* new available fabrication technologies which help to generate more knowledge, continuing to act upon knowledge, as the driver of capitalist economic evolution.

8.6 Future Research

While my research focused on the new emerging activities in connection with the 3D printing technology, further research could investigate the role and adoption of this same technology in existing activities within established firms. This potential future study could be designed either horizontally across multiple sub-sectors as my own study or focused on specific sub-sectors. Both approaches would help to assess whether there is an argument for supporting manufacturing technology in existing activities as well as in new enterprises, and in what ways it may contribute to innovation in established knowledge and creative organisations.

Besides this study, the same premise of diversification of post-industrial economies with technologically aided manufacturing activities could be investigated in a different post-industrial context located outside major metropolitan areas, for example in a suburban de-industrialised area or in a smaller city or town. The same problem of loss of manufacturing and over predominance of knowledge intensive activities has been highlighted for the U.K. as a whole (BIS 2012)[62], thus the same enquiry is pertinent. For this approach an equally horizontal, cross sector study would need to find out about the emergence of activities related to new fabrication technologies. This study is also necessary as many other towns or cities have had the problem of how to recreate sustained growth and how to initiate innovation. And, as seen in literature and media which have influenced my own research, advanced manufacturing has also been proposed as potentially beneficial for smaller cities, towns and hinterlands to contribute to economic resilience (Pike et al. 2013). Within my own research a brief mention of participants' views on the non-metropolitan industry entities was included in the empirical chapters when the information gathered contributed to analysis of the findings. I also searched for the presence of activities emerging in connection with 3D printing in other contexts, but have concluded that such literature is still inexistent and for understanding to progress, a database of activities would have to be constructed just like I had to construct at the start of this study. My research therefore lays a foundation for more empirical studies on innovative material production around 3D and other emerging technologies. Innovation in this field is significant, and it may be pertinent to compare findings in future research with those of this study.

Additionally, while gathering data in my research I participated in groups for meetups such as those in Romford or at the City Hackspace. Based on my observations there, I suggest that more research, perhaps of a more ethnographic or sociological

[62] According to the BIS (2012) knowledge intensive industries accounted for around a third of UK output and a quarter of total employment in 2011. By comparison, manufacturing contributed just over a tenth to UK output and slightly less to employment, having been in continuous decline since late 1970s. This shift has been marked by the proportional growth of services, creative industries, professional services, education, health and construction as the U.K.'s population aged, education levels increased and the country's export market opportunities expanded in these sub-sectors.

nature, could be done on these groups to expand our understanding of the role and the construction of social spaces like the makers' framework, which are important knowledge exchange spaces. The purpose would be twofold: to add to our understanding of these practices and their social spaces as there is not much in literature yet, plus to articulate their motivations, backgrounds and actions with the outcomes of their work and reflect on their power in sharing and shaping knowledge. This research could, and should, not be restricted by the fabrication technology theme of my research, as these groups – the Makers Movement, or the Hackers revolve around other matters.

Lastly, it is necessary to continue to understand the gap between policies destined to promote urban making, material production, maker spaces, etc in London and the reality of practices and innovative activities, so that policymakers can design the right instruments to achieve the right outcomes. Transforming the framework of separation of economic data between goods and services, and between manufacturing and knowledge sectors, is recommended, and would be a significant overhaul of how most industrial policy is structured. Further research should assess the impacts of a new integrated framework approach of material production embedded within abstract production for the design of various urban, spatial and industrial policies.

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http://nexusstudios.com/vr-studio
http://rpplatform.com/
http://thepolyflossfactory.com
http://vertexmodelling.co.uk/
http://wonderluk.com/
http://www.3ddc.eu/
http://www.3dlifeprints.com/
http://www.3dprinteros.com/
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http://www.3dprintuae.com
http://www.altergaze.com/
http://www.base-models.co.uk
http://www.cavendishimaging.com
http://www.cd-writer.com/
http://www.chalkstudios.co.uk/
http://www.cinterdesign.com/
http://www.cocoon-networks.com/
http://www.createeducation.co.uk/
http://www.croftam.co.uk/
http://www.darksidestudio.com/
http://www.dawoodandtanner.co.uk/
http://www.digits2widgets.com/
http://www.ecommerceexpo.co.uk/
http://www.electrobloom.com
http://www.explainingthefuture.com/
http://www.fabbaloo.com/
http://www.fablablondon.org/
http://www.fundaciocim.org/en/recerca/fabricacio-additiva
http://www.imeche.org/contact-us
http://www.julianhakes.co.uk/index.html
http://www.letablilondon.com/
http://www.makerbot.com/
http://www.materialise.com/
http://www.michelebadia.com/
http://www.michelebadiashoes.com/
http://www.nickervinck.com
http://www.openbionics.com/
http://www.openspaceagency.com/
http://www.printhub.london/

http://www.sculpteo.com
http://www.shapeways.com/
http://www.silviaweidenbach.com/
http://www.solid-scape.com/
http://www.stratasys.com/
http://www.thingiverse.com/
http://www.ucodo.com/
http://www.wahootifandango.com/
http://www.whitemaqui.com/
https://3dprintedjobs.com
https://3dprintingindustry.com/news
https://angel.co/chorogenesis
https://en.wikipedia.org/wiki/WonderLuk
https://grow.am
https://ultimaker.com
https://wonderluk.com/
https://wtvox.com
https://www.3dhubs.com/
https://www.3dhubs.com/users/ianadan
https://www.coolcomponents.co.uk/
https://www.digitalforming.com
https://www.digitalforming.com/Home/Technology
https://www.fuel-3d.com/
https://www.imperial.ac.uk/advanced-hackspace/
https://www.myminifactory.com
https://www.myminifactory.com/users/Michele%20Badia
https://www.peckhamlevels.org/
https://www.re-work.co/
https://www.stratasysdirect.com/
https://www.the3dprintingassociation.com
https://www.wevolver.com/home/
Impossible Gears Steampunk / North East Steam Society
Infection Music
Institute of Physics
Jewellery Making
Junkcraft
Just Add Sharks
Kitronik
Laserlines.co.uk
Leeds Hackspace
Leeds Hackspace Ubercube
Little Printmakers with Dabble Dabble
lizciokajlo.co.uk
Lnyx3d.org
LoveScience
MadLab
Make Your Own VR 3D Machine From Scratch
Maker Space
Maker Space – Penguin Race

Mcortechnologies.com
Media Molecule ‘Dreams’
Metavurt Ltd
Mirobot
Mitch Altman – Learn To Solder
My3dtwin.com
Nesta/Make Things Do Stuff
Newcastle University: School of Electrical and Electronic Engineering
Noisy Toys: Audio Assault Buggy & Bass in Your Face
Northumbria University Health and Life Sciences
Northumbria University: Department of Physics and Electrical Engineering
Nottingham Hackspace
O’Reilly
Paper Jam Comics Collective
Paw Tread Studios
Paynetech
pcDuino based Home Automation
PiKon – 3D printed, Raspberry Pi powered telescope
pi-top | CEED Ltd
Printrbot.com
Rapide-3d.com
Ray Phillips Sculptor/Prop Maker
Rebel Legion UK
Red Robotics
Remap
Rigid.ink/
Robo Challenge
Robosavvy.com/site
Robotical
Rubbish Puppets
SAM Labs
Sculpteo.com/en
Selassi.com
shapefactory.com
Shapeways.com
Sharebot.it
Sheffield Hardware Hackers and Makers Hackspace
Sicnova3d.com
Sketchfab.com
Smartfriendz.com/en
St Cuthbert’s Catholic High School
Sticker Forge
Stratasys.com
STU-ART Aviation Furniture ltd
SUN-Dress for the Yellow Giantess: Space Agency
Superpants
Suzanne Jewellery
Sweet Surprise – “Make your own sweet cone”
Taxidermy

The Crafty Robot
The Curious Electric Company
The HEdWorks Project
The Jam Jar Collective
The Raygun Consultancy
The Ultimaker CREATE Education Project
The Wall of Enlightenment
Theo Lasers
Things that Seg
Think Physics: Light Wall
Think Physics: Technology Wishing Well
Tingbot
TITANOX – Water is the best fuel
TOG Dublin
Toy Hacker & Creative Stitch
UAV Monkey and Drone Ops
Ultimaker.com
Underwater Robotics
Vacuum Former
Velleman
Verbatim-europe.co.uk
Waspproject.it
Whole Body Interactions: Non-Exercise Activity Thermogenesis (NEAT)
wonderluk.com
wrks24.com
www.3dealise.com
www.3distributed.com
www.3dlifeprints.com
www.3dprintshow.com
www.3dprint-uk.co.uk
www.altergaze.com
www.banneya.com
www.betaty.pe
www.cadventure.co.uk
www.chorogenesis.com
www.color.co.uk
www.curvoxels.com/
www.danielwidrig.com
www.ebpgroup.com
www.econolyst.co.uk
www.ellis-miller.com
www.frippdesign.co.uk
www.gambody.com
www.hobsstudio.com
www.inition.co.uk
www.jonespartners.eu
www.kidesign.org
www.lee3d.co.uk/
www.luma-id.com

www.makie.me
www.materials4me.co.uk
www.modla.co.uk
www.pixellounge.co.uk
www.printme3d.com
www.printtopeer.com
www.proddesigns.co.uk
www.propsplanet.com
www.st3di.com
www.tarsus.com/
www.think3dcad.com
York Hackspace
zetoff.com
Zmorph3d.com

Appendix A

The Cases Studied in Detail [63]

[63] Firms and / or individuals have been attributed pseudonyms to protect their identities and ensure confidentiality of information

A. 1 BrownBear

Location	Possibly Charing Cross area, and another branch in Amsterdam
Size	2 founders; number of employees not available; 300,000 followers
Date of foundation	2012
Own key definition/ key quote	'At BrownBear we want to empower makers to turn their ideas into reality. That's why we've built a platform that is powerful, flexible and intuitive. Our clean and friendly interface allows you to focus on exploring or building your projects. BrownBear aims to be social, inspiring and most of all open. Let's create the future of technology together.'

BrownBear is an online open source community, where users can register for free and access a large data set of information about 3D printed models or projects which use this technology for high quality engineering projects. Through this platform, people can share data and files, chat, co-create projects in association with other users and also 'hack' existing projects, which means to duplicate an existing project at their current stage and then continue the project in a different direction. The scope of shared information is extensive, including robots, drones, machines, exoskeletons-prosthesis, computer parts, car and other vehicle parts, 3D printers, design products and devices for renewable energy generation. It is common to find folders with all files (design, calculations, etc) of entire engineering projects and prototypes. Although participation is free, users have to register with their true identity. Downloading information is only possible by providing a real name and identification to the platform, to ensure authenticity and quality of information. It was not possible to confirm the address from where this online platform operates.

A. 2 Eszilook

Location	Old Street area/ Tech City
Size	2 founders; 3 temporary/ on demand employees; 100 partners

Date of foundation	2014
Own key definition/ key quote	'Smartphone based virtual reality visor designed for casual mobile gamers and practical VR applications'

Eszilook is a small tech firm, based near Old Street, which developed high performing devices for Virtual Reality (VR) and gaming hardware for mobile phones which can be customisable and are 3D printed. They can offer printed services, but most commonly the customers print the hardware, so they develop only the designs. In addition, they offer visualisation services such as renderings and VR. The firm was founded by Slavis T. Prioli, who is from East Europe and is a well-known specialist in VR applied to stage effects and gaming.

A. 3 Paul's Hub

Location	No address available/ Business through Print Point 3D online only. Print Point 3D indicates London-based. Having met Paul, he lives near Romford, and 3D prints on the go (at home, in his office, at meet ups, at a friend's house, etc) and he transports the printer in his car boot.
Size	1 (Paul only)
Date of foundation	2013
Own key definition/ key quote	'I used to provide Tech Support for Printrbot Distributors and have a number of Printrbot printers, as well as a Prusa i3 and a Fabtotum "Personal Fabricator" '

Paul is the sole owner of a 3D printing services online hub. Services are provided to orders submitted online on Print Point 3D, or exceptionally in person if repeat clients contact him directly. His involvement in 3D printing started as a hobby, and his business is not his main occupation. Paul is well known in the 3D printing community in London and the South-East, being a usual speaker at fairs, the organiser of meetups, a co-leader of the Romford group, and part of the board at the City Hackspace. He does not have a fixed location for his 3D printing operations, and transports the 3D printer with him to multiple locations.

A. 4 Medical Prints

Location	Head Office in Clerkenwell, London Satellite offices in Liverpool and in Nairobi.
Size	16 people
Date of foundation	2013
Own key definition/ key quote	'Medical Prints are an SME that focuses on bringing 3D technologies to the medical industry.'

Medical Prints is a technology company developing solutions to the medical sector using a range of 3D technologies including 3D printing. Their services are for private clients as well as for the NHS and for health charities. The company operates from London, Liverpool and Nairobi, and occasionally from other locations on a project basis. They are also based directly at medical institutions wherever their services are needed. The work, all within the medical field, comprises of high and low-cost implants, prothesis, 3D applications, designs, research and training.

A. 5 City Fab Lab

Location	City of London
Size	9 people
Date of foundation	2013
Own key definition/ key quote	'Creative workspace in the City of London for early-stage hardware startups.'
Note	Closed activities in June 2017

City Fab Lab is a fabrication laboratory workshop. It is part of a small network of similar spaces across London, where people can use a wide range of traditional and technological tools for material production such as 3D printing, CNC cutting, 3D scanning, casting, lasers, wood shop, metalworks, etc. To access these, customers need to register and pay a monthly fee, according to various levels of membership and access. Fab Labs are a popularly recognised type of fabrication facility for the Makers community internationally, and it is known to have a certain code of conduct and ways of operating. At City Fab Lab this has been formalised through a Charter.

A. 6 Heterotopia

Location	Not available/ Online only Note: Webpage indicates Angel area.
Size	Linked In indicates 11 to 50 people
Date of foundation	2010
Own key definition/ key quote	'6D Fabrication platform'
Note	Closed activities in 2017

Heterotopia is a technology firm which provides a specialist CAD platform for parametric modelling and design for construction elements intended for 3D printing. The software was originally developed by the firm founders in 2012 and expanded in 2014 to various construction sectors including engineering and architecture. The platform's key properties are its compatibility across multiple popular software of the construction industry.

A. 7 Fantazy Moss

Location	Brick Lane / Whitechapel
Size	2 people + 20 collaborating designers
Date of foundation	2013
Own key definition/ quote	'Unique 3D Printed Jewellery'

Note	Closed activities in 2017

Fantazy Moss is a fashion online marketplace for 3D printed items ranging from shoes to jewellery. This website is publicly accessible and has many designs created by recognised fashion designers. Customers can edit and personalise many aspects of each design, such as materials, parts of shapes, engrave or texturize elements, etc. so there are almost infinite possible final versions of the products. The items are 3D printed by the company and delivered to the customer's address. This company does not print, but outsources or links the customer to a 3D printer which they have certified for quality, as these are high end and relatively expensive items.

A. 8 Patricio Frater

Location	Hackney / London Fields
Size	1 (Patricio only)
Date of foundation	2012
Own key definition/ quote	'Industrial designer'

Patricio Frater is an Italian fashion designer based in London who has a variety of activities. He designs fashion items such as shoes, accessories and clothing specifically to be 3D printed. He has various ranges of products, from very high end of which he does only a few numbered copies, to more affordable items available to download from a marketplace a medium-range price. His name is his brand, and he also signs and authors interior designs for kitchens which are not related to 3D printing.

A. 9 Print Point 3D

Location	Head office in Amsterdam Satellite offices in Chicago, Berlin, Paris. London by phone or email only

Size	130 employees, 35,000 businesses
Date of foundation	2013
Own key definition/ quote	'Your online manufacturing supplies. On demand manufacturing and rapid prototyping. Get your quote in seconds, parts delivered in days.'

Print Point 3D is a global platform which connects printers with potential clients. Printers, designated as 'hubs', are those which own one (or multiple) printers and receive orders for printing via the platform. Each hub has a simple page on the website and a history of service provision, with ratings including batches. The cost is negotiated between the hub and the client, and delivered to the client's address. Print Point 3D receive a percentage of the order. This platform also promotes 3D printing – related information sharing and organises events in main cities.

A. 10 Models & Gadgets (M & G)

Location	Head office in Camden Medical office (another associated entity) in Marylebone
Size	10 people
Date of foundation	2009
Own key definition/ key quote	'We help the world's most influential manufacturers, designers, engineers, architects and artists turn ideas into reality. Our services range from design to production, all based under one roof. We tackle problems from a multidisciplinary perspective to achieve the very best results.'

Models & Gadgets (also known as M & G) is a well-known 3D printing firm with associated design, modelling and 3D scanning services. It receives projects from clients, and advises on designs for 3D printing and for other production processes too. Its specialism is in the quality of their 3D printing production, the range of materials available, and the preparation of models. It offers complementary modelling services to develop a client's idea, and it receives models ready for 3D printing too which sometimes need improvement to be more adequate and achieve better results.

Having originated in the medical dentistry sector, the firm expanded to other sectors afterwards. At the time of data gathering, M&G was the main branch for all non-medical services, and it shared some machines with its three sister companies dedicated to medical and dentistry projects. M & G also does research in 3D printing-related subjects for public or academic bodies across various sectors.

A. 11 City Hackspace

Location	Hackney Note: During this research, it re-opened in Wembley after a period of closure.
Size	1-10 people
Date of foundation	2013
Own key definition/ key quote	'Additive Manufacturing Execution System & Workflow Automation Software'
Note	During the course of the research it closed activities, and re-opened later in a different location in an outer London borough

City Hackspace is a membership association for access to a building with a workshop with various tools and other spaces like desks and meeting rooms. It also holds events related to a range of 'making' -related themes. The term 'Hack', which gave name to this space, was first used in the U.S. for makers' activity to signify making things from rubbish. Accordingly, the only thing people using this space and the tools available have in common is that they all make something but their backgrounds, processes and outputs vary significantly. It is a not-for-profit community type of workshop, run mostly on a membership monthly fee which is 'what members consider fair and can afford' plus donations. It is opened 24 hours a day for 7 days a week for members simply using the London Oyster card to access.

A. 12 SB Hub

Location	Clerkenwell
Size	1-10 people
Date of foundation	2013
Own key definition/ key quote	'Additive Manufacturing Execution System & Workflow Automation Software'
Note	During the course of the research the firm went public and rebranded to AFMG

SB Hub is a small technology company dedicated to the creation of automation software for industrial 3D printing. The firm provides consultancy to large industries who wish to employ 3D printing (in total or part) of their production line and customizes the software to each client's specific needs. Their clients are located across the country and overseas.

A. 13 Micro Tech

Location	Camden During the research it moved to Bow
Size	3 people
Date of foundation	2012
Own key definition/ key quote	'A Powerful & Flexible Technology Stack for Metal AM. The full portfolio of Micro Tech digital technologies greatly extends the performance capabilities of the metal laser Powder Bed Fusion (PBF) process. Complex design and manufacturing challenges can be overcome by applying Micro Tech core technologies during AM application development to optimize design for additive manufacturing (DfAM) and deliver significant production efficiencies through advanced process control.'

Micro Tech is a technology firm offering tailored solutions to optimise metal-based additive manufacturing in terms of output quality, costs and productivity. It employs a series of own patented technologies to improve the geometries and structures of objects and the manufacturing processes for 3D printing in metal leagues and laser cut for metals. Their consultancy and technologies are mostly applied to large scale manufacturing located across the country.

A. 14 Atelier León

Location	Hackney Wick
Size	2 people
Date of foundation	2015
Own key definition/ quote	Not available

Atelier León is a small product design start up established in East London by two people, a designer and an architect. They design various items for 3D printing, such as vases, lamps, seats, tools, glasses. Some of their designs are printed by them in their printers, and some are only prototyped and printed in small quantities by them and prepared to be sent to 3D print in more quantities elsewhere – either at a Fab Lab or elsewhere with printer availability.

A. 15 3D Masters Shoreditch

Location	Shoreditch
Size	2 people
Date of foundation	2015
Own key definition/ key quote	Not available

3D Masters Shoreditch is a small privately-owned firm in Shoreditch who provides design and fabrication consultancy in product development across any sector. They are specialists in developing prototype products for scaling up to 3D printing, and they use the technology as part of their product development process with their clients.

A. 16 Story Lab

Location	Chiswick
Size	12 people
Date of foundation	2010
Own key definition/ key quote	'Product designers. Creative engineers On a mission to make stuff that matters'

Story Lab is a small firm dedicated to consultancy for product design, prototyping and engineering. They create prototypes for engineering sectors including mechanical and construction. Their product development process makes use of 3D printing, but it is not exclusively for products to be 3D printed. Their specialism is in simplifying designs and in low-tech solutions.

A. 17 CUCKOOZ

Location	Westminster
Size	120,000 members in 140 countries
Date of foundation	1847
Own key definition/ key quote	'Improving the world through engineering'

CUCKOOZ is a global professional institution for mechanical engineering. Within the institution there is research on manufacturing technologies including 3D Printing, a database and library. There is also training on subjects relating to the technology and associated seminars, forums and webinars.

A. 18 The Werewolf

Location	Hackney Downs
Size	1 (Ronald only)
Date of foundation	2015
Own key definition/ key quote	'Personal Fabrication Shop, 3D Shop'

The Werewolf is a single-owned firm set up by a designer and engineer, with two 3D printers. He provides consultancy and product development in product design, gadgets and entertainment sectors.

A. 19 Romford Makers

Location	Romford
Size	68 members
Date of foundation	N/a – group discussion how to set up the activity
Own key definition/ key quote	N/a

Romford Makers is not an entity from the 131 list. It was a large group volunteering weekly at the time of the research to discuss the inception of a maker space organisation to be set up in the local area. The discussions included characteristics of the future maker space, funding, and what would be a suitable space and a suitable location within Romford.

Appendix B

3D Printing Firms and Organisations' Websites Accessed Between May 2015 and November 2021

.:oomlout:.
3dsvp.com
4delta.co.uk
abx-labs
Agoom
Artificial Life meets Artificial Intelligence
asylumsfx.com
Badge Making
Battle of the Drones
BBC Television and Mobile Platforms
Bento Lab
Build-IT
Caroline Makes
CEL Robox
CoderDojo North East
Cooler Master
CPC
Deer Shed Festival
Discovery School
DoES Liverpool
Efficiency of Energy Consumption
FabLab Sunderland
Fabulous Beasts
Felt Making
Flying Things by The Take-Off RC Group
formwurx
Geophysics for Home and Schools
Giant Drawing Machines
Greeblies – From Junk to Heroes
Grumpy Mike's Electro Gadgets
gwk woodshed
HacMan / LaMM
Helen Taylor Photography
http://2015.interlaced.co/
http://3Ders.org
http://3dprintingindustry.com
http://3dshook.com/
http://andiamo.io
http://art.kleintobias.com/
http://bigrep.com/
http://chorogenesis.com/
http://creativecommons.org/
http://disruptivemagazine.com/
http://forums.agvr.co
http://futurefactories.com/
http://hacker.agvr.co/
http://machinemachine.net/
http://makerscafe.com/
http://makerversity.org/

http://mamou-mani.com/
http://n-e-r-v-o-u-s.com/
http://newton3d.com/
http://nexusstudios.com/vr-studio
http://rpplatform.com/
http://thepolyflossfactory.com
http://vertexmodelling.co.uk/
http://wonderluk.com/
http://www.3ddc.eu/
http://www.3dlifeprints.com/
http://www.3dprinteros.com/
http://www.3d-printing-additive-manufacturing-2014.com/
http://www.3dprintuae.com
http://www.altergaze.com/
http://www.base-models.co.uk
http://www.cavendishimaging.com
http://www.cd-writer.com/
http://www.chalkstudios.co.uk/
http://www.cinterdesign.com/
http://www.cocoon-networks.com/
http://www.createeducation.co.uk/
http://www.croftam.co.uk/
http://www.darksidestudio.com/
http://www.dawoodandtanner.co.uk/
http://www.digits2widgets.com/
http://www.ecommerceexpo.co.uk/
http://www.electrobloom.com
http://www.explainingthefuture.com/
http://www.fabbaloo.com/
http://www.fablablondon.org/
http://www.fundaciocim.org/en/recerca/fabricacio-additiva
http://www.imeche.org/contact-us
http://www.julianhakes.co.uk/index.html
http://www.letablilondon.com/
http://www.makerbot.com/
http://www.materialise.com/
http://www.michelebadia.com/
http://www.michelebadiashoes.com/
http://www.nickervinck.com
http://www.openbionics.com/
http://www.openspaceagency.com/
http://www.printhub.london/
http://www.sculpteo.com
http://www.shapeways.com/
http://www.silviaweidenbach.com/
http://www.solid-scape.com/
http://www.stratasys.com/
http://www.thingiverse.com/
http://www.ucodo.com/

http://www.wahootifandango.com/
http://www.whitemaqui.com/
https://3dprintedjobs.com
https://3dprintingindustry.com/news
https://angel.co/chorogenesis
https://en.wikipedia.org/wiki/WonderLuk
https://grow.am
https://ultimaker.com
https://wonderluk.com/
https://wtvox.com
https://www.3dhubs.com/
https://www.3dhubs.com/users/ianadan
https://www.coolcomponents.co.uk/
https://www.digitalforming.com
https://www.digitalforming.com/Home/Technology
https://www.fuel-3d.com/
https://www.imperial.ac.uk/advanced-hackspace/
https://www.myminifactory.com
https://www.myminifactory.com/users/Michele%20Badia
https://www.peckhamlevels.org/
https://www.re-work.co/
https://www.stratasysdirect.com/
https://www.the3dprintingassociation.com
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Impossible Gears Steampunk / North East Steam Society
Infection Music
Institute of Physics
Jewellery Making
Junkcraft
Just Add Sharks
Kitronik
Laserlines.co.uk
Leeds Hackspace
Leeds Hackspace Ubercube
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LoveScience
MadLab
Make Your Own VR 3D Machine From Scratch
Maker Space
Maker Space – Penguin Race
Mcortechnologies.com
Media Molecule 'Dreams'
Metavurt Ltd
Mirobot
Mitch Altman – Learn To Solder
My3dtwin.com
Nesta/Make Things Do Stuff

Newcastle University: School of Electrical and Electronic Engineering
Noisy Toys: Audio Assault Buggy & Bass in Your Face
Northumbria University Health and Life Sciences
Northumbria University: Department of Physics and Electrical Engineering
Nottingham Hackspace
O'Reilly
Paper Jam Comics Collective
Paw Tread Studios
Paynetech
pcDuino based Home Automation
PiKon – 3D printed, Raspberry Pi powered telescope
pi-top | CEED Ltd
Printrbot.com
Rapide-3d.com
Ray Phillips Sculptor/Prop Maker
Rebel Legion UK
Red Robotics
Remap
Rigid.ink/
Robo Challenge
Robosavvy.com/site
Robotical
Rubbish Puppets
SAM Labs
Sculpteo.com/en
Selassi.com
shapefactory.com
Shapeways.com
Sharebot.it
Sheffield Hardware Hackers and Makers Hackspace
Sicnova3d.com
Sketchfab.com
Smartfriendz.com/en
St Cuthbert's Catholic High School
Sticker Forge
Stratasys.com
STU-ART Aviation Furniture ltd
SUN-Dress for the Yellow Giantess: Space Agency
Superpants
Suzanne Jewellery
Sweet Surprise – "Make your own sweet cone"
Taxidermy
The Crafty Robot
The Curious Electric Company
The HEdWorks Project
The Jam Jar Collective
The Raygun Consultancy
The Ultimaker CREATE Education Project
The Wall of Enlightenment

Theo Lasers
Things that Seg
Think Physics: Light Wall
Think Physics: Technology Wishing Well
Tingbot
TITANOX – Water is the best fuel
TOG Dublin
Toy Hacker & Creative Stitch
UAV Monkey and Drone Ops
Ultimaker.com
Underwater Robotics
Vacuum Former
Velleman
Verbatim-europe.co.uk
Waspproject.it
Whole Body Interactions: Non-Exercise Activity Thermogenesis (NEAT)
wonderluk.com
wrks24.com
www.3dealise.com
www.3distributed.com
www.3dlifeprints.com
www.3dprintshow.com
www.3dprint-uk.co.uk
www.altergaze.com
www.banneya.com
www.betaty.pe
www.cadventure.co.uk
www.chorogenesis.com
www.color.co.uk
www.curvoxels.com/
www.danielwidrig.com
www.ebpgroup.com
www.econolyst.co.uk
www.ellis-miller.com
www.frippdesign.co.uk
www.gambody.com
www.hobsstudio.com
www.inition.co.uk
www.jonespartners.eu
www.kidesign.org
www.lee3d.co.uk/
www.luma-id.com
www.makie.me
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www.modla.co.uk
www.pixellounge.co.uk
www.printme3d.com
www.printtopeer.com
www.proddesigns.co.uk

www.propsplanet.com
www.st3di.com
www.tarsus.com/
www.think3dcad.com
York Hackspace
zetoff.com
Zmorph3d.com

Appendix C

3D Printing Processes

The process of 3D printing starts with a digital design, which is then converted by a software application into multiple layers. These are then transmitted to a 3D printing machine which will print the object by extruding, hardening or positioning liquid material according to those layers and coordinates which solidify. There are many techniques and processes which are:

1) **Stereolithography (SLA)** which consists of a liquid curable photopolymer – typically a resin – in a container that is hardened by a pointer applying focused light or Ultraviolet light according to coordinates. This technique produces extremely detailed objects and geometries, with parts as thin as a human hair;

2) **Selective Layer Sintering (SLS)** uses powder material which is thinly layered and then pointed at by a laser according to points defined in a digital layered model which fuses the power material. A new layer of material is applied as the base lowers in the machine, and the pointer again fuses more material successively until the object is formed. The outcomes of SLS are solid and structurally very resistant, and this technique is appropriate for low volume batches;

3) **Direct Metal Laser Sintering (DMLS) or Direct Metal Laser Melting (DMLM)** is a similar technique to SLS, except the powder material used is metal powder;

4) **Fused Deposition Modelling (FDM)** is the technique of extruding a filament of material according to layered coordinates on a machine bed. The material is melted and deposited by a precision nozzle and solidifies naturally when exposed to air. This technique is very flexible and has been expanded to include a vast range of materials and multi-materials;

5) **Polyjet** consists in spraying photopolymer materials onto a tray in thin layers. Each layer is dried with an Ultraviolet light after being extruded; and

6) **Binder Jetting** is the technique by which layers of various powder materials are glued together when a pointer deposits a liquid binding agent to join the powder according to layered coordinates, not requiring heat sources or lighting. For this reason it is a flexible process used for less precise geometries but with quick and cost-effective results (Shapeways.com accessed 24th April 2016; Zhang 2014; 3dHubs.com accessed 11th March 2021).

Appendix D

Survey Letter, Questionnaire Form and Interview Questions

UCL DEPARTMENT OF GEOGRAPHY
AND
UCL BARTLETT FACULTY OF THE BUILT ENVIRONMENT
BARTLETT SCHOOL OF PLANNING

Ana McMillin
[redacted]

London, 7th April 2017

Dear Sir/ Madam

I am researching 3D Printing Industry businesses in the London area, as part of my Doctoral degree in Economic Geography.

The purpose of this study is to find out more about the industry, particularly regarding business sizes, growth, value, relationship with other sectors such as with creative industries, and about premises and location preferences in London.

For this it would be very helpful if you could please complete the survey and return in the stamped envelope included.

If you prefer, my survey is available to fill in online here:
https://surveyplanet.com/581f712a52f9586263f3805e

Please do not hesitate to contact me if you require further information.

Thank you very much.

Kind regards

Ana McMillin

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3D Printing London Survey

Ana McMillin – [redacted]

Please enter your email ________________________________
Please enter the name of your organisation ________________

Q1 – What best describes this organisation within the 3D Printing Industry?

□ Printer/ Maker
□ Designer
□ Software developer
□ Hardware or materials supplier
□ Advertisement agency
□ Consultant
□ Marketplace
□ Industry magazine/ journal
□ Other (Please specify) _______________

Q2- When was this organisation founded?

□ This year
□ 2016
□ 2015
□ 2014
□ 2013
□ 2012
□ 2011
□ 2010
□ Between 2009 and 2000
□ Before 2000
□ Don't know

Q3 – Is this organisation…

□ Sole trader
□ A limited company by shares, by guarantee or publicly limited
□ An Ordinary Business Partnership, Limited Partnership or Limited Liability Partnership
□ Social enterprise/ Not for profit
□ Public Institution, i.e. University or Government Office or other

□ Don't Know

Q4- What are the activities of this organisation?
(Please tick all that apply)

□ Idea or product development
□ Design
□ Prototyping
□ Modelling
□ Printing/ Making
□ Finishing
□ Monitoring use
□ Selling for consumption or use
□ Selling for production/ supplies
□ Advertising
□ Other (Please specify) _______________

Q5 – How many people are employed by this organisation?

□ Just myself
□ 2 to 3 employees
□ 3 to 5 employees
□ 5 to 10 employees
□ 10 to 20 employees
□ 20 to 50 employees
□ over 50 employees

Q6- How many non-paid employees does this organisation have?

□ None
□ 1 non-paid employee
□ 2 to 4 non-paid employees
□ 5 to 10 non-paid employees
□ more than 10 non-paid employees

Q7 – Has this organisation grown in total number of employees in the last 2 years?

□ Yes
□ No

Q8 – How much has this organisation grown in total number of employees in the last 2 years?

□ Has not grown/ not applicable
□ 1 to 10%
□ 10 to 20%
□ 20 to 30%
□ 30 to 40%
□ 40 to 50%
□ over 50%

Q9 – Has this organisation grown in turnover or profit in the last 2 years?

□ Yes
□ No

Q10 – Does this organisation receive any public or private funding?

□ Yes
□ No

Q11 – How much has this organisation grown in turnover or profit over the last year?

□ Has not grown/ not applicable
□ 1 to 2%
□ 2 to 5%
□ 5 to 10%
□ 10 to 15%
□ 15 to 20%
□ over 20%

Q12 – In which London borough is this organisation located?

□ Barnet
□ Brent
□ Camden
□ City of London
□ Ealing
□ Greenwich
□ Hackney
□ Hammersmith and Fulham
□ Haringey
□ Hounslow
□ Islington
□ Kensington and Chelsea
□ Kingston upon Thames
□ Lambeth
□ Lewisham
□ Merton
□ Newham
□ Southwark
□ Tower Hamlets
□ Wandsworth
□ Westminster
□ Don't Know
□ Other (Please specify) _______________

Q13 – How do you describe this organisation's premises?

□ High specification office
□ Medium specification office
□ Studio
□ Makerspace
□ Warehouse conversion
□ Public building
□ Terraced house/ house
□ Flat
□ Other (Please specify) _______________

Q14 – What amount of space is allocated for 3D Printing related activities?

□ 5 to 10 Sqm (approx. 1 to 2 desk spaces)
□ 10 to 20 Sqm (approx. 1 small room)
□ 20 to 40 Sqm (approx. 1 large room)
□ 40 to 100 Sqm (approx. 1 small office)
□ over 100 Sqm (approx. 1 large office or makerspace)

Q15 – What determined this organisation's location?
(Please tick all that apply)

□ Rent/ Cost per Sq. Ft
□ Proximity to clients
□ Proximity to collaborating firms
□ Proximity to public transport
□ Proximity to competitors
□ Proximity to employees' homes
□ Proximity to College or University
□ Proximity to owner's personal address
□ General character of the area
□ Type of space
□ Other (Please specify) _______________

Q16 – What is the most important factor for this organisation's location?
(Please tick one only)

□ Rent/ Cost per Sq. Ft
□ Proximity to clients
□ Proximity to collaborating firms
□ Proximity to public transport
□ Proximity to competitors
□ Proximity to employees' homes
□ Proximity to College or University
□ Proximity to owner's personal address
□ General character of the area
□ Type of space
□ Other (Please specify) _______________

Q17 – In your own words: Why is this organisation located here?

Answer: ____

Q18 – What would make this organisation move to another location?

□ Rent/ Cost per Sq. Ft
□ Proximity to clients
□ Proximity to collaborating firms
□ Proximity to public transport
□ Proximity to competitors
□ Proximity to employees' homes
□ Proximity to College or University
□ Proximity to owner's personal address
□ General character of the area
□ Type of space
□ Other (Please specify)

Q19 – Is this organisation considering moving to another location soon?

□ Yes
□ No
□ Don't Know
Comments ______________________________

Q20 – Are this organisation's clients other firms?

□ Yes
□ No

Q21 – Who are this organisation's clients?

(Please tick all that apply)
□ Other organisations within the 3D Printing Industry
□ Private organisations in the creative sector
□ Private organisations in non-creative sectors
□ Students
□ Education Institutions
□ Government organisations, i.e. Local councils or Museums
□ Not for profit institutions
□ Individuals or Families
□ Other (Please specify) _______________

Thank you very much for your participation.

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Interview Questions to 3D Printing Businesses

To 8 Selected Case Studies

Theme: Nature of Activity

1. Please describe your activities/ business within the 3D Printing Industry.
2. Considering the production cycle, where you see your activities – Pre production/ Production/ Post-production? And why?
3. Where is value created in this production cycle? In the kind of things you do, or someone else profits more than you?
4. Please could you describe the work you do?

Theme: Business/ Activity strength

1. For how long have you been in business/ doing this activity?
2. Why/ how did it start?
3. Have you been growing your business/ activity? In number of people involved or turnover, or both?
4. How do you see the business/ activity progressing in the future?
5. What would put you out of business/ lead you to terminate your activity?

Theme: Links with other activities

1. Do you receive any funding?
2. Do you have links to any institutions? i.e. universities, industry associations? Other?
3. Please tell me about your clients, who do you work for?
4. Please tell me about your collaborators, who do you work with?

Theme: Location – (Note the location of the interviewed)

1. Why are your activities located here? Why did you choose this location?
2. Is this location: close to your home/ home of employees?/ Close to university/ close to clients/ close to competitors/ close to collaborators?
3. What would make you move out of this location?
4. Do you think you are in your preferred type of location, or not? And why?

Theme: Policy

1. Do you consider that current policy positively contributes to 3D Printing industry growth in London?
2. Or do you consider that policy is actually holding you back or negatively affecting your activity?
3. What policies or incentives would you think be most critical for growing 3D printing activities in London?

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Interview Questions to Martina Ricci Calabria, Print Point 3D

Theme: How do we theorise the resurgence of manufacturing / 'making things' within contemporary urban economic geography and reconcile this with post-Fordism

1. Wat is your role in Print Point 3D?
2. How involved are you personally in the Makers Movement?
3. What is your background/ education?
4. Why do you think people are so interested in 'making things' again?

Theme: Location

1. Most hubs are in urban centres. Amsterdam/ London, NY etc. Why do you think this is the case?
2. Do you see any particular characteristic or difference between the hubs in London/ the hubs in other places?

Theme: Growth

1. What is your perception/ Do you think work (3D print work) volume is growing more or hubs are growing more?
2. Will this remain the same?

Theme: Links to other activities

1. Is Print Point 3D linked to institutions? Universities/ other?
2. From your perception, are the hubs linked to non-private sector too/ support for the technology?
3. Where do you think value is created in eth process of 3D printing? In design/ prototyping/ or in printing a lot?

Theme: Shared economy/ knowledge transfer

1. What do you think about the role of the shared economy in general (Print Point 3D, co-working spaces) in the technology's development? And what about the value of Print Point 3D in particularly?
2. How do you see the shared economy? As a benefit to 3D printing/ or not?
3. What do you think is the key value of the groups and community of makers and 3D Meetups?

Theme: Policy/ regulations

1. Do you see any barriers to Print Point 3D's growth?
2. And to the technology's growth?