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Review

A Systematic Review on FabLab Environments and Creativity: Implications for Design

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Abstract: Fabrication laboratories (FabLabs) and makerspaces are used to transform ideas into tangible products. Used in a design–learning context, they can enhance cognitive and creative skills. Creativity is the pivotal ability to produce innovative outcomes in makerspaces, and several studies have attempted to understand the role of makerspaces and creativity in specific fields. However, a comprehensive study offering a holistic view of the contributions of the makerspaces as built environments that foster creativity is lacking. Therefore, we conducted a systematic literature review on FabLabs, makerspaces, and creativity to address this research gap. While the review was performed using five major databases, only peer reviewed journal articles were considered. The findings revealed that makerspaces help to develop person, product, physical, and social environments, as well as process aspects of creativity. Moreover, makerspaces induce problem solving, collaborative, and communication skills; they also offer appealing environments and technologies for developing creative solutions to real-life problems. We identified and analysed five major themes dealing with technical skills, technological and environmental elements, STEM learning, and skill development, and elaborated upon their importance for enhancing creativity in FabLab and makerspace environments.

Keywords: collaborative learning environment; creative physical environment; creative process; creative skills; creative social environment; creativity; design; fabrication laboratories; makerspace; technology

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1. Introduction

A makerspace is an overreaching concept understood as "a creative, uniquely adaptable learning environment with tools and materials, which can be physical and/or virtual, where students have an opportunity to explore, design, play, tinker, collaborate, inquire, experiment, solve problems and invent" [1]. Makerspaces are built environments utilized for interdisciplinary applications and research, helping users to coordinate between different disciplines to develop complex engineering designs [2]. Fabrication laboratories (FabLabs) are similar to or are a type of makerspace. However, in FabLabs stronger emphasis is laid on the use of an often-predefined equipment (e.g., 3D printers, laser cutters, or electronic workbenches) and on the scope of related training (see [3]). The technology used in makerspaces and FabLabs are referred to as digital fabrication or digital manufacturing [4]. Such technology enables computer-supported additive and subtractive manufacturing, design and rapid prototyping, and the easy materialization of highly customized products. Digital fabrication technology is considered to be an indispensable part of makerspaces and FabLabs [5], invention studios [6], personal fabrication setups [7,8], design labs, and hackerspaces. Schmidt [9] coined "open creative labs" as an umbrella term referring to all kinds of makerspaces mentioned in the literature. Makerspaces are used in a variety of disciplines, and the literature has paid a good amount of attention to its wide applications. Makerspaces were found to be highly impactful in different domains. The nature of this influence was examined in economy [10], entrepreneurship [11], public libraries [12], design education [13,14], higher education [15], science, technology, engineering, and mathematics (STEM) education [16], medical practices [17], and sustainability [18] among many others. Built environments used for designing are essential for supporting creative activities [19]. Most of the studies conducted on makerspaces and FabLabs considered them to be creative, built environments that help students, engineers, designers, architects, and healthcare workers come up with innovative solutions to real-life problems [3,20–23]. In this regard, creative ideas and solutions are fostered by the stimulating atmosphere and environment [24]. There is evidence of a growing influence of workspace environments such as makerspaces on creativity and innovation [25]. For example, the quality of the physical environment was found to have a positive influence on the individual and team creativity. By contrast, negative qualities of the physical environment can hinder creativity [26].

Creativity is a comprehensive term with many definitions in the literature. This study adopted that proposed by Rhodes [27]: "The word creativity is a noun naming the phenomenon in which a Person communicates a new concept (which is the Product). Mental activity (or mental Process) is implicit in the definition, and of course, no one could conceive of a Person (Individual) living or operating in a vacuum, so the term Press (Environment) is also implicit." Generally, the creativity inherent in an output or product depends on its novelty and suitability [28]. Creativity is also associated with skills such as creative thinking, problem-solving, critical thinking, imagination, and active learning [29–31].

Digital fabrication technology used in FabLabs and makerspaces affects users' thinking, ideas, creation skills, and the ability to produce creative solutions in a wide variety of domains such as art, science, and engineering. Schmidt described "creative labs" as sites for social innovation that foster individual creativity and learning, leading to creation of knowledge and value [32]. Culpepper and Gauntlett [33] conceived makerspaces as creative settings for generating creativity and curiosity in individuals. An empirical study conducted by Saorin et al. [34] in makerspaces concluded that digital editing tools and 3D printers helped in developing the engineering students' creative ability. In addition to the development of creative abilities, makerspaces are helpful in promoting collaboration, problem-solving, and communication in areas such as science, technology, engineering, and mathematics (STEM) [35,36]. Specifically, the relationship between creativity and makerspaces has been investigated in different research articles in the context of specific disciplines [37–39]. However, no study has focused simultaneously on all the aspects of creativity (person, collaboration, process, physical, social features of the environment, and product) in the context of makerspaces. Consequently, it was suggested that further research is needed to explore the specifics of makerspaces as types of creative work and learning environments [40].

The aim of this study, thus, was to conduct a comprehensive systematic literature re-view (SLR) to understand the influence of built environments such as makerspaces on creativity according to person, process, product, (physical and social) environmental features, and collaboration aspects. The present study identified five themes in the articles discussing the topic of creativity in relation to makerspaces included in the review. The main contribution of this review is that it summarizes and maps the state-of-the-art research work carried out on creativity in makerspaces thus far, particularly pertaining to the five mentioned aspects of creativity.

2. Method

An SLR was conducted following the preferred reporting items for systematic re-views and meta-analyses (PRISMA) model [41]. SLR is known to provide strong theoretical knowledge and insights into current trends associated with a research topic [42]. This section outlines the keywords and databases employed in the search, and provides examples of included and excluded articles.

2.1. Search Criteria, Databases, and Keywords

An initial search was conducted using keywords such as makerspace, FabLab, creativity, and cognition. However, due to the limited number of results and to gain a broader view of the topic, the authors decided to use three rather than four search terms (i.e., makerspace, FabLab, and creativity) to gain a broader view of the topic. The search was conducted on five online databases, and only peer-reviewed journal articles were included in the sample. Table 1 shows the main parameters and corresponding values used in the database searches.

Table 1. Search criteria.

Search String	("Fab Lab" OR Fablab* OR "Maker Space" OR Makerspace*) AND Creativity
Databases	Scopus, Web of Science, EBSCOhost (Academic Search Ultimate), ProQuest, ACM digital library
Document Type	Journal articles
Searched in	Title, abstract, and keywords only
Language	English
Last update	4 June 2022

2.2. Article Selection Process

In the initial stage (i.e., Identification), 264 articles were found from all five databases and stored using a reference manager software. After removing duplicates, 170 articles were identified. In the second stage (i.e., Screening), the 170 articles were reviewed for their central idea, application area, research methods, and contributions to determine their relevance for this review. Thereafter, the articles that specifically discussed creativity (person, collaboration, process, social, physical environment, or product) in the contexts of FabLabs and makerspaces were selected for a full text reading (a detailed description of the inclusion and exclusion process is given in Section 2.3). In the third stage (i.e., Eligibility), 45 articles were deemed eligible and included for quantitative and qualitative analysis. Figure 1 shows the SLR process followed as well as the number of publications at the end of each stage of the process.

2.3. Reliability of the Selection Process

To ensure reliability of the article selection process, a second researcher independently screened the full texts of 40 articles randomly selected from the 170 articles. To check validity, the resulting selection of 13 articles eligible for inclusion from the 40 screened, was compared to the selection of 12 articles eligible for inclusion by the first researcher. The result corresponded to Cohen's kappa [43] of 0.94 indicating almost perfect agreement between evaluators [44].

2.4. Article Inclusion and Exclusion Criteria

Articles were eligible if they focused on the role of FabLabs, makerspaces, or any other related terms, such as lab/space, in fostering any aspect of creativity (person, process, environment, product, or collaboration). As an example, Saorin et al. [34] examined the effect of using 3D printing technology in a university makerspace on engineering students' creative competence and perception. In this case, the personal aspect of creativity was studied in the context of a makerspace and the study was included in the review. Another example is a cross-disciplinary study that combined medical and engineering students in makerspaces who were engaged in creative product development [45].

Studies that did not focus on the creative issue of FabLabs or makerspaces were excluded. In this regard, an article stated that "makerspaces offer a pedagogical approach promoting creativity in students" [46]. However, because the relationship between creativity and makerspaces was not investigated, it was excluded. The practice of calling makerspace a "creative place" is common in the literature (e.g., [47,48]). However, though several articles included the words "creativity," "FabLab," or "makerspace," their study topic was unrelated to these notions. This is one main reason behind the exclusion of many articles from the present review. Newspapers and magazines (e.g., [49–52]) were also excluded. These articles were retrieved from EBSCOhost and ProQUEST databases during the search for peer-reviewed journal articles.

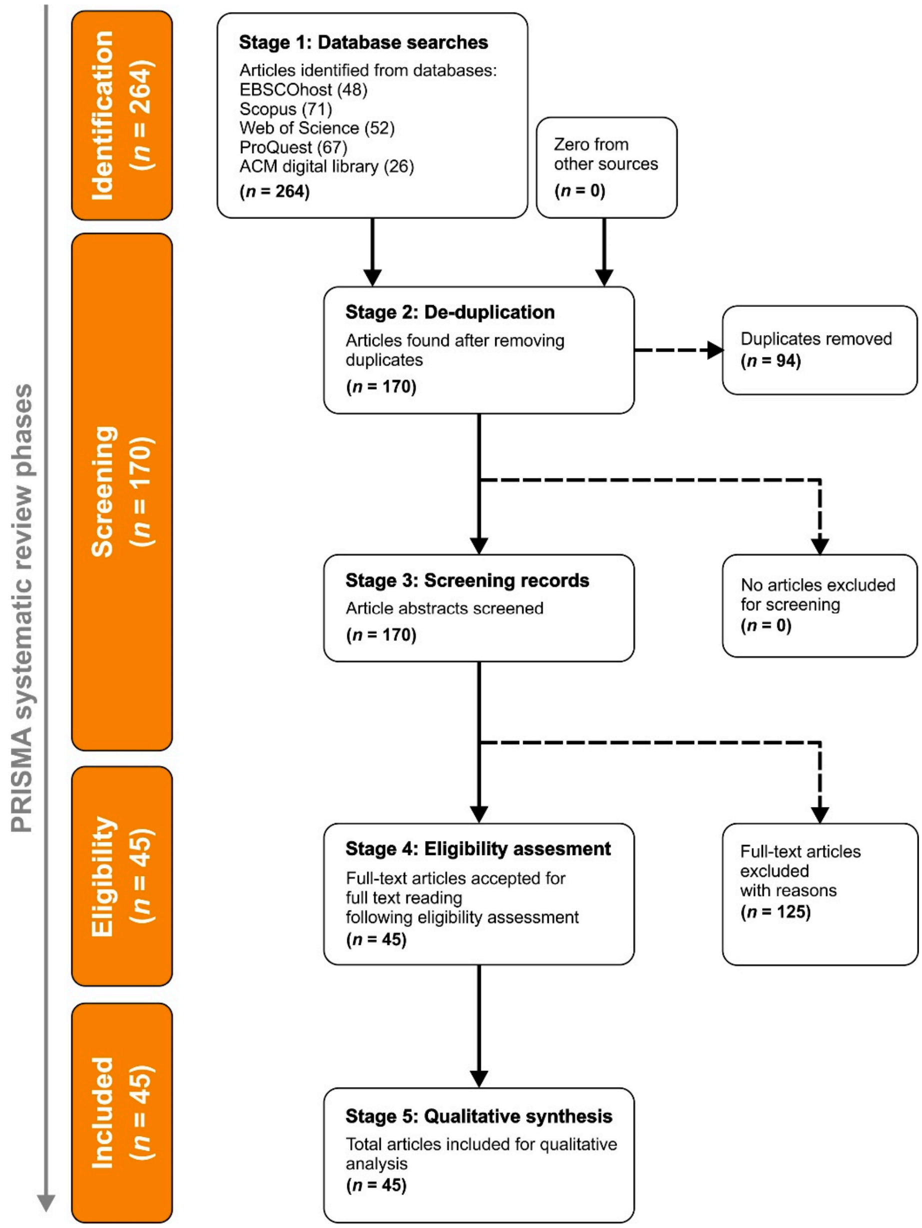

Figure 1. Flow diagram of literature review.

3. Results

First, word analysis was carried out to find the themes in the literature as presented. Then, the qualitative analysis was conducted to identify the main themes, the research method used, and the aspects of creativity addressed in the literature as outlined. Results are summarized in Figure 2.

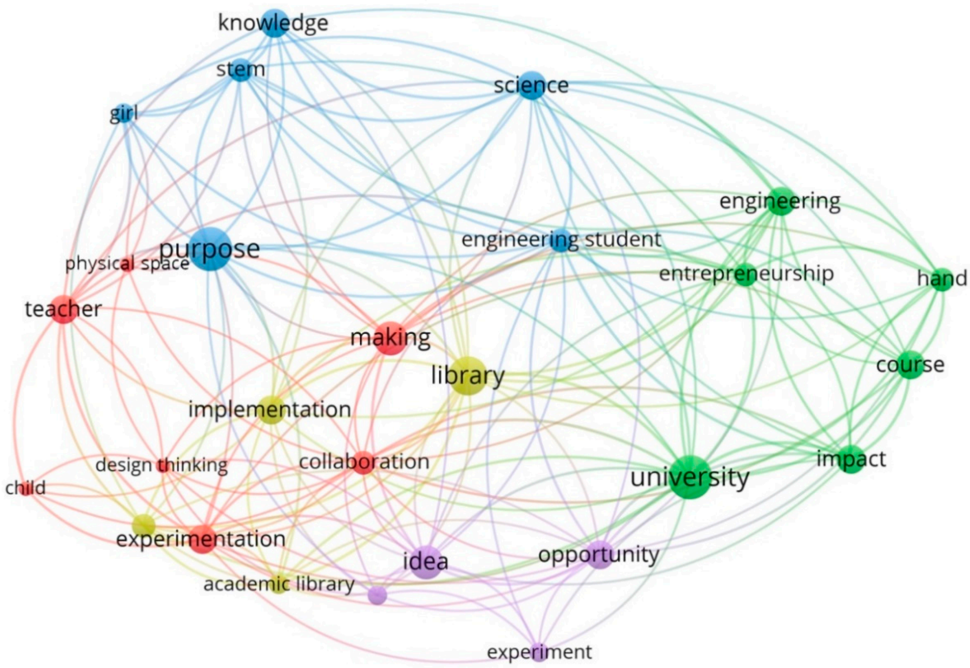

Figure 2. Occurrence of frequent words and clusters (Note: "hand" represents hands-on learning).

3.1. Word Analysis and Clustering

Word analysis was performed via VOSviewer software [53] using the titles and abstracts of the selected articles. The analysis showed the most common words used in the selected articles and the strength of the links between them. Link strength is the number of articles in which two terms occur together. These pairs of words were then used to form clusters of words based on their frequency, as well as on the strength of the links between the words. The co-occurrence of words was based on binary counting, meaning that similar words from a single paper were counted only once. The algorithm used to create clusters was based on the technique by van Eck and Waltman [53]. Search terms such as "creativity," "FabLab," "makerspace," common words such as "year" and "finding," as well as articles and prepositions were filtered out because their occurrence in the clusters was irrelevant to the scope of this study. Accordingly, the emerging clusters were used to find key themes in the reviewed literature.

The clusters were formed by words that appeared at least three times in the included articles. The minimum occurrence was set to three to create clusters with the most frequent and relevant words, which enabled the authors to define the themes associated with these clusters. Setting the minimum to one or two would have resulted in thousands of words with even more connections, producing too many clusters with few words in each. Ultimately, this would have made the word analysis more error-sensitive, and each cluster would have been difficult to interoperate. Since words from one cluster relate to words from other clusters, the clusters were mutually connected. To enhance visibility and clarity of the outcome, the links between words are not shown in Figure 2. After carrying out a qualitative analysis of all the included articles, each of the emerging clusters was categorised under a specific theme. The clusters and their associated themes are illustrated in Table 2.

Table 2. Identified clusters and themes.

Theme No.	Cluster	Theme	Label
1	Red	Technological and physical environmental aspects of makerspaces in the context of creativity	Physical environment and technology
2	Yellow	Use of makerspaces in learning environments such as academic and public libraries to offer creative built environments to users	Learning environment
3	Purple	Person-focused studies examining the use of makerspaces for creative and technical skill development	Person-focused studies
4	Green	Use of makerspaces in undergraduate courses, particularly in engineering programs aimed at skill development and the generation of creative products	Hands-on learning in higher education
5	Blue	Use of makerspaces for primary and secondary education focusing on STEM learning and skills development	Learning and skills development in STEM education

3.2. Theme of Each Word Cluster

The following steps were followed to assign a theme to each cluster: (i) select a cluster; (ii) search each word from that particular cluster in the full text of all articles included in this review; (iii) read the context of a word where it appears in the corresponding articles; (iv) select common articles having most of the words from that particular cluster; (v) carefully read the selected articles to find the central idea or theme; (vi) assign a theme to that particular cluster. The same process was repeated for all the clusters shown in Figure 2. For example, for the purple cluster, four articles [36,54–56] were found, which contained most of the words corresponding to this cluster. After qualitative analysis, we found that all the articles were discussing the use of makerspace in developing creative skills and encouraging technical skill development related to STEM disciplines. Therefore, the theme "Person-focused studies" theme that revealed the use of makerspaces for creative and technical skill development was assigned to the purple cluster. The themes assigned to each cluster are shown in Table 2.

3.3. Classification of Selected Articles

Table 3 provides a comprehensive view of all the articles included in this study. It maps each article according to the main themes and aspects of creativity. In addition to the themes described in Table 2, a qualitative analysis was conducted to classify the selected articles based on creativity issues. Creativity issues were organized according to the four Ps of creativity model by Rhodes [27]) that include: (i) person (personality, intellect, temperament, traits, habits, attitudes, self-concept, value systems, defence mechanisms, and behaviour), (ii) process (motivation, perception, learning, thinking, and problem-solving skills), (iii) product (output of creative process concerned with novelty, originality, uniqueness, practicality, usefulness, and/or functionality [27,57], and (iv) press (built environment directly or indirectly influencing creativity [19,26,58]. The environment aspect of creativity represents research articles discussing physical and social aspects of the built environment that motivates, inspires students, and engages them in an unpredictable and risk-taking atmosphere that fosters creativity [27,59]. In addition to the four Ps of creativity, the collaborative aspect of creativity was included in this review. Collaborative creativity refers to studies where experts (designers or creators) and stakeholders design products together [60].

Table 3. Literature review summary classified into year, themes, and creativity aspects.

Year	Theme					Creativity					Author(s), Reference
	Physical Environment and Technology	**Learning Environments**	**Person-Focused Studies**	**Hands-on Learning in Higher Education**	**Learning and Skills Development in STEM Education**	**Person**	**Environment (Physical/Social)**	**Process**	**Product**	**Collaboration**	
2009			X				X	X			Dlodlo & Beyers, [54]
2010					X		X	X			Beyers, [61]
2014				X		X	X	X			Forest et al. [6]
2015	X				X		X	X			Bevan et al. [16]
2016					X			X			Fonda & Canessa, [62]
	X								X	X	Fleischmann et al. [63]
2017		X				X	X				Bieraugel & Neil, [64]
	X						X	X			Georgiev et al. [65]
	X						X			X	Giannakos et al. [66]
				X				X	X		Marshall & McGrew, [39]
					X		X	X			Milara et al. [67]
		X					X	X			Noh, [68]
	X							X	X	X	Roma et al. [69]
		X					X	X			Schuck et al. [70]
				X		X					Saorin et al. [34]
			X					X			Sheffield et al. [36]
	X						X				Smith, [71]
2018				X			X	X			Albala et al. [72]
		X					X				Li et al. [73]
	X						X	X			Meyer et al. [74]
		X					X				Zaugg & Warr, [75]
2019	X					X		X			Barrett et al. [76]
				X				X	X		Geist et al. [45]
		X						X			Stover et al. [77]
	X						X			X	Schmidt, [9]
			X			X	X			X	Trahan et al. [55]

Table 3. *Cont.*

Year	Theme					Creativity					Author(s), Reference
	Physical Environment and Technology	Learning Environments	Person-Focused Studies	Hands-on Learning in Higher Education	Learning and Skills Development in STEM Education	Person	Environment (Physical/Social)	Process	Product	Collaboration	
2020	X						X				Culpepper & Gauntlett, [33]
				X			X	X			Duenyas & Perkins, [21]
				X			X	X			Taheri et al. [78]
				X			X	X			Hoople et al. [79]
				X			X	X			Jalal & Anis, [80]
		X					X				Skåland et al. [81]
			X	X			X	X			Tomko et al. [82]
		X					X	X			Velicu & Giannis, [83]
2021					X			X		X	Dittert et al. [84]
			X		X		X	X			Hatzigianni et al. [46]
				X				X			Enkin et al. [85]
					X		X				Gurjar, [86]
				X	X			X			Lam et al. [87]
	X			X			X				Santos et al. [88]
				X			X	X			Sawyer, [89]
	X			X			X				Wu et al. [90]
2022	X					X	X				Gantert et al. [91]
	X					X	X			X	Huang et al. [92]
					X	X		X			Richterich, [93]

4. Discussion

This section presents an analysis based on the themes identified in the results section as well as the aspects of creativity addressed in the articles in the context of makerspaces and Fablabs.

4.1. Thematic Analysis

4.1.1. Physical Environment and Technology

This theme reflected how the introduction of technology (digital fabrication tools) in built environments such as FabLabs or makerspaces can have a positive impact on creativity. Both physical and non-physical workspace environments influence human behaviour and through this, creativity, and innovation performance [92]. The use of technology in makerspaces is essential to support design creativity (e.g., prototyping) [19]. In fact, shared creative environments are instrumental for not only for design studios [71,94], but also for any prototyping-focused environments such as FabLabs and makerspaces [65]. These are seen as a variety of collaborative spaces for experimentation, tinkering, and innovation [32] that complement other educational environments [74]. The availability of various facilities, including shaped spatial architecture and infrastructure, stimulate the innovativeness of the users operating in these makerspaces [9,32,33,91]. It is suggested that rounded versus angular physical work environment is more likely to enhance divergent creativity [90]. Physical attributes of a makerspace play an important role in generating proper balance of structure with autonomy, interaction with seclusion, and comfort with usability, and are a fundamental metric of creativity [88]. Creativity is greatly connected with the production place [69]. Georgiev et al. [65] divided FabLabs and makerspaces into three places in which creativity can be captured: (i) the creative place (the physical space where activities are performed), (ii) the interaction between users (teams) as well as users and tools/machines (creativity can be observed capturing such interaction), and (iii) the creativity related to the work the users produce in the FabLab or makerspace. In contrast, Bevan et al. [16], who focused on the activities and interactions performed in makerspaces, argued that these helped students develop creative and improvisational problem-solving skills through making and tinkering. Fleischmann et al. [63] used digital fabrication technology in makerspaces for product co-creation by involving users in both the product design and fabrication processes. Mandavilli [52] suggested that selecting appropriate digital fabrication technology helped to make the most "wildly expressive things". Furthermore, FabLabs were found to promote creativity and technological entrepreneurship derived from knowledge, advancing by this key concepts of collaborative economy [95]. Considering these studies, it can be argued that employing different technologies in support of activities such as design and prototyping can contribute to the development of problem-solving skills and innovative products.

The main gap observed in this review was that very few empirical studies (e.g., [90]) discuss the relationship between the physical layout of a makerspace and its impact on creativity. Despite its importance, no other studies focus on Fab Lab specifically. Those discussing aspects related to the physical environment of makerspaces generally stress on the technology and tools used in makerspaces, but do not explore how the space should be designed (i.e., layout organization, materials used, acoustics, ventilation, illumination issues, and location of machines). For example, operating certain machines in FabLabs—such as large 3D printers, laser cutters, and Computer Numerical Control (CNC) tools—generates noise that can negatively affect other activities carried out in this environment, as well as the health of the designers. For this reason, CNC tools are typically put in separate rooms aimed at minimising the effect of noise. Future research should be carried out to investigate the effect of noise on FabLab activities. Carrying out design activities individually or in teams near such machines can affect the performance and creativity of the designers and their outcomes. Similarly, for proper functioning, machines such as laser cutters and soldering stations require intensive ventilation. These areas should be away from facilities where designers interact in activities such as prototyping or the creation of Computer-Aided

Design (CAD) models. This is not only important from a cognitive perspective but also from a health and safety one.

4.1.2. Learning Environments

As environments supporting effective exploration and learning, FabLabs and makerspaces can positively influence behaviours such as observation, experimentation, questioning, and networking. FabLabs and makerspaces are seen as types of creative work and learning environments [40]. In such spaces, the users are able to acquire complex knowledge about digital technologies through social-focused learning [95]. These are fundamental for fostering creativity and innovation in places such as academic libraries [64]. Bieraugel and Neil [64] found that in traditional libraries, the potential for creativity is not fully realized. This can be rectified by shifting the role of academic libraries from storing and serving up existing knowledge, to creating, discovering, and developing knowledge, hence fostering creativity and innovation in learning environments.

Another study endorsed the idea of constructing creative spaces in learning environments such as libraries, as they support the philosophy of collaboration, discovery, and integration of library services [75]. Creating makerspaces in libraries to support students' creative abilities was also endorsed by Schuck et al. [70]. Makerspaces in libraries are also considered to be innovative for business education and entrepreneurship and are often combined with other features encouraging creativity [77]. Ocholla et al. [96] related the notion of the fourth industrial revolution with the aim of creating makerspaces in academic libraries to promote innovation and creativity. A significant number of articles addressing creativity and FabLabs or makerspaces were based on designing such built environments of this type in public and university libraries [75], some of which were created under tight budgets [97]. These studies show the importance and increasing popularity of makerspaces in both public and academic libraries, suggesting that the addition of these environments in these existing learning environments can make them a place for not only storing and managing knowledge, but also for experimentation and innovation.

4.1.3. Person-Focused Studies

This theme focuses on students and stakeholders in FabLab and makerspace education. Some studies identified FabLabs and digital fabrication technology as a field dominated by male students [55,82]. However, other works found that the use of digital fabrication technology by both men and women was equally helpful in enhancing their creativity and critical thinking skills [54]. Women makers can enhance their confidence and resilience by developing a culture of learning, facilitating their own design journeys, and creating a "laboratory for creativity" [82]. In the context of psychological counselling, makerspaces can adjust personal definitions of creativity, integrate creativity into professional identity, and foster an environment for creative expression and problem solving [21]. These findings prompted further attempts to foster women's engagement and creative development in makerspaces by combining practical activities [56,98]. Velicu and Giannis showed that playing with support tools in makerspaces could dramatically change the way children perceive and approach a task demanding creative skills [83]. Applying design thinking in makerspaces was found to enhance open-ended, flexible, and transferable skills, such as creativity and critical thinking [46]. Overall, the studies dealt with different groups of people, roles, and skill development. Specifically, the above studies confirmed that makerspaces play a critical role in fostering important creative thinking skills required in both basic and higher education, as demanded by many of the 21st century challenges [36].

4.1.4. Hands-on Learning in Higher Education

This theme deals with hands-on learning in disciplines such as engineering, architectural design, medical education, and interdisciplinary studies. Most of these fields have an interest in fostering the personal and product aspects of creativity in Fablabs and makerspaces by using digital fabrication technology and through inter-disciplinary collaboration. In engineering education, efforts are made to stimulate individual creative competence supported by digital fabrication tools. Creativity and innovation have been identified by faculty and staff members as affordances of university-based makerspaces [99]. Using digital editing tools and 3D printers was found to positively influence users' creative skills [34,45,79], facilitate task motivation, and foster artistic creativity [85]. Moreover, integrating FabLabs with digital fabrication technology in the formal education of engineering students was identified as beneficial for enhancing their creative and entrepreneurial skills [78]. Makerspaces are seen as community-based organizations helping achieve goals, and develop self-confidence in manual activities demanding creativity [78,87]. Another study conducted on architecture and design education in FabLabs, showed a positive relation between the cognitive behaviour of student designers working in parametric settings and the creativity of their outcomes [100]. In medical education, students were found to be acquainted with digital fabrication technology to design and produce customized creative solutions to real-life problems aimed at improving healthcare or related products [39,72,101]. Another study demonstrated that collaboration between different disciplines while using makerspaces can lead to the production of largely innovative products [45]. Based on the above studies, it can be said that the integration of FabLabs and makerspace environments in higher education is of para-mount importance to enhance individual and collaborative creative hands-on skills of students, which may offer unique opportunities to make innovative products.

4.1.5. Learning and Skills Development in STEM Education

This theme addresses how makerspaces contribute to STEM education and creativity. Makerspace education plays an important role in helping students develop their creative thinking, communication, and collaboration skills mainly when offered the necessary means for implementing the "learning-by-doing" approach [3,61]. The type of pedagogy used in makerspaces was another influential aspect in fostering the students' creative skills [46,84]. Specifically, a joyful engagement in the learning process accompanied by the existence of a supportive technological environment were major factors that motivated students to learn, think, and act creatively [67]. From an experiential level, exploration, inquiry, and examination of materials were also found to encourage the production of creative outcomes [86]. Studies on FabLabs and makerspaces also dealt with the motivation for creativity in STEM education. Smith [71] demonstrated that makerspaces in STEM can be used to enhance creative skills and abilities, such as critical thinking, problem-solving, and design collaboration. It is important to demonstrate creative and collaborative skills to other participants in makerspaces [84]. From the above examples, it can be concluded that the learning-by-doing approach and joyful engagement in makerspaces motivate students to learn STEM related technological skills. In this regard, material artifacts and scrap materials found in makerspaces can have important implications for learning how to enhance creativity [89]. Particularly, makerspaces and FabLabs facilitate conducive learning environments where prototyping and other design activities are fundamental for developing creative thinking, problem solving, and collaborative skills.

4.2. Aspects of Creativity

4.2.1. Creative Process

The creative process can be considered as the course of action by the means of which creative skills are developed. As Rhodes [27] posited, the process aspect of creativity consists of motivation, perception, learning, thinking, and communicating. All these properties can be positively affected in FabLabs and makerspaces focusing on constructionist approaches (described in more detail below). The creative process can also be fostered by providing the required technical help to implement ideas in practice, contributing by this to the learning process [102].

When makerspaces are used to support of education, learning by doing has the potential to foster the creative process [22,23]. Constructionists believe that knowledge is constructed, and that learning occurs in the process of creating artifacts, especially when these artifacts and the environments in which they are created are relevant and meaningful to the creator [61]. An example could be when learning how to generate, develop, and implement ideas along the creative process by means of prototyping in a makerspace environment [61]. Imagination and idea generation are also key to producing innovative solutions [29,31]. If ideas are limited due to the lack of adequate means of implementation, the ability to produce solutions through a creative process will be also limited. Accordingly, providing an appropriate environment equipped with technological tools and the right assistance enhances the creative process. In this regard, Milara et al. [67] found that implementing ideas (e.g., prototyping electronics) and programming them in a makerspace context were the most significant challenges of a learning-by-doing design process. The degree of welcoming and supportiveness of the environment in university-based makerspaces was seen as essential for developing knowledge and skills [99].

Makerspaces were also found to help develop creative skills in engineering and medical fields by fostering creative problem-solving abilities along the process. A study dealing with medical students found that their critical-thinking and creative problem-solving skills increased when they were supported with digital fabrication tools along the process [72]. Learning digital fabrication tools in makerspace made students capable of hacking existing medical devices and customizing them to improve healthcare [72]. Thus, providing support along the creation process (e.g., digital fabrication tools) to implement ideas enhanced creative thinking and helped envisage innovative solutions aimed at challenging real-life problems.

4.2.2. Fostering Individual Creative Competence

Creative competence is essential for success in various domains, including architecture, design, and engineering. It is fundamental to create alternative innovative solutions to a problem. A study in engineering found that makerspaces equipped with digital editing software and 3D printers largely fostered creative ability [34]. Likewise, Duenyas and Perkins showed that makerspaces facilitating the interaction with various tools and materials helped users develop creative competences such as self-awareness, improve self-esteem, cope with unwanted emotions, and build positive inter-relationships [21]. Similarly, Taheri et al. [78] showed that in addition to enhancing creativity, FabLabs contributed to a large sense of community, self-confidence, and entrepreneurial skills for engineering studies. They also improved individual problem solving, communication, and collaboration skills. Hoople et al. found that key factors supporting both formal and informal creative competence development in makerspaces were the presence of experienced practitioners and clear rules of engagement [79]. In conclusion, FabLabs and makerspaces make a critical contribution in the development of individual creative competences [103], particularly in the engineering disciplines.

4.2.3. Creative Product Development

Creative products should not be only original and unique, but also practical, useful, and/or functional [27,57]. Developing creative products is considered a complex activity requiring collaboration with the appropriate tools among varied disciplinary areas. In this regard, the creativity of outcomes (i.e., prototypes and products) can be fostered through interdisciplinary collaboration supported by the use of digital fabrications tools in FabLabs and makerspaces. A work in nursing and engineering showed that collaborative work in a FabLab environment helped to identify real-life problems, generate creative ideas, and develop commercially viable prototypes [45]. Other studies also referred to the positive role of makerspaces in envisioning and developing sustainable, creative, and viable products [11,63,72]. Based on the articles reviewed, FabLabs and makerspaces should be considered suitable settings for the development and production of creative outcomes. As supportive built environments, such settings seem to offer the physical conditions and tools necessary for developing and implementing tangible ideas onto unique and sustainable products.

4.2.4. Fostering Creativity through Motivational and Inspiring Learning Environments

When supported by appropriate means, such as digital fabrication tools, makerspaces can be seen as powerful and exciting learning environments engaging users in creative activities [66]. As a learning environment, makerspaces provide opportunities for people to express themselves, thus enhancing the possibility of producing creative solutions. Trahan et al. found that creating a learning atmosphere where students and teachers were allowed to fail, encouraged them to experiment and explore without fear, and to integrate other participants in their making activities [55].

Forest et al. [6] studied the impact of makerspaces on self-perception. They found that 90% of the users believed that makerspaces as learning environments motivated them to pursue careers involving creativity, design, innovation, and invention. Their study also demonstrated that hands-on design-build education stimulates innovation, creativity, and entrepreneurship in engineering. By providing encouraging and supportive physical and social environments, studies showed that FabLabs and makerspaces' positive influence could be considered as encouraging self-expression, inspiration, motivation, and creative abilities of the users.

4.2.5. Co-Creation

Co-creation refers to an act of collaborative creativity that is shared by two or more individuals [104]. Usually, the designers and entrepreneurs, users, or consumers work together to define design goals, making common decisions, and designing and developing a product solution. FabLabs and makerspaces are ideal places to encourage a culture of co-creation and design participation. The sample of articles reviewed in this study classifies co-creation into two types. In the first one, experts develop a sustainable and suitable product for a community with the participation of the community members [63,69]. In the second one, which takes place in an academic context, prototypes are developed with collaborative knowledge, teamwork, and cross-college collaboration [2]. Overall, both types of studies showed that makerspaces should be considered as fundamental environments supporting co-creation aimed at developing creative, valuable, and viable products.

4.3. Contribution

The SLR contributed to state of the art in the field in several ways, such as (1) based on the well-known model of Rhodes [27], focusing on environment, process, product, and collaboration aspects, we analysed and reflected upon major creativity issues that play an essential role in the FabLab and makerspace context; (2) we identified and analysed five major themes dealing with technical skills, technological and environmental elements, STEM learning, and skill development, and elaborated upon their importance on creativity in the area of FabLab and makerspace environments; and (3) as a consequence of the above, we aimed at enhancing awareness of researchers, educators and practitioners about the importance of FabLabs and makerspaces for enhancing creativity.

5. Conclusions

A systematic literature review was conducted by exploring articles dealing with the makerspaces, FabLabs, and creativity, published on five major online databases. Adopting Rhodes' [27] approach, creativity was analysed through four main aspects: person, process, product, and environment. The present work identified major research areas (themes) where FabLabs and makerspaces foster creativity in a wide range of disciplines. These included physical environment and technology, learning environments, person-focused studies, hands-on learning, and STEM education.

In engineering, business, and medicine, makerspaces equipped with digital fabrication technology provide an opportunity to collaborate and implement innovative ideas.

FabLabs and makerspace environments motivate students to engage in STEM education, and facilitate the development of hands-on learning experiences, confidence, problem solving, and communication skills. Another emerging area pointed out by the studies where makerspaces are flourishing is in learning environments such as public libraries. Indeed, in the studies on libraries makerspaces are viewed as creative and innovative spaces offering a suitable physical setting for innovation and knowledge generation. Besides education and healthcare, FabLabs and makerspaces are ideal built environments for co-creation, as they provide the opportunity to design and create products in mono- or multi-disciplinary teamwork. These environments also encourage the participation of experts together with entrepreneurs, community members, and consumers, who can collaborate on the design and fabrication processes. An outcome of these collaborations is the generation of innovative and sustainable products.

However, studies about FabLabs and makerspaces involving creativity set a large stress on the use of 3D software and printing technology. Consequently, other aspects of the physical environment including equipment concerned with additive and subtractive manufacturing tools and technologies should be studied to evaluate their impact on creativity. Suitable pedagogies used in makerspaces to promote creative learning is another emerging research area. A limitation of this systematic literature review is that it only focused on journal articles and the creativity aspect of FabLabs and makerspaces. Further research should extend the scope of this study to include conference articles and other cognitive skills associated with FabLabs and makerspaces to provide a larger view on the topic.

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