



Review of alternative business models for open design and distributed production

Deliverable 3.1 – version 1

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Abstract

The purpose of this deliverable is to systematically analyse the literature at the intersection of open design and distributed production in an attempt to reveal truly alternative business models being explored. 131 journal articles were identified through a systematic search of three databases (ie. Web of Science, Scopus, EBSCO) and reviewed according to value creation processes, drivers/themes, business model elements, forms of collaboration, people's involvement, and governance, intellectual property mechanisms, alternative modes of production & consumption, economic sustainability of open design business models, and life cycle stages. As a result, the review resulted in a novel conceptualisation of stakeholders, a framing of decentralised and distributed production and consumption, the identification of newly emerging stakeholders to establish value creation networks, and a future vision of sustainable production and consumption facilitated by open design knowledge – all of which will inform the upcoming work packages of the DF-MOD project.

This report constitutes Deliverable 3.1, for Work Package 3 of the DF-MOD project.

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1. The purpose of D3.1

Work package 3 aims to systematically search for, and critically analyse, the literature on open design and business models to explore various forms of alternative design and business practices emerging at their intersection. The purpose here is to understand how the literature currently defines the roles of varying actors, how they empirically reveal – or foresee – alternative forms of *doing business* that can enable circular economies on micro, meso and macro scales, that can (re-)capture and (re-)create value through open design knowledge sharing and diffused collaboration, that can facilitate - at the minimum - active participation of users, makers, prosumers and mass-producers through the design of parts, products and services.

DF-MOD largely differs from the existing literature through its emphasis on the mass production of open designs. The researcher regards mass production simply as an enabling tool capable of copying and pasting in real life and asserts that the traditional market fragmentation and audience of mass-produced products are *passee*. The study builds on the paradigm shift in the democratisation of design, from creating accessibility to products by reducing the production costs and thus retail prices, towards creating accessibility to decision-making throughout the design process through open-to-participate process and openly shared design knowledge (Bakırlioğlu & Kohtala, 2019; Richardson, 2015). As a phenomenon emerged at and been informed by the intersection of open-source software (OSS) development, maker and hacker culture, and increasingly hybridised roles of users, designers and producers, open design presents various potentials for diffused and decentralized codesign, localisation of production along with global collaboration, open accessibility to design knowledge to drive innovation and enable circular economy strategies at varying scales.

The problem lies with the under-conceptualisation of what open design knowledge can achieve (Bakırlioğlu & Doğan, 2020). Many researchers give credit to open design's potentials for transitioning towards sustainable futures through espousing socially beneficial practices by offering new opportunities for embodied creativity and invention through making, in contrast to passive consumption, or empowering individuals to influence what is produced (Manzini, 2015), through economically beneficial practices by providing new types of enterprise and entrepreneurship and new ways to manufacture more attractive products (Raasch & Herstatt, 2011), or through environmentally beneficial practices by fostering material and resource eco-efficiency, localizing production, closing loops and empowering communities to meet their own local needs, as well as needs of citizens in the future through open, adaptable solutions and knowledge sharing (Kostakis et al., 2015). These potentials presented in literature often embody varying sustainable future visions in terms of governance and levels of technology and deploy – or expect – varying assumptions about the roles of consumers/users/citizens, makers/prosumers/

producers and policy makers/government (Bauwens et al., 2020). The literature also warns about open design being absorbed into business-as-usual practices and becoming incapable to contribute to any transition towards sustainability (Thackara, 2011). Furthermore, any such potential is continuously challenged by the *physicality* of the open designs - eg. affordances of materials, costs for production, durability of outcomes, etc. (Bakırlıođlu & Dođan, 2020; Kadish & Dulic, 2015; Kohtala, 2017; Malinen et al., 2011).

In this project that aims to explore (1) truly alternative businesses driven by open design and responsive to sustainability concerns, and (2) how open design should be practised in turn to socially and economically sustain these alternative businesses, it is important to collate and critically assess the most recent literature on open design, distributed production and business models. The term 'business model' is defined rather loosely and encompasses any form of systematic financial, social or environmental value creation. The term 'open design' is also defined broadly and refers to both openly shared design knowledge and open-to-participate processes. Through the analysis of literature, the purpose is to distil definitions of various actors, business model elements, forms of collaboration, and implications for sustainability – which will inform the following stages of this project (ie. work packages 4 & 5).

The following section presents the methodology of the systematic literature review. Section 3 presents the overview of the literature on open design and business models under the headings of (1) distributed value creation through openness, (2) conceptualising stakeholders, collaboration, and distributed production, (3) business models identified, and (4) sustainability and the Circular Economy through open design and distributed production. Section 4 presents the conclusions drawn from this review, highlighting the gaps in literature and how DF-MOD is positioned among these gaps.

2. Methodology

2.1. Systematic Literature Review

Systematic literature reviews aim to aggregate all sources on a defined topic of interest and synthesize them (Pattinson et al., 2016; Pittaway et al., 2004). In line with the purpose of work package 3 (ie. reviewing the relevant literature at the intersection of open design, distributed production and business models), the researcher initially identified various keywords related to open design (ie. open-source design, open hardware, distributed production, collaborative production, peer production, fabrication lab, makerspace, and open-source appropriate technologies) and in series of tries, formed the below search string to identify the peer-reviewed literature that clearly mentions business models *and* open design or relevant terms.

```
TS ("business model*" AND ("open design*" OR "open*source design*" OR "open hardware" OR "distributed production" OR "collaborative production" OR "peer production" OR "fab*lab*" OR "fabrication lab*" OR "fablab*" OR "makerspace*" OR "open*source appropriate"))
```

The search string aimed to cover the fields of title, abstract, and keywords of peer-reviewed articles to provide a satisfactory snapshot of the existing literature, as of September 2021, that clearly contains 'business models' and 'open design' or other terms presented. Asterix symbol (*) was utilised wherever found necessary to account for different uses of these terms, including the plural suffixes (-s, -ies) and dashes (-). This was necessary as the literature uses these terms differently in different cases: 'open design' as a process or approach and 'open designs' referring to multiple open design solutions, open source and open-source (with a dash) as different uses. Furthermore, the researcher noticed that 'fab lab' is sometimes used in a compounded form (ie. fablab) and included that in the search string.

This search string was run in three academic databases (ie. Web of Science, Scopus, and EBSCO Academic Search Elite) with amendments regarding the field identifiers (eg. TS in Web of Science covers title, abstract and keyword fields, while TITLE-ABS-KEY covers these fields in Scopus), and Boolean operators (eg. AND, OR). The resulting lists of literature were exported to Comma-separated Value (.csv) files and imported to the MS Excel application. These three lists of resources were aggregated and duplicate entries were removed using the 'find duplicates' function of the software. This resulted in a list of 1069 entries written in any language and forms (eg. journal articles, conference proceedings, periodicals, editorials, etc.). The researcher removed any manuscripts in languages other than English. The researcher also removed manuscripts other than journal articles, since

studies in other formats present preliminary work (eg. conference proceedings), extended manuscripts based on earlier works published as journal articles (eg. books, book chapters), expert opinions not necessarily grounded in research work (eg. periodicals), or review of others' work (eg. book reviews). This resulted in **an initial pool of 512 peer-reviewed journal articles written in English**. The earliest article in this list was published in 2005, and it is apparent that increasingly more and more researchers are engaging with this study's research area, reaching 123 journal articles published in 2020 and 79 journal articles in 2021 until September (see Figure 1).

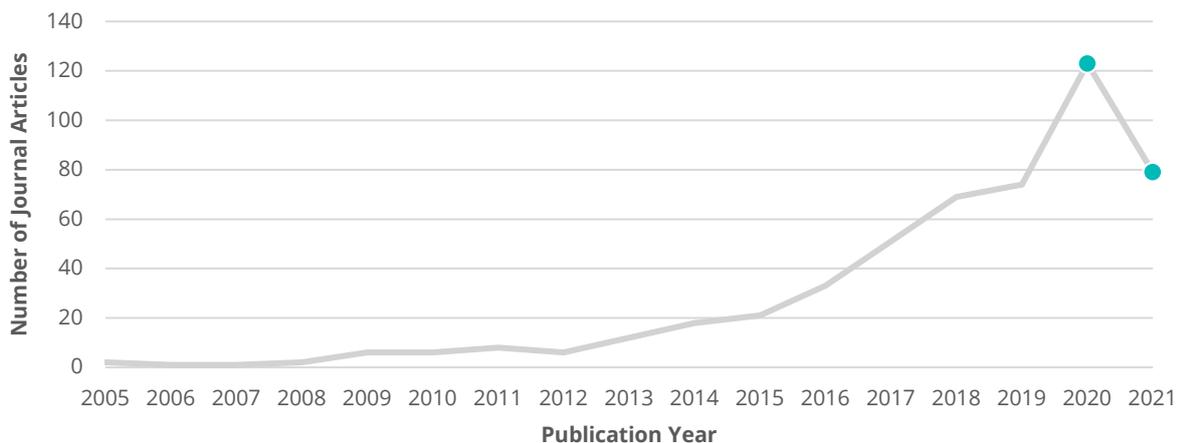


Figure 1 Number of journal articles across the years, between 2005 and September 2021 (*the 2021 numbers only reflect the number of articles published until September 2021*)

While the number of articles indicates a raised interest in open design, distributed production and business models in academia over the years, not all the articles specifically target this intersection per se. There were many articles that mention open design and the other relevant concepts identified to:

- (1) mention open design and/or business models *en passe*, but the paper is not directly related to them
- (2) support their arguments about another approach (eg. sharing economy, helix models of innovation, etc.),
- (3) identify different approaches in digital products and services (eg. open-source software, open education, etc.), rather than physical products and services,
- (4) refer to other meanings of openness (eg. open-ended or unsolved processes, modular structures, open knowledge, etc.) not in the scope of this review.

That's why the researcher reviewed the abstracts of this list and identified 174 journal articles that initially appeared related to the topic of the DF-MOD project. Then, the author read the articles, and through the assessment of contents and removed articles that are not relevant to DF-MOD content-wise. This further reduced the number of articles to **a final list of 131 articles** (the list of reviewed articles can be found in Appendix

A). The inclusion/exclusion criteria utilised to identify these papers are presented in Table 1.

Table 1 Inclusion/exclusion criteria

	Inclusion criteria	Exclusion criteria
Step 1	Is a peer-reviewed journal article	Is a conference proceeding, book chapter, or a non-peer-reviewed article (eg. periodical, editorial, etc.)
	Is in English	Is in a language other than English
Step 2	Has business models & open design and relevant concepts used in a manner meaningful to DF-MOD in Title, Abstract or Keywords fields.	Does not have business models OR open design and relevant concepts meaningful to DF-MOD in Title, Abstract or Keywords fields.
Step 3	Presents a study directly related to business models & open design and relevant concepts	Refers to open design and/or business models (1) superficially, (2) to support arguments about another approach, (3) in relation to completely digital practices, (4) to explain other concepts (5) to define open-source software projects and processes only
	Does not overlap with other manuscripts, ie. completely different studies, different analysis techniques deployed to the same data sets, different theoretical framings, and conclusions	Contains a large amount of overlap with another paper of the same authors on the list, in terms of data, analysis, results and conclusions.

2.2. Initial coding and emerging concepts

The first step mapped the origins of studies and their focuses through their meta-data (ie. subject classifications of journals and conferences and author keywords). This was done for the reduced list of **131 peer-reviewed journal articles** to present the widespread concepts and terms in the reviewed literature at the intersection of open design and business models. Subject classifications were also analysed to provide a snapshot of the literature from a disciplinary perspective and reveal which disciplinary perspectives are dominant in this literature.

The second stage started with inductive coding of sources by the researcher without any previous categories in mind. This initial coding of 15 papers revealed **eight thematic areas** of analysis, namely (1) value creation, (2) drivers/themes, (3) business model elements, (4)

collaboration, people's involvement, and governance, (5) intellectual property mechanisms, (6) alternative, sustainable production & consumption, (7) economic sustainability of open design business models, and (8) life cycle stage.

These thematic areas were further scrutinized revealing tendencies about approaching distributed production from different angles and how they affect the perception of stakeholders and forms of collaboration. Several environmental sustainability – especially circular economy – opportunities are also highlighted in literature, albeit they are mostly theoretically conceptualised through case studies and qualitative data, and in different levels (eg. from material efficiency at micro-level to localisation as a paradigm shift at macro scale). Open design, both in terms of open design data and knowledge and in terms of open-to-participate processes, is visibly considered in all papers; however, the ways it is conceptualised varied greatly according to the conceptualisation of stakeholders, value creation and form of collaboration. Lastly, from a broader perspective, various opportunities and gaps in the reviewed literature relevant to DF-MOD are highlighted in the conclusion section.

3. Overview of literature

The sources of the articles reviewed in this systematic review are presented in Table 2. ‘Technological Forecasting and Social Change’ journal, a journal focusing more on future studies through interrelated social, environmental and technological factors, is at the top of the list with 9 articles. It is followed by two sustainability-focused journals (ie. ‘Sustainability’ and ‘Journal of Cleaner Production’). These indicate that the sustainability and circular economy focus of this literature review – as well as the DF-MOD project – is indeed relevant and in concordance with the overall research direction academics are pursuing. But, it can also be seen that there are many articles published in many different journals – *85 source titles in total* – indicating that there is a fair amount of distribution among different sources with regards to open design, distributed production and business models.

Table 2. Sources with more than one article in the final list

Source Title	Number of articles
Technological Forecasting and Social Change	9
Sustainability (Switzerland)	7
Journal of Cleaner Production	7
Journal of Manufacturing Technology Management	5
Strategic Design Research Journal	5
International Journal of Sustainable Engineering	4
Business Horizons	3
International Journal of Production Research	3
Technology in Society	3
Production Planning and Control	3
Technovation	2
Technology Analysis and Strategic Management	2
International Journal of Production Economics	2
Design Science	2
Creativity and Innovation Management	2
IIC International Review of Intellectual Property and Competition Law	2
Design Journal	2
<i>Others</i>	<i>68</i>

The source titles were coded according to their first/highest ranking Scopus Database Subject Areas to present an overview of the reviewed literature (Figure 2). As expected due to the business models focus of the literature search, most articles were published in journals under Business, Management and Accounting subject (24%). This is followed by Engineering (17%), Social Sciences – general (13%) and Computer Science (11%). Since design journals do not have their own ‘Design’ subject area classification, they are not

represented in Figure 2; however, referring back to Table 2, it can be seen that several design journals published more than one article on this topic (ie. Strategic Design Research Journal, Design Journal, Design Science). There are also many articles published under different subject areas not visible in Figure 2, such as Life & Health Sciences (i.e. Neuroscience, Pharmacology, Toxicology and Pharmaceuticals, Biochemistry, Genetics and Molecular Biology, Nursing, Medicine); Earth and Planetary Sciences; Materials Science; and Physics and Astronomy.

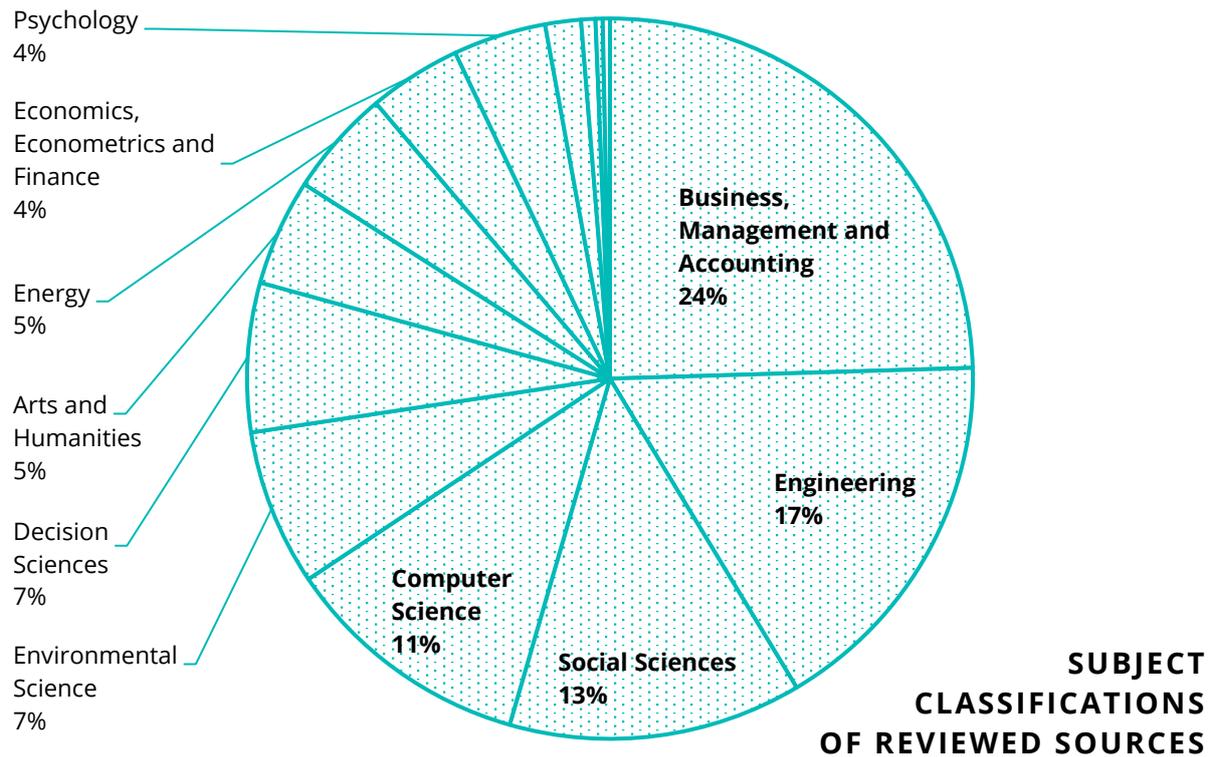


Figure 2. Subject classifications of sources according to their highest-ranking Scopus subject areas

The overall spread among different subject areas and source titles hints at wider exploration of distributed production and open design topics than the researcher initially expected; however, this data does not indicate that distributed production or open design practices are becoming mainstream. The researcher's previous review of articles on open design until January 2017 (Bakırlıoğlu & Kohtala, 2019) also revealed a spread among different subject classifications, especially due to articles of *open-source appropriate technology* case studies. The researcher can attest that this review is fundamentally different from the previous review (there are only a handful of overlaps in reviewed content) in the sense that the spread visualised in Figure 2 seems to stem from expected paradigm shifts in the modes of production and consumption in near future and the researchers from different backgrounds simply attempted to explore the impact of distributed production and open design concepts in their own disciplines.

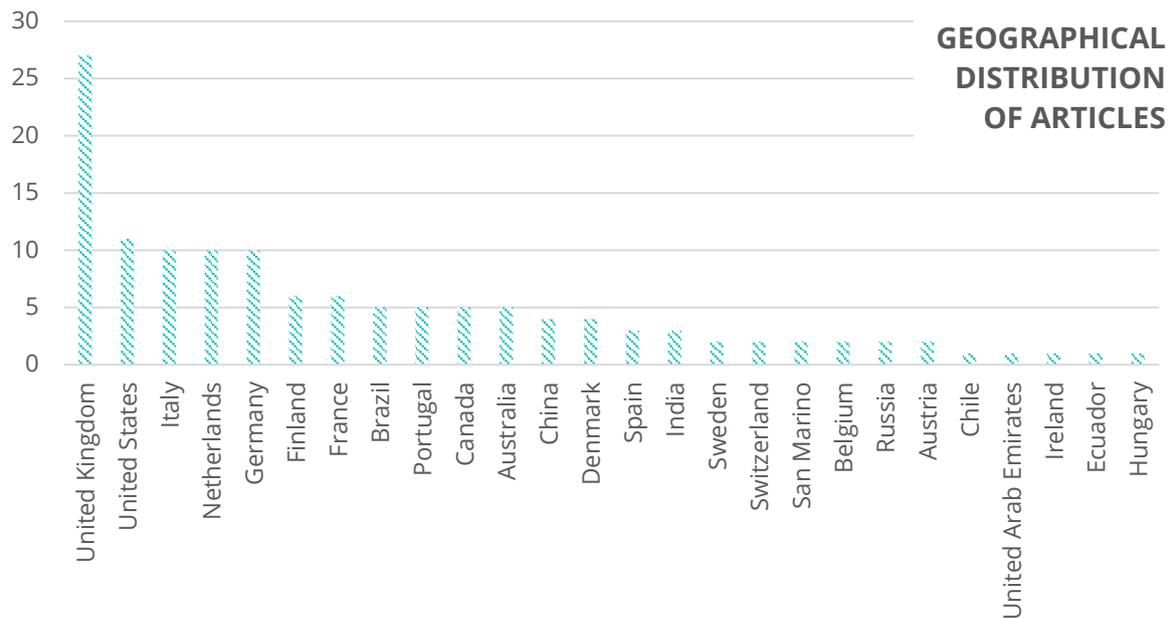


Figure 3. Geographical distribution of articles (according to first authors' affiliations)

However, the geographical distribution of the articles' first authors' affiliations paints a different picture (Figure 3). Firstly, most of the reviewed articles are authored by researchers from the UK ($n=27$), and it is more than twice the number of articles from the second country in the list, the USA ($n=11$). Secondly, it can be seen that the authors are mostly in the Global North, especially in Europe and Northern America. While we see articles originating from the Global South, such as Brazil ($n=5$), China ($n=4$), India ($n=3$), Chile ($n=1$), the UAE ($n=1$) and Ecuador ($n=1$), their share in this literature is considerably low. The researcher suspects various factors in this situation, including the number of research funding programmes in the Global North focusing on distributed production, the difference in the number of makerspaces and other publicly accessible creative workshops, and the increased emphasis on localisation and sustainability in the Global North. Especially for the articles from the UK, sustainability and the circular economy are of pivotal importance and the relationship between (re-)distributed manufacturing and sustainability is mostly demonstrated (eg. Bessi re et al., 2019; Bonvoisin, 2017a; Despeisse et al., 2017; Kuzmina et al., 2019; Moreno et al., 2018; Prendeville et al., 2016, 2017a).

Finally, to provide an overview of the literature in terms of the keywords authors used in the literature, Figure 4 presents the most used keywords relevant to the DF-MOD project. **3D printing** and similar keywords (3D printer, 3D printed..., 3DP, etc.) are highly used in literature ($n=25$), especially because additive manufacturing is becoming more widespread and adopted both in industrial settings and in the consumer market, also presenting potentials for distributed and decentralised modes of production as well as other approaches to next-generation production (eg. industry 4.0, cloud manufacturing, manufacturing-as-a-service, etc.). This keyword is followed by **distributed** ($n=23$, also including distributed production, distributed manufacturing and re-distributed manufacturing) and **maker** ($n=22$, also including maker movement, maker spaces, maker

entrepreneur, etc.). Interestingly, **business model** (n=19) is the fourth on the list despite the emphasis on the search string. This indicates that although all the papers in this review address business models in relation to eg. distributed production and open design, the focus is not always on the business models.

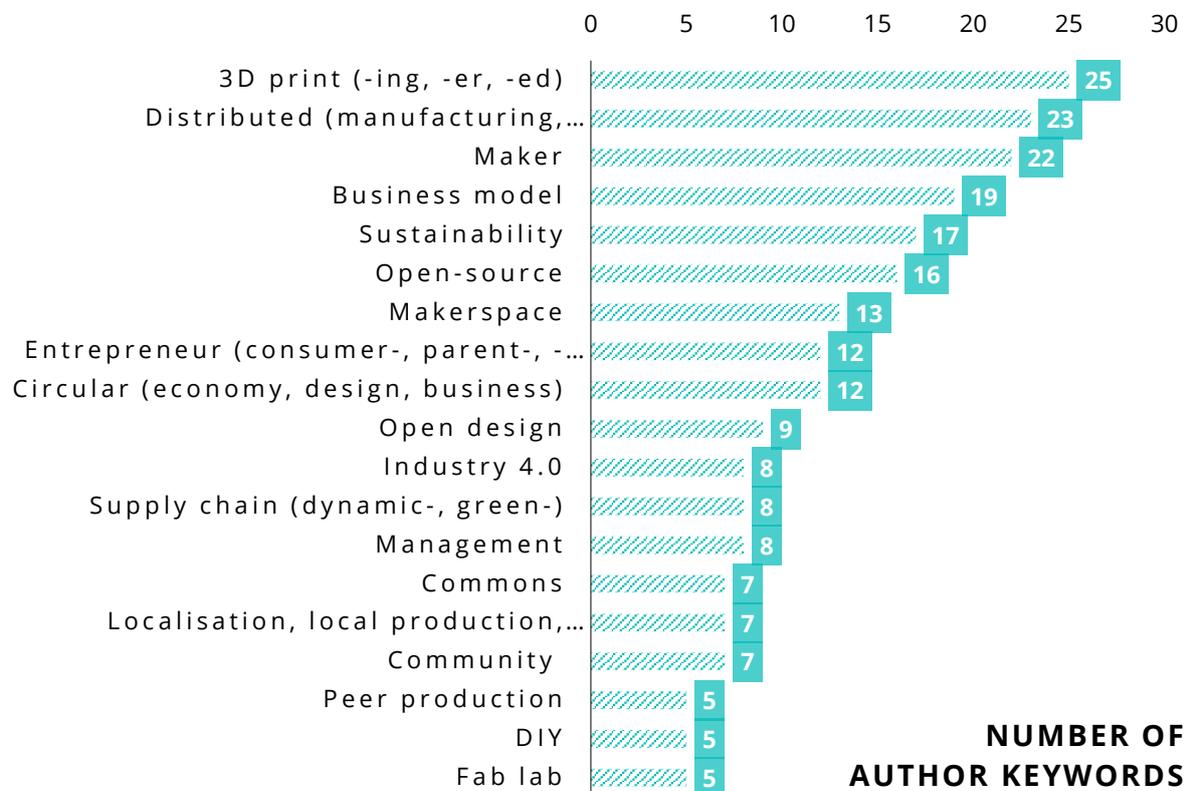


Figure 4. Number of keywords relevant to the purposes of this study

Another interesting aspect is that **sustainability** (n=17) and relevant keywords of **circular economy** (n=12, also includes circular design and circular business) and **localisation** (n=7, also includes local production and localised manufacturing) do not overlap as much, pointing towards an overall interest in academia on the relationship between distributed production and sustainability.

Beyond the above-mentioned quantitative data, this review will not attempt to quantify the reviewed literature due to the following reasons:

- The definition for 'business model' is rather vague and casts a large net for various forms creating and capturing value, as well as different approaches to formalising these processes – or parts of these processes.
- The reviewed literature is rooted in a wide range of subject areas (see Figure 2) and a wide range of disciplines that do not readily share common terminologies or formalised approaches in terms of openness in design and production, distributed production, processes of value creation or sustainability.
- A similar situation is also recognisable in terms of potentially involved stakeholders, as their conceptualisation varies greatly according to the focused (parts of) value creation and (re)capture processes.

Hence, the qualitative analysis is conducted with a more pragmatic approach in an attempt to distil the literature to build the necessary background for the DF-MOD project. In the following sections, the analysis of literature will be presented in terms of distributed value creation through openness; conceptualisation of stakeholders, collaboration, and distributed production; identified business models; and opportunities for sustainability and the circular economy.

3.1. Distributed value creation through openness

The open design approach has created much enthusiasm at the beginning of new millennia through the opportunities conceptualised around it, and after twenty years, it is also possible to observe the consolidation of certain open design practices (Gasparotto, 2020). Such open practices are discussed as open-source technologies, open governance, open innovation, open business model through value share, open access and open production (Seo-Zindy & Heeks, 2017). These practices, however, are interrelated and should be formalised in tandem. From this point of view, and in relation to DF-MOD's goals of exploring alternative open design-led business models through various scales of production, it becomes increasingly important to identify the drivers for adopting openness in distributed value creation processes. Throughout the literature, 'openness' in design and how it contributes to value creation seem to be divided into two points-of-view. On the one hand, there are communities of like-minded people advocating for openness as an ideological stance for democratisation of knowledge and resources; on the other hand, there are companies that utilise openness as a competitive business component (Ferdinand & Meyer, 2017). While such separation between different perspectives on openness is conceptually possible, it should also be noted that these do not necessarily result in strictly separated communities. It is important to understand the similarities and differences between these perspectives nonetheless, to be able to understand what drives different kinds of stakeholders into adopting open practices.

3.1.1. *Openness as an ideal*

This thread of conceptualising openness advocates for limitation-free access to data, knowledge and resources for design and production/fabrication, and involves various drivers, like altruism (Troxler & Wolf, 2017), hedonism (Fox, 2017; Halassi et al., 2019; Wolf & Troxler, 2016), democratisation (eg. Arndt et al., 2021; Beltagui et al., 2021; Mortara & Parisot, 2018), sustainability (eg. Bonvoisin, 2017a; Hobson, 2019), degrowth (eg. Hankammer & Kleer, 2018), empowerment (de Rosnay & Musiani, 2016; Nascimento & Pólvara, 2018; You et al., 2020), and so on. These drivers are also aspirations towards an environmentally, socially and economically sustainable and just future.

Such ideals are, however, hard to enact upon in the current situations – or the attempts at them are short of what is being idealised. For example, Hankammer & Kleer (2018)

identify the lack of and the need for formalising organisational models that do not aim at maximising profits in the degrowth literature, in addition to alternative forms of collaborations between consumers and organisations. Unterfrauner et al. (2019) identifies the novel practices emerging from the maker movement in terms of value creation innovation and value proposition, which might define new strands for the economical sustainability of such practices in the existing environment unfit for them to flourish. These involve opportunities stemming from new capabilities through digital fabrication technologies and material innovation, new forms of collaborations and partnerships, and novel types of supply chains (eg. through distributed production), resulting in on-demand production, localisation, reduction of transportation costs, etc. Friesike et al. (2019) points out the potential for empowerment through open design communities, not only for learning and skills building but also through designing things beyond one's capabilities. Schmidt (2019) points at the social innovation potential through people getting involved in creativity labs.

These are in tension with the real-life implications of such practices, as openness of design data can be sacrificed for economical sustainability (eg. Balka et al., 2010) or for compliance with safety and regulations in certain sectors – like healthcare (eg. Carpentier, 2021). Furthermore, such communities are a form of social curation with various implicit and explicit selection mechanisms (Schmidt, 2019), which may result in exclusionary practices albeit unintended.

3.1.2. Openness as a competitive tool

Openness can become a strong competitive tool in value creation with open product development processes, platformisation, open innovation and similar approaches. This strand relates to collaborating stakeholders through openly shared knowledge and expertise, usually taking on predefined roles and responsibilities with clear, pre-determined frames. The level of openness of designs, governance, accessibility and production varies greatly according to the economic concerns of the collaborating parties and the hierarchical relationships amongst them. However, it is safe to assume that this strand places technological innovation and economic growth at its core compared to more idealistic concepts identified in the previous section.

For example, as a result of their study with the participants of Quirky – a crowdsourcing design platform and company, Coelho et al. (2018) identified the most prominent motivations of the participants were the possibility to earn money – if their designs are selected by the community and Quirky for production – and access to the wide range of ideas shared on the platform. One of the downsides highlighted was; however, the excessive number of product ideas that are not picked by the community, not being developed any further. Upon further analysis, the authors conclude that such social design platforms bringing together designers and non-designers for collaboration is not detrimental to designers' future job prospects (Coelho et al., 2018). There are various ethical concerns in crowdsourcing, such as unpaid 'voluntary' labour the community

members put in and exploitation of participants' knowledge and expertise without proper compensation (Standing & Standing, 2018).

There is also the platformisation approach, where the main offering is an open-source platform open to adaptations for both commercial and non-commercial purposes, and the company offers certain services around this platform. On the software side, there are many examples of such platforms, like the open-source Android operating system and Google Play services around them that provide access to secure app store, payment processing, etc. for developers. Cota et al. (2020) explores the opportunities of building such platforms for open-source hardware, especially for creating the infrastructure to drive technological innovation and entrepreneurship. There is also evidence that open hardware can be utilised as a knowledge transfer strategy that is low-cost and practical, that enables the development of an institution-led (and secured) OSH community and that does not erode commercial value (Kauttu, 2018). The latter might be especially true for high-tech innovations that require not only the knowledge and expertise to develop but also large investments and physical infrastructure to set up – as such innovations cannot be *realised* apart from a handful of market actors anyway.

For low-tech open designs that can be produced increasingly more easily with the dissemination of digital fabrication equipment, there remains the risk of licensing infringement. In such cases, such open designs can be supported by expert design and production services as sources of income and economic sustainability. For example, the Open Desk company that openly shares their office furniture designs complements their businesses with interior design services and acting as intermediaries between the end-users and producers around them, effectively becoming a platform (Gasparotto, 2017). Such examples will be presented in more detail later.

In both strands, whether openness is deployed as an ideal or as a tool for competitive advantage, it is important to recognise the opportunities it enables in terms of accessibility to design knowledge and distributed forms of collaboration in design, development and production. For DF-MOD, following the vagueness of the term 'business model', the researcher regards the 'value' created through them as loosely, including non-economic values such as social, cultural and environmental values. This project is an exploratory attempt at reconciling both strands of openness identified by (Ferdinand & Meyer, 2017), and this deliverable aims to culminate the existing literature to inspire such explorations.

3.2. Conceptualising stakeholders, collaboration, and distributed production

This section presents various conceptualisations of stakeholders and forms of collaboration, and how they build towards identifying the contours of distributed

production. The reviewed literature deploys various definitions of stakeholders and varying levels of collaboration among them according to the originating disciplines, focused sectors and/or products, and theoretical standpoint. As such, these definitions are often contradicting, same terms used for different purposes according to the different contexts introduced by the articles. Similarly, the ways collaboration is framed varies greatly as well. As such, the researcher found it necessary to introduce these differences and re-conceptualise them in a way contributing to the DF-MOD and its purposes.

3.2.1. Stakeholders and capabilities

The traditional separation among users, designers and producers have long been challenged with various approaches such as participatory design (Björgvinsson et al., 2010) and codesign (Fuad-Luke, 2013), and the lines among stakeholders are getting increasingly blurry in the past couple of decades, espousing hybrid roles and novel forms of collaboration (Stappers et al., 2011). Open design is an approach suggesting different forms of collaboration and co-creation among these stakeholders with varying degrees of skills, capabilities and resources, through transparency and accessibility of design knowledge to formulate more accessibly, participatory and expansive processes (Bakırlioğlu & Kohtala, 2019). However, there is a need to formalise these stakeholders in a manner that would enable conceptualising novel, collaborative and open value creation processes for DF-MOD, and this section aims to present such definitions of stakeholders, their skills and capabilities, and their engagement with open (design) knowledge in a meaningful way.

Through a literature review about users' active design engagement in various literature bodies, Kohtala et al. (2020) distilled various forms of engagement to propose a scale of active user participation from *use-as-is* to *active use*, *user design* and *user innovation*. These user practices are very useful in categorising the user practices in a potential distributed economies model. For this project, however, there is a need to categorise different stakeholders not only in terms of practices they enact but also roles they embody in a distributed production settings. The reviewed literature revealed various conceptualisations of stakeholders in open, collaborative design and production processes depending on the framing of the studies and focussed sectors. For example, Fox & Stephen (2014) distinguishes *DIY innovation* and *prosumption* and further identifies *DIY entrepreneurship* that facilitates *prosumption* - that is DIY. The authors identify the opportunities for DIY entrepreneurship especially where traditional manufactured goods don't reach, and DIY-ers can take on the production of such goods through the knowledge and resources provided by DIY entrepreneurs (Fox & Stephen, 2014). In their study on social product development (SPD) companies, Coelho et al. (2018) differentiates the community members as *designers* and *non-designers*, and the SPD company acts as the governance structure and facilitator for these community members and takes on the production and distribution of produced goods. Similarly, Fiaidhi and Mohammed (2018) also differentiates Industry 4.0, local entrepreneurs and individual makers.

The reviewed literature also identifies the roles of manufacturer/producer stakeholders and their changing supply chain management strategies in the face of emerging and increasingly more capable digital fabrication tools. About the latter, the reviewed literature presented an enhanced focus on 3D printing (see Figure 4) and there were articles discussing the potentials for decentralised nodes of manufacturing firms (eg. Verboeket et al., 2021; Verboeket & Krikke, 2019), potentials for dynamic and adaptable production nodes and business-to-business collaborations at regional scale for cloud manufacturing (Fisher et al., 2018b; Wu et al., 2013) and manufacturing-as-a-service (Chaudhuri et al., 2021; Gong et al., 2021; Purvis et al., 2020). There were also studies on the roles of local producer SMEs, maker entrepreneurs, crafts producers and other small-scale producer stakeholders (eg. Campos & Cipolla, 2021; England, 2020a; González-Varona et al., 2020a; Moreno et al., 2019). With varying capabilities, resources and levels of market reach, these stakeholders can form diffuse networks of production that are dynamic and responsive to the needs and preferences of different localities and individuals.

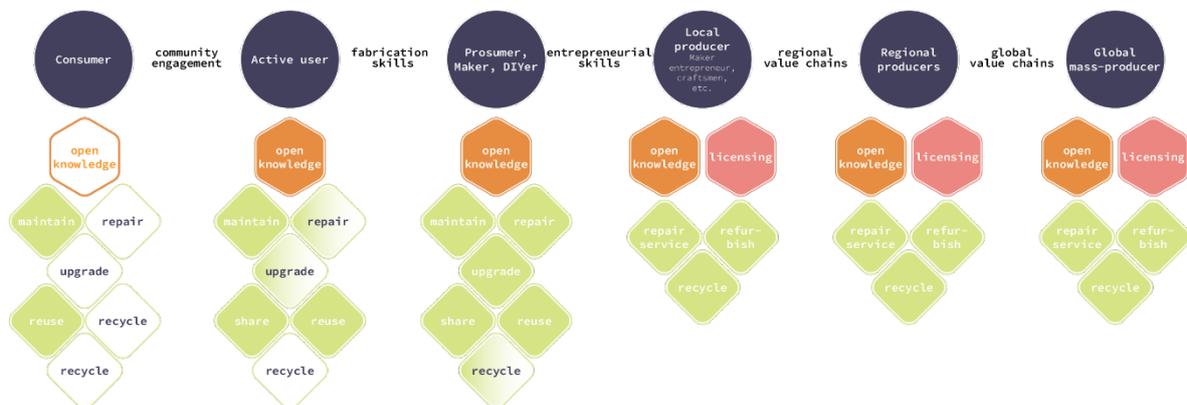


Figure 5. Stakeholders identified, along with open knowledge and circular economy strategies

Considering these, Figure 5 identifies the types of stakeholders informed by the reviewed literature. While there are many ways of conceptualising stakeholders observed, certain separations were observed in the literature in terms of developing new design-led business models as intended in DF-MOD. The main categorisation is *value creation for self* and *value creation for others*.

3.2.1.1. Value creation for self

The initial set of stakeholders represent stakeholders that participate in a potential distributed production system with the purpose of creating and recapturing value for themselves or their communities. The set includes:

- **responsible users/consumers** who acquire products designed and produced by local, regional and/or global, mass-producers to use them *as-is* – without any involvement in their design or production. These stakeholders do not partake in the production of open design knowledge. They can maintain or get maintenance

service for their products. Similarly, they can choose to reuse certain products initially used by others or initiate the reuse of their products through eg. second-hand markets, sharing services, leasing services, etc. For the remainder of the circular economy strategies (ie. repair, upgrading and recycling) they are only initiators sending their end-of-life products to other relevant stakeholders.

- **active users** acquire products designed and produced by local, regional and/or global producers, and adapt them to their own needs, preferences and wants through add-ons/interventions. The interventions can be made either during design and production stages through pre-defined intervention areas (ie. mass-customization), or post-purchase via adding parts and features. Former can be achieved through closer to end-user production nodes and additive manufacturing supported by IoT technologies facilitating mass-customization with the flexibility of digital fabrication technologies (eg. Hankammer et al., 2018; Helms et al., 2008; Hora et al., 2016; Ul Haq & Franceschini, 2020). It can also be achieved through community engagement – online or offline – through actively participating in the design and production processes. Post-purchase alterations can happen through simpler DIY tinkering, fabricating add-ons, etc. These stakeholders both utilizes openly shared design knowledge and partakes in the production of new open knowledge. They can carry out self-repair or self-upgrading practices to certain extent and actively share resources (eg. equipment, space, etc.) to carry them out.
- **prosumers / makers / DIY-ers** are the stakeholders that carry out fabrication and assembly of parts and components to create objects unique to their needs, preferences and wants. They can radically alter components, bring them together in different ways, reutilize these components for self-repair and self-upgrading practices. They also actively share knowledge and resources among themselves. They acquire certain parts and components – produced at local, regional or mass/global scale – for these purposes, and design and fabricate their own parts and components.

These set of stakeholders create value for themselves individually, or for their community, in the forms of knowledge, resources and collaboration. Their skills and capabilities vary greatly in terms of community engagement and fabrication skills, affecting their participation to design, production and post-use processes. However, the researcher also noticed and overlooked aspect of these stakeholders in literature. These roles are interchangeable in the face of complex material realities; one person can design and fabricate a unique object as part of one distributed manufacturing system, and also simply consume a product as part of another. While community engagement and fabrication skills are influential in this, it is also important to note other limitations people have. Some products are too *complex* and expensive to individually produce, and some are too *simple* to spend time and effort on. As such, the distributed production systems should be designed with this in mind, both accommodating responsible users by offering value recapture services and enabling makers/prosumers/DIY-ers to fabricate their

personal objects. Providing all these options must be the part of the business models of stakeholders that create value for others, and openness is a crucial part of such endeavour.

3.2.1.2. *Value creation for others*

The second set of stakeholders create products and services for others' use and involve business models for creating social and environmental value, as well as monetary value for their economic sustainability. These stakeholders can collaborate in design and production of components and products through eg. open innovation, manufacturing-as-a-service, supply chain innovation, etc., while also enabling the levels of engagement outlined in the previous section. The literature reveals that all of these stakeholders deploy various licensing strategies to manage open knowledge, which will be presented later in *Section 3.2.3 - IPR management strategies for open design knowledge*. The set includes:

- **local producers** (eg. maker entrepreneurs, craftsmen) that produces components and products for selling at the local scale. These stakeholders produce certain components through digital fabrication equipment and/or crafts, and bring them together with regionally and globally produces components to create value. They can produce *on-demand* and adapt the designs of their components and products according to the needs and preferences of their local customers. The direct involvement of active users and prosumers/makers/DIY-ers into the design and production of components and products is facilitated through open knowledge, which in turn can initiate and innovative, iterative open design process. The accessibility of these producers – in terms of proximity – highly improves the realisation of post-use services offered by them; whether they repair, refurbish and recycle components and products or act as intermediaries between customers and regional and global producers.
- **regional producers** are larger nodes in the distributed production ecosystem that develop products with their batch produced components and globally mass-produced components. Their product offerings can be adapted according to the region/market they are serving and can be iterated accordingly. The components are products are adaptive to regional needs and wants and produced from regionally available material resources. The openness of their designs enable local producers to develop and iterate new product offerings, and they utilise the openness of mass-produced components to outsource the production of more complex components that require higher accuracy and safety regulations.
- **global mass-producers** are the largest nodes with the least range of component and product offerings that are either too simple and widely used so that it is economically sustainable to produce them only *en masse* or too complex and require precise production that require flawless repetition. Mass-production can be regarded as physical copy-paste function open designs that enable regional and local producers to build their own product offerings on top of, as well as active

users and prosumers/makers/DIY-ers to undertake *value creation for self*. This is against the current market segmentation practice of global producers, which forcibly categorises varying individual, local and regional needs and preferences into tidy segments. Openness of these mass-produced designs are crucial not only for enabling alternative business models to emerge at local and regional scales, but also to ensure standardisation of post-use practices at all scales through interoperability. For simpler components and products, the design strategy might be to simplify design features and offer a basis for new iterations; while the design and development of more complex components and products would require inclusive open innovation practices with local and regional producers as well as prosumers/makers/DIY-ers.

This separation between stakeholders that create *value for themselves* and stakeholders that create *value for others* is crucial in conceptualising novel open design-led business models. Such a separation enables clear conceptualisation of what kinds of value is offered and what kinds of value is self-created, as well as how they are enacted at different scales (from individual to local, regional and global). It also frames when business models are required and how the roles of stakeholders can shift in distributed production ecosystems – not only among stakeholders that create value for themselves but also between them and stakeholders that create value for others.

3.2.2. Collaborative encounters

The stakeholders presented in the previous section is conceptualised according to the various, newly emerging forms of collaboration presented in the literature on open design, open innovation and distributed production, following the technological advancements in production, communication and automation technologies. Unsurprisingly, makerspaces, fab labs and other similar collaborative spaces that brings people together, based on sharing space, high and low technology fabrication equipment, expertise and knowledge are frequently mentioned in the literature as drivers of this change. Similarly, online communities formed for collaborative action is another driver to initiate such changes as they initiate knowledge exchange around the globe and unrestrained by physical distance.

Caccamo (2020) conceptualises the potential impact of innovation spaces for collaborative innovation, if they can accommodate combining disciplinary knowledge through *convergence* and *generativity*, and the development of new practices through *socialisation* and *collaborative learning*. Similarly, fab labs are perceived as democratising innovation due to their accessibility for people (ie. open access), as they are places bringing individuals together to espouse collaboration and provide the necessary infrastructure to enable them to pursue projects according to their needs, preferences and wants (eg. Beltagui et al., 2021; Mortara & Parisot, 2016). Various activities co-located in such spaces can initiate and facilitate knowledge exchange and collaboration among its users, primarily because of physical proximity (Santos et al., 2018). This is also thought

to democratise innovation processes for disadvantaged DIY-ers and entrepreneurs, as such spaces initiate interaction among everyone in it and provide the resources for everyone to pursue their desires (Rezaee Vessal et al., 2021). Alternative forms of collaboration can emerge in such places befitting to what is suggested by the democratisation of innovation (Browder et al., 2019).

However, there are also concerns about if and how such collaborative innovation places are really espousing such collaborations *and* if these collaborations are evolving into entrepreneurial practices. Vinodrai et al. (2021) highlights the lack of necessary training and infrastructure to support entrepreneurship in such places. These spaces have gotten more and more widespread, especially in the Global North. Although such spaces can espouse alternative forms of collaboration and innovative solutions, these outcomes might be disjointed from local economic development programs supporting local entrepreneurs (ibid). This actually impacts the diversity in such spaces, as they do not necessarily develop and deploy strategies or programmes to engage diverse groups of people (ibid). On another note, such places can easily become exploitative for the participants. In their study on such collaborative innovation spaces affiliated with corporate bodies, Browder et al. (2019) highlight the exploitation occurring now that such places attract increasingly more volunteer experts. These places now embody larger number of groups and espouses more innovative solutions, yet the participants are forced to do a lot more to stand out in such a crowd, gain reputation and even turn their ideas into businesses. In such cases, there is a risk of these spaces becoming cheap testbeds for innovative solutions, where many novel ideas are developed, prototyped and tested at the expense of exploiting the free knowledge creation efforts of participants.

Similar concerns are also highlighted for online communities. These can be regarded as digital spaces bringing people together and espouse alternative forms of collaboration. From a design perspective, these communities can consist of designers - loosely defined to include many disciplines designing products and services and active users informing the design process through openly sharing knowledge and experience (Yang & Jiang, 2020). Such communities can include people with a wide range of background, including different disciplines and can espouse the formation of interdisciplinary collaboration processes among them. However, the study of Bonvoisin et al. (2018) on open-source innovation communities through social interaction analysis reveals that such communities may not be attracting an effective number of people to successfully proceed the design and product development of different ideas shared on these communities. This is parallel to the findings of Coelho et al. (2018), as they also highlight the large number of ideas shared on online design communities that are not picked up by the community for further development and remain undeveloped.

These potentials for and barriers against alternative forms of collaboration enabled through shared spaces (online and offline) and democratising innovations; however, adopts a straightforward definition of collaboration based on project-based thinking and reflects a process that ends by producing certain outcomes. Open design – as

conceptualised in eg. Bakırlioğlu & Doğan (2020) and Tooze et al. (2014) – deploys an even looser and more diffuse form of collaboration that is governed by the openness of design knowledge and data and shared standards. DF-MOD also concerns itself with such diffuse collaborations open design can initiate that would facilitate widespread distributed fabrication and aims to present alternatives business models to overcome the barriers stemming from the *physicality* of open designs.

Physical-digital divide in open-source design and hardware projects mostly stems from lack of documentation, or rather the fact that the participants of OSH projects are not motivated to document their processes and outcomes in a way that allows those designs to be replicated or further iterated (Dai et al., 2020). There is also a lack of standardisation or taxonomy of forms of contribution (ibid). Such barriers make it increasingly harder for horizontal management or governance of such communities, especially when they are espousing open-ended processes, rather than project- or product-oriented processes (Bakırlioğlu & Kohtala, 2019).

3.2.3. *IPR management strategies for open design knowledge*

In literature, the rise and dissemination of digital fabrication technologies are sometimes considered as risky in terms infringement (eg. Bechtold, 2016; van Overwalle & Leys, 2017). That might be true within the existing intellectual property mechanisms and framing; however, open-source sharing has brought about different opportunities for more democratised innovation practices unbound by time or space, as well as a more broadened understanding of how intellectual property should be managed. In their review of literature on open design, Bakırlioğlu & Kohtala (2019) categorises various licensing strategies of open design knowledge as *public domain*, *community ownership*, *share-alike*, *trademarking* and *selective intellectual property*. These strategies, except for public domain, are discussed to provide:

- **safeguarding** the openness of outcomes and democratization of the knowledge commons
- **reliability** of open outcomes where, e.g. safety concerns are prevalent
- **value capture** in businesses through selective reveal for economic sustainability.

However, their categorisation is focused on the openness of outcomes and processes rather than legal implications of these strategies. In order to illustrate the alternative strategies for co-creation, the study of Tekic & Willoughby (2020) on various co-creation contexts is quite illuminating. They categorise different IPR management strategies observed in the automotive industry according six dimensions: (1) Transfer of ownership, (2) Licensing arrangement, (3) Compensation structure, (4) Non-disclosure Agreements, (5) Additional agreement, and (6) Waiver option. Accordingly, they identify 5 prevalent categories as follows:

1. Full transfer of ownership

2. Exclusive licensing
3. Non-exclusive licensing
4. Open Source/Creative Commons licensing
5. Neither transfer of ownership nor licensing

They state that more restrictive IP management strategies (ie. full transfer of ownership, exclusive licensing) are perceived as more favourable by companies especially when the co-creation process is carried out with a smaller number of people and intellectual property can be controlled in a straightforward manner. However, when the number of contributors – thus, potentials for “spontaneous recombination of contributions” - are higher, intellectual property becomes harder to control and more permissive strategies (i.e. non-exclusive licensing, open-source licensing, no licensing) are adopted (Tekic & Willoughby, 2020). The potential of open design lies in the latter, as it espouses a form of co-creation process undertaken by diverse and distributed stakeholders, not necessarily collaborating towards a consensus. The open designs can fork into different directions, espouse novel design solutions as well as novel ways of doing business around them.

It is important to recognise the mismatch between regulation policies around the existing IPR mechanisms and democratisation of design and innovation. For example, existing regulatory policies around medical devices inhibits the deployment of open-source licensing of medical device designs, in which case the OSH community around it might need to utilise partial or temporary privatisation of the knowledge commons they generate just to protect them and undergo regulatory processes (Carpentier, 2021). The regulatory differences among different countries further hamper open-source medical device development as the design and development of devices would need to conform to multiple regulatory conditions – some of which might be contradictory (de Maria et al., 2018). The lack or insufficiency of regulatory frameworks is also one of the biggest barriers against the adoption of distributed manufacturing as well (Luthra et al., 2019). It is apparent that the regulatory mechanisms and policies are lagging behind, hampering the potentials for open-source design knowledge sharing and distributed production. There are various directions identified in the literature, most prominent of which is both the universal standardisation of safety and security regulations (eg. de Maria et al., 2018) and the widespread adoption and standardisation of production techniques, materials and outcomes (eg. Peeters et al., 2019).

3.2.4. Centralised, decentralised, and distributed production

The existing mode of production and consumption demonstrates the centralisation of different stages of the product life cycle at different geographical locations, such as raw material extraction in South America or production and assembly in the Far East, resulting in value accumulation in the Global North. This places transportation in between each value creation process and ends up large amounts of CO2 emissions throughout the production and consumption process (Diez, 2011). Furthermore, such accumulation of

value in certain geographical regions further entrenches inequality in terms of accessibility to resources and well-being of people. Localisation of design and production through integrating global, regional and local scales for environmental sustainability has been discussed in literature for a long while, and conceptualised to empower local skills and improve the wellbeing of individuals (eg. Dogan & Walker, 2008). The literature on distributed economies emphasises such integrated scales of design and production through improved fabrication and ICT technologies, and proposes a radical shift towards more equal distribution of value, democratisation of innovation and demand-driven production.

Srai et al. (2016) presents distributed manufacturing enabled through digital fabrication and IoT technologies as an opportunity to bring production much closer to end-users through smaller and even micro-scale manufacturing units that are flexible and adaptable. This can result in active participation of end-users and other stakeholders into design, development and production, enable personalisation of products, and democratisation of design (Ul-Haq & Franceschini, 2020). Such processes can be supported by artificial intelligence for decision making and enable individual, local and regional stakeholders to devise their production and diffuse supply chains more responsive to environmental issues and social inequalities (Fox, 2017). Outsourcing certain tasks to automated systems or supporting software can facilitate the involvement of larger audiences into design and production, such as the open-source customizer presented by Nilsiam & Pearce (2017) for adapting openly shared CAD models online and enabling personalisation of shared designs for non-CAD-literate people. While such developments in digital fabrication technologies are influential in conceptualising distributed production, there are also certain limitations of these technologies. For example, additive manufacturing technologies are not developed to a point where they can assure no production defects (Baumers et al., 2017). Similarly, pre- and post-processing technologies are not as adaptive as additive manufacturing (Despeisse et al., 2017). Considering these, Rayna & Striukova (2021) proposes a hybridisation of production methodologies and value chains, where standardised, mass-produced parts, such as Arduino circuit boards, are combined with 3D printed components to exploit the potential opportunities enabled by local manufacturing. However, there seems to be a lack of standards or 'plug-and-play' solutions for mass-produced components that would accommodate such flexibility (Chaudhuri et al., 2019).

Kumar et al. (2020) introduces various strategies for mass-producers in distributed manufacturing settings as follows:

1. *Small-scale distributed manufacturing* involves centrally producing and stocking large volumes of products, while undertaking customised production closer to consumption. As such, local and regional nodes end up producing smaller volumes of products customised according to the needs and preference of the local stakeholders.

2. *In-house decoupled manufacturing* involves centrally governed decoupled production nodes, offering local manufacturing and personalisation closer to consumption. This, however, involves large investments from the company to set up production lines at various locations.
3. *Outsourced decoupled manufacturing* is about outsourcing primary manufacturing to external stakeholders, while value-added processes are carried out closer to the consumers to offer personalisation.

These strategies suggested depict highly specialised production nodes and external collaborators while focal firm retains value added process and sales channels. These strategies are similar to *decentralised production*, and does not reveal much about active users or prosumers/makers/DIY-ers that create value for self. Nonetheless, such distributed processes present various opportunities, especially when local actors are engaged in it. Distributed production especially with active, local production networks can respond to global trends or barriers more easily thanks to shorter and more responsive supply chains (Freeman et al., 2017). Such scenarios require very small, local production units collaborating in shorter supply chains and undertaking peer production.

Considering the above discussion, DF-MOD proposes the framework in Figure 6. Building on previously identified stakeholders in Section 3.2.1 Stakeholders and capabilities, this framing identifies not only contours of centralised, decentralised and distributed production systems but also identifies what is being manufactured or fabricated by each stakeholder and if and how these are brought together at different scales.

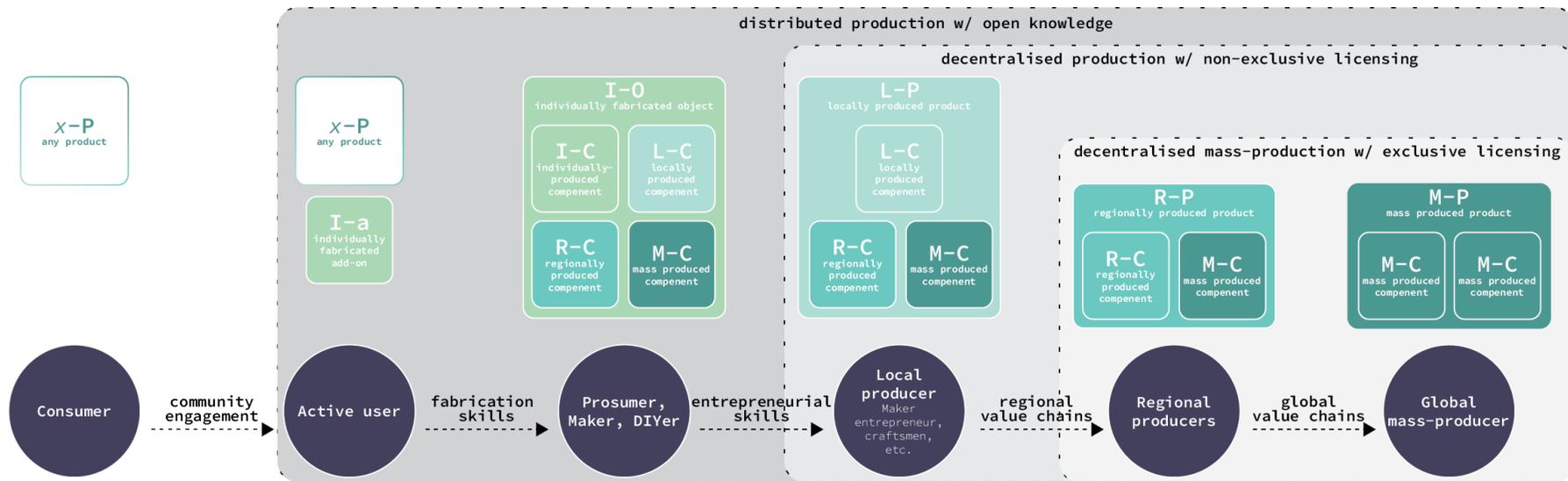


Figure 6. Decentralised and distributed production boundaries conceptualised for DF-MOD through literature

The right side of Figure 6 presents '*value creation for others*' stakeholders. There, global mass-producers collaborating with regional producers in the form of **decentralised mass-production** can be seen, resembling the *outsourced decoupled manufacturing* presented by Kumar et al. (2020). In this framing, mass-produced parts are brought together with regionally produced parts to offer customised production attuned to regional market demands. With the involvement of smaller, local producers (eg. maker entrepreneurs, crafts producers) **decentralised on-demand manufacturing** can be achieved to

produce products closer to consumption by bringing together locally, regionally and mass-produced components to create locally attuned value. Another opportunity arising here is the possibility of **distributed production through collaborating local producers** by forming shorter, local supply networks. These options are not strictly separated, and probably will happen in a hybrid manner.

The left side of presents '*value creation for self*' stakeholders, and it can be seen that prosumers/makers/DIY-ers with necessary skills and resources can undertake personal fabrication to

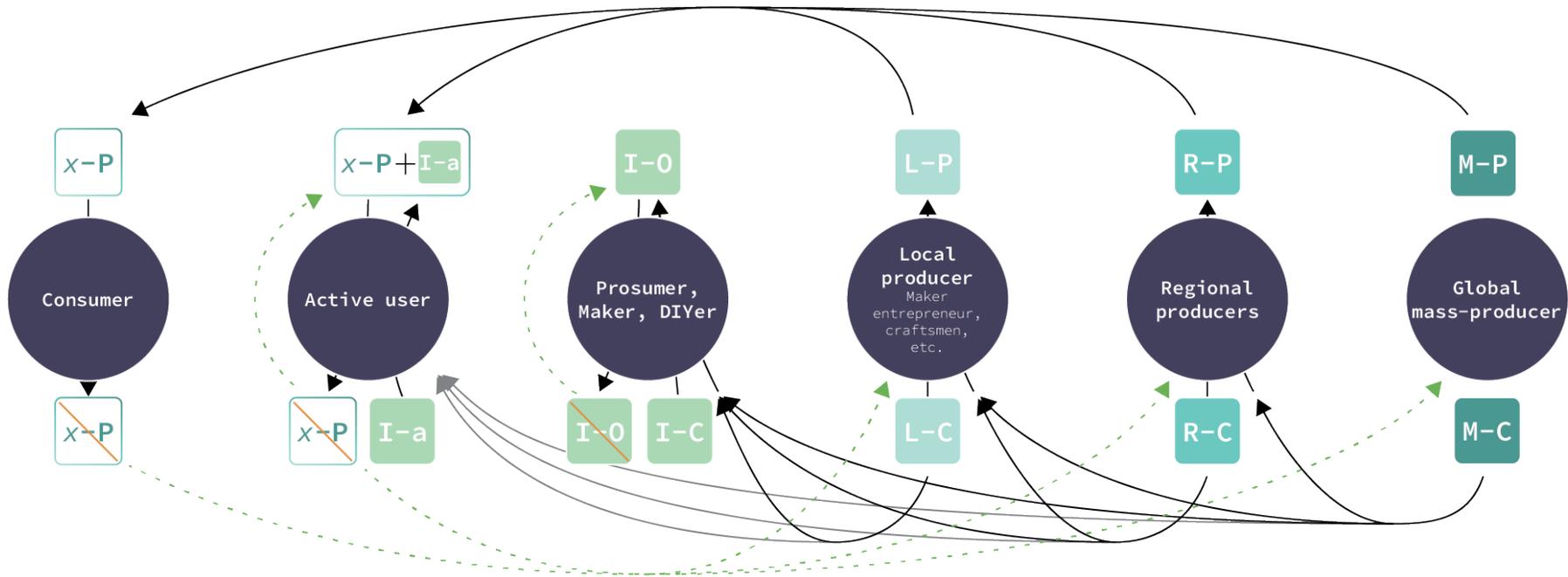


Figure 7. Distribution of parts and products, as well as potential circular economy loops illustrated for DF-MOD

fabricate components and bring them together with locally, regionally and mass-produced components to create *individually fabricated objects* for personal use. Or, not having the resources (eg. time, money, access to facility, etc.), active users can still choose purchase products from producer stakeholders and adapt them to their individual needs, preferences and desires through *individually fabricated add-ons* including any physical interventions to products. Such practices can be enabled through open design knowledge sharing among all stakeholders in Figure 6 and enable **distributed production with open knowledge**.

Figure 7 presents possible scenarios in this last framing. Producers on all scales can collaborate in production by providing components to each other, while also making them available for active users and prosumers/makers /DIY-ers. In turn these stakeholders can also undertake post-use practices themselves. In such settings, the business models can incorporate post-use services at varying levels through open design knowledge sharing, enabling local stakeholders to perform repair, refurbishing and recycling practices effectively for shorter, local CE loops.

3.2.5. New stakeholders, changing roles

The framing introduced in Figures 6 and 7 puts emphasis on production and end-user stakeholders without addressing **other ecosystem actors** for eg. transportation, material provision, point-of-acquisition, etc. While such a framing enables easier comprehension of the potentials of distributed fabrication, in DF-MOD, the researcher acknowledges the importance of other ecosystem actors. Especially at the local scale, there are studies highlighting importance of existing innovation ecosystem in cities (Eisenburger et al., 2019), as well as shared spaces for maker entrepreneurs and manufacturers (Tabarés & Kuittinen, 2020). Additionally, in order to initiate and sustain such a societal transition towards alternative modes of production and consumption facilitated by open design knowledge sharing and distributed production networks, stakeholders' motivations and aspirations must be aligned with a societal future vision (England, 2020b) and grassroots needs and preferences (Wolf et al., 2021). Building upon the general categorisation of stakeholders (ie. *value creation for self* and *value creation for others*), it is important to recognise users' – including active users and prosumers/makers/DIY-ers – inability to navigate complex socio-technical systems since these involve multiple producer stakeholders and other stakeholders in the ecosystem (Hobson, 2020).

As part of the Pop-Machina H2020 R&I project, I observed the need for a broader understanding of changing roles of stakeholders beyond the expanding roles and practices of users (towards active users and prosumers) and producers (towards regional and local value nodes). There is a need to recognise the barriers against connecting the nodes in local value chains for smaller circular economy loops, and to adopt a *maker symbiosis* approach to negotiate the roles and capabilities of local actors and their *product* and *non-product* outcomes (Bakırlioğlu et al., 2021). Such a perspective enables the stakeholders to connect the dots for local value creation networks through creative re-interpretation of non-product outcomes as secondary material inputs.

The literature also presents various opportunities for other stakeholders. For example, Purvis et al., (2020) proposes an expansion of services for logistic companies, by re-configuring logistics nodes (ie. local final stop before end-users) with digital fabrication equipment, effectively transforming them into local distributed production nodes. González-Varona et al. (2020a) proposes the potentials for on-demand spare parts production by existing shared machine shops with additive manufacturing. Santander et al. (2020) envisions waste management companies collaborating with certain local stakeholders to acquire and process plastics into filaments to physically shorten the recycling loops.

All in all, it is important to note that the circular economy approach places too much credit on users and local stakeholders in terms of reforming existing practices. Imagining, developing and deploying alternative business models at individual, local, regional and global scales remains the most important challenge of distributed production that need

to involve re-configuring perceptions on the capabilities of all ecosystem actors in a manner that distributes the value creation with open business models, which underpins the need for exploratory research like DF-MOD.

3.3. Business models identified

The reviewed literature highlights the need for novel, innovative business models required to facilitate distributed production, in terms of bringing production closer to consumption (eg. Bessière et al., 2019), adoption of additive manufacturing for production (eg. Santos et al., 2018) as well as post-use services (eg. González-Varona et al., 2020b), on-demand point-of-use fabrication (eg. Zaki et al., 2019), open businesses and value sharing (eg. Seo-Zindy & Heeks, 2017) and co-evolving businesses (eg. Bogers et al., 2017). Business models are rather underexplored not only for distributed production but also in adjacent production paradigms such as cloud manufacturing or industry 4.0 (eg. Savastano et al., 2019).

The business models explored at this intersection of distributed production and open design originates from changes in production technologies, sustainability concerns, local empowerment, democratisation of design and innovation processes. As mentioned before, this review defines 'business model' rather loosely, as ways of creation and recapture of any form of value (ie. environmental, social, cultural and economic). This is due to the fact that the literature does not utilise a shared template to present value creation and capture processes, and the following business models are collated with this in mind. Furthermore, there are various categorisations of business models according to additive manufacturing or open innovation, but no such categorisation is presented for open design-led business models in distributed production. Thus, this section will present the below alternative, newly emerging or recently conceptualised business models. These include, in no particular order:

- Sharing knowledge, equipment, and resources
- Decentralised manufacturing services and micro-factories
- Material provision through reformed waste management
- Open design platforms
- Sustainable Product Service Systems coupled with distributed production

3.3.1. *Sharing knowledge, equipment, and resources*

A sharing economy model – based on sharing space and equipment – is prominent in makerspaces, fab labs, DIY labs, or machine shops, and they are salient forms of spaces in literature around open design, open hardware and open innovation. These spaces are considered to espouse innovative encounters and democratise innovation process at least through accessibility to knowledge, equipment and resources. While these spaces present various opportunities in terms of knowledge exchange and collaborative innovation processes, their economic sustainability varies greatly depending on their

affiliation, income generation practices, and business models. There are various costs attached to maintaining such a space – including rents, expenses, wages, fees, external suppliers, and partners, and for the space to last, it should at least reach the break-even point and be financially sustainable (Menichinelli, 2013). There are various business models involving various business model elements; however, four main categories are identified in literature:

1. *Enabler* - that launches new labs or provide maintenance, supply chain, or similar service for existing labs.
2. *Education* – that provides education through engaging global experts and facilitate peer-to-peer learning among lab users.
3. *Incubator* – that provides infrastructure for entrepreneurs to turn their creations into sustainable businesses
4. *Replicated/network* – that provides a product, service, or curriculum by utilizing the infrastructure, staff, and expertise and the developed business model can be replicated by other labs.

While this provides an overview of potential business models for creativity labs, the mechanisms that drive financial input are also crucial. These spaces are reliant on income generating services to last (Faludi, 2020). Two mechanisms are prominent in the literature for such creativity spaces. The *membership model* involves collection of fees in intervals (monthly, weekly, etc.) from the users of the space to fund the upkeep of the space, the maintenance of equipment and the acquisition of frequently used materials (England, 2020a; Faludi, 2020; You et al., 2020). *Grant acquisition* is another mechanism for financial input, as some of these spaces seek for and acquire external funding (Faludi, 2020; You et al., 2020).

Beyond the economic value creation, these spaces present potentials for creating environmental and social value as well. In their study with 27 fab labs in Italy, Bravi et al. (2018) highlights the potential of transforming consumers into co-designers and help them espouse new businesses. Bergman & McMullen (2020) also highlight this potential; however, they also raise that these spaces need to provide entrepreneurial support, networking and brokerage services to enact on this potential. These spaces create unique, temporary social settings with diverse actors that promotes democratization, flexibility, commercialization, and decentralization of innovation processes, which might enable exploration of truly alternative business models (Schmidt et al., 2015), so long as they are supported by knowledge exchange on more practical aspects. In terms of environmental sustainability, the practices in such labs are not necessarily sustainable although their users are concerned with environmental issues from an idealistic perspective (Kohtala, 2017; Maldini, 2016). This might be attributed to a lack of day-to-day practices widely adopted in makerspaces. For example, Prendeville et al. (2017b) underlines that makerspace managers to need to adopt and promote a circular economy vision, as well as to adopt and use the practical tools to implement that vision into day-to-day practices.

3.3.2. Decentralised manufacturing services and micro-factories

In the reviewed literature, both for distributed production and for other novel production paradigms such as industry 4.0, the advancements in additive manufacturing and IoT technologies are mentioned frequently for their enhanced flexibility and efficiency. Fisher et al. (2018a) defines cloud manufacturing as a novel business model based on sharing production capabilities (ie. expertise, equipment, and resources). Cloud manufacturing can be economically sustainable through collaborative design, greater automation, improved resilience and enhanced waste reduction, reuse and recovery (ibid). It can also be categorised as manufacturing-as-a-service (MaaS) (Gong et al., 2021; Laplume et al., 2015). Additive manufacturing and IoT technologies enable flexibility in value chain by bypassing the need for tooling and enabling remote monitoring (Fisher et al., 2018a). Furthermore, the management of supply chains and expertise can be outsourced as needed and decision making can be complemented with supporting technologies like IoT for monitoring and artificial intelligence for decision making (Gong et al., 2021).

This is closer to decentralised manufacturing through outsourcing and non-exclusive licensing strategies, in which the nodes are manufacturing agents to carry out certain tasks in the value chain (Gong et al., 2021). This concept allows effective use of manufacturing capabilities of these nodes, and the adoption of digital fabrication technologies enables resilient production nodes through flexibility of the nodes' functions. Eco-efficient production seems to be main environmental value generated here through reduction in both material use and shortened transportation between the nodes and the end-user – especially when final manufacturing nodes (or micro-factories) are geographically closer to consumers. However, from a social aspect, the increased emphasis on automation in supply chains and manufacturing networks raises the issue of job losses (Verboeket & Krikke, 2019). In terms of open design knowledge, these opportunities are enabled through more distributed open innovation processes; however, there is a strict IPR management strategy involving the ownership of IPR with the firm/person outsourcing production and non-exclusive, yet limited use licensing with manufacturing nodes (Gong et al., 2021), indicating centrally governed decentralised manufacturing networks. As such, new stakeholders emerge in the form of outsourcing brokers that provide innovation and evaluation management services (ibid).

There is an interesting strand observed in the reviewed literature that demonstrates the changing roles of existing stakeholders. Logistics services have become increasingly more effective and has become widespread over the years, and they readily have local nodes in the forms of drop-off/pick-up points, post offices, etc. Pilz et al. (2020) points out the potentials of decentralised additive manufacturing in reducing the need for transportation overall; however, they also acknowledge the current state of 3D printing in terms output quality and that it does not replace conventional manufacturing. Indeed, 3D printed parts would still require additional processing – and facilities to carry them out at manufacturing nodes. Purvis et al. (2020) brings forward an interesting business

model to address this issue by expanding the roles of logistics operations and nodes in a way that is similar to MaaS. If the logistics companies can improve their capabilities and partake in the manufacturing network of decentralised production, they can become assembly and testing nodes a lot closer to consumption. They can even act as outsourcing brokers (Gong et al., 2021) in setting up flexible, resilient supply chains. This creates opportunities for on-demand fabrication as well through re-arrangement of stakeholders and flexibility of manufacturing nodes.

3.3.3. *Material provision through reformed waste management*

As the least desired circular economy strategy – due to complete abandoning of all the added value throughout the value chain – recycling is the very last resort to prevent disposal. However, there are many technical barriers that inhibit recycling including the design of parts and components and the production techniques deployed. For plastics, contamination, mixed use of plastics types, inability to cleanly separate them and quality degradation over time can be listed as such technical barriers (Peeters et al., 2019), some of which can be overcome at the design stage, while others – like quality degradation – are harder to overcome. In their study on opportunities for and barriers against 3D printer recycling, Peeters et al. (2019) list the barriers as:

- *Technical barriers*, including diameter sensitivity, external contamination, varying plastics, extruder capabilities, quality degradation, etc.;
- *Regulatory barriers*, including complying with safety and health regulations, trade secrets, copyrights and patents;
- *Behaviour change*, including the linear economy, the lack of awareness and the perception of quality;
- *Lack of standardization*, including types of materials, assembly techniques, etc.

All these indicate the need for either a highly standardised fabrication process widely adopted by makers and producers or sustainable product-service systems that allow strict and complete control over specific value chains. The former requires a complete paradigm shift in the modes of production and consumption, and such a transition most likely requires time and policy intervention. For the latter, Santander et al. (2020) presents an exploratory study of devising a PSS for distributed sources of standardised waste in a specific region for a localised recycling network. This PSS identifies 3D printer users (eg. schools) in a specific region and offers two-way transport and delivery services: (1) collecting 3D printer filament waste and (2) supplying recycled 3D printer filaments. In between, the PSS recycles the collected, highly standardised filament waste into rolls of filament and resells them to the local actors, closing the loop. This involves the emergence of a novel actor that is not a full-scale waste management company, but a secondary raw material provider.

3.3.4. Open design platforms

There are various examples presented in the literature in terms of platformisation, which can be categorized as (1) through standardization of participation forms, (2) through standardisation of designs, and (3) through standardisation of functional parts. All of these deploy open design knowledge in varying ways but mostly as a competitive business element.

Standardisation of participation forms mostly refers to design crowdsourcing platforms, such as Quirky, where the roles of platform owners and contributors are clearly defined. These are sometimes referred to as social product development (SPD) communities as well (Coelho et al. 2018). The platform owners can act as intermediaries between contributors and interested third-party companies that are interested in producing the collaboratively designed outcomes (Gasparotto, 2017). They can also act as producers of prominent design solutions, bringing them to the market directly (ibid). For the contributors, the form of participation varies according to expertise and relevance, which can also be categorised in different ways according to the main theme of the platform. For example, Coelho et al. (2018) categorise platform participants as trained designers, non-design trained participants, and observers. In such platforms, the community attracted by the platform partakes in the selection of the design solutions to be commercialised and their involvement usually ends there.

Standardisation of designs refers to a firm developing and releasing design solutions with non-commercial commons licensing and retaining non-exclusive commercial licensing for their own utilisation. The platform involves distributed production nodes as local producers, and end-users can order design solutions to be produced in a location near them by collecting offers from platform participants. Platform owners act as intermediaries between end-users and local producers. They can also offer additional services. For example, in the case of OpenDesk, the platform offers interior design services to end-users in addition to acting as intermediaries between local producers and end-users (Gasparotto, 2017).

Standardisation of functional parts refers to the design and production of components widely adopted by other producers and prosumers/makers/DIY-ers in their design and production processes. The most prominent example is Arduino, an Italian company that mass-produces and sells electronic components. In Arduino's case, complex components are designed in a way to be utilised as parts of other design solutions developed by its community. They are readily available for people to utilise and complement with individually fabricated or locally produced parts to create novel design solutions (Rayna & Striukova, 2021). The Arduino components effectively constitute a physical platform for everyone to develop design solutions with.

3.3.5. Sustainable Product Service Systems coupled with distributed production

There are explorations about developing product-service systems (PSS) as part of distributed manufacturing settings to facilitate local circular economy networks, effectively creating sustainable product-service systems with local, accessible production nodes (Petruilaityte et al., 2020). The implications highlighted are two-fold: (1) PSS for enabling distributed production, eg. maker spaces, local production and resale nodes, and (2) PSS enabled by distributed production, eg. on-demand local producers, local repair shops with spare part production, etc. Petruilaityte et al. (2020) proposes that such business models need to facilitate customer buy-in for getting involved in the design and production, through offering expertise and services accommodating varying levels of design and production capabilities. Indeed, small and innovative firms can initiate sustainable value chain networks through sPSS, and actively engage users at varying stages (Beltagui et al., 2020).

Malakuczi (2020) highlights three distinct barriers for distributed design and fabrication, which are also highlighted in the reviewed literature in various contexts. First and foremost comes the limited material options for widely-used digital fabrication equipment and their limited capabilities imply that certain parts and components are not suitable for production at local nodes (ibid.). Furthermore, these fabrication equipment are currently incapable of fabricating highly precise parts or components, which poses problems when those parts require higher levels of accuracy and precision to function (ibid.). 'Maker tech' may not be suitable for every sector or type of products, as they probably have different needs for local design and production (Eisenburger et al., 2019). There is also the question of whether certain parts even need to be produced at distinct nodes if they are either highly standardised or highly complex, even if material types diversified and precision is enhanced. The third barrier Malakuczi (2020) highlights is that "distributed form of production cannot impose values like mass-production and marketing." I disagree with this proposition while I recognise the sentiment. Indeed, incumbent forms of production and consumption is formidable in imposing values through marketing and the linear economy matching the existing consumer practices; and distributed forms of production may not be able to compete in the same playing field. However, there is also an increasing awareness on social and environmental crisis around the world, more active engagement of users into design and production, and movements and approaches supporting these. The risk here is that sustainable supply chain innovation initiated and deployed by small, innovative firms through sPSS + distributed production may struggle to compete when larger firms are persuaded to imitate such practices (Beltagui et al., 2020).

The reviewed literature also presents more grounded business model proposals for circular economy, especially for repair and additive manufacturing of spare parts. Especially for global SMEs (ie. SMEs providing products in multiple countries, regions, etc.), producing a stock of spare parts and storing them requires additional monetary and

human resources. As such, González-Varona et al. (2020b) proposes distributed, on-demand production of parts at local nodes, which can become a viable alternative for such firms through connecting local 3D printing companies with global SMEs in a network. I would take this proposal one step further and suggest that open design knowledge on spare part designs and repair processes can enable individual fabrication or independent repair services to carry them out. However, the literature notes that not every part or component is suitable for distributed spare parts production through additive manufacturing, especially when they are highly complex or they require high precision (Frandsen et al., 2020).

3.4. Sustainability and the Circular Economy through open design and distributed production

(Bauwens et al., 2020) identify four different future circular economy visions based on (de-)centralized governance and high-low tech innovations, that is highly relevant for this project. In terms of governance (centralised and de-centralised) and level of technology (low tech to high tech), they define these scenarios as (1) planned circularity, (2) bottom-up sufficiency, (3) circular modernism, and (4) peer-to-peer circularity (see Figure 8).

- *Planned circularity* suggests rather authoritarian scenarios in which consumers are constrained to adopt circular practices, especially higher Rs (ie. refuse, reduce and reuse). Centralised governance sets strict restrictions on resource consumption, bans certain material types, etc. This scenario more likely happens at a national scale.
- *Bottom-up sufficiency* suggests scenarios of decentralised and small-scale production nodes for self-sufficiency of local communities. These scenarios require voluntary behaviour change on a large scale toward reductions in consumption patterns. Small-scale production nodes innovate for reducing demand and mitigating consumption behaviour, and the nature of innovations are social. This scenario suggests a radical localisation of production and consumption.
- *Circular Modernism* is centralised governance of high-tech innovation practices that can decouple environmental impacts of incumbent modes of production and consumption from nature. This is an eco-efficiency approach with large research and development investment, that does not differentiate much from the existing linear economy in terms of business models.
- *Peer-to-peer circularity* suggests decentralised economic activities enabled through emerging technologies, such as blockchain, 3D printing, IoT, etc., and shift towards eg. sharing economy, collaborative consumption, etc. This involves the servitisation of on-demand accessibility to resources – rather than ownership of

products – and there is a shift in perception from consumers to users, who can get more actively involved in value creation processes.

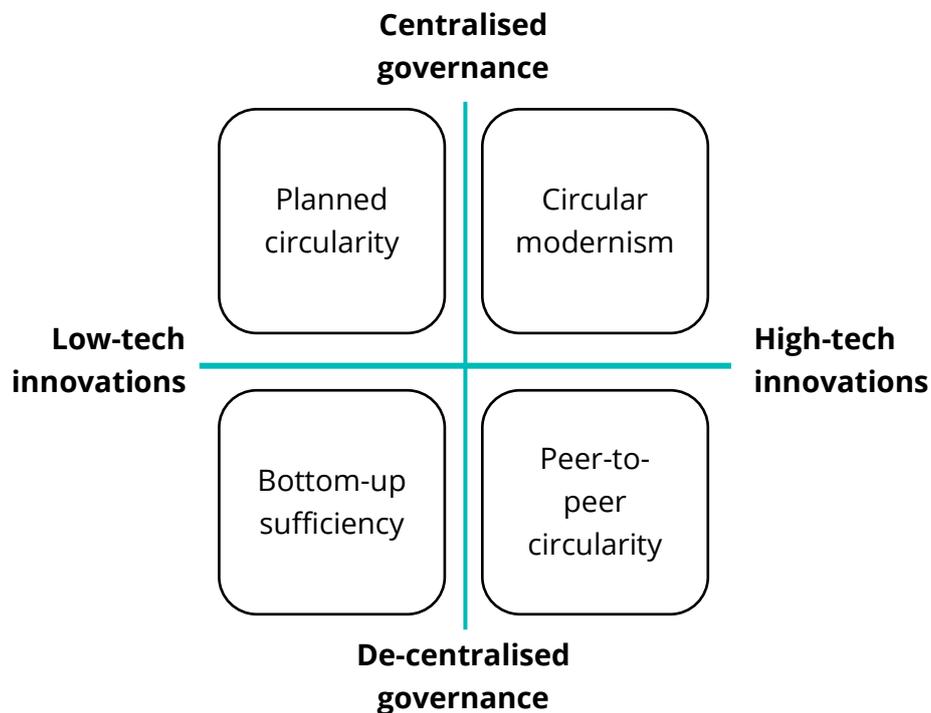


Figure 8. Scenarios for distributed circular economy futures (adapted from (Bauwens et al., 2020)

In addition to developing distinct, plausible future scenarios, the authors highlight that a combination of these scenarios – rather than any one of them purely realising – is more preferable (Bauwens et al., 2020). This involves a combination of centralised and de-centralised modes of governance, ie. setting and enforcing broader societal goals at higher, policy level and autonomous local actors enacting on these goals through social innovation (ibid).

The limitations for each one of these future scenarios are also highlighted in various contexts in the reviewed literature. For example, while horizontal governance in communities of practice and DIY labs are considered to democratise innovation (Arndt et al., 2021), such governance is also difficult to enact due to many actors involved at varying stages of the processes – which might require core decision making teams to compensate for community turnover effects (Dai et al., 2020). Another point is that advancements in production and decision-making technologies may not always lead towards the adoption of circular practices. While additive manufacturing technologies can re-shore manufacturing practices and decentralise production in a global sense, increased accessibility to such production capabilities also runs the risk of promoting faster fashion cycles, hence increased disposal, and reinforcing the inequalities in the existing supply chains with less reliance on manual labour (Hohn & Durach, 2021). Advanced technologies can be utilised as support for decision making in design and production. For

example, artificial intelligence can be utilised to communicate micro, meso and macro-level impacts of design decisions of local producers or individual makers (Eglash et al., 2020). These illustrate the importance of regarding such technologies as the tools they are and how their uses need to be conceptualised in ways to improve environmental, social and cultural well-being. DF-MOD is a project that aims to ground the opportunities and barriers through exploring novel business models that *enable* distributed value networks at the intersection of the future scenarios presented by Bauwens et al. (2020). The combination of envisioned futures requires a change of perception on the roles of stakeholders and technologies, probably resulting in additional stakeholders that connect the dots among individual, local, regional and global actors (Bakırlioğlu et al., 2021).

4. Conclusion

This deliverable (Deliverable 3.1) aims to present an up-to-date review of existing literature at the intersection of distributed production and open design, especially to collate novel business models explored at this intersection. The search was carried out using three databases (ie. Web of Science, Scopus, EBSCO Academic Search Elite) and yielded an initial list of 512 peer-reviewed journal articles written in English. The number of journal articles has increased dramatically in the past decade, from 6 *articles* published in 2010 to 123 *articles* published in 2020 at this intersection. Through the review of abstracts and the assessment of contents, the final list is reduced to a total of **131 articles** to be analysed according to (1) value creation, (2) drivers/themes, (3) business model elements, (4) collaboration, people's involvement, and governance, (5) intellectual property mechanisms, (6) alternative, sustainable production & consumption, (7) economic sustainability of open design business models, and (8) life cycle stage.

The analysis revealed that openness is regarded differently when it comes to business models. Some articles regarded **openness as an ideal** and used it alongside various drivers, such as altruism, democratisation, empowerment, degrowth, etc. Others regarded **openness as a competitive tool** through eg. crowdsourcing, platformisation, which involved often voluntary stakeholders and firms capitalising. The analysis also revealed an overall division of stakeholders according to the intentions of their value creation processes. Accordingly, there are stakeholders that **create value for themselves or their communities**, and stakeholders that **create value for others**. This separation enabled an alternative to traditional producer-consumer separation and is especially useful to recognise the differences between stakeholders (eg. maker who makes things for personal use vs. maker entrepreneur creating a business to provide products and services to others).

As such, DF-MOD aims to explore a distributed production setting enabled through open design knowledge sharing that can espouse decentralised forms of collaborative production among global, regional and local producers through non-exclusive licensing of open knowledge, as well as the active involvement of active users and prosumers/makers/DIY-ers into the design, production and post-use processes. Enabling practices such as practices at all scales (ie. from individual to local, regional and global) inevitably affects the way parts and components are designed, and arguably requires open design knowledge to diffuse and mainstream active participation of stakeholders that create value for themselves. Alternative business models that DF-MOD aims to explore in the following work packages become meaningful for *value-creation-for-others* stakeholders whether they create value for other global, regional and local producers or for *value-creation-for-self* stakeholders.

The reviewed literature does not present a shared conceptualisation of a 'business model', rather it is defined loosely as any depiction of economic, environmental and social

value creation processes. While there were many nuanced business models presented from varying perspectives, they can be categorised under five main headings: (1) sharing knowledge, equipment, and resources, (2) decentralised manufacturing services and micro-factories, (3) material provision through reformed waste management, (4) open design platforms, and (5) sustainable product-service systems coupled with distributed production. All these types of businesses involve *a change of perception on the roles of stakeholders and technologies* to formalise **resilient, flexible value networks** that can diffuse and become mainstream. Such a transition towards distributed economies requires envisioning plausible future scenarios on networked value creation and potential future production nodes in such a network.

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Appendix A – Full List of Reviewed Articles

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