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Co-creation through digital fabrication technology: a systematic review

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Co-creation is one of the popular methods for designing nowadays. Similarly, digital fabrication technology (DFT) is commonly used in all design research, education, and manufacturing industries. DFT is considered an effective way to make prototypes of any design due to the usage of multiple types of tools. DFT is primarily used in various fabrication spaces like Fab Labs and makerspaces. Therefore, using DFT in makerspaces to materialize a design using co-creation is apparently a desired scenario for making prototypes of design ideas. Previous research points towards the use of design thinking model while making designs in makerspaces using DFT. However, there is a gap in a systematic literature review that gives us a holistic view of co-creation methods used for designing artifacts using DFT. Such a literature review will also give a better understanding of the relationship between the fields of co-creation and DFT. Therefore, in this paper, we conduct a systematic literature review on the topic of co-creation using DFT in makerspaces. To achieve this objective, a search was performed for relevant articles in three major databases and identified 92 articles. A systematic review methodology was used for screening. Overall, 21 articles were included in the final analysis. The results show that collaboration and co-design types of co-creations are popular in the literature of makerspace and DFT. Future recommendations and limitations are also provided to extend this research work in the future.

Keywords: digital fabrication; makerspace; collaboration; co-design

1 Introduction

Digital fabrication is the digital revolution of the modern world. The notion of “How to Make (Almost) Anything” by giving tangible shape to an idea forms the basis of digital fabrication (Gershenfeld, 2012). Digital fabrication technology employs computer-controlled machines like 3D printers, scanners, laser cutters, computer and numerical control-based milling, printed circuit board designing, etc. With the help of digital fabrication tools and techniques, designers, students, developers, and the general public can create prototypes of products in the designated fabrication labs. Mostly, an idea of any product or prototype is first designed using computer-aided design (CAD) tools using different 2D or 3D software. The CAD file of the design is then passed to a computer-aided manufacturing software which drives machines like 3D printing or laser cutter to produce the tangible prototype of the idea. Digital fabrication tools and design processes are used to create sustainable and creative digital artefacts (Jung et al., 2010), empower the product designer, engineer, businesses, hobbyists, or anyone to create a final product from a prototype. Along with that, digital fabrication technology is also used in digital "do it yourself" DIY-based projects for making medical devices (Stead et al., 2018) and in learning 21st-century skills (Salvia et al., 2016).

Makerspaces and Fab Labs share working and ideological principles with the DIY movement, open-source engineering, and software movement. The Fab Lab idea originates from an outreach program at Massachusetts Information Technology's Center for Bits and Atoms to support disadvantaged communities to have access to powerful technology and equipment to meet their local needs (Gershenfeld et al., 2017). The first Fab Labs emerged in 2003, and gradually they gained popularity; currently, the network of Fab Labs counts 2133 Fab Labs around the globe according to the list maintained by https://fablabs.io/. The fab lab idea was further adopted by maker movement and independent makerspaces. The Fab Lab and makerspaces create perfect eco-systems for user-driven designing and manufacturing prototypes.

Since the last decade, digital fabrication also gained widespread recognition in education to teach young people. Further, makerspaces as a platform for learning were created to teach 21st-century skills, including creativity and computational thinking to students, instructors, designers, hobbyists, and makers (Soomro et al., 2022). Makerspaces provide a collaborative atmosphere where people from multidisciplinary fields can come together to create, innovate, and design using digital fabrication technologies. This technology is not only used in education, but also used in different industries (Paio et al., 2012; Valamanesh & Shin, 2013). The core idea of makerspaces like Fab Labs (Blikstein, 2018) and rapid prototyping labs (Hamblen & Bekkum, 2013) is to develop a prototype of a design. And the design of a product comes from an idea. So basically, this is a journey of an abstract idea to its physical prototype in the makerspace. This journey follows a design process. There are design processes used in literature for prototype development using digital fabrication technology (Soomro & Georgiev, 2020) . The most popular one is Stanford's five-stage design thinking model (Tschimmel, 2012). Therefore, it can be said that design and digital fabrication are well connected with each other.

However, co-creation is a relatively new concept in designing through digital fabrication. On the other hand, co-creation is inherent in a makerspace-based design project because makerspaces allow users to collaborate between different disciplines to make a project (see, e.g., Geist et al., 2019). Co-creation allows tinkering with existing products and design concepts collaboratively. Makerspaces are considered the place for digital innovation and co-creation (Duh & Kos, 2016). Makerspaces also provide the opportunity to co-design where user and designer can collaborate to develop a product (Fleischmann et al., 2016). Even though digital fabrication and makerspaces provide a platform for co-creation, this aspect of digital fabrication technology is not explored deeply. Therefore, the aim of this study is to understand how co-creation manifests and integrates in digital fabrication in makerspaces. In particular, the research question addressed in this study is how co-creation using digital fabrication in makerspaces can be used for design and development of prototypes.

This paper is divided into five parts. The first part introduced the concepts of digital fabrication, makerspaces, and co-creation. The second part describes the research method used in the study, namely systematic literature review. The third part discusses the results obtained from the quantitative, qualitative, and thematic analysis. The paper concludes by presenting ideas for future work to further improve the analysis obtained from this literature review.

2 Methodology

To answer the research question, a systematic literature review was conducted using the PRISMA methodology (Preferred Reporting Items for Systematic Reviews and Meta-analysis; Liberati et al., 2009). Systematic literature reviews are commonly conducted to extensively scan all the studies presented on a specific topic to help find answers to a clearly defined research question. This is done by following some predefined steps and criteria to exclude and include the reports which will be reviewed to support the suggested solution of a research topic or question. Then, qualitative, and quantitative methods can be incorporated to interpret, synthesize, and present the results. In this study, the PRISMA guidelines are used to conduct an evidence-based systematic review of the research question for this study. There are mainly four stages in PRISMA, namely, identification, screening, eligibility, and inclusion (Liberati et al., 2009). PRISMA is used because its clear guidelines are widely used to get deep insights of a topic from the existing literature (Subirana et al., 2005).

2.1 Search process and filters

At the identification stage, three databases were selected for searching relevant articles, namely Scopus, Web of Science, and ACM. The search string focused on including words like co-creation, digital fabrication, and makerspaces. As a result, the databases generated reports with these keywords. The search focused on articles written in English, and the search field included the title, abstract, and keywords. A summarized version of the search parameters and applied filters are shown in Table 1.

Table 1. Search parameters and filters

Item	Criteria
Search string	Co-creation AND (“digital fabrication” OR makerspace)
Publication type	Peer reviewed Journal articles and conference proceedings
Publication dates	Published by 2021
Language	English
Platforms	Scopus, Web of science, and ACM
Search field	Title, abstract and keywords

2.2 Inclusion criteria

The search parameters and filters were applied on each of the databases mentioned in Table 1. As a result, 90 reports were found relevant for the literature review. Table 2 shows the distribution of the retrieved articles by database. A snowballing method was used to identify additional articles, resulting in the inclusion of 2 articles. Consequently, a total number of 92 reports were collected and included for initial screening. After excluding 6 duplicate papers, the other 86 reports were assessed. These 86 papers were passed through an inclusion criterion that the abstract of a paper should be discussing co-creation in context of digital fabrication technology or makerspace. Otherwise, that paper will be excluded. Thus, 21 reports fulfilled this criterion and were included for the systematic literature review. The summary of inclusion and exclusion of reports from different databases is shown in Table 2. Figure 1 shows the complete workflow followed to get targeted articles following PRISMA. Including a maximum number of articles is desirable to achieve a better synthesis of the subject matter. However, the official guidelines of PRISMA methodology do not set any limit on the number of studies to apply this methodology. Therefore, this research work achieves the objective of conducting a systematic literature review and fulfils the criteria mentioned in the official guidelines of PRISMA (Liberati et al., 2009).

Table 2. Reports obtained from different databases

Databases	No. of articles
Scopus	16
Web of science	8
ACM	66
Manual entries	2
Total	92
Duplicates	6
Exclusion during the initial screening	65
Total included articles	21

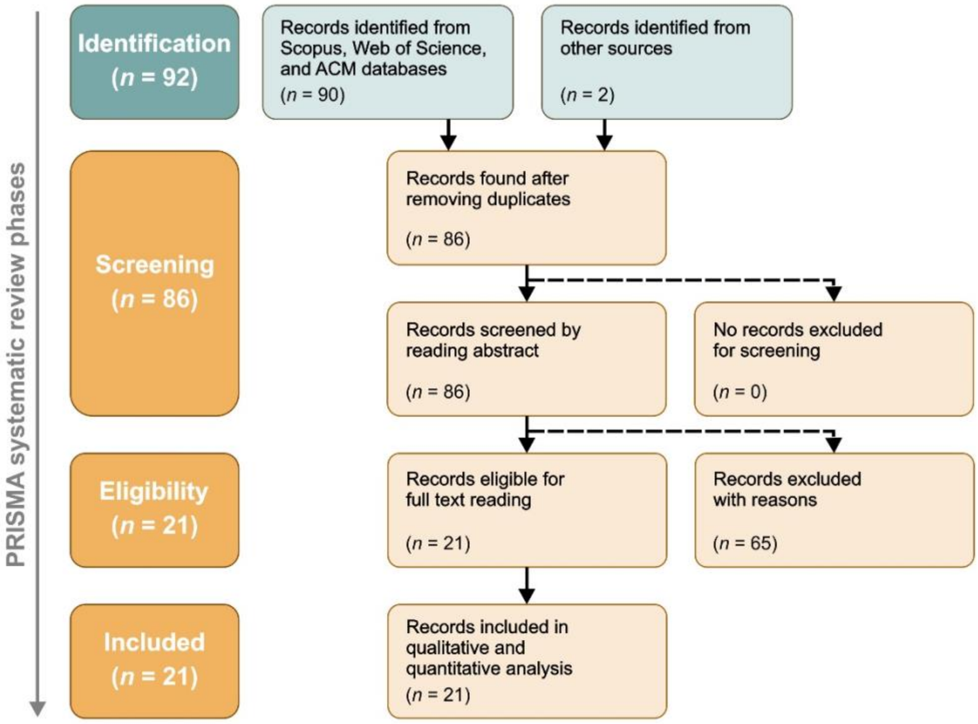

Figure 1. Article selection process followed.

2.3 Data analysis, mapping, and clustering

To support the bibliometric analyses of the 21 selected articles for the review, the VOSviewer computer program was selected as a co-word analysis tool. The VOSviewer is an open-source software tool that uses mapping and clustering techniques to produce maps based on network data. It is used to create, construct, visualize, and explore the bibliometric data to be easier to interpret it (van Eck & Waltman, 2010). It is a freely available tool that uses mapping and clustering techniques; it creates maps based on network data and includes extensive text mining functionality for creating term maps based on a corpus of documents (van Eck & Waltman, 2010). With the VOSviewer text mining functionality, a map for term co-occurrence based on text data was generated. This map generation is a representation of popular words that appear in the papers selected for extensive review. This map shows a popular word (repeated more than two times) with a bubble, and the size of the bubble is directly proportional to the frequency of the word in the literature (see Figure 3).

3 Results

This section reports the results of the analysis performed on the 21 included research papers. Two types of analysis have been performed, quantitative and qualitative.

3.1 Publications per year

Figure 2 shows the number of publications per year. One of the notable things in Figure 2 is that no research paper was found before 2015. The first paper on the topic was found in 2015, which shows that co-creation using digital fabrication is a relatively new topic and emerged in research in the last seven years before 2021. This thing can be endorsed by the number of articles per year, that is, only 3 articles published per year. This also shows that this topic is yet to be explored.

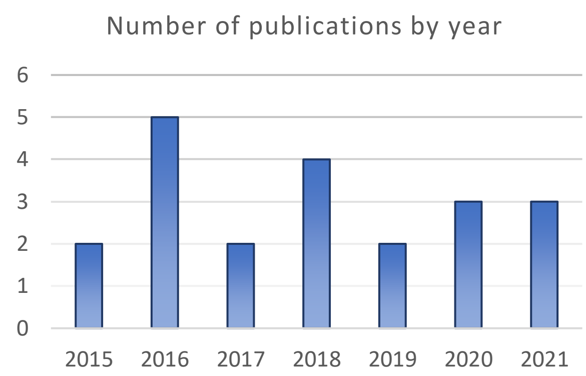

Figure 2. Publication trend.

3.2 Frequent keywords

Figure 3 shows the results of the keyword analysis generated by VOSviewer. The size of each word bubble shows the occurrence of the word in the literature. During the analysis, a binary count of words was performed, which ensures the counting of a word once from one paper. Therefore, a higher occurrence of a word shows that the word is repeated in a higher number of research papers. Hence, the size of each word bubble shows its significance in the literature.

The term “digital fabrication” is the most frequent word in selected literature. This is obvious because all included papers focus on digital fabrication. Digital fabrication is about making products in form of prototypes, which is emphasized here with the word “product.” The creation of prototypes is done in creative spaces, for example, a digital fabrication lab, space and makerspace. This is higlighted by the prominence of word “makerspace”, but also with the word “space”. Moreover, the word “collaboration” gives us a meaningful information, that the most common type of co-creation in digital fabrication literature is collaborative type of co-creation. Other frequent words include “study”, “worksphop”, and “participants”, which show that most of the studies included in this review are empirical studies. Results from such studies are considered original and more practical oriented; therefore, more applied towards the topic Figure 3 also highlights different participants in the co-creation process such as community, students, teachers, designers, and stakeholders. Moreover, the nature of work is characterized by words such as “creation”, “collaboration”, “experience”, “co-creation”, “safety”, “process”, “ideation”, “design”, “approach”, and using “tools”.

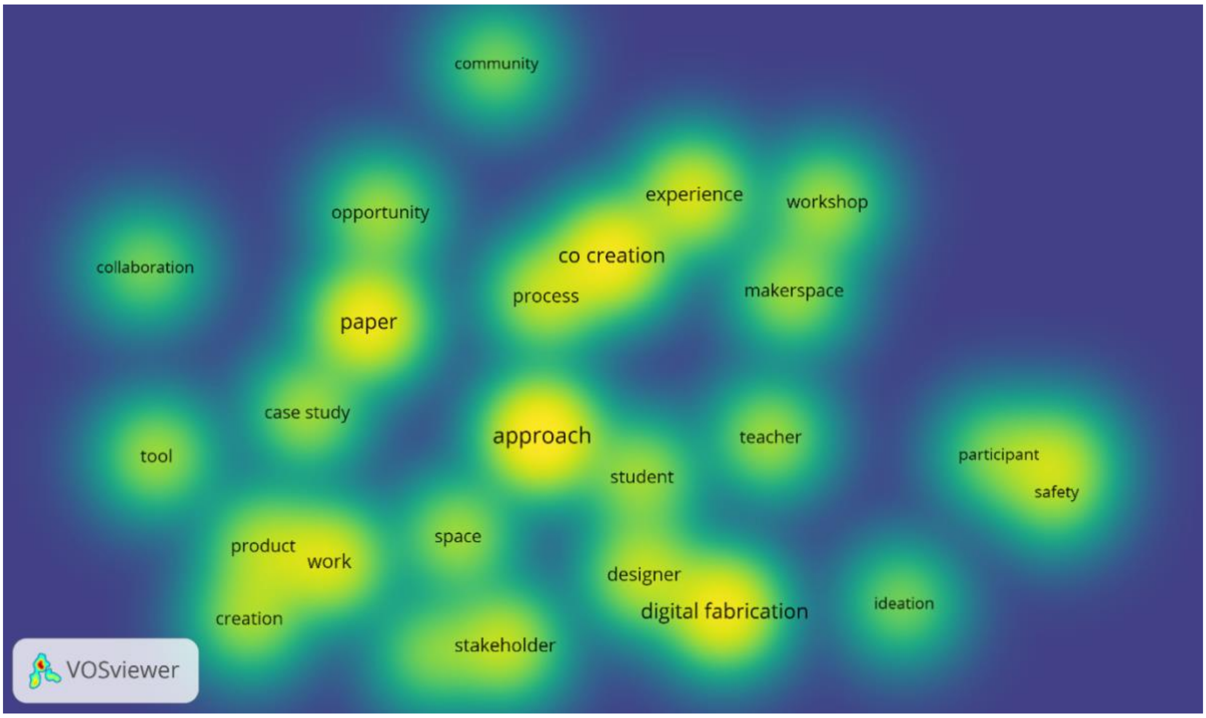

Figure 3. Occurrence of frequent words.

3.3 Clusters and keyword maps

Figure 4 contains four items. (i) Frequency of a word, which is represented by the size of the bubble. (ii) The link between two words, which shows the occurrence of two connected words in the same study. (iii) The thickness of the link, which shows the strength of the connection between the words. (iv) Colour of the bubble and links, where the colour shows a particular cluster of connected words. Here, a cluster shows a similar group of ideas or a theme in the literature. In the VOSviewer, each word has links with words of other clusters. It means the clusters are also mutually connected.

It can be interpreted from Figure 4 that there is a strong link between keywords like “creation”, “tool”, “collaboration”, “community”, “case study”, and “opportunity” in research conducted during 2017. Later in 2018, more research work is carried out on topics including the keywords “co-creation”, “experience”, “workshop” and others shown by dark green colored links. Moreover, “digital fabrication”, “designer”, “stakeholder”, and “student” have been the targeted keywords for research in this domain. It is worth noticing that these themes are of great interest to researchers, designers, educators, and other relevant stakeholders.

Around 2020, the focus has been shifted toward participants and their safety in fabrication spaces. A literature review (Love, 2022) has highlighted little research on safety in makerspaces and STEM in educational institutes. According to authors (Love, 2022), proper training and supervision are critical to deal with issues related to the safety of participants’ usage of machines in makerspace environments. Ensuring safety is not limited to the safe use of tools and equipment only, but it extends to incorporating the culture of safety in making and processes of making the products (Wilczynski & Adrezin, 2016). In the wake of Covid-19, serious challenges were faced with keeping makerspaces functioning along with practicing safe measures. In this regard, the findings of (Lieber et al., (2021)) can serve as a good guide for practicing safety culture in makerspaces and educational institutes.

Figure 5 gives an intresting and clear picture of the way different themes have been created from the existing literature. There are three different clusters shown in red, blue, and yellow colored bubbles. These colors are randomly created by the software to distinguish one group of words from the others. However, any specific color does not signify the importance of one cluster over the others. The set of keywords appearing in a particular color, for instance red, are all strongly connected because they occur frequently in same papers. Similarly, the keywords in blue colored bubble are highly relevant with other keywords in blue color and appear in same papers. The occurrence of these clusters shows the strong association in different topics of research and signify the growing trend of research work in different areas of making and digital fabrication.

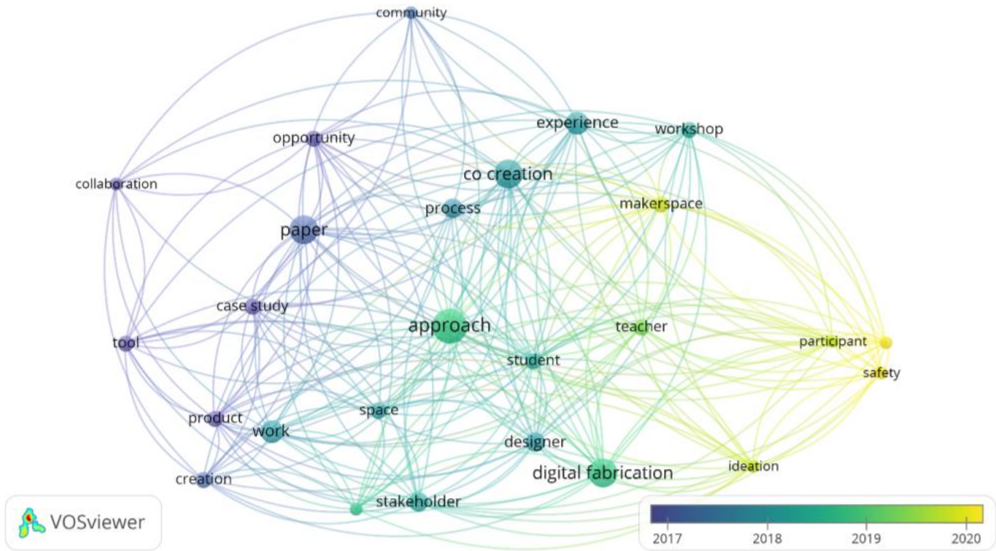

Figure 4. Links between the different clusters of words and their connection with publication years.

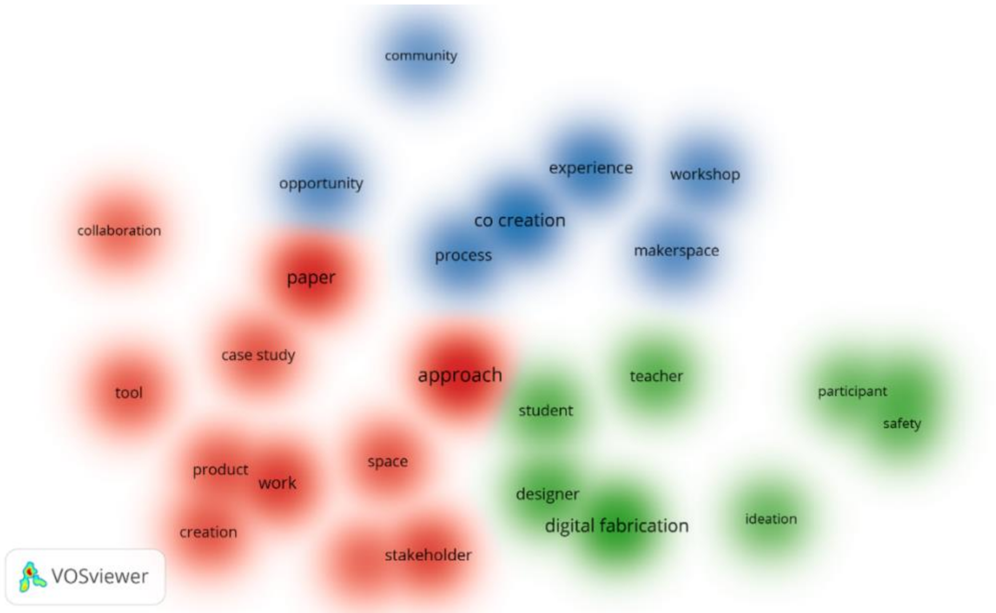

Figure 5. Clusters map using frequent words.

The results from the keyword analysis show that some themes exist in the literature which need to be studied separately. The scope of this research is limited to co-creation. Therefore, independent thematic analysis is recommended for future studies focusing on one or selected themes.

3.4 Qualitative analysis

One of the popular classifications of co-creation was done by O'Hern and Rindfleisch (2010). They described that there are four types of co-creation namely, co-design, collaboration, submitting and tinkering (OHern & Rindfleisch, 2010). Co-designing is defined as "a process in which a relatively small group of customers provides a firm with most of its new product content or designs, while a larger group of customers helps select which content or designs should be adopted by the firm." (O'Hern & Rindfleisch, 2010). Collaboration is defined as "a process in which customers have the power to collectively develop and improve a new product's core components and underlying structure." (OHern & Rindfleisch, 2010). Submitting is defined as "a process in which customers directly communicate ideas for new product offerings to a firm." (OHern & Rindfleisch, 2010). Finally, tinkering is defined as "a process in which customers make modifications to a commercially available product and some of these modifications are incorporated into subsequent product releases." (OHern & Rindfleisch, 2010). This classification is one of the most cited and utilized in the literature. Therefore, this analysis is also performed based on above-mentioned classification of co-creation but in terms of designing through digital fabrication. Table 3 summarizes the reviewed studies by the type of co-creation that was identified in the paper.

It can be seen from Table 3 that the "collaboration" is the most common type of co-creation in the reviewed literature with 50% occurrences, followed by "co-design" with 40% occurrences. These findings reflect the way in which prototypes are developed in a makerspace using digital fabrication. As makerspaces are multidisciplinary in nature, because of electronics, programming, mechanical machines etc., people from different disciplinary backgrounds create together for better design and product outcomes. In collaboration type of co-creation, the customers are given the capacity to put efforts with designers to make the final product. In the co-design, a small number of consumes help the designer with their input to finalize the product. The suggestions by the small group of consumers are further assessed with the help of many consumers before being implemented by the designer. Thus, co-creation and its different tools become useful to generate solutions to the problems at hand. To achieve this purpose, makerspaces provide a lot of opportunities where different stakeholders from makerspace community share values and design ambitions.

Tinkering type of co-creation was found less common in the reviewed literature of digital fabrication. Tinkering was mostly used where the design is guided by developers, mainly for learning purposes. This happens in learning new skills by children in school. Therefore, from design and creation perspective it is not that relevant, however from learning and education prospective tinkering can be a common aspect of co-creation. The submitting type of co-creation was not found in the selected literature.

Table 3. Classification of selected articles in terms of types of co-creation.

No.	Title	Co design (40%)	Collaboration (50%)	Tinkering (10%)	Reference
1	"From souvenirs to 3D printed souvenirs". Exploring the capabilities of additive manufacturing technologies in (re)-framing tourist souvenirs	X			(Anastasiadou & Vettese, 2019)
2	Living Designs	X	X		(Bernabei & Power, 2016)
3	Co-creating opportunities for extracurricular design learning with makerspace students		X		(Bill & Fayard, 2018)
4	Investigating the Implications of 3D Printing in Special Education	X			(Buehler et al., 2016)
5	Digital Entanglements: Craft, Computation and Collaboration in Fine Art Furniture Production		X		(Cheatle & Jackson, 2015)
6	Shifting Expectations: Understanding Youth Employees' Handoffs in a 3D Print Shop		X		(Easley et al., 2018)
7	Participatory co-creation of a public sculpture incorporating 3D digital technologies		X		(Echavarria et al., 2018)
8	Toward a Sustainable Model for Maker Education in Public Education: Teachers as Co-Designers in an Implementation of Educational Makerspaces	X			(Fernandez et al., 2020)
9	Making things in Fab Labs: a case study on sustainability and co-creation	X			(Fleischmann et al., 2016)
10	Shall We Fabricate? Collaborative, Bidirectional, Incremental Fabrication		X		(Kim, 2017)
11	Children's learning in focus: Creating value through diversity and transdisciplinary work in design, digital fabrication, and making with children		X		(Kinnula et al., 2021)
12	Co-design visions of public makerspaces in China	X			(Lam et al., 2020)
13	Towards Ultra Personalized 4D Printed Shoes	X			(Nachtigall et al., 2018)
14	Learning Through STEM-Rich Tinkering: Findings from a Jointly Negotiated Research Project Taken Up in Practice			X	(Bevan et al., 2015)
15	Safety culture in digital fabrication: Perceptions, model and co-creation approach		X		(D. Rajanen & Rajanen, 2020)
16	Co-creation of a Safety Culture in Digital Fabrication		X		(D. Rajanen & Rajanen, 2019)
17	Three Approaches for Shaping Safety Culture in Digital Fabrication: A Research Roadmap		X		(M. Rajanen & Rajanen, 2021)
18	Circular design - learning for innovative design for sustainability: eramus plus		X		(Segalas et al., 2017)

	knowledge alliance project for sustainable design				
19	From Digital Fabrication to Meaningful Creations: Pedagogical Perspectives			X	(Suero Montero et al., 2020)
20	Fablabs as drivers for open innovation and co-creation to foster rural development	X			(Duh & Kos, 2016)
21	OpenLabs - Open Source Microfactories Enhancing the FabLab Idea	X			(Redlich et al., 2016)

4 Discussion

4.1 Thematic analysis

To find patterns in a qualitative dataset, Holton (1988) presents the idea of Thematic analysis. According to Willig & Rogers (2017), a pattern is a collection of thoughts with a common meaning that are gathered under a central idea or topic. Based on the type of co-creation discussed in included articles in this review, all articles are classified into three central ideas or themes under the topic of co-creation, namely co-design, collaboration, and tinkering. To provide a detailed overview of the reviewed literature, example research studies under each theme are discussed below.

4.1.1 Co-design

The definition of Co-design in terms of DFT and maker space can be derived from O'Hern and Rindfleisch (2010) as a process in which a relatively small group of learners provides new product content or designs. Following are a few examples of such work in the context of DFT and makerspaces.

Anastasiadou & Vettese's study (2019) is an example of co-design where participants provided their feedback about the whole process of creating 3D printed souvenirs and proposed the final idea of 3D printed souvenirs. In their study, tourists used 3D printing and digital fabrication technologies to co-create desired souvenirs along with designers, resulting in more dynamic and personalized 3D printed souvenirs. The study included research challenges like technological implications and ethical constraints while designing souvenirs related to cultural heritage. In a different research study, Buehler et al. (2016) present a case study where 3D printing is used for consumer-grade digital fabrication for students with cognitive impairments and vision impairments. The researchers co-designed with the therapists an assistive adaptive handgrip device for students. They also developed GripFab software for therapists after analysing the needs and putting constraints on the therapists to develop the device. The case study was performed at three special sites of education and discussed the challenges encountered to maximize the efficiency of 3D printing for the said purpose. Fernandez et al. (2020) provide an implementation model for co-designing enriched curriculum units with co-creation of makerspace teachers and science teachers. This is basically a co-design type of co-creation between schoolteachers and makerspace instructors.

The co-design theme is present in the reviewed literature in two main contexts of digital fabrication: (i) designing new products and (ii) designing new educational programmes.

4.1.2 Collaboration

The collaboration type of co-creation can be defined as a process in which end users can collectively develop and improve a new product's core components and underlying structure (OHern & Rindfleisch, 2010). In the context of DFT following are some exemplary works from the literature. The study by Cheatle & Jackson (2015) describe an example of collaborative co-creation where a community with a background in diverse disciplines co-create together, especially cultural heritage, and its interpretations are given due importance in communities. Cheatle & Jackson (2015) present the creation of a piece of artwork with the collaborative efforts of community members by using digital fabrication tools and designing skills to 3D print the selected artefacts. The whole process of community collaboration and co-creation is discussed. Bill & Fayard (2018) present a collaborative work where students make use of open-source resources to create and learn under instructors' guidelines. This paper highlights the importance of extracurricular activities in makerspaces. The series of student-led workshops were conducted to teach design thinking mindset using a combination of extracurricular learning and peer-to-peer learning. Easley et al. (2018) discuss about potential of technology to assist collaboration in the workplace, which is an important notion in the computer-supported cooperative work research community. With the mainstream of digital fabrication tools and techniques, youth are utilizing many mainstream communication tools to collaborate with each other in the workplace, i.e., a digital fabrication shop.

Three papers addressing safety in digital fabrication in makerspaces (Rajanen & Rajanen, 2019, 2020, 2021) are also identified in this category as using collaboration type of co-creation. In one of the studies (D. Rajanen & M. Rajanen, 2019) a workshop where participants co-create materials for promoting safety in a fab lab or makerspace is introduced. This resulted in several storyboards as prototypes for future instructional video materials (D. Rajanen & M. Rajanen, 2020). The collaboration nature of the co-creation work is also highlighted in the future agenda for studying the co-creation of safety culture in digital fabrication, as safety culture is achieved through the collaboration between different stakeholders participating in different activities and processes in makerspaces such as users and stakeholders of various ages and backgrounds (M. Rajanen & D. Rajanen, 2021).

To summarize, the collaboration theme was found in four main contexts in digital fabrication: (i) community involvement in art co-creation, (ii) collaborative learning, (iii) collaborative work among youth, and (iv) co-creation of safety culture in digital fabrication.

4.1.3 Tinkering

Tinkering in terms of digital fabrication and makerspace can be defined as a process in which students make modifications to an available product and come up with a new product idea. Tinkering was found to provide opportunities for students to develop skills such as problem-solving, creativity, and critical thinking. The research suggests that tinkering can be a valuable addition to traditional classroom instruction in STEM subjects (Bevan et al., 2015). Suero Montero et al. (2020) promote a pedagogical strategy that stresses experimentation and tinkering to promote creativity and innovation. The four main components of the framework the authors suggest for pedagogical tinkering are engagement, discovery, expression, and reflection. Students can gain a deeper understanding of the technology and its potential uses by including these components in digital fabrication activities.

4.1.4 Co-creation and user-driven innovation

Apart from these themes, other themes like circular or user-driven innovation can also be interesting for further investigations—particularly the role of consumer-designed artefacts using co-creation in makerspace facilities. Circular or user-driven innovation is concerned with the influence and contribution of the user in manufacturing the end products. Digital fabrication labs offer opportunities where users can either entirely self-direct the creation of consumer products or highly influence the process from ideation to the embodiment of the final product. (Premyanov et al., (2022)) discussed a circular maker entrepreneurship program for entrepreneurs from six EU countries to learn skills of circular innovation, utilise materials in makerspaces to meet their entrepreneurial objectives, and network with the local community. This way, people from multidisciplinary fields co-create through collaboration and help in the democratisation of social innovation. Van der Have & Rubalcaba (2016) define social innovation as the practices of organizations to create products with the sole purpose of benefiting humanity rather than gaining monetary benefits from innovating products. Teaching circular innovation to designers as well as local citizens is equally important to unleash the maximum potential of co-creation opportunities in makerspaces and creative environments. One such effort is discussed in (Ballie et al., 2016), where textile designers and citizens use makerspaces to create purposeful solutions for reusing textile waste rather than 'throwaway and replace' culture.

4.2 Implication for design

The implications for design include interventions for design education and design practice. In the context of design education, interventions using co-creation, co-design, and collaboration involving instructors and students can be targeted for achieving learning outcomes, skill sets, and competencies. Such competences can range from design creativity to computational or critical thinking. In the context of design practice, co-creation, co-design, and collaboration involving different designers, team members with different backgrounds, and other stakeholders open doors for empowering experimental activities and materializations, shortening the way from prototyping to marketable products. Sustainability and innovation can be explicit aims of the interventions here.

4.3 Future work and limitations

This research work can be extended in two ways. First, a future study can include more search terms, such as synonymous terms, expanding the initial search and generating more potentially relevant articles. The publication types in this research include journal and conference research papers. Chapters and books can also be a valuable addition. Furthermore, the search can be extended to more databases and search platforms. The second future work direction is to investigate more closely the fact that the submitting type of co-creation has not been identified among the reviewed articles. Future searches can investigate if these types of approaches are encountered in digital fabrication, and the reasons and implications can be analysed and discussed.

No predefined number of minimum studies is required to include when conducting a systematic literature review using PRISMA methodology. A higher number of relevant studies might improve the quality of the review. Thus, one limitation of our study is that the number of included articles might be increased in the future to enhance the quality of the review. Furthermore, it will also be interesting to include themes like the circular economy or user-driven innovation and its role in co-creation in makerspaces using digital fabrication technology.

5 Conclusion

In this systematic literature review, we have identified four prominent types of co-creation which are used in makerspaces and Fab Labs. We reviewed 92 papers based on the inclusion criteria and included 21 papers for quantitative and qualitative analyses. The following results were found from the analyses: (i) In publication trends, an increment in articles per year shows that this is a promising area of research. (ii) Most of the studies come from academia, which is due to the increasing use of makerspaces for education and training. (iii) Most of the studies (50%) in this case show a collaborative type of co-creation. Because collaboration in makerspace is the key skill for making prototypes or learn digital skills, this collaboration can be between (a) instructor and students, (b) between students or participants with background from various disciplines, (c) between students of various age groups, (d) between instructors with various level of education and expertise. (iv) No paper from submitting type of co-creativity may be due to the nature of makerspace works. In a makerspace, no one controls the constraints of a design and contribution. In contrast, it is based on open-ended learning and design. Similarly, the analysis done with graphs analysis software contributes to the thematic analysis, showing that collaboration and co-design are the two most popular types of co-creation to create prototypes in makerspaces and Fab Labs. In summary, our study serves as a promising start to fill the research gap in studying the relationship between different types of co-creation used in makerspaces to create prototypes.

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