Karlsruhe Institute of Technology

Sociotechnical Visions of 3D Printing – from Visions to Sociotechnical Scenarios

2nd Report of the Vision Assessment Study in the Cluster of Excellence 3D Matter Made to Order

by Maximilian Roßmann, Christoph Schneider, Mariana Leshkovych, Andreas Lösch

KIT SCIENTIFIC WORKING PAPERS 177

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Acknowledgements:

The authors thank the Carl Zeiss Foundation for the financial support.

The Vision Assessment Study is part of the 3DMM2O Cluster funded by the Deutsche Forschungsgemeinschaft (DFG, German Research Foundation) under Germany's Excellence Strategy – 2082/1 – 390761711.

Coverpage artwork:

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Impressum

Karlsruher Institut für Technologie (KIT) www.kit.edu

2021

ISSN: 2194-1629

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November 2021

This report presents interim results of the project "*Vision assessment of scalable 3D printing in the Cluster of Excellence 3D Matter Made to Order*". The study is part of the 3DMM2O Cluster funded by the Deutsche Forschungsgemeinschaft (DFG, German Research Foundation) under Germany's Excellence Strategy – 2082/1 – 390761711 and is funded by the Carl Zeiss Foundation.

3D MATTER
MADE TO ORDER

Carl Zeiss
Stiftung

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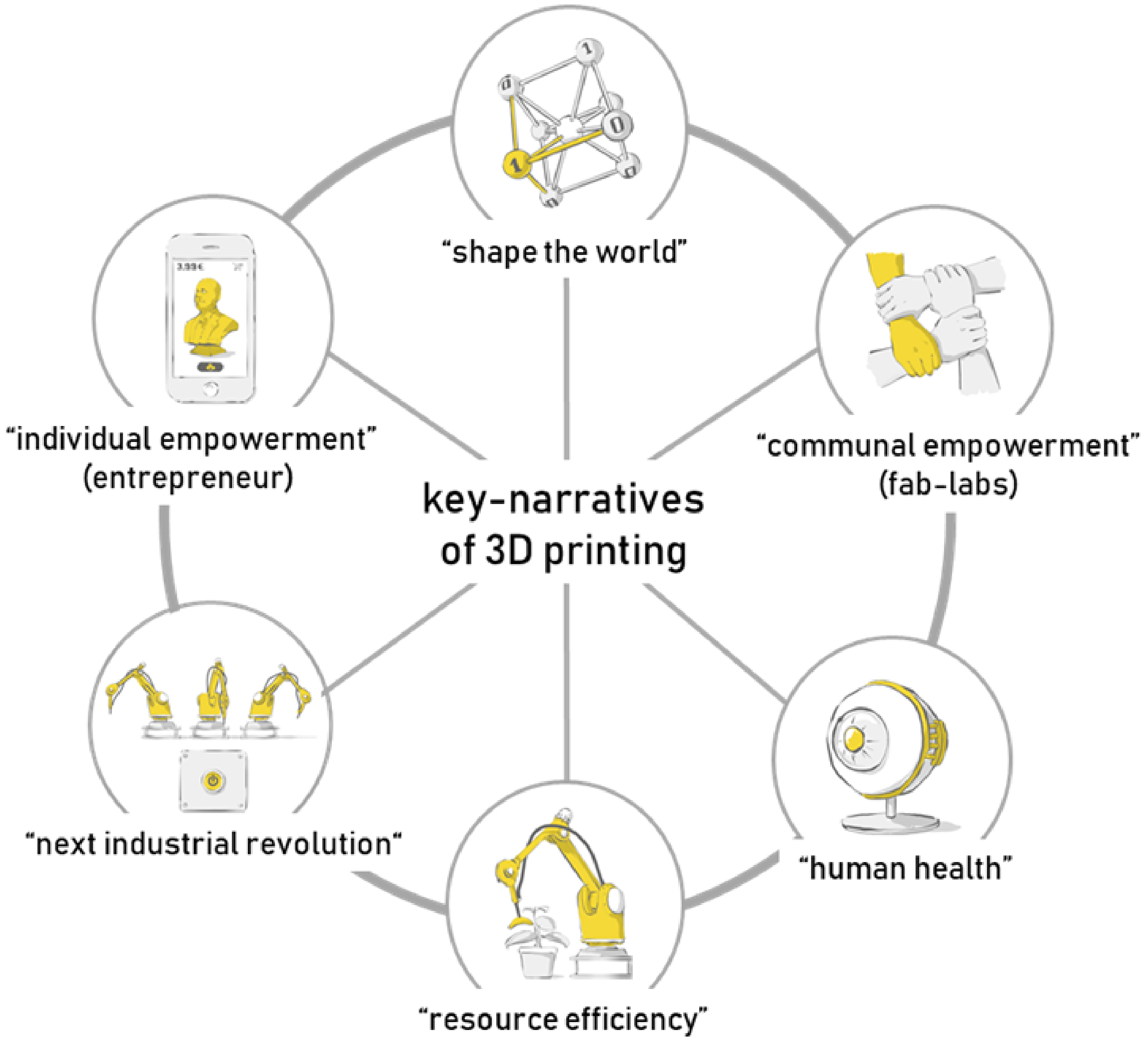
1 Introduction

3D printing is a visionary technology – with an uncertain future. Applications of 3D printing are established in industry, teaching, architecture, medicine, fashion, and community-driven workshops. However, given recent efforts in research and the great promises about revolutionizing entire societal fields circulating in mass media, one might find oneself still only at the beginning. Playing these visions down with a sober look would ignore their significance for the orientation and motivation of projects and activities, as well as for coordinating versatile efforts and the often-controversial media debate about liberation due to 3D printed weapons or mad surgeons. Research over the past decades revealed that imagined futures shape technology development and societal integration of technology.

Our study "Vision Assessment of Scalable 3D Printing in the Cluster of Excellence 3D Matter Made to Order" (2019-2022) takes visions – or more generally: imaginations of the future – as vehicles to analyze social dynamics that shape the next generation of 3D printing in society. In this project, an interdisciplinary team of Technology Assessment (TA) scholars collaborates with the KIT and Heidelberg University Cluster of Excellence on the project "3D Matter Made to Order" (n.d.), which aims at advancing the next-generation 3D printing technologies. Our mission is not only to better understand the variety, diffusion, and functions of imagined futures for shaping 3D printing technology in society. We also want to foster a reflexive debate about technology futures in science and society. Since imagination is central to deliberating viable pathways into the future, we convert findings into narratives that tear down and expand imaginary boundaries and co-create scenarios that outline different possible pathways for 3D printing in society. This report documents our work-in-progress and moves from the analysis of visions to the creation and modulation of future scenarios. We address everyone with a deeper interest in the contingent futures of 3D printing, the TA methodology of vision assessment, or both.

The first part of this report focuses on the importance of vision in the development of technologies, using 3D printing in response to the demands of the current COVID-19 pandemic as an example. We do so by presenting visionary key narratives (see Figure 1) from our first report and applying them to an interpretation of the large yet short-lived 3D printing projects that produced medical and protective equipment in the initial phase of the pandemic. The second part of this report presents our analysis of contemporary visions of 3D printing in the media and the perception of tensions between visions and reality by 3D printing experts from different domains. In our first report, we argued that the first hype of 3D printing around 2010-2015 established visionary key narratives in the public domain. Now we present our findings on what happened during the past years to the public perception of 3D printing. Based on a quantitative and qualitative media analysis (Chapter 3) we show that although 3D printing and its applications are vastly diverse by now, imaginaries of the technology remain focused on core themes and perspectives. Using qualitative expert interviews, we trace and discuss the visions' impact and tensions between imagined and factual possibilities in expert contexts of engineering, social sciences, education, healthcare, and science journalism (Chapter 4). The third part of the report combines analysis and modulation of imaginations of the future – intending to facilitate more reflexive dialogues on 3D printing between science and society. We discuss our approach of co-creative scenario building (Chapter 5) and present the current state of the process through four possible pathways of 3D printing in society based on the results of two expert workshops. In conclusion, we reflect on our ongoing advancement of the vision assessment method through this study (Chapter 6) and discuss how circumstances, such as large-scale research organization and remote work due to the COVID-19-pandemic, have impacted this, and how further research might follow-up on it. Each chapter ends with key points for fast readers.

Our report intends to be an interface for enabling dialogue between various disciplines and science and society. Therefore, we would like to take the chance to ask for your feedback on the findings, claims, and interpretations presented in this report (see Chapter 6).



Individual empowerment

3D printing liberates and **empowers the individual**, as now everyone can become an entrepreneur. Individual designs are customized, shared, and marketed at online platforms, and 3D printing fosters a new dynamic that will challenge existing industrial giants.

Shape the world

The possibilities of 3D printing do not know any limits. In the long run, the digital world and the material world will merge once and for all. We will re-**shape the world** – atom by atom, bit by bit. This boundless horizon finally puts mankind in its rightful place.

Communal empowerment

The 3D printer is not at the center but rather a means for experimenting with creative collaboration, sharing knowledge and ideas, and **empowering the community**. Thinking big – one could overtake the classic consumer/ producer relationship.

Next industrial revolution

In the vision of 3D printing for the **next industrial revolution**, all products can be manufactured at the touch of a button. Fully automatized factories are part of a global network, so that production is scaled up at will and new products reach the market much faster.

Resource efficiency

3D printing allows repairing and producing spare parts on demand so that warehouses and logistics become obsolete. Nature-inspired design rises **resource efficiency** for the same function – if biodegradables and recycling don't close the loop anyway.

Human health

3D printing **medical applications** mean that prostheses and treatment methods are studied on the model, customized towards individual demands, and implemented. Living cells and 3D printed matter will merge in the long run. But why stop at healing human abilities when enhancement is possible?

Figure 1: The key narratives of 3D printing, as stated by Schneider, Roßmann, & Lösch (2020), to distinguish the most prominent visions of its valuable applications in society.

2 3D Printing and COVID-19 – a case for the impact of visions

The COVID-19 pandemic has not only made visible many tensions and challenges in our societies. It also provided a stage for the promises and power of technology visions. It is astonishing how in early March 2020, with Western states almost simultaneously taking lockdown measures, stories about people printing spare parts for respirators or mass-producing face shields circulated and 3D printing received a renewed media hype. Most notable here was the project of two young Italian engineers whose picture featuring them wearing face masks and holding the 3D printed supply parts for medical respirators became almost iconic (Figure 2). What made these stories and promises so powerful? And what does it tell us about the role of visions in the public perception of 3D printing? To explore the recent relevance of 3D printing, this chapter observes socio-epistemic practices in the COVID-19 pandemic through the lenses of visionary key narratives that represent and distinguish established patterns of meaning attributed to the emerging technology that guide its perception and evaluation.

Figure 2: The founder of Fablab Milano, Massimo Temporelli (2020), recruited the engineers Cristian Fracassi and Alessandro Romaioli, who have reverse engineered a patented valve to help overcome the shortage of spare parts in hospitals.

From a social science perspective, the socio-technical collaboration for overcoming present challenges using 3D printers is presuppositional as well as is the dissemination of respective success stories. Technically, functioning and available 3D printers, as well as suitable filament and templates, are a prerequisite. Socially, certain prior knowledge about what is 3D printing, as well as networks for the exchange of experiences and templates as well as for the dissemination of the masks, are necessary. From the vision assessment perspective, the expectations of 3D printing play a central role here. Expectations of how 3D printing offers the potential solution to a current problem motivate action and provide a shared imagination of what activities and steps need to be organized. In the public discourse, narratives already published about 3D printing visions provide the necessary redundancy of expected challenges, technological features, players, and opportunities to facilitate telling variances as exciting and surprising cases without overly extensive explanations. In the first report, we summarized and distinguished the most popular visions of how 3D printing should help to overcome major challenges in key narratives (Figure 1). These key narratives provide the entry point for examining the utilized potential of 3D printing in the pandemic, as they allow distinguishing the relationship between technology and aspired societal values and foster assembling constraints for the imagination (Roßmann & Rösch, 2020). Given the expectations expressed therein, the question is whether the pandemic is the great moment of 3D printing visionaries and the Maker movement? Did the pandemic provide an opportunity to draw on existing resources and could the visions meet their promises?

The key promises of 3D printing in the wake of the pandemic involved agility and rapid scaling of production. In the narrative of the "next industrial revolution", 3D printing thus allows a digital template to be materially replicated at the touch of a button in an easily scalable way so that new products reach the market more quickly. The necessary initiative and organization of citizens to design and produce spare parts and face shields do not play a role here. The focus is on digital networks, technology, and economic gains. If one takes the promise seriously, "3D printing for the next industrial revolution" would have had the potential to prove itself in the pandemic, as there was a demand for face shields and spare parts, especially at the beginning of the pandemic. From this perspective, it can be criticized that although the technology was ready, large-scale industrial structures hindered a rapid response to the pandemic.

In the narrative of "3D printing for individual empowerment," new, agile startups can respond more quickly than large companies to such shocks, so that a market for printed customizable products and templates is becoming established, especially online. In particular, spare parts for medical equipment were sold online by small businesses during the pandemic. In an interview with an expert for the approval and implementation of medical technology in hospitals, the difficulties of printed spare parts for medical use were explained to us: They must be sterilizable as well as fit accurately, be non-porous and safely meet standardized requirements for patient safety. In the end, the majority of individualized products in the pandemic consisted of printed and self-designed face masks – until they, too, vanished from the public eye again due to standardized requirements and the deployment of conventional supply chains. Standardization, regulation, and liability issues hindered both printed replacement parts and homemade textile masks in the short and long run. Again, the pandemic has shed new light on requirements for 3D printing: How can the safety and compliance of decentralized production using 3D printing be assured?

In the narrative of “social empowerment”, 3D printers offer self-organizing citizens the means to step out of their consumer role and take the initiative to autonomously develop, try out, and produce what they need. This vision already spawned a global network of the FabLab and Maker community (Schneider, 2018) that was important in the pandemic. The initiative “Corona-Hilfe Karlsruhe,” (2020) co-organized by the FabLabs in Bruchsal and Karlsruhe, for example, printed and assembled more than 5000 face shields within a couple of weeks in a time when conventional industry and global trade could not deliver these goods. The initiative was non-profit and run by volunteers that updated the print templates continuously according to recent experiences, shared this knowledge globally, organized themselves into shifts for production and maintenance of the printers, which were not designed for mass production, and also managed the distribution to users of the face shields. The different tasks allowed to bring in different competencies so that the network expanded in the vision to contribute something useful in the pandemic. Although it became apparent as the pandemic progressed that face shields did not provide effective protection against the virus, the participants involved reported a remarkable period of learning new organizational and technical skills while experiencing a unique self-efficacy and responsibility for a community carrying forward the vision of social empowerment and makes look for new opportunities.

Certainly, it can be said that the pandemic gave 3D printing opportunities to prove its promises. The “social empowerment” narrative and the maker movement, in particular, benefited from the attention: already existing social structures were updated and strengthened, and promises of rapid response and shared learning were realized. In the narrative of “the next industrial revolution”, it became all the clearer that it is not so much technical innovation as social-organizational innovation that is needed to deliver on the promise of fast and scalable production at the push of a button. While production under one corporate name at least provides an addressee for responsibility and reliability, unresolved issues of standardization and regulation emerged as obstacles to “individual empowerment”. Particularly in the medical sector, this needs to be addressed if 3D printing is to deliver on its promises here. The Maker movement had a great moment. However, the question now is what concrete social challenge will draw on the existing structures before the emerged network and vision slowly become porous again.

Key messages:

- ❖ Visions were an important enabler of the spontaneous 3D printing projects for medical equipment during the early phase of the COVID-19 pandemic.
- ❖ The pandemic offered a stage for different promises of 3D printing. However, while there was initial success and recognition, it seems that no long-term benefit was gained.

3 3D printing after the hype – Mass media and economy

Our study started with an analysis of the key narratives that shaped early 3D printing and have become fundamental to its perception. The presentation and analysis of 3D printing visions in the first report were based primarily on studies on 3D printing that focused on the hype around 2010-2015 (Schneider et al., 2020). A hype means the disproportionate overvaluation of advantages in the communication of facts (Intemann, 2020). Experts, scientists, and journalists are therefore obliged to carefully balance their communication intentions, e.g. the presentation of motivating research objectives or the generation of attention, with the consequences of exaggerated expectations, such as motivating malicious actions and a general loss of credibility (ibid.). Hypes arise intentionally and unintentionally in the momentum of disseminating stories. Especially in short-lived media, they, therefore, become visible in a sharp rise of a topic followed by a fall within a few months. Empirically, it is mainly in retrospect that it becomes apparent whether expectations are disappointed and disappointments acknowledged. This study follows on from the previous analysis to answer whether a hype, in form of growing anticipation followed by disillusionment, can be found equally in data across the different societal subsystems, such as mass media, economy, or science.

The chapter starts with a view towards 3D printing hypes in the economy by way of analyzing economic journalism and stock market prices of 3D printing companies. Recent findings (Beckert, 2016) suggest that future imagination is central to economy and innovation. This chapter, therefore, examines the correlation of publication and stock price development – but without postulating a direction of causality. Regarding mass media, we assume that mass media mirror and form public interests, as editors and contributors are guided by the interest and expectations of their readers and help shape their current interests and expectations. Furthermore, mass media are central for distributing and shaping public knowledge (Luhmann, 1998, p. 1108) as well as legitimizing science (Rödder, Franzen, & Weingart, 2012). A high number of relevant publications in the major weekly newspapers, branch newspapers, or social media, therefore, represent a great interest in this area. Of particular interest is the media representation in the last 3 years to complement, update, or critique the qualitative insights of the key narratives in the last report. To provide a more up-to-date insight, the quantitative and qualitative results of our media research in the more recent period are presented below.

3.1 3D printing in finance

Marketwatch.com is considered a popular website for financial data and analysis. To determine the economic hype around 3D printing, all articles listed on MarketWatch for the search term "3D printing" were listed in a time series. To illustrate the hype character, Figure 4 compares the normalized results for "3D printing" with the results for "blockchain" and "virtual reality", representing other technologies that were considered as hyped in recent years. The development of all three digital technologies is accompanied by promissory stories and versatile application scenarios projected into the future. Compared to the regular interest in the technology, you can see that in 2014 the most articles were published on 3D printing (68 per quarter), in 2016 on virtual reality, and in 2018 the most articles were published on Blockchain (268 per quarter). Unlike blockchain, 3D printing has not seen renewed hype in early 2021 measured by the number of articles published.

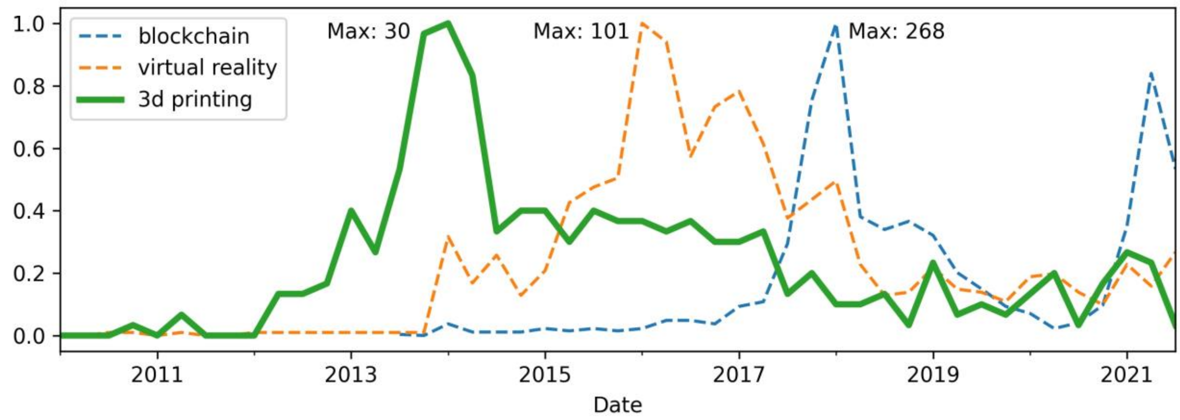


Figure 4: Commercial hypes about "3D printing" and "Blockchain" as represented in the number of articles per quarter published on MarketWatch (2021).

Through an automated retrieval of the linked articles, the mentioned ticker symbols in 3D printing stories were counted to get an overview of the most important listed companies in the field of 3D printing (Figure 3). The list also includes the major tech companies like Apple (AAPL), Microsoft (MSFT), Amazon (AMZN), Alphabet (GOOG), Facebook (FB), and Tesla (TSLA). The share price performance of these companies shows that the technology sector has grown strongly in recent years. However, one learns little about the success of 3D printing by looking at these technology giants. A better insight into the success of 3D printing is provided by the publicly listed companies that specialize in 3D printing, which can be obtained by filtering out the large companies by market capitalization and scanning the share description. Figure 5 summarizes this section's data generation pipeline from searching 3D printing stories on MarketWatch to discussing prices charts.

Figure 3: Word cloud of the most frequently mentioned tickers in the articles for the search term "3D printing" on MarketWatch. Font size represents the count of mentions.

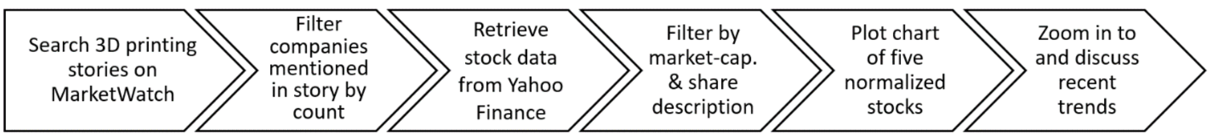


Figure 5: Overview of the data generation pipeline for comparing the stock trends of most relevant 3D printing companies.

The largest companies specialized in 3D printing are 3D Systems Corporation (DDD), Proto Labs, Inc. (PRLB), Nano Dimension Ltd. (NNDM), and Stratasys Ltd. (SSYS) (Table 1). These companies will now be used to trace how the economic trend in 3D printing has developed since 2010.

Table 1: Lower market capitalization segment of 3D printing stocks discussed on MarketWatch over the past 10 years up to Nov. 11, 2021. The highlighted tickers are companies with a focus on 3D printing, according to their descriptions. Their mentioned number (count) shows their average relevance in the articles.

Company Name	Ticker	Articles count	Market Capitalization	Varying Stock price in a 52-week range
Organovo Holdings, Inc.	**ONVO**	6	0.06 B $	6.02 - 23.92 $
voxeljet AG	**VJET**	**12**	0.09 B $	4.67 - 40.0 $
The ExOne Company	**XONE**	**30**	0.49 B $	8.1 - 66.48 $
Groupon, Inc.	GRPN	5	1.37 B $	14.95 - 64.69 $
Stratasys Ltd.	**SSYS**	**64**	1.52 B $	11.89 - 56.95 $
Nano Dimension Ltd.	**NNDM**	6	1.88 B $	1.31 - 17.89 $
Proto Labs, Inc.	**PRLB**	6	2.46 B $	85.5 - 286.57 $
Yelp Inc.	YELP	6	2.94 B $	18.67 - 43.86 $
3D Systems Corporation	**DDD**	**85**	3.80 B $	4.6 - 56.5 $

A recall of the share prices (retrieving data from yahoo-finance with pandas-DataReader) shows that 3D Systems Corporation and Stratasys Ltd. benefited briefly from the hype around 2014 and then collapsed to one-tenth of the maximal enterprise value, respectively to the size before the hype (Figure 6). Nano Dimension Ltd., a company that has only been listed since 2016 and focuses on printing electronics and micro components, shows an unbroken downward trend. Accordingly, this “next generation of 3D printing” referred to in the company description has so far failed to deliver on its lofty promises. What all share prices have in common, however, is an upswing in 2021. While 3D Systems Corporation and Stratasys Ltd. were unable to match the hype around 2014, Proto Labs, Inc. found a new all-time high. The high of Proto Labs, Inc looks comparatively stronger than it is in the normalized chart. However, if we normalize the price trend from mid-2020 to mid-2021, we see that the prices all followed a common trend (Figure 6). In January 2021, the shares rose sharply and just as quickly fell again. The corresponding articles on MarketWatch draw a parallel to the hype around 2014 and explain the rise in the context of speculation around Gamestop (GME), related short squeeze as well as an economic rebound, “especially in the auto and aerospace markets, and in the elective surgery and dental markets once the pandemic passes" (Cherney, 2021; Kilgore, 2021). However, this explanation is still insufficient to assign 3D printing a superior stance compared to the average technology sector. Just because visionary technologies have risen in the short term as part of the hype around "meme-stocks" (shares whose value rises or falls with the popularity of associated internet memes on social media platforms like Twitter or Reddit (Griffith, 2021)), does not mean that the technologies now contribute to demanded problem solutions henceforth.

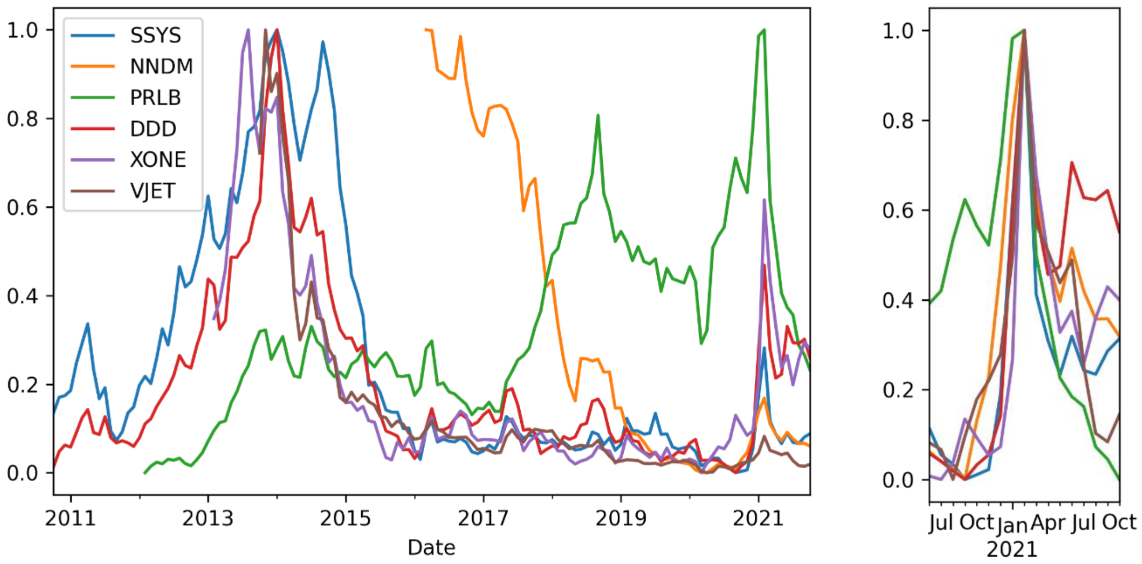


Figure 6: Normalized share price of the most relevant 3D printing companies from 2011 to October 2021 (left). Normalized share price development from July 2020 to October 2021 shows the related trend in January 2021 (right).

Both the publications on MarketWatch and the 3D printing companies' tickers with medium market capitalization mentioned therein show a hype curve around 2014. The rise in 2021 cannot be linked to innovations of individual companies and is rather interpreted as an artifact of meme speculation. The slightly rising prices overall do not reach the 2014 range in their absolute values and so far, do not indicate that investors expect the old promises to be realized soon.

Key Messages

- There was a hype about 3D Printing in 2014 according to the time series of the number of articles published on the finance website MarketWatch.
- The largest companies specialized in 3D printing are 3D Systems Corporation (DDD), Proto Labs, Inc. (PRLB), Nano Dimension Ltd. (NNDM), and Stratasys Ltd. (SSYS). Two smaller listed companies with frequent mentions are voxeljet AG (VJET) and The ExOne Company (XONE).
- The share prices of companies specialized in 3D printing fell or stagnated until a short rise in January 2021 that might be related to a Meme-Stock hype.

- ❖ The general hype on 3D Printing outweighs the companies' individual developments according to similar financial valuation trends.

3.2 Quantitative findings in German mass-media

A hype of 3D printing was visible on the stock market and stock news trends in 2014. The FabLab community also witnessed a significant upswing during this period. In the scene and research close to practice, this hype is therefore considered to be a given. But was this hype even present in the wider public? Or was 3D printing rather a continuous niche topic?

To investigate this question of public relevance, a look at the mass media helps. Mass medial representation is considered central to public discourse. The choice of topic for an article is based on the relevance and novelty of the information for a potential readership. Only if there is something beyond the ordinary to report is it worth telling a story, with the prospect of resonance and purchase of the newspaper. Even in the age of social media, newspapers remain a relevant point of reference, on the one hand, to fuel social media debates and on the other echoing social media viewpoints. The number of publications in national newspapers is, therefore (still) a good indicator for determining a hype. Next, we look at quantitative insights to understand the development of 3D printing in the media during recent years.

The quantitative media research is based on data from Genios.de, which was extracted from the corpus search “Superregional Newspaper” via web scraping. GBI-Genios Deutsche Wirtschaftsdatenbank GmbH (2021) is the market-leading provider of press information in Germany. A Python script sends the search query to the website and reads out the freely available tables on the results pages. Quantitative results were sampled to see if they related to 3D printing or, for example, 3D cinemas. For the detection of hype, the background noise is assumed to be constant over the entire period. The Genios data source was positively validated by making the same search query in the Media Cloud (2021) corpus, evaluating it, and comparing it with the results. As for business news, the search for blockchain serves as a reference to determine hype. For direct comparison, the number of articles published was normalized to the quarter with the most and least publications.

Both, the Genios and MediaCloud databases show that there was increased attention for 3D printing in the German newspapers in 2014, compared to the preceding and following two years (Figure 7). However, the further course shows that there is continuous reporting on 3D printing, FabLab, and Additive Manufacturing. There are 55 articles on “Fab Labs” since 2001, 256 on “Additive Manufacturing” and 1712 on “3D Printing”. If you filter out duplicate articles, you get 1757 articles with one of the 3 search terms which are referred to in the following as 3D printing articles. While Blockchain shows a clear peak with 432 publications in the fourth quarter of 2018, 3D printing has its maximum in the first quarter of 2017 with 87 publications. However, this does not stand out much compared to the median of 102 publications in the period under consideration, or 48% of the maximum. For comparison, the median of blockchain articles since the first article in August 2013 is 188, or 33% of the maximum.

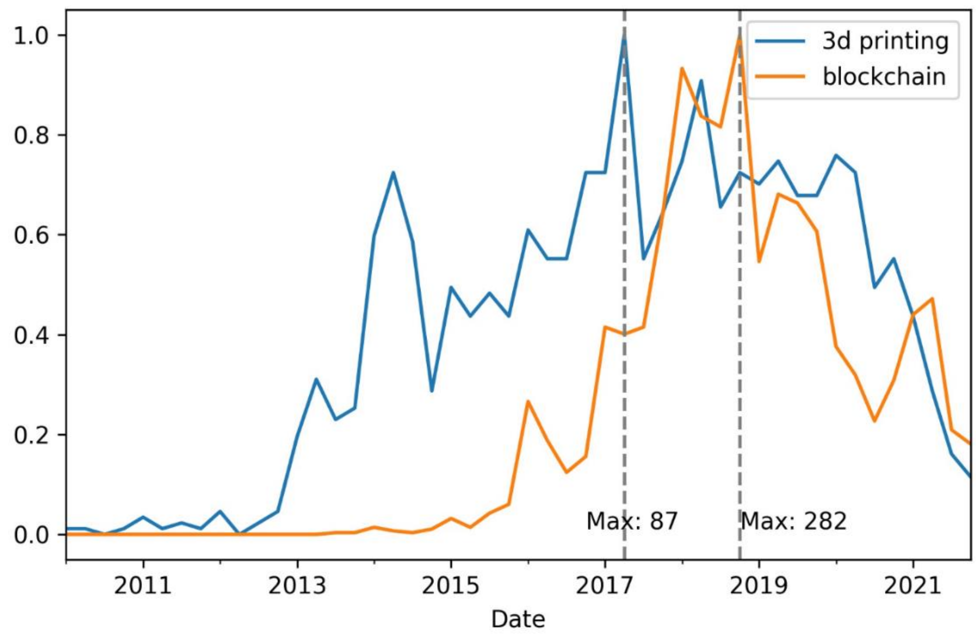


Figure 7: Popularity of 3D printing in German print media, represented in the number of search results for "3D Druck" and "Blockchain" in the Genios Corpus.

The observation, therefore, allows two interpretations: Either there was no hype about 3D printing in German newspapers, but a continuous interest since 2014. Or there was a minor hype that established 3D printing as a visionary technology in many debates as an exciting promise.

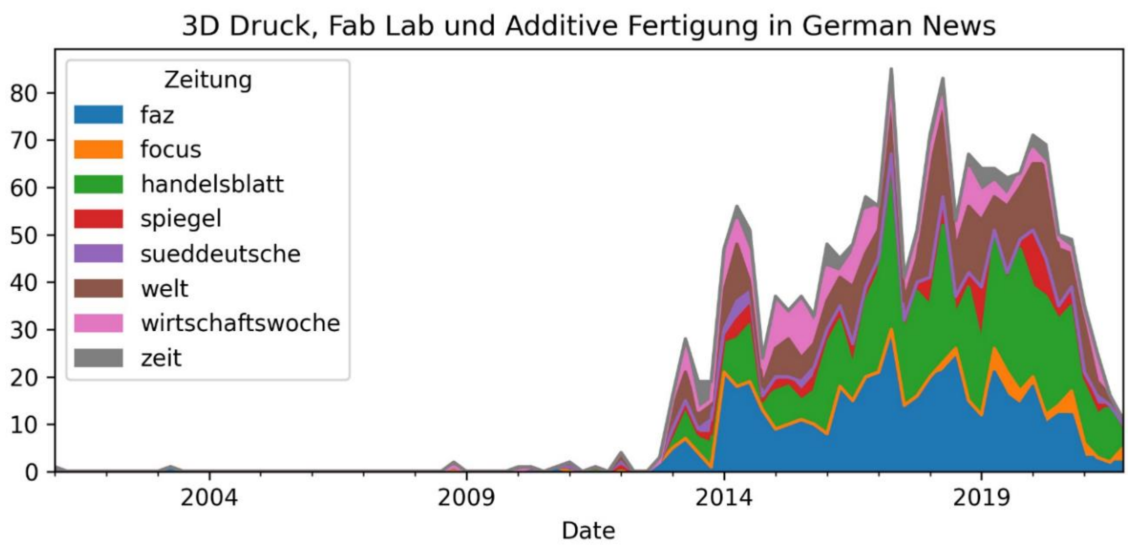


Figure 8: Mass-media presence of 3D printing, fab-labs, and Additive Manufacturing in German Newspapers

The history of 3D printing in the German media goes back further into the past. Figure 8 provides an overview of the historical development of 3D printing articles in newspapers. The term

"Additive Manufacturing" only began to appear more frequently around 2013. There are 6 reports on "Fab Lab" in 2006 and 2007, then the term peaks once in 2014 with 10 articles and again in 2017 with 12 articles. The first article on 3D printing appeared in *Die Welt* on 14.03.2001 predicting an emerging market for 3D printers, followed by an article in 06.05.2003 in the *FAZ* and a strong increase in 2013 and 2014 to a level that is maintained in the following years. In the German media, it is evident that more business-related magazines, such as *Handelsblatt* and *FAZ* are reporting on 3D printing. However, this impression is somewhat put into perspective if one compares the number of articles on 3D printing with the total number of articles published in the journals (Figure 9).

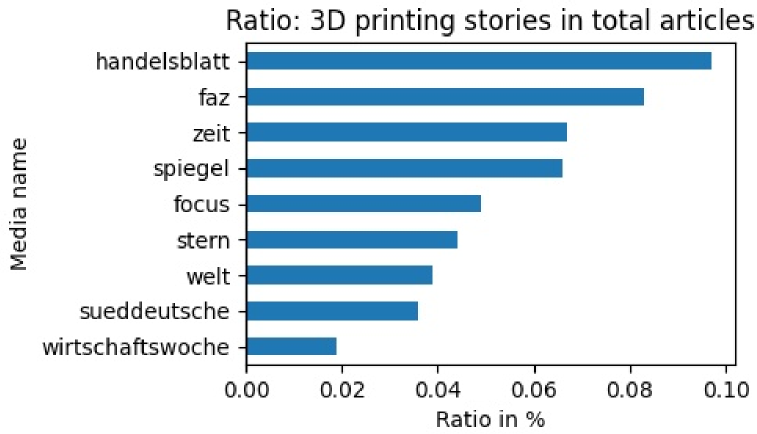


Figure 9: Relevance of different German newspapers for circulating 3D printing stories

To assess whether "Fab Labs", "Additive Manufacturing", or "3D Printing" are considered trending topics in recent years, various searches across the corpus since 2017 were compared on a logarithmic scale (Figure 10). A larger overview can be found in the Annex.

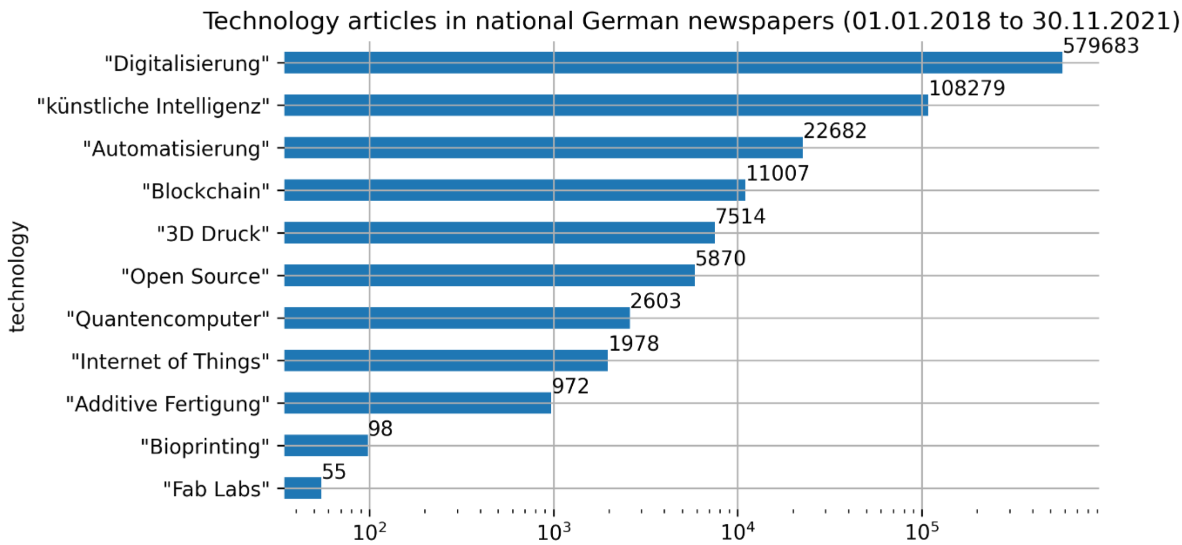


Figure 10: Comparison of the number of published articles in major German newspapers in logarithmic scaling to represent the popularity of recent technology visions according to search term frequency.

In summary, it can be said that one can, strictly speaking, not observe a hype about 3D printing technology in the public, or respectively in German national newspapers, but an ongoing interest in 3D printing visions, since 3D printing gained strong attention through a hype in 2014. The course of the publication numbers does not indicate that exaggerated expectations would have been disappointed. Also compared to more recent visions, such as quantum computing, 3D printing still has a presence, represented in search results. However, other digital topics, such as artificial intelligence, automation, blockchain, cloud computing, or virtual reality, play a much bigger role in recent German mass media. As mass media needs a current occasion to report on technology, one can distinguish two occasions for reporting on 3D printing. Either there is a relevant, technical innovation that is being reported on, or there is a current problem whose characteristics and solution may be described more interestingly through the lens of a 3D printing vision. Since technical details are less relevant in the latter account than the description of the “non-place” (Utopia) as the solution to a current challenge, technology visions remain in circulation regardless of setbacks being reported in techno-scientific discourse (Roßmann, 2021, p. 17). The more ambiguously the technology is delimited by an abstract term, such as 3D printing, AI, or digitalization, the more suitable seem regarding technology visions for different occasions. A qualitative analysis will therefore provide insight into the different topics and narratives about 3D printing in recent years.

Key Messages

- ❖ In German newspapers, there is no typical hype curve but ongoing interest in 3D printing. Although there are exaggerated ideas about 3D printing's potential, it cannot be observed that disillusionment has affected popularity.
- ❖ The first stories about 3D printing reached the major German newspapers in the early 2000s. The technology only really became popular in Germany starting in 2013.
- ❖ Since around 2013, interest in 3D printing has been on the rise in Germany, especially in business-related media.
- ❖ Compared to digital technologies, such as AI, Automation, Cloud Computing, and Blockchain, 3D printing plays a minor role in mass-media circulation.
- ❖ In media theory, either recent developments or a current challenge for which 3D printing is known to be a possible solution give reason to publish on 3D printing. Rises and peaks in the publication history can therefore be attributed to current events or technological achievements, as will be further discussed in the next chapter.

3.3 Qualitative findings in German mass-media

In this section, we look at the contents of media coverage of 3D printing using qualitative content analysis. This allows us to show in detail which topics, problems, and evaluations are associated with 3D printing. To reflect the societal discourse, the most widely distributed German-language magazines were analyzed. These include daily and weekly newspapers, as well as general-interest magazines. Table 2 provides an overview of the print media considered and their circulation (including e-papers) at the time of the query in the fourth quarter of 2020, retrieved from the German Audit Bureau of Circulation (Informationsgemeinschaft zur Feststellung der Verbreitung von Werbeträgern e.V. (IVW), 2021). The minimum circulation for inclusion in the further evaluation was set at 120,000 for this quarter.

Table 2: Distribution of national daily/weekly newspapers and general-interest magazines in Germany in quarter 04/2020. Newspapers and magazines not used for data collection are greyed out.

Newspaper title	**Circulation 04/2020**
Daily newspapers (Mon-Fri/Sat)	
BILD/B.Z. Deutschland	1.246.696
Süddeutsche Zeitung	318.093
Frankfurter Allgemeine	210.488
Handelsblatt	138.196
Der Tagesspiegel	107.087
WELT	77.731
Taz. die Tageszeitung	51.715
Weekly newspapers	
Die Zeit	610.667
VDI Nachrichten	128.739
General-interest magazines	
DER SPIEGEL	655.371
Stern	373.889
Focus	254.823

The following daily and weekly newspapers were therefore considered for this study: *Süddeutsche Zeitung*, *Frankfurter Allgemeine*, *Handelsblatt* and *Die Zeit*. Sunday editions (e.g. *Frankfurter Allgemeine Sonntagszeitung*). Supplements (e.g. *Zeit Wissen*), regional editions of national media (e.g. *taz.die tageszeitung nord bremen*) and the *BILD/B.Z.* Newspapers are not considered due to their tabloid genre. Duplicates and articles unrelated to 3D printing, such as *3D film*, *3D scanner,* and *3D image*, were manually sorted out during the collection and coding of the articles. As a result, 494 articles published between July 01, 2018, and June 30, 2020, remained and were taken for this study.

To be able to proceed with the qualitative content analysis, this sample still had to be narrowed down considerably. Therefore, the data corpus for the qualitative study was reduced to the second half of 2018 (01.07.2018-31.12.2018) and the first half of 2020 (01.01.2020-30.06.2020). This made it possible to examine the development of 3D printing visions over time despite the halved data volume.

Four observations of the content analysis are summarized as follows. First, there are mostly economic articles that frame 3D printing as efficiency and profit advantage or stories about the lack of regulation (weapons & medicine). Second, it is apparent that the Maker and Fab Lab movement has increasingly turned its attention to social challenges such as climate protection in recent years. Third, it can be seen how industrial companies are adopting the visionary concepts of the Fab Lab and Maker Movement, so that the visions remain, but the protagonist changes in the mass media reporting. Forth, it became evident that the setting of the COVID-19 pandemic provided a stage for the visionary hopes of self-sufficiency and rapid spare parts production through 3D printing. Overall, the relevant topics are summarized in Table 3.

Table 3: Most mentioned application areas of 3D printing, as revealed by the structured content analysis of German Newspapers.

3D Printing Vision	2018	2020
Next Industrial Revolution	37%	27%
Governance & Security	13%	10%
Medical Application and Human Enhancement	12%	25%
Sustainability & Self-sufficiency	10%	24%
Others	28%	14%

As seen in Figure 11, mass media discourse on visionary technology is oriented around current issues and events. In 2018 and 2019, gun printing increased security discourse, while in 2020, the COVID-19 pandemic led to an increase in coverage of the medical field. 3D printing in the media in the first half of 2020 does not peak at any point compared to past coverage (See Figure 8, Chapter 3.2, and Figure 11).

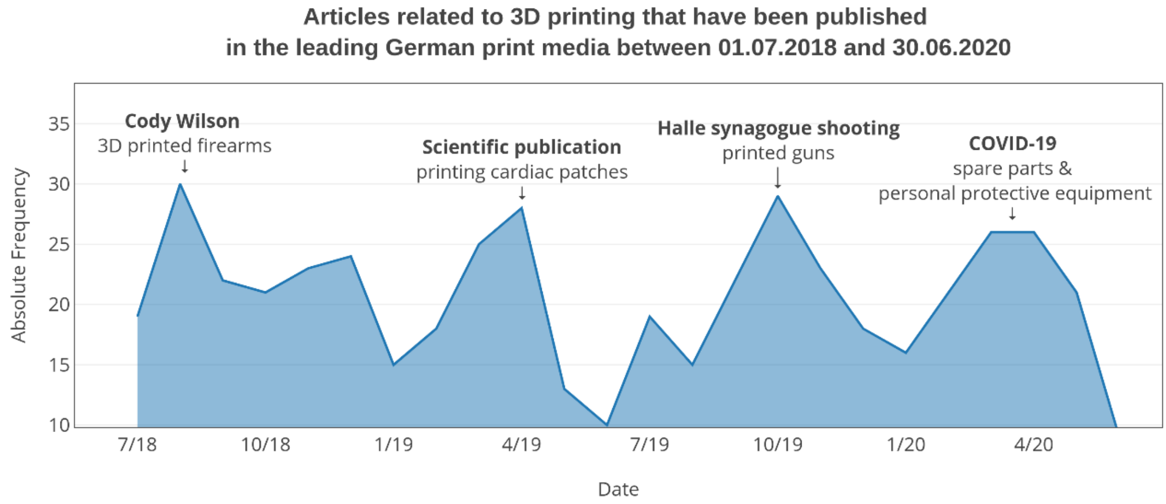


Figure 11: Absolute frequency of articles published each month during the study period and mentioning the events leading to each peak in coverage. While three peaks can be attributed to DIY and Maker activity, in one case, the scientific publication of Noor et al., 2019 led to increased media attention.

Certain key stories could be identified: Makers do not linger with the often-associated production of individualized items, toys, or controversial objects, such as the headline-grabbing gun manufactured by the American Cody Wilson. Instead, the scene seeks for contributing **to societal and environmental causes**. A prominent attempt is about reusing plastic waste as filament or replacing filament with a biodegradable material. In the further expansion of the Makers' DIY concept, visionary 3D-printed real estate is imagined to be **self-sufficient** regarding electricity, food, and water (Parstorfer, 2018). Besides, 3D printing for self-sufficiency a central theme is space visions for making extraterrestrial objects habitable. The story goes that, for the settlement of the **lunar surface**, 3D printers produce all necessary items on-site, from tools to houses, since they cannot be taken from Earth. The proximity to space again manifested itself in the story about the 3D printing company EOS printing parts for the space rocket manufacturer SpaceX.

At the end of 2018, major commercial companies dreamed of "**unmanned production**" using 3D printing technology. Reports say that 3D printers, some of them controlled by robots, would operate autonomously around the clock and without human supervision. A common imaginary is the idea of a worker-free and fully automated construction site, where robots use 3D printing to layer buildings including floor coverings, and household technology in all colors and shapes (Briegleb, 2018). Reports associate "unmanned production" and its descending personnel costs for construction companies with **rising unemployment**. On the one hand, stories assert that 3D printing does not replace but only complements existing professions and thereby fosters re-shoring production from low-wage countries to customers in Germany. On the other hand, there is a high **demand for 3D specialists** in various application areas, while there are hardly any qualifications and further training opportunities in Germany. Thus, there are narratives and counter-narratives about 3D printing in the industry being both social and resource-saving. By 2020, the industry had also taken over media attention in narratives related to sustainability and social empowerment, pushing the maker movement out of the public discourse. One might say that the visions remain in discourse, but the main protagonists of the news stories changed.

3D printing became prominent again in 2020 (see Figure 8, Chapter 3.2, and Figure 11) with the coverage of the **COVID-19 pandemic**, due sudden shortage of protective equipment, respirators, and their spare parts. The Maker scene quickly gained attention here, as it was able to offer a self-sufficient short-term solution with the coordinated fabrication of face shields and other protective equipment. However, the very high demands on medical equipment could not be met for a permanent solution. The printing medical devices have been described as equipment that only helps in a disaster when everything else has failed (Schmidbauer, 2020). Besides, the COVID-19 pandemic highlighted the vulnerability of global supply chains for industry and thus drives visions about becoming more self-sufficient further.

According to the mass-media discourse, there seems to be little change on the other topics. In science, 3D printing is still mainly reported as a tool for rapid prototyping. Medical applications continue to be reported regularly (Table 3) but the printing of organic material is of secondary relevance. A heart printed from stem cells attracted wider attention, however, it quickly dropped (see Figure 11), and according to the experts interviewed, it is still far from being suitable for living systems. In medicine, 3D printers are used in the field of dentistry and the production of prostheses, as already summarized by Ferrari et al. (2018). Worth mentioning is the re-mixing of visionary concepts, such as space exploration and medical application in form of a **zero-gravity 3D printer** being imagined as the key solution for organ printing in the next few years. The question of whether this adds up or multiplies the probability of being feasible or rather delightful entertainment is left to the imagination.

The following chapter will look in more depth into expert domains and how 3D printing is envisioned and perceived there. This will help to put these broad and abstract findings into perspective.

Key messages:

- 3D printing is widely established as a topic in mass media discourse and economic reporting.
- The data show no new hype for 3D printing but rather suggest that 3D printing remains of moderate interest within a landscape of other visionary technologies such as artificial intelligence.
- The mainly reported key narrative in mass media is about 3D printing affecting industrial change. Other topics, such as 3D printing and health or science, remain on the fringes of public discourse.
- As expected, mass media discourse on visionary technology follows actual issues and events, such as stories about security issues due to a 3D printed gun in 2018, or stories about vulnerable supply chains during the COVID-19 pandemic.
- The Maker and Fab Lab movement have increasingly turned their attention to social challenges such as climate protection in recent years.
- Makers became trendsetters for the industry by raising visions of sustainable and self-sustaining futures through 3D printing.
- The COVID-19 pandemic provided a stage for the visionary promises of self-sufficiency and rapidly produces spare parts through 3D printing.

4 Expert Interviews on 3D Printing

To trace the influence of technology visions not only as a trending phenomenon at the macro level but also to comprehend the perceptions and judgments at the actor level, we conducted structured interviews with selected actors. Since the printing of an artificial retina is a key project to the Cluster of Excellence 3DMM2O, bioprinting actors were initially at the center of our qualitative research. That's why we interviewed the head of a 3D printing research institute (*I-TechSci*), a person responsible for establishing 3D printing in hospitals (*I-MedSci*), and a leading social science researcher on bio-3D printing (*I-SocSci*). Since education was highlighted as a central concern for the establishment of 3D printing in the recent report of German academies of science (Leopoldina, acatech, & Akademienunion, 2020), we interviewed a teacher and staff member responsible for 3D printing at the Ministry of Education (*I-Teaching*). As different interviewees perceived hype and tried to explain, we also interviewed a journalist and science resort manager of a major German newspaper (*I-Journalism*).

The questionnaires are designed to create a fictional vision of the application of 3D printing based on the interviewees' notions about their work, current trends, and recent key developments in the field (Figure 12). Once a common reference point for imagining a 3D printing future is created, questions about key designers, players involved, and opportunities to exploit the potential follow. Sustaining questions and follow-up questions were prepared in advance on the interviewee's work in the field of 3D printing. However, the interviewee keeps the freedom to set the focus in the interview and to envision the image of the future with his or her own experiences and narratives.

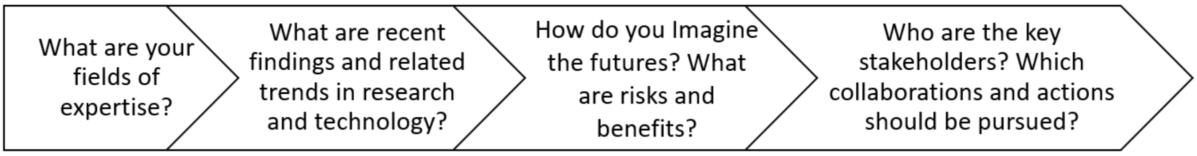


Figure 12: Designing the semi-structured interviews to (1) make-believe 3D printing scenarios, according to the perceived domain of research, and (2) inquire socio-technical means for their implementation.

The interviews are recorded and protocolled by 2 researchers. Instead of a full transcription of all interviews, the subsequent analysis is partly based on an experience protocol with audio markers, so that relevant passages can be relistened to and cited.

Expert interviews are a valuable method to gain insight into the practice contexts of experts, their ways of doing their work, and seeing the world. Therefore, the analysis of the expert interviews helps to get a perspective on the relevance, usage, and evaluation of 3D printing in expert practice. We expected that this will be quite different from the media and public discourses on 3D printing. And whereas the public discourses were mentioned and interpreted by the experts we found many tensions between a mainstream visionary discourse of 3D printing and the actual usage of 3D printing in contemporary expert practice. The following sections discuss these findings, grouped by common visible topics, not by interviewees.

Through our expert interviews, we have found several such tensions between imagined and presently feasible 3D printing. The following section details these tensions concerning theories about the role of imagination in innovation.

4.1 Excessive expectations due to the confusion of model-use and production technology

The most commonly found tension in our interviews was between the promises 3D printing holds told by the media compared to that which science is currently capable of. A commonly found friction is the epistemic use of 3D printing, i.e. as a technology for experiments and research, for example, to explore the biological self-assembly of cells in three-dimensional space, compared to 3D printing as a production technology (*I-TechSci, I-MedSci,* and *I-SocSci*). Scientists use 3D printing to address questions in scientific discourse. However, in the interpretation and narrativization of what this research means for society, the imaginaries of 3D printing as a production technology seem to dominate, so that the visions of 3D printing ("printing an organ") take precedence over the scientifically addressed question ("how to know more about cells?"). Sociotechnical imaginaries are a-theoretical understandings that enable larger groups and entire populations to make sense and converse about their sociotechnical environment in everyday life (Jasanoff & Kim, 2009). To speak publicly about science and technology, researchers also draw on such concepts and analogies, usually with a reference to the limitations of this analogy. For example, *I-TechSci* stated that "structures that can be printed now still have basically no added value to what can be made with the pipette." There is, however, still an underlining vision that one day 3D printing has a big upside. Retelling and dissemination of stories usually resemble a kind of inverted Chinese whisper effect towards alignment with normality expectations, so that sociotechnical imaginaries dominate the discourse. As epistemic tools, i.e. imaginations that raise questions, subsumed under the umbrella term 3D printing, 3D printing imaginaries find use in different disciplines, "the visions of 3D printing develop faster than the science" (*I-MedSci*).

A researcher on the societal dimensions of bioprinting described how she was pushed by a journalist to speculate about what it may mean if we become able to print humans (*I-SocSci*). The researcher, however, refused to answer such questions as they are not founded on the realistic potentials of the technology in her view. However, societal debates build on sociotechnical imaginaries and arguments, such as: "if I had to choose between a pig's heart and a bioprinted heart [using your own cells] ... what would you prefer? And you offer them something that is not available. And they're all like, yeah, that's what I want" (*I-SocSci*). The juxtaposition makes it clear how what is currently possible is often juxtaposed with futuristic technologies. Consequently, another bioprinting researcher reported that his research team received inquiries from people with health problems about 3D printed organs for transplantation. This, however, is far from possible by now in his view, and therefore these exaggerated or simply "false" expectations by others and especially people in need are seen as a big problem. Many experts, therefore, criticize the missing distinction of what is to be imagined "metaphorically" to understand complex or abstract concepts and what is to be believed as the state of the art, so that 3D printing is seen as far more powerful than it currently is. Stakeholders involved in communicating about 3D printing need to be aware and raise awareness of this distinction. Imagining 3D printing as an epistemic device does not mean that there exists a feasible production technology.

4.2 Trial and Error: 3D printing to meet the "Collingridge Dilemma"?

While sociotechnical imaginaries and cognitive frames on the keyword 3D printing in hospitals bring printed organs to mind, our expert for medical applications distinguishes quite different areas: 3D printing is not only an epistemic tool, but together with virtual reality it offers new possibilities in patient communication and teaching, as printed models can be used to explain things more easily. 3D printing is also used for chirurgical splints to aid surgery and healing. For prosthetic applications, printed cartilage appears to be possible in the near future. For both cases, patient contact requires special features to the printed material, such as homogeneity and sterilizability, and liability. Especially in the context of the liability question, our expert elaborated on his dystopia of the "mad surgeon" who operates in free accordance with his ideas and patient's wishes with the help of 3D printing, without following standards and being liable (*I-MedSci*). The most important innovation, therefore, seems to him to answer the regulation and liability questions – linked to the diverse players involved in such prostheses: 3D printer and printing filament manufacturers, software developers, surgeons, pharmacists, hospitals, and their managers.

A diverse set of stakeholders from professional environments and with very different concepts of 3D printing must come together in time to resolve the aforementioned liability issues. In Technology Assessment, this problem is known as the "Collingridge dilemma" (Collingridge, 1980). One must make decisions with uncertain knowledge about the design, application, and consequences of technology with major implications for the consequences of the technology. In the process, decisions about liability must be made before it is clear which actors will participate and how. Once the technology is established, it is difficult to decide about it retroactively. In particular, it becomes problematic where the line between what is feasible and what is visionary becomes blurred, as our expert points out using a true story:

At the onset of the COVID-19 pandemic, it was expected that spare parts for ventilators might become scarce. However, an article by two Italian engineers who used 3D printing to manufacture certain valves spread through the mass media. Based on the expectation that 3D printers worked like ordinary printers in the office, the hospital manager had now ordered 62 3D printers (*I-MedSci*). Despite using online templates, the printed spare parts did not meet the medical requirements regarding their porosity and compatibility with standardized connectors and were useless. Our interviewee states that this was expected, but unfortunately, his expertise was only requested when the question arose as to what to do with the 3D printers that had been purchased.

The example illustrates how important it is to involve diverse stakeholders in design and decision-making at an early stage. Understood positively, however, the story also answers to the Collingridge Dilemma in an “intelligent trial and error”, as relevant actors have been brought together and in a limited scope experiences worth telling have been made that can be disseminated. Both, visionary narratives and stories of their disillusionment influence technology design and decision-making. When used reflectively, they serve as a medium to deliberately enable communication among different stakeholders in time for a more responsible design of technology in society.

4.3 The end of the expert loner: 3D printing teaches creative collaboration

“Trial and error” could also be the central motif of 3D printing, however, if you look back at the beginnings of Fab Labs (above) and take seriously its potential in education. Our interview partner from an educational background (*I-Teaching*) who organizes 3D printing in schools emphasized the shift from learning about technology to learning about social collaboration. The expectation for the use of 3D printers in technical high schools and vocational schools was to motivate students to learn CAD and to train skilled workers for new industry requirements. Quickly, it became apparent that 3D printing, by enabling rapid trial and error, was particularly well-suited to teaching team collaboration for the creative solving of problems. Examples of project-shaped work with the 3D printer include competitions with 3D printed racing cars or representing the school in a printed model designed in a Minecraft-like design tool. In order not to encourage exaggerated expectations, it should be mentioned that only certain parts of the cars came out of the printer. Students focus on issues such as downloading, mixing, and designing templates and producing high-quality print results. Along the way, they learn to organize themselves socially, plan uncertain projects to trial and error and divide up work. However, schools and teachers need to network more closely, and issues of data protection and safety need to be adequately pointed out, as it is possible to injure oneself on a 3D printer. *I-Teaching* ultimately summarizes his assessment of 3D printing as follows “I don't see any risks that can't be overcome.... [nevertheless] 3D printing does not save from current challenges”. Perhaps, therefore, 3D printing in schools does not (only) respond to the industry's requested demand for technology-skilled loners. Instead, learning with means of 3D printers might help to respond to the societal demand for creative and collaborative people for solving grand societal challenges.

4.4 Promissory stories? Not in science journalism.

The tension between feasible technology and 3D printing visions was also recognized from the other perspective by a science journalist (*I-Journalism*) who claimed that many present applications are by now "banal" from a journalistic perspective, i.e. they are not newsworthy. The example he gave was 3D-printed face shields at the beginning of the COVID-19 pandemic. Besides, utopias and visions also do not provide sufficient genuine contention for reporting until technological innovation turns into business and patents. His media outlet, therefore, published very little content about 3D printing in the past years since they want to provide sound scientific journalism and avoid hyped topics that include too much speculation. The "sober" scientific journalistic treatment of 3D printing, therefore, seems to be very different from the above-presented mass media presence, especially in feature pages and economic contexts. Public interest in distant applications of 3D printing in visionary stories, for example, to colonize alien planets within the recent space race revival, is distinct from an interest in discourse about what is currently feasible. However, the question arises why the risk of causing misleading expectations is perceived less strongly in the economic context. Capitalism and especially technical innovation depend on imagined futures to attract investment (Beckert, 2016). If the developed technology proves useful but deviates from the expectation that made the financing possible, this may be considered less of a (moral) failure in economy and industry than in science and science journalism.

Key messages

In summary, the interviews addressed 3D printing in the following tensions:

- 3D printing as an epistemic tool vs. means of production.
- 3D printing in mass media vs. expert practice contexts.
- 3D printing as part of visionary stories vs. solving current problems.
- 3D printing to generate living matter vs. assembling living cells in three dimensions.
- Exaggerated expectations vs. feasibilities of 3D printing.
- 3D printing used by loners vs. team collaboration.

***

Our findings throughout the media analysis and expert interviews support the insight that there is not yet a robust, reflexive, and (self-)critical discourse concerning 3D printing, its potentials, and limitations in German society. A set of visionary narratives circulate an extremely heterogeneous field of technology. To foster more responsible and reflexive use of future anticipations, our study has engaged in scenario co-creation, a structured method to organize and contrast the different assignments about the future, and to explore possible futures from different perspectives.

5 Co-creating scenarios for 3D printing in society

For structuring the scenario process and fostering responsible and reflexive anticipation, we apply the "transformative Vision Assessment" (Lösch, Roßmann, & Schneider, 2021; Schneider, Roßmann, Lösch, & Grunwald, 2021). Here, the goal is to facilitate processes wherein different actors can re-imagine visions, reflect upon them and engage in learning about the complexities of technology futures. In short, this approach is about transforming visions and how they are used in a particular setting. Drawing on co-creative scenario methods, we facilitated the creation of scenarios of 3D printing with a focus on sustainability and inclusion. The goal is to move from often little reflected technology-driven visions to reflexive sociotechnical scenarios that highlight the complexity of the future and different options and pathways to shape it. The transformative aspects include: setting up the process (who should participate?), framing the scenarios (what should the focus be?) and using the results (how should the scenarios be used?).

There are many different ways to design a scenario process: scenarios and their construction can have different functions (Dieckhoff, Appelrath, Fischedick, Grunwald, & Höffler, 2014; Keeler, Bernstein, & Selin, 2019; Selin et al., 2017). The main function is to see possible future pathways and alternative directions that certain changes might take. This helps to see the future as an open space and the possibilities of shaping different options in the present. Furthermore, in our project, a key aim is that the scenarios help to integrate different bodies of knowledge that are otherwise often separated. Namely social scientific expertise and techno-scientific expertise, as well as the knowledge of 3D printing stakeholders outside of science and citizens.

Our study specifically opted for two grand challenges concerning 3D printing to look at: inclusion in innovation and the economy and sustainability of production and consumption. Why did we choose inclusion and sustainability for the scenario axes? Both ideas are already voiced to some degree in the visionary discourses of 3D printing – with the technology being seen as a means to democratize innovation and with hopes for the technology being more efficient than conventional approaches to production. We hoped that these would be compatible with a heterogeneous scenario process as concepts that are widely shared and flexibly usable. We decided to keep flexibility in the usage of the terms to encourage the participants to articulate their understandings of them. With a view towards 3D printing potentially being a game-changer in production and consumption, the project team agreed that it is necessary to envision inclusive and sustainable scenarios of 3D printing in society.

A key step in the scenario process was the conference "Re-imagining 3D printing in society" (2021, March 23-24) that our project organized in collaboration with the Cluster of Excellence 3DMM2O. Here leading social scientists from all over the world who work on 3D printing came together for discussing their latest research in four strands of the conference: 3D printing and economy, 3D printing and the environment, Bioprinting and 3D printing regulation, and the politics of 3D printing. The conference entailed a scenario workshop in which 30 experts and researchers participated. The workshop aimed to delineate the key perspectives of these experts concerning the future of 3D printing in society. This expert workshop set the foundation for the scenarios. This was followed by a workshop with experts in citizen science and inclusion in innovation during another conference. The input for this workshop was the scenario drafts that resulted during the first workshop. Again, the project team is updating the scenarios and these will be the input for discussions with 3D printing stakeholders and citizens. The scenarios are discussed in the research cluster through Ph.D. courses and a workshop will take place with members of the research cluster to present the results of the scenario process and to discuss them concerning the 3D printing research.

Below the following four scenarios document the state of the process. It is important to note that none of these narrative scenarios should be seen as a prediction of the future. Rather, they aim to highlight how different dynamics in society and technology might combine to shape the usage of 3D printing in society. These scenarios are collectively reflected upon and are grounded in different forms of expertise on 3D printing. They are images of the present possibilities of 3D printing in society and imaginations of how these could shape future options.

Why do we call these sociotechnical scenarios? This is because these narratives focus on societal developments, different values, and distributions of power between groups and less on the technological features of the imagined innovations. They foreground society and its malleability to add to the futures discourse on 3D printing. Any significant innovation is always a combination of social and technological change.

Key messages:

- ❖ Scenarios can contribute to more responsible and reflexive use of imaginations of the future.
- ❖ We have co-created four different scenarios with a focus on 3D printing in society together with researchers, stakeholders, and citizens.

The next pages represent findings of our scenario development, followed by a discussion (Chapter 6) about how engaging with and modulating visions has worked out in the study to point towards lessons learned for similar projects in futures research.

5.1 Scenario: Sustainable & Exclusive - 3D-icrosoft in charge

3D printing is dominated by a few corporations who make use of the efficiency gains and design possibilities of the technology (Figure 13). The technologies, materials, and software for 3D printing are strongly commercialized, patented, proprietary and expensive. 3D printing is developed and used in elitist science-industry networks. And 3D printing experts work in high-tech medicine and specialized industry, which are located in the global north. Advanced 3D printing is only available for the wealthy. As a result, the knowledge about advanced 3D printing is not widely shared and 3D printing innovations focus only on the economically most profitable domains. Small-scale and low-cost 3D printing is used by hobbyists at home but they lack the resources to produce sophisticated products or have a significant socio-economic impact.

Sustainability: some efficiency gains of a niche technology

A narrow understanding of ecological sustainability guides regulatory politics and the economy. 3D printing is valued for its efficiency gains and the increase in sustainable production. Yet, overall, its sustainability impact is low, since it remains a niche technology that does not transform the mainstream production of goods.

Challenges

Unequal access to the high-tech economy deepens polarization. The global south continues to be exploited especially for raw materials but increasingly so for digital data. Many opportunities of 3D printing are not used and technological progress in 3D printing is steady but narrowly focused on expert domains.

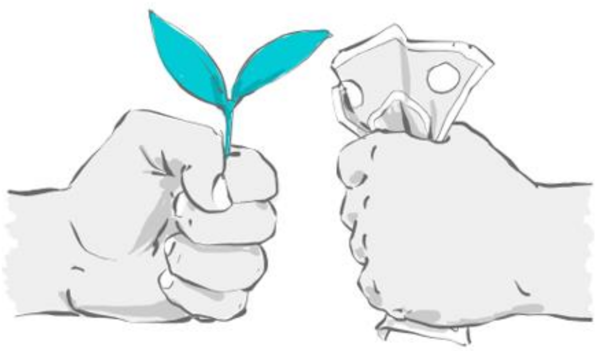


Figure 13: Exclusion - 3D printing for experts and the wealthy

5.2 Scenario: Sustainable & Inclusive – Shared needs, knowledge, and 3D printers

In this sharing economy networked communities, including many different people, shape 3D printing development and use (Figure 14). They are supported by new state institutions that foster collaborations between different actors in society. 3D printing is a key technology for local, sustainable communities and cities that are digitally and globally connected. Knowledge is seen as a common good, not as private property, and is shared worldwide through the internet. Many community organizations actively reach out to include different groups in 3D printing usage. Many people have shortened their workweek and engage in high-tech self-providing with 3D printers to produce and repair things that they need. Universities have become open organizations where citizens and professional experts work together on 3D printing research resulting in 3D printing innovations in many areas of society.

Sustainability: A new, sustainable economy based on needs

There is a fundamental reorientation of the economy towards needs, sustainability, and cooperation. 3D printing is seen as a key technology for producing circularly and democratically. A culture of care, repair, and sufficiency enables the sustainable use of 3D printing.

Challenges

Capitalist actors lobby against the sharing economy. Free riders abuse the commons. The still existing digital divide hinders global knowledge transfer.

Figure 14: Inclusion - 3D printing is a shared resource in communities

5.3 Scenario: Unsustainable & Exclusive – Anarcho-capitalism in 3D

3D printing is a sought-after technology since global supply chains have collapsed due to the climate crisis. In unregulated markets, companies and criminals with printers offer products to the highest bidder. Many people cannot afford the specialized 3D printed goods and neither do they have access to the technology. Due to a lack of cooperation and public funding research and innovation are slow (Figure 15).

Unsustainable competition

There is extreme competition for resources that hinders cooperation and makes effective sustainability politics impossible. 3D printing does not contribute in any way to solving extreme sustainability problems.

Challenges

There are many 3D printing-related accidents and negative consequences due to a lack of regulation and oversight. 3D printing is a means of power in a highly divided society and the emancipatory potential of the technology falls victim to the competitive approach.

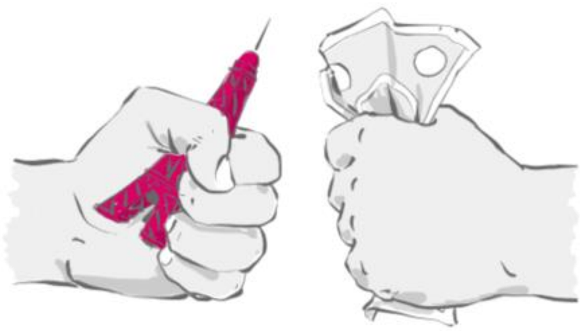


Figure 15: Exclusion - Winners take all, losers get nothing.

5.4 Scenario: Unsustainable & Inclusive – Print, consume and throw away

3D printing has become a central technology for consumers. Almost everyone has access to inexpensive 3D-printed products. And many households have a 3D printer at home, wealthier households use it as a status symbol. There's a huge ecosystem of customization and online sharing around the products of the main 3D printing brands that serve every aspect of everyday life. The individualized 3D printed products complement – and do not replace – mass-produced goods. DIY courses for 3D printing are popular as they help people to customize their consumer gadgets (Figure 16).

Unsustainable production of waste

Immediate fulfillment of desires and throw-away consumption guide the economy. Little importance is attached to questions of sustainability. There are few regulations in place, so new products will come to market faster. Many low-quality 3D printed goods are thrown away right after usage

Challenges

Sustainability targets are not met, environmental crises and social unrest emerge. 3D printing is only regulated by private platforms. The focus on consumption distracts people and politics from shaping more meaningful 3D printing innovations.

Figure 16: Inclusion - Consumer paradise

6 Implications of the 3DMM2O study for the Vision Assessment method

This report documented that 3D printing visions and imaginations are present in public and expert discourse, they are diverse and they have different impacts. We showed that a naïve attitude towards imagining and communication about 3D printing visions can lead to misdirected resources, unredeemable hopes, and consequences. On the other hand, 3D printing visions enabled (1) orienting the present state of research within the past and possible innovation pathways, (2) generating mass-media relevance and possible affectedness required for the democratic deliberation, (3) coordinating research and innovation beyond disciplinary boundaries, and (4) motivating action, work, and funding for technology projects despite uncertainty. Compared to the visions, 3D printing is still in its infancy and there is a demand for democratically and responsibly shaping the technology and its applications in society. This study, therefore, not only wants to show the significance of more participatory and complex ways of imagining 3D printing futures to shape the trajectories of innovation. It also aims to provide stepping stones in such a direction by co-creating sociotechnical scenarios of 3D printing in society.

The project "Vision Assessment of Scalable 3D Printing" was launched to contribute to the analysis and modulation of the technology development and to promote the dialogue between stakeholders, researchers, developers, and citizens. With this in mind, the vision assessment should be developed into a transformative vision assessment (Schneider et al., 2021). Normative goals such as enhancing the reflexivity of technology design and democratizing research, and associated subprojects, such as the symposium and feedback dialogues, were formulated for modulation and dialogue, but no indicators of success were determined. As with many other transformative research practices, transformative vision assessment struggles to track the success of its practices, modulation, and dialogue. For other transformative research approaches to learn from the experience of this study, the following section does not formulate further normative goals but rather notes hypothetical obstacles which are seemingly underrepresented in the discourse about the power of imaginaries, expectations, and visions in technology development.

Even without a final evaluation, two circumstances of the study can be designated that are poorly represented in previous studies and the theoretical conceptualization of vision assessment, namely the circumstances of the pandemic and the size of the partnering 3DMM2O research cluster. First and foremost, the pandemic required a change in empirical approaches. Instead of face-to-face contact with researchers and decision-makers through workshops and ethnographic methods, we switched to digital methods. Here, the vision assessment gained a lot of valuable experience with participation platforms, digital methods for data analysis as well as online interviews. One could even glimpse the potential of a digital vision assessment, which could potentially become more traceable and interculturally inclusive through algorithms that merge different data sources in a comprehensible way, automatic recording of interviews, and the resource-efficient bridging of distances. Comparisons of the distribution, contents, and influences of visions in different cultural areas are thus more easily possible and can reveal special characteristics. However, some in-depth observations are likely to be lost due to the digital distance.

Given the experience with the size and organization of the research cluster, the question also arises in general whether the vision assessment would have succeeded in analyzing and modulating visions in the cluster in a comprehensible way and in facilitating a dialogue even without a pandemic. Many previous vision assessment project settings involved collaboration with a modest number of stakeholders and flat hierarchies so that eye-level collaboration was easily managed. Conceptually, therefore, it was possible to locate the effectiveness and resonance of visions at a micro level, in the laboratories, or rather in the visions of individual actor constellations. Vision assessment and similar concepts rely on observations and dialogues with lab staff to reveal and modulate what visions motivate the development of the technology. This is the foundation of sociotechnical integration research (Fisher & Schuurbiers, 2013), a key source of inspiration for our study. Besides the digital distance, the sheer size and heterogeneous scope of the Cluster of Excellence made it difficult to deeply engage with particular persons and specific visions.

To more adequately examine large-scale research, such as the cluster of excellence, the theoretical conceptualization could incorporate more knowledge from organizational sociology. A conceptual linkage of the macro-micro-meso-level in vision assessment has been in planning for some time and should be further deepened with this experience. On the one hand, visionary narratives establish themselves in discourse as cognitive frames, familiar explanations, and cultural speech habits. At the micro-level, these visions unfold their motivational and coordinative power being transformed into concrete plans, collaboration, and action. However, the prerequisite for this is both that the visionary discourse reaches these actors and that they have and perceive a scope for shaping within their organizational embedding. Organizations play an intermediary role between levels by both constraining the range of formative action of individuals and preconditioning the sociocultural and material resources for imagining the future. Their relationship to the vision needs to be much better addressed conceptually so that the necessary resources and stability provided by organizations can be leveraged and not become a barrier to transformation. Therefore, the experiences from the 3D printing project must be reflected for further developing the concepts of vision assessment and transformative research.

Besides the integrated dimension of our study, we have begun to emphasize its public and transdisciplinary dimensions through involving citizens and stakeholders in scenario discussions and planning for a podcast on 3D printing futures in collaboration with the Cluster of Excellence. Regarding our aim of modulating the visionary discourse (to a more sociotechnical perspective), it equally remains open whether and how this will have an impact.

In summary, vision assessment, related concepts to sociotechnical futures and expectations, and transformative research formats can benefit from the experiences of the project if they are systematically documented and communicated. Here, the potentials of digital methods and platforms as well as insights from organizational sociology seem to be promising.

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Please do give us feedback.

Our study is motivated to fostering open and reflexive debates about the future. If this report or any aspect of it inspired questions, thoughts, or criticism please feel free to share it with us. You can reach us via email:

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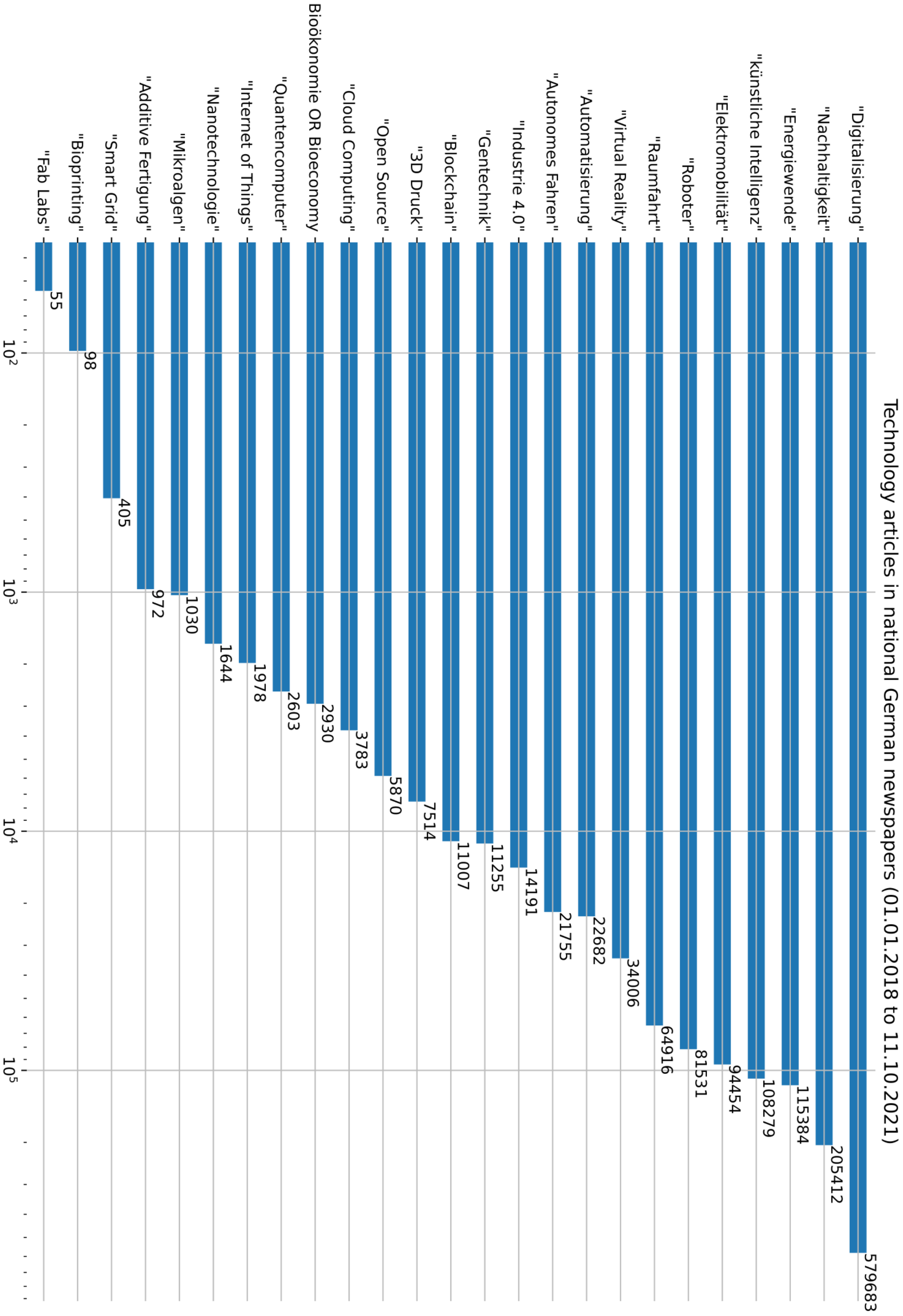
8 Annex



Technology articles in national German newspapers (01.01.2018 to 11.10.2021)
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"Nachhaltigkeit" 205412
"Energiewende" 115384
"künstliche Intelligenz" 108279
"Elektromobilität" 94454
"Roboter" 81531
"Raumfahrt" 64916
"Virtual Reality" 34006
"Automatisierung" 22682
"Autonomes Fahren" 21755
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"Blockchain" 11007
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