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'Making' in India: Understanding Makerspaces and Fablabs in the Indian Informal Innovation Context

Gautam Sharma

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Abstract

This study explores makerspaces and fablabs within India's informal innovation context, traditionally associated with grassroots innovators, frugal innovations, and 'jugaad' practices. It introduces a Global South perspective to the largely Global North-dominated discourse on makerspaces and fablabs, highlighting how these spaces function in a unique socio-economic context in India. The research examines the foundational reasons for establishing makerspaces and fablabs in India, their role in fostering innovation networks, and the specific challenges they face, especially in terms of their operations. This paper contrasts with the existing literature, which often focuses on perspectives and experiences from more advanced regions. Using in-depth, semi-structured interviews with 20 respondents, including founders, managers, employees, and users of various makerspaces, the study provides an insightful understanding of the Indian scenario. Findings reveal that these spaces in India primarily support startups and entrepreneurial initiatives, marking a shift from the original maker movement's DIY focus. Efforts to include rural, artisan, and grassroots innovator communities are evident, reflecting a commitment to broader innovation inclusivity. This paper contributes to the understanding of the changing dynamics of makerspaces and fablabs in the context of India's innovation landscape. It emphasizes the need for strategies to ensure equitable access and participation, crucial for the sustainability and growth of these innovation spaces. The insights are valuable for policymakers, educators, and makerspaces practitioners in fostering inclusive innovation ecosystems.

Keywords: makerspaces, fabrication laboratories, fablabs, innovation, informal innovation, India

JEL Codes: O30; O31; O53

[1] Postdoctoral Researcher, Center for Innovation Research (CIRCLE) and Division of Innovation, Department of Design Sciences, LTH, Lund University, Sweden Email: gautam.sharma@circle.lu.se

1. Introduction

Makerspaces and fabrication laboratories (fablabs), variably referred to as hackerspaces, HackLabs, community labs, innovation spaces, 100KGarages, and open creative labs (Hielscher & Smith, 2014; Davies, 2018; Schmidt & Brinks, 2017) are community centered spaces where individuals gather to tinker, innovate, and work on collaborative technology-oriented projects (Smith, 2017). These spaces are described as a new infrastructure (Halbinger, 2020) that are equipped with modern digital tools such as 3D printers, laser cutters, CNC machines, and advanced electronics, needed for rapid prototyping in addition to traditional non-digital tools required for woodworking, soldering, sewing, and even Lego blocks (Rayna & Striukova, 2021). Due to their role in fostering community-driven innovations and peer learning, makerspaces have received increasing scholarly attention for democratizing access to technology and empowering individuals to engage in creative problem-solving (Lakind et al., 2019; Diaz et al., 2021; Taylor et al., 2016; Tan, 2016).

The scholarly reviews of makerspaces and fablabs as catalysts for innovation and creativity is extensively documented (Sharma & Haldar, 2023). These spaces are distinct in their integration with end users or communities, leading to their characterization as grassroots phenomena (Ensign & Leupold, 2018) or as part of a broader grassroots innovation movement (Smith et al., 2017). Unlike traditional innovation settings dominated by corporations, research institutions, or universities, makerspaces and fablabs empower ordinary individuals at the grassroots level to be the primary innovators (Smith et al., 2013). Consequently, these spaces are posited to possess the transformative capacity to redefine practices in design, innovation, and production. The concept of a contemporary makerspace or fablab is frequently credited to Neil Gershenfeld of the Massachusetts Institute of Technology's Center for Bits and Atoms, noted for establishing the first fablab in Boston (West & Greul, 2016). These spaces proliferated predominantly in the global north, with a significant emphasis on community-level makerspaces designed to foster tinkering, collaboration, and creation. As of December 2023, a total of 2,489 such spaces are recorded on hackerspaces.org, a global database cataloging these facilities.

Makerspaces are recognized for their role in facilitating economic development by promoting entrepreneurship and providing informal training and skill development within communities

(van Holm, 2017). This recognition has spurred their expansion, especially in the Global North, notably in Europe and the United States. In these regions, makerspaces are perceived as having the potential to revolutionize the industrial economy (Chiappini & Törnberg, 2019). Moreover, makerspaces have expanded beyond community settings to include academic and corporate environments, where they are utilized for product ideation and testing by students and employees, respectively (Wilczynski, 2015; Rieken et al., 2020). Recognizing their potential, various nations and regions have integrated makerspaces and fabrication laboratories into their regional development policies (Cattabriga, 2018). An example of this is China's Mass Innovation and Mass Entrepreneurship initiative, which incorporates makerspaces within its broader innovation framework to foster a culture of creativity and innovation (Fu et al., 2021). However, despite increasing scholarly and policy interest, the "*maker movement*" (Dougherty, 2012) is predominantly viewed as a global north phenomenon, with a relative scarcity of research on the operation and impact of these spaces in the global south (a few studies include: de Beer et al.; 2017; ElHoussamy & Rizk, 2020; Corsini, 2022; Haldar & Sharma, 2022).

The do-it-yourself (DIY) movement, of which makerspaces are considered a modern extension, has its origins in the counterculture movement of the 1960s in western societies (Kohtala et al., 2020). However, DIY practices are a routine part of daily life in Global South countries. India serves as a notable example, where DIY practices are documented as a necessity among people living on the margins (Gupta, 2016). This phenomenon is conceptualized using various terms, such as grassroots innovations (Bhaduri & Kumar, 2011), *jugaad* (Radjou et al., 2012), and frugal innovations (Bhaduri, 2016). These innovative practices are also often classified as 'informal innovations,' reflecting their origins in non-formal settings (Cozzens & Sutz, 2014; Sharma & Dahlstrand, 2023). India is recognized for cultivating a distinctive landscape of informal innovation, wherein innovators are acknowledged, rewarded, and integrated into the mainstream through various state and non-state mechanisms (Ustyuzhantseva, 2015).

As a result, the Indian scenario presents a compelling case study for exploring how makerspaces and fablabs function, due to its established tradition of appreciating and aiding necessity-driven grassroots innovators, who employ creativity in resolving issues related to the uneven distribution of technology resources and requirements. This paper aims to address this knowledge gap by exploring the development of makerspaces and fablabs in India,

studying their relation to both the global maker movement and the local landscape of informal innovation in India. Therefore, the research questions addressed in this study are as follows:

- RQ1: What were the foundational reasons and societal or technological needs that led to the establishment of makerspaces and fablabs in India?
- RQ2: How do Indian makerspaces and fablabs foster community building and what are their learning and knowledge sharing mechanisms?
- RQ3: What factors shape the future growth of makerspaces and fablabs in India, and what challenges could affect this?

Addressing these research questions fills a notable gap in existing scholarly literature, which predominantly centers on makerspaces and fablabs in the global north. Thus, this paper outlines the operational modes of these spaces within the context of an emerging economy in the global south, specifically focusing on India. The analysis extends to interpreting how these environments serve as platforms for grassroots communities in India, thereby emerging as critical infrastructures in supporting the nation's informal innovators. The methodology employed for this study uses semi-structured interviews with managers, founders, employees, and users of various makerspaces across India. The research sample includes three distinct categories of makerspaces: independent community makerspaces, state-funded makerspaces and fab labs, and academic makerspaces situated within higher education institutions. The findings of this study carry significant implications for both academic literature and policy formulation.

The remainder of the paper is structured as follows: First, I review the literature on the evolution of makerspaces and fablabs worldwide, focusing on how they support grassroots communities. This is followed by an introduction to the discourse on the informal innovation landscape in India. Next, I detail the methods used for collecting data on the functioning of makerspaces and fablabs in India. Finally, the results are presented, followed by a discussion and conclusions.

2. Literature review

2.1 Evolution of makerspaces and fablabs

The rise of makerspaces in numerous advanced nations has been characterized as a 'maker movement' (Dougherty, 2012) or as heralding a new industrial revolution (Anderson, 2012). The significance of these spaces stems from their role in offering advanced digital tools and technologies to the public, an aspect characterized as the democratization of innovation and entrepreneurship (Beltagui et al., 2021; Aldrich, 2014). Moreover, makerspaces also facilitate peer-to-peer interactions, community engagement, and learning through which members with varied competencies and skills voluntarily share knowledge with each other (Pettersen et al., 2020). This accessibility to tools and technologies as well as a dedicated network of peers harbors the potential to disrupt traditional manufacturing and innovation processes (van Holm, 2014).

Presently, makerspaces predominantly exist as physical entities, although they can also operate in a virtual capacity. They are founded on the principles of community and are typically funded through membership fees, crowdsourcing, or donations (Halbinger, 2018). The advent of makerspaces has been interpreted as a form of activism against a consumer culture that traditionally alienates individuals from the process of creating artifacts for their own use (Marusteru, 2017). These spaces empower end-users, allowing them to design products that align with their personal preferences and needs. Individuals utilizing these spaces are generally referred to as *makers* (Dougherty, 2016). The makers include a broad spectrum of participants, ranging from hobbyists, who engage in making as a form of self-expression, to professional innovators who utilize these spaces for innovating, prototyping, and manufacturing, aiming to create tangible products that address specific problems (Browder et al., 2017).

Makerspaces, along with other community-oriented spaces under various names, have established a novel framework for grassroots communities to collaborate using digital fabrication tools (Smith et al., 2013). Makerspace communities frequently adhere to the tenets of the open-source movement, wherein the free exchange of knowledge and innovation is highly valued, however, it is important to note that some makers operate with

the intention of maintaining proprietary rights over their innovations (Langley et al., 2017). Yet, numerous makerspaces have contributed to open-source innovation by facilitating the creation of accessible and practical solutions to real-world problems using the digital tools available in these spaces (Kantaros et al., 2022).

Regarding the geography of these spaces, it has been observed that most of these facilities are situated in or near major cities and metropolitan areas. Nevertheless, there is an emerging trend of these spaces being established in smaller or non-urban communities. Ensign & Leupold (2018) observe that while the level of innovation and entrepreneurship in non-urban makerspaces may be relatively low, these spaces nonetheless provide a valuable platform for skill development and enhancing the innovation capacities of citizens. However, it is noted that most makerspaces tend to attract primarily hobbyists and individuals from more privileged backgrounds, potentially overlooking existing grassroots innovators who are active in informal sectors (Waldman-Brown et al., 2015).

The gender dimension of the makerspaces has received fair share of criticism along with its sustainability aspects. In terms of representation, studies have observed a notable gender balance in makerspaces which reflects the broader gender disparity in STEM related disciplines (Lewis, 2015). The maker movement therefore perpetuates gendered stereotypes. Eckhardt et al. (2021) writes that makerspaces draw a higher number of male participants than female, showcasing a culture largely characterized by masculine norms. The authors write that this bias is evident even in the decor of these spaces, as well as in the language and demeanor of their members.

Moreover, certain makerspaces are noted to have a membership primarily from upper- and middle-class backgrounds, often representing dominant racial identities (Schor et al., 2016). To address the gender imbalance in these spaces, various strategies have been proposed. One such approach involves redefining the concept of 'making'. This would require not limiting it to technology-focused projects but expanding it to encompass diverse forms of art, design, and crafts (Eckhardt et al., 2021). This broader interpretation could make makerspaces more inclusive and appealing to a wider range of participants, including those from different gender backgrounds. Likewise, it is advocated that makerspaces should foster greater collaborative opportunities for individuals from the informal sector. This approach would enable these

individuals to display their skills and leverage the resources and potential offered by makerspaces (Waldman-Brown et al., 2015).

Makerspaces, initially emerging from independent community initiatives, have evolved to play a vital role in practical and experiential learning, professional development, and bridging the theoretical-practical divide. This evolution led to their integration within academic institutions and corporate entities (Wong & Partridge, 2016; Browder et al., 2023). Numerous higher education institutions have incorporated makerspaces, promoting an environment where students are motivated to participate in informal activities and collaborate on projects that extend beyond the traditional confines of formal labs and classrooms and top-down education approaches, and thereby offering practical, real-world applicability (Wilczynski & Adrezin, 2016). Moreover, makerspaces are even being incorporated into libraries (Willingham & De Boer, 2015), hospitals (Marshall & McGrew, 2017), and museums (Wardrip & Brahms, 2017) further extending their function as hubs of innovation and interactive learning. While makerspaces are increasingly appearing in emerging countries (de Beer et al, 2017; Holm et al., 2020; ElHoussamy & Rizk, 2020; Corsini, 2022; Haldar & Sharma, 2022), scholarly attention and studies predominantly focus on those located in the Global North.

The existing gap in literature on the evolution of makerspaces in Global South nations, along with the unique challenges and opportunities presented by their specific socio-economic and cultural contexts, indicates a significant research potential. This is particularly pertinent considering that many emerging countries, such as India, exhibit a substantial prevalence of informal innovations. Consequently, it becomes interesting to examine India as a context for the study of makerspaces, exploring how these spaces are established and function in a country already recognized for its informal innovation activities. In the next section, the paper reviews existing research on the informal innovation in India, aiming to establish a connection between makerspaces and their role as an evolving infrastructure within the scope of informal innovations.

2.2 Informal innovations in India

Innovation studies traditionally adopt a formal perspective, viewing innovation as a product of interactions between various actors and institutions within established systems such as academia, research and development laboratories, research institutes, and firms (Lundvall,

2016). However, in many regions of the Global South, there is a notable prevalence of informality within the economic structure, evident in both employment and economic activities (Chen, 2005). This aspect of informality, though not extensively covered, has garnered attention from scholars, particularly in the intersection of innovation and development research (Kramer-Mbula & Wunsch-Vincent, 2016; Muchie et al., 2017; for a review on this area see Sharma & Dahlstrand, 2023). Cozzens & Sutz (2014), for example, describe informal innovations as innovative practices and ideas that originate and are implemented within informal settings. The informal settings here, as per by Cozzens & Sutz, refer to the environments where marginalized communities live and work, as well as the informal economy, characterized by economic activities that operate outside the scope of government regulation.

There are several concepts used to describe the nature of informal innovations arising from these settings, particularly pertinent to the Global South. These include grassroots innovations (Gupta, 2016), frugal innovations (Bhaduri, 2016), and *jugaad*, a term used in the Indian innovation context (Radjou et al., 2011). A critical element common to these terms is the emphasis on the agency of individuals at the grassroots level to innovate products and services tailored to their specific contexts, driven by motivations and objectives distinct from those of products emerging from more formalized structures.

Grassroots innovation in the context of India, as described by Bhaduri & Kumar (2011), are efforts by individual innovators to solve localized problems, often outside formal organizations. These innovations, as per the authors, are intrinsically motivated, typically involve minor or incremental changes to existing technologies, and draw from diverse knowledge sources, including local traditions and modern technologies. Grassroots innovations are often developed with the objective of alleviating the burdens associated with manual, physically demanding tasks, addressing fundamental needs such as health and sanitation, and resolving issues that remain unaddressed by state institutions and mainstream markets (Sheikh & Bhaduri, 2021). A key characteristic of these innovations is their non-commercial orientation. The primary motivation behind their development is centered on addressing pressing societal or community issues, rather than being driven by economic incentives.

Sometimes, these innovative products from the grassroots level are also addressed as frugal innovation in academic literature. Frugal innovation is described as the process of redesigning products and processes to eliminate unnecessary costs, often resulting in “no frills” products that are affordable, sustainable, and of acceptable quality (Bhaduri, 2016). Businesses of various sizes, including both large and small, have the capability to develop frugal innovations. Frugal innovations, in the context of informal innovation, specifically pertain to those developed by individuals and local producers as a response to resource constraints in their environments, often driven by necessity, and encompass broader aspects of reducing costs and introducing new business models while maintaining user value, as described by Knorringa et al. (2016). Both grassroots and frugal innovations are often viewed through the lens of *'jugaad*,' a concept originating from India.

The jugaad perspective, as described by Radjou et al. (2012), emphasizes an inventive and expedient approach to product development, a concept derived from a colloquial Hindi term that signifies the creation of makeshift solutions for immediate problems. This term can describe both a product and a process. Radjou and colleagues, view *jugaad* as a mindset essential for developing innovations suitable for low-income settings. It closely aligns with localized methods of tinkering and designing solutions. However, what sets *jugaad* apart from conventional making activities is its reliance on discarded or repurposed materials, rather than sophisticated tools and technologies. *Jugaad* is also seen as a critical, inclusive, and culturally embedded practice of making and tinkering, one that challenges conventional power structures and offers an alternative way of thinking and creating in various cultural contexts (Butoliya, 2022). Thus, *jugaad* in the context of tinkering and making is a widespread practice in low-income settings that power the informal market economies in India (Badami, 2018). Jugaad in making and tinkering represents a resourceful approach to material use, combining innovative fabrication with smart repurposing and practical experimentation within non-specialist knowledge domains, often in resource-limited settings (Kailey, 2019).

The literature on informal innovation and makerspaces has largely neglected the role of these spaces in India as a novel platform for innovation. This oversight is consequential, as it overlooks the potential of these collaborative spaces to further our understanding of informal innovation practices in India. This paper aims to fill this gap by examining the organization, management, and operation of makerspaces in India, and their role in fostering, shaping, and

nurturing an innovation community. This study is therefore crucial for moving beyond the traditional Western-centric perspective of makerspaces, recognizing their significance in creating a unique space for a distinctively Indian innovation approach that is contextually relevant and resource-efficient. The subsequent section of this paper will detail the methodology employed for data collection and analysis.

3. Methods

This paper adopts an exploratory approach, employing qualitative methods to address the research questions. Data collection is carried out through semi-structured interviews, while thematic analysis is utilized to examine the operationalization of makerspaces within the Indian context. Further information regarding sampling, interview processes, and data analysis methodologies is detailed in the subsequent subsections.

3.1 Sampling and data collection

Makerspaces in India are currently in a nascent stage and are predominantly found in major metropolitan cities such as Bangalore, Mumbai, Pune, Hyderabad, and Kolkata. The initial phase of my data collection involved identifying and mapping the operational makerspaces across the country. To accomplish this, I employed online search and desk research, utilizing keywords like “makerspaces in India”. Moreover, I utilized resources such as https://www.fablabs.io and https://www.hackerspaces.org, which function as databases for makerspaces, fablabs, and similar creative open innovation spaces globally. The information about different makerspaces in India, including contact details like telephone numbers or email addresses of contact persons, was compiled in an Excel sheet. Subsequently, an email outlining the study's objectives and requesting participation was sent to the makerspaces. This outreach mainly occurred during February and March 2023. The response rate was notably low, leading to follow-up attempts by searching for the individuals responsible for these makerspaces on social media platforms, such as LinkedIn.

After the initial outreach, several founders of makerspaces were contacted via personal messages on LinkedIn for further briefing about the study. Responses revealed that numerous makerspaces in India, initially identified through online search, were either non-operational or temporarily shut down due to various factors, including founders’ other commitments or

challenges in resuming operations post-pandemic. Still, I successfully received affirmative responses from at least 12 makerspaces in India, facilitated by the managers or founders of these spaces. Some agreed to in-person interviews at their makerspace, offering an opportunity for direct observation of the space, its participants, and activities. However, due to work commitments, many participants were only able to partake in brief online interviews to contribute data to this study. The fieldwork for this research was conducted in May and June 2023.

For data collection, I undertook travel to six cities in four states of India with the objective of conducting in-person interviews and visiting the makerspaces. This endeavor resulted in successful interviews with 20 individuals comprising founders, managers, employees, and makers. The participant details are provided in Appendix A. The methodology for data collection was centered around semi-structured, in-depth interviews. During these interviews, I posed open-ended questions such as, 'Can you briefly describe the genesis of this makerspace/fablab and what inspired its creation?' and 'Can you describe the networks and collaborations that have emerged within and outside of your makerspace/fablab?'. The intention behind utilizing open-ended questions was to allow interviewees the freedom to answer comprehensively and discuss topics in a manner reflective of their personal experiences and perspectives.

Throughout the interview process, I ensured that no questions sought personal information related to sensitive topics such as race or ethnic origin, political views, religious or philosophical beliefs, trade union membership, health, sexual orientation, genetic data, biometric data, or any legal issues including crimes, criminal convictions, or administrative detentions. Prior to conducting the interviews, I obtained oral informed consent from all participants, including permission for audio recording. While some participants consented to the audiotaping of their interviews, others declined. To complement the recorded data, I also took detailed notes during the interviews. Moreover, at the end of each day, I prepared interview memos to aid in the subsequent data analysis process.

The duration of the interviews varied significantly, ranging from 15 minutes to 90 minutes, primarily dependent on the availability and willingness of the participants. For the transcription of interviews conducted in English, I utilized Otter.ai software, followed by

manual cleaning and verification by listening to the interview recordings. Interviews conducted in Hindi were transcribed manually by me. In cases where participants requested, I shared the interview transcripts with them. In alignment with the data management plan of this project, all personal identifiers, including names of makerspaces and respondents, were precisely removed from the transcripts. To maintain confidentiality and anonymity, pseudonyms were assigned to each makerspace and respondent(s) involved in the study. This approach was critical in ensuring the privacy and ethical treatment of the data collected during the research.

3.2 Data analysis

The analysis of the collected data was done using the thematic analysis approach, a widely recognized method for analyzing qualitative data. I adhered to the procedural guidelines outlined by Braun & Clarke (2006) for an effective thematic analysis, which involves several key steps. The initial step involved immersing myself in the data, necessitating extensive reading and re-reading of the interview transcripts to grasp the nuances and depth of the data gathered. Following this, I engaged in open coding of the data, using NVivo software to assign codes to relevant quotations from the dataset. The subsequent phase of the analysis focused on the identification of themes. During this stage, I reviewed the initial codes to search for emerging themes, leading to the consolidation of similar codes into a defined number of overarching themes. In the reviewing stage, potential themes were methodically examined against the coded extracts to verify their internal coherence. This process included the integration of several themes into higher-level themes or a category, ensuring that each represented a broader aspect of the data set. The final phases involved defining and naming each higher-level theme or category to maintain a coherent narrative that accurately reflected the essence of the data. Finally, these themes are presented as findings in the study, accompanied by representative quotations from the interviews and contextualized within the broader scope of existing literature on the subject. A summary of data structure is provided in Appendix B.

4. Findings

4.1 Foundational purpose

The establishment of makerspaces and fablabs in the country arose from a variety of motivations, each specific to the context of these environments. Makerspaces targeting startups, for example, were created to address a gap in hardware and prototyping infrastructure readily accessible to individuals with entrepreneurial aspirations:

> "They (startups) were totally dependent on either vendors here who couldn't build quality products, or they had to depend on foreign countries like China, where they had to actually meet this. We couldn't realize a lot of projects becoming successful back then, even with a lot of money being spent from grants and other government programs. But it was then that we had the idea that you need to have your own hardware space for the start of a medical device." (R1)

This response highlights the challenge of finding suitable spaces for efficient and rapid prototyping, particularly near startup incubation areas. The inception of makerspaces by some science parks in the country was a response to this challenge. These spaces received state investment as part of a broader mission to expand and support regional startups. Consequently, startups and emerging entrepreneurs represent a significant user group of these facilities:

> "When it comes to startups, without a facility like this, they would need to approach different facilities for various aspects of product development. However, since we provide multiple services under one roof, they just have to walk through this door, and most of their needs can be catered for by the machines we have here." (R16)

This perspective underlines the integral role of makerspaces in supporting diverse startup needs through consolidated services.

Community-oriented makerspaces emerged from distinct motivations. Many founders of such spaces in India had previously encountered similar environments in countries like the United States, where the culture of open sharing of tools and technology inspired them:

> "That culture was missing – a culture of being around similar people, learning from each other, openly sharing – that open-source culture, which is also very important." (R8)

This observation catalyzed the establishment of one of the first community-oriented makerspaces in urban India. While urban regions are common sites for these spaces, rural

areas in India have also seen the emergence of makerspaces. These are primarily aimed at providing technical training to local youth and school dropouts, enabling them to find opportunities in the industrial sector. Besides, rural innovation and creative spaces have been initiated to support local products:

> "We began to engage with the 'handmade' sector. The importance of handmade goods is often overlooked in our current era where one can order almost anything online from platforms like Amazon, often cheaper than any handmade alternative. However, there's a growing appreciation for organic, naturally handcrafted items." (R19)

The objective of these spaces is to explore how modern technologies can enhance and add value to traditional handmade products, which have long been a livelihood source for many. Funding for these community makerspaces initially came from their private savings, and help from their family and friends, and later expanded to include various grants and financial assistance. This approach highlights the grassroots nature of these initiatives, reflecting a commitment to fostering a culture of innovation and collaboration in both urban and rural contexts.

Academic makerspaces, distinct in their objectives, primarily focus on offering practical training to students within educational institutions. These facilities, often utilized by engineering students, are accessible to all learners:

> "The goal (of our makerspace) is to nurture students' ideas and help them develop these ideas." (R13)

This statement emphasizes the commitment to fostering student creativity. In most cases, these academic makerspaces do not levy fees for access, although students may incur costs for materials like filaments used in 3D printing. Students are encouraged to engage actively in these spaces, utilizing available machines and resources to enhance the practical aspects of their projects. This hands-on experience is invaluable, particularly for those working on master's projects. Several faculty members from these institutions have integrated makerspace activities into their curricula, recognizing the value of experiential learning. The trend of incorporating makerspaces and fablabs is not limited to higher education institutions; it is increasingly prevalent in primary education settings as well:

> "If you want to create a 24-year-old entrepreneur, you need to start when they're 10 years old." (R5)

This view emphasizes the significance of introducing creative and practical skills early on, as a key factor in nurturing future innovators and entrepreneurs.

4.2 Primary users

The study's exploration into the main users and purposes of makerspaces revealed varied responses, depending upon the specific context and foundational mandate of each space. Makerspaces linked with science and knowledge parks, or regional startup ecosystems predominantly serve individuals with an entrepreneurial focus. These environments provide a vital platform for startups to prototype their designs:

> "The majority of them are medical devices (startups). From that background of startups, broadly, it's healthcare startups. Then we have agri startups. We have robotics. We have drones." (R1)

Similarly:

> "Our clientele is primarily made up of startups based in the (…) region. A large number of our clients operate in hardware domains." (R15)

While these spaces primarily cater to startups and individuals seeking to develop prototypes, they also cater to a broad range of clients seeking assistance with aspects of product development. These also include various educational institutes:

> "We are on the vendor list of quite a few institutes. When you're on the vendor list, it makes things easier. If the institute wants a service, they can take it directly." (R4)

This relationship streamlines the process for institutes requiring specific services. Besides, these makerspaces are utilized by students from academic institutions lacking in-house prototyping facilities.

Community-based makerspaces diverge in their primary user focus compared to their counterparts associated with entrepreneurial or academic pursuits. These spaces are envisioned as hubs for individuals from various backgrounds to engage in creative making and experimentation:

> "So, our central idea was always to bring people from various walks of life into this space, place the tools directly in their midst, allow them unrestricted access, and observe what they could construct using these machines. That's when the truly beautiful creations began to emerge." (R8)

Interestingly, community innovation spaces are not exclusively utilized by hobbyists or tinkerers. They have also proven to be fertile grounds for startup development:

> "From the outset, over 30 startups have emerged from this dynamic environment, ranging from a variety of fields." (R8)

The appeal of these community spaces lies in their collaborative atmosphere, offering a stark contrast to isolated working environments. They provide opportunities for networking, knowledge sharing, and collective learning, which are highly valued in the creative process. Academic makerspaces, predominantly used by engineering students, also see participation from students in other disciplines:

> "Some of them (users) are from architecture, management, pharmacy, and dentistry. Engineering students mainly use the Makerspace due to the opportunities available for interacting with students from different disciplines, as all the colleges and institutes are nearby." (R20)

It is important to note that academic makerspaces typically do not attract much interest from hobbyists or those who are generally interested in maker activities:

> "Mostly PhD students utilize this Makerspace. BTech and MTech students also come, but primarily when their project submissions are nearing. As for the hobbyist culture or general culture around Makerspace—where one can go and create anything—we haven't quite reached that point yet." (R14)

4.3 Learning and knowledge sharing

Makerspaces and related creative environments are known for facilitating knowledge exchange and nurturing informal learning. This theme examines the dynamics of such exchanges in Indian makerspaces. Given that these spaces are accessible to the public, open to individuals with hobbies or entrepreneurial aspirations, it was interesting to understand how participants discover these spaces and learn about the equipment and resources they offer. Commonly, the primary methods for these spaces to attract and educate individuals about their activities include networking events, social media outreach, and word-of-mouth. These channels are utilized by makerspaces to engage with interested individuals, who in turn collaborate and network with others:

> "we have social media groups on WhatsApp, LinkedIn, and other platforms where members can engage with each other, ask questions, and build a forum within our ecosystem." (R1)

Another founder described their promotional strategies:

> "there are four ways to promote our services. One is through exhibitions and expos. Second is through Google. Third is through Just Dial, where a lot of leads come from. We've listed all the services we can offer, including student services, on various platforms in India. And lastly, our location in the city plays a crucial role." (R15)

Also, makerspaces often host a variety of workshops in collaboration with national and international partners:

> "We have conducted a few workshops, including the Fab Academy under Fab Lab (city name). We also collaborated with (…) Engineering College, one of the reputed engineering colleges in (the city), to conduct a Global Summer School (GSS). We provided local architecture and engineering students with exposure through a 14-day program held at one location. We had a collaboration with IAAC Barcelona, and along with a few tutors from Barcelona, we designed a curriculum for those 14 days. The students engaged in practical activities involving electronics, 3D printing, laser cutters, and CNC machines. We prefer organizing these structured workshops over a community-driven approach where individuals casually enter and use the machines." (R3)

In academic makerspaces, training and courses are offered to students to familiarize them with the available resources:

> "We offer a foundational course on material properties and manufacturing processes to educate our students in their first year. In this course, my technicians and I assist students in understanding the nature and applications of different materials (….) Currently, our emphasis in knowledge dissemination is primarily on materials and manufacturing processes." (R13)

In state-supported spaces, various methods of knowledge sharing, and community building are employed:

> "Knowledge sharing takes place through three main modes. The first one is obviously the Fab Academy program, a six-month program conducted under the Global Fab Foundation. In addition to this, we conduct short-term workshops for individuals within (the state), as well as those from outside the region. In these workshops, we deliver sessions on various digital fabrication technologies, such as 3D printing and laser cutting. Last, we offer seminars and workshops for people from different walks of life, facilitated through various mediums." (R15)

For spaces focusing on rural areas, in-person meetings are crucial for increasing awareness about their activities:

> "We have been actively participating in conferences, meetings, and other platforms, showcasing our work and approach. We've received tremendous interest in our approach and the projects we undertake. Many people want to come and learn from us. As a result, our team has conducted numerous workshops in various places. Apart from that, camps are one significant way we engage with different audiences." (R19)

The aspect of knowledge sharing in these spaces, particularly through collaboration and group work, presents an intriguing dynamic in terms of knowledge appropriation and work

conducted therein. It's notable how knowledge is both protected and shared in Indian makerspaces. Entrepreneurs utilizing makerspaces, which are often established as supportive infrastructures for their startup ventures, tend to prioritize confidentiality and the filing of patents for their prototypes:

> "We have never taken ownership of prototypes; instead, we've always allowed the startup funding the project to retain it." (R2)

Moreover, these spaces often have dedicated patent cells to guide users through the intellectual property (IP) filing process:

> "We have an IP team that helps the people to file for patents. It is also mandated by the government." (R1)

This inclination towards intellectual property protection is similarly observed in academic makerspaces:

> "We emphasize to our students that, as soon as they produce a viable prototype, they should consider filing for a patent, design patent, copyright, or other intellectual property rights. This applies to software as well. This procedure is an essential part of their startup or entrepreneurial journey." (R20)

Conversely, makerspaces with a community focus often advocate for the open sharing of collaboratively created knowledge products, though the final decision on this matter lies with the individuals working on the projects:

> "Everything that we do here is open source. All the programs and projects that leave our organization are also open source. So, we, as an organization, and our students do not file patents. Instead, we put everything out into the open universe, as we believe in sharing. The reason for this approach is that (our space) is a learning space, a playground for creation and learning. If we had too many barriers related to intellectual property and other aspects, we wouldn't be as open as we are today, which is very important to us. In terms of philosophy we're open…..There have been students and organizations that have used (our space) and wanted to file intellectual property (IP). We don't stop them; there's nothing wrong with it. It's a great thing to be able to file IP, and they're more than welcome to do that. However, our focus is on raising awareness about open source." (R8)

The respondent also highlighted the technical aspect of projects undertaken in these environments and their contribution to open-source hardware:

> "Most people at a makerspace or in a place like this are working on low-tech solutions. They're working on games, various startup ideas, robots, electronics; they're building on top of open-source hardware. Since they're building on open-source hardware, we encourage them and share with them the importance of open source, guiding them on how to document and share

> their work in the most beneficial way. Thus, they continue to reap the benefits while still promoting sharing. We began applying for Open-Source Hardware Association (OSHWA) licenses for all our projects around 2022. Before that, all our projects were open source, and our GitHub repositories have been available for quite some time." (R8)

Therefore, a range of knowledge sharing, and protection mechanisms are evident, spanning from non-disclosure agreements and patents to open-source models. This diversity reflects the varied objectives and philosophies of different makerspaces, whether they are driven by entrepreneurial, educational, or community-oriented goals.

4.4 Innovation and creativity

The presence of advanced fabrication technologies in these specialized, open environments, which are essential for prototyping, significantly facilitates innovative projects for individuals. In the absence of such spaces, the development of proof of concepts becomes challenging due to limited access to necessary resources and materials, often leading individuals to depend on temporary solutions for prototype creation. The respondents offer diverse perspectives on how these resources enable a shift from temporary fixes to the development of more robust prototypes:

> "(…) people start with a makeshift solution and then transition to more sophisticated ones as they gain access to better facilities and resources. If someone is building a temporary solution, we don't stop them, nor do we have the right to do so. However, as professionals with strong engineering and science backgrounds, we encourage the adoption of proven technologies and innovations, rather than relying solely on makeshift approaches." (R1)

Makerspaces enable individuals to utilize advanced digital tools, which can significantly hasten the process of innovation development:

> "From the makerspace perspective, I've seen numerous innovations, like the development of drones using our 3D printing and machining services." (R2)

and,

> "Instead of using regular parts, they leverage our CNC routers to craft acrylic and wood-based components, as well as smaller tools. This approach has proven to be more cost-effective than traditional manufacturing methods." (R2)

The availability of such sophisticated resources in makerspaces is particularly appealing to individuals with entrepreneurial ambitions, as it aids in the creation of high-quality product designs:

> "The culture of innovation and frugality was high, but people were more entrepreneurial than hands-on makers. We were contacted more by startups who had just incorporated and already had products or ideas they wanted to develop. They would ask us to help them make their ideas more professional before seeking seed investments." (R4)

This indicates that while many individuals possess innovative ideas, their ability to design is often limited. Makerspaces, with their expert guidance and prototyping equipment, play a crucial role in bridging this gap. Despite the lack of a widespread makerspace culture in India, numerous instances of user-generated innovations have been reported, documented, and researched, often emerging from individuals without formal backgrounds in science, technology, or higher education (Gupta, 2016). These instances are often categorized as informal innovations, and makerspaces are recognized for their potential to lend these practices a more professional and formal structure:

> "Makerspaces are institutionalized forms of innovation and creative spaces. They can help jugaad take a more formal version. When people use a hammer not only for pushing things but for the right purpose, or when they use screws and drivers for the right function, it's just formalizing those practices – nothing else." (R3)

Adopting a *jugaad* mindset is considered beneficial in utilizing makerspaces, potentially leading to significant advancements in product development:

> "Jugaad does make sense in India, because not everyone in India has enough resources to develop a complete, holistic solution for the problems we face. So Jugaad is indeed a necessity. But that should not be the norm. I mean, it should be an exception, right? We should not approach product development from a Jugaad perspective." (R19)

The responses regarding the innovation potential of these spaces suggest that while the makeshift mindset for creation is appreciated, it is not the sole approach. Makerspaces, with their resources and facilities, are perceived as highly beneficial for individuals with such a mindset, particularly in enhancing the impact of their designed products and solutions.

4.5 Diversity and inclusion

The theme of diversity and inclusion in Indian makerspaces primarily focuses on integrating two key groups into the activities and participation within these spaces: women and individuals from artisan and rural communities. Makerspaces and fabrication laboratories, as extensions of science and technology, have historically experienced a gender gap in participation, a fact widely recognized by those overseeing Indian makerspaces. However,

recent initiatives and programs aimed at attracting a more diverse group have begun to narrow this gap, leading to increased female participation:

> "we've observed an increase in female representation in these areas. I recall that when this movement first started, there were only a couple of women involved in creating significant projects." (R2)

Interestingly, another respondent pointed out the distinct nature of projects pursued by female participants in makerspaces, in comparison to their male counterparts:

> "female makers often have more social impact-based projects. I myself am not from a technical background; I come from a social sciences background. However, I did immerse myself in the DIY culture, visiting various makerspaces. I had that physics and math-oriented mindset, and I wanted to explore engineering through my own passion. That's why I went to Fab Academy and eventually started our own makerspace. The skills and expertise we have, comes entirely from our experiences. One day we're designing shoe soles, another day we're doing carbon-based material research with some researchers, and the next we're working with 3D printer nozzles for specialized industries." (R3)

The disparity in women's participation is notably greater in spaces dedicated to village levels:

> "It's rare for girls to enroll in vocational skill courses, and we often have to put in additional effort to encourage their participation. In a recent batch, we had eight female students. However, these numbers vary each year, sometimes being as low as one. No matter the count, we welcome all interested female students." (R10)

This gender gap is also evident in the staffing of some these spaces:

> "We don't have great diversity at the moment; our team is entirely male. However, this wasn't a conscious decision. It's more indicative of the issue with STEM education in (the state). Recently, we posted job openings for three technical officer positions and, disappointingly, we didn't receive a single application from a woman." (R15)

The lack of diversity in the workforce of these spaces could also act as a deterrent for many female enthusiasts in utilizing these facilities. However, several spaces are taking proactive steps to encourage female participation:

> "We conduct programs like 'Tech for Women,' where we encourage women to take up tech roles and to generate hardware startup ideas. We facilitate workshops for women to make them aware that this facility is just as open to them. One problem that exists in our society is that women may feel hesitant to enter facilities that are conventionally dominated by men because they may feel unwelcome. So, we consciously make an effort to assure our women community that we are open for all." (R15)

Another aspect of diversity and inclusion in Indian makerspaces and fabrication laboratories (fablabs) focuses on engaging with rural communities, particularly artisans and farmers:

> "We are even part of a German foundation that is actively working with artisans in pottery and handicrafts. In these collaborations, we contribute by using technology to make the processes easier for those NGOs. We approached the more experienced potters because they have greater influence in the community. We introduced them to the concept of clay 3D printing and encouraged them to create unique pots that could be sold at higher prices in malls or through more expensive brands. These master artisans created a couple of designs that were difficult to reproduce. We explained the concept of 3D scanning to them, and once they had created their masterpieces, or perfect designs, we 3D scanned them, introduced clay printing, and provided the G-code. So, whenever they have a requirement, the master artisan doesn't need to reproduce the design manually; they can simply have it 3D printed in clay, give it back to the artisans to be treated and vitrified, and then sell it for a much higher price." (R4)

Likewise, a community-led makerspace has collaborated with rural communities:

> "we actually established a textile lab for woman artisans, in partnership with the French government. The French funded this initiative, and the lab is a physical space equipped with modern tools. It's an exciting model that invites students from all over the world, who are involved in textile work, to collaborate with female artisans and learn from each other. This lab exists and we have been working on it. It has been a beautiful learning journey, even though the pandemic has disrupted many aspects of our operations." (R8)

An interesting point was raised of a space dedicated to rural community regarding their reluctance to adopt modern tools for traditional crafts:

> "we realized that the rural communities were not as enthusiastic as we expected. They questioned why we were taking them back to what they perceived as their caste culture or traditional basket-making, a task they weren't overly interested in. They were more curious about new possibilities for income rather than seeing basket making as a worthwhile activity." (R19)

This observation suggests that the over-romanticization of the potential of modern digital tools for rural livelihood and artisans can sometimes act as a barrier when engaging with the communities transitioning from traditional livelihood practices. Nevertheless, the involvement of rural communities in these spaces introduces an inclusiveness dynamic, highlighting the potential benefits that rural craftsmen, artisans, and farmers can gain by accessing the resources available in these spaces.

4.6 Future prospects

The respondents offered insights regarding their perceptions of the future of these spaces, including the likelihood of more such spaces emerging and the level of interest shown by various stakeholders, particularly the government. Many respondents acknowledged the government's interest in promoting these spaces. However, they raised skepticism on the

implementation approach, noting that merely establishing a center is insufficient. For spaces like makerspaces or fablabs to thrive, fostering a community is crucial, yet efforts in this direction are inadequate:

> "Tinkering labs only solved the first part; they created a center but failed to create a community. And of course, without the community, you can't build a culture to start with. So, they have not been successful. Governments cannot build community or culture; it has to be done in a different way. But they look at it as something governments can do – spend money to buy machines and stuff. You don't need an expensive lab to build a community or culture." (R5)

A similar view was expressed by the founder of a community makerspace who emphasized the importance of cultivating a culture, not just creating a space:

> "I do believe that the government's approach lacks the cultural aspect of these spaces. I've visited many of the makerspaces that the government is setting up. I was even invited to advise them on the tools that should be included, among other things, before this initiative began. Nonetheless, I believe these spaces should not merely provide tools, but should also inspire students to think creatively and construct things. For that, students need exposure to this culture and access to a community." (R8)

Another respondent speculated on the future diversification of these spaces, reflecting regional strengths and needs:

> "I anticipate that makerspaces will specialize in different sectors based on regional strengths and needs. For example, a makerspace in Goa might focus more on tourism-related innovations, while one in Tirupathi might concentrate on mobility in religious tourism. A makerspace in Delhi could emphasize mobility solutions, whereas one in South India might be more geared towards medical devices." (R1)

Academic institutions are also expected to develop such spaces:

> "The model we are following, where students should have the facility to work, is being adopted by all higher education institutes in India. They all have Makerspaces, co-working spaces, and rapid prototyping spaces, and these are set to grow as most innovations stem from these labs." (R20)

The adoption of academic makerspaces by higher education institutions is not only increasing, but the existing ones are also expected to expand in size and resources, in response to student interest. This trend highlights the necessity for trained staff to manage these spaces, particularly those who have experience working in similar environments:

> "One area of improvement I've observed is the need for more people trained to manage these spaces. We need individuals who are well-versed with the ins and outs of the equipment and can offer guidance to anyone who asks." (R14)

A manager of a state-funded lab also expressed a similar viewpoint, emphasizing the need for adequate training for personnel:

> "Another area is providing exposure to the people who run these facilities to the developments happening across the globe. Personnel selected from these facilities should be given access to training programs, workshops, or events happening globally in similar facilities. This is an area where policymakers can make additions to their annual policies for value addition." (R15)

Given the anticipated growth of these spaces and increased participation from individuals from diverse backgrounds, there is a pressing need for training and development. This training should focus on equipping skilled individuals with knowledge and understanding of the activities, culture, resources, and tools available in these spaces.

5. Discussion

Rooted in DIY culture, the global maker movement emerged as a response to rising consumerism, empowering individuals to embrace creativity and hands-on tinkering (Dougherty, 2016; Mota, 2011). However, such practices of tinkering and crafting items for daily use have long been integral to lifestyles in the Global South. In these communities, driven by necessity and limited resources, there is a tradition of creating and developing products to satisfy their needs (Rai, 2019; Kaur, 2016). This phenomenon is evident in various grassroots innovations and *jugaad* practices, particularly documented within the Indian context (Gupta, 2016; Radjou et al., 2012). The contemporary makerspace in India instead aligns more closely with broader public policy initiatives that support startups and emerging entrepreneurs. These spaces are primarily designed to bridge the gap in prototyping infrastructure, providing advanced tools and resources to individuals with entrepreneurial ambitions. Consequently, the creation of state-supported fablabs and makerspaces represents a departure from the initial ethos of the global maker movement, which began as an activist stance against corporate mass production (Willett, 2016). In India, many makerspaces are integral to national innovation strategies, playing a pivotal role in fostering the startup ecosystem in the region. This evolution highlights a shift from the movement's grassroots origins to a more structured, policy-driven approach, reflecting the diverse interpretations and applications of the maker movement globally.

Globally, makerspaces are increasingly recognized as a manifestation of a grassroots innovation movement, characterized by decentralized and community-driven innovation (Ensign & Leupold, 2018; Smith, 2017). This facet of makerspaces is evident in India through the community-oriented spaces that focus on providing the public with access to tools and resources, thereby enabling them to create solutions tailored to their local environments. The grassroots innovation aspect of makerspaces is further exemplified in rural fablabs, and state supported similar spaces. These spaces actively engage rural communities, offering skills training and education on how to utilize available resources for community betterment (Kulkarni et al., 2012; Vones, 2021). This approach not only nurtures local innovation but also contributes to sustainable community development. The emphasis on grassroots innovation has been a longstanding feature in countries like India. Makerspaces are increasingly regarded as platforms where local innovators can acquire training in sophisticated and advanced technologies. This training enhances their ability to design products that are not only innovative but also relevant and appropriate to the specific needs of their communities (Kulkarni, 2022). Consequently, makerspaces in India play a critical role in bridging the gap between traditional grassroots innovation and modern technological advancements, fostering an ecosystem where local knowledge and high-tech tools conjoin to drive community-centric innovation.

Urban makerspaces and fablabs, in contrast, are often integrated with coworking spaces and the startup ecosystem, thereby assisting innovators in scaling their innovations (Haldar & Sharma, 2021). These spaces, apart from offering tools also provide platforms for networking, collaboration, and the acquisition of necessary state support to expand innovations (Akhavan, 2021). However, it is noteworthy that urban makerspaces remain accessible to grassroots innovators and individuals from rural communities who have ideas and prototypes addressing their specific contextual problems. These urban makerspaces and fablabs aspire to extend their services to rural communities, offering expansive opportunities to merge traditional practices with modern digital tools. This convergence can enhance product design and potentially reduce costs, thereby creating a symbiotic relationship between traditional grassroots methods and contemporary technological advancements. Such a dynamic highlights the potential of makerspaces in India to serve as catalysts for innovation across

diverse socio-economic and geographical landscapes, fostering an inclusive environment where both urban and rural innovators can thrive.

The approach to knowledge protection and appropriation within Indian makerspaces and fablabs indicates another departure from the foundational ethos of the global maker movement that is more of commons-based peer production (Braybrooke & Smith, 2020). Many of these spaces in India actively encourage and support the patenting of innovations. This trend reflects the influence of the startup culture, which contributed to the development of these spaces and emphasizes the importance of intellectual property rights. This association is further highlighted by the implementation of non-disclosure agreements in some makerspaces, aimed at protecting designs and knowledge, particularly for users with entrepreneurial aspirations. On the other hand, community-oriented makerspaces in India align more closely with the open-source principles central to the maker movement (Saari et al., 2021; Langley et al., 2017). These spaces frequently share their projects on platforms like GitHub, fostering a culture of open and communal knowledge sharing. The grassroots innovations literature from India places considerable emphasis on protecting the knowledge of local innovators (Smith et al., 2017). Several agencies and organizations assist grassroots innovators in securing patents for their innovations (Sharma & Kumar, 2018). This contradiction presents an intriguing aspect of the maker movement in India, illustrating a complex interplay between communal knowledge sharing and individual intellectual property rights (Braybrooke & Smith, 2020).

Makerspaces are gaining prominence in higher education institutions across India, marking a shift from traditional rote learning to a more hands-on, practical approach (Schad & Jones, 2020). These spaces function as laboratories where students can apply theoretical knowledge and engage in collaborative projects with peers (Hynes & Hynes, 2018). Despite this progress, there is a noticeable trend: students from engineering and technical disciplines predominantly utilize these spaces, with limited participation from those in non-technical fields (Noel et al., 2016; Masters, 2018). In addition to serving educational purposes, these spaces play a vital role in nurturing creativity and innovation among young adults. This is evident in various state policies, such as the Atal Tinkering Labs initiative by Niti Aayog, India's premier policy think tank, which aims to establish makerspaces in schools and colleges throughout the country (Gupta, 2019). Despite the growing support for and confidence in the

maker culture in India, there remains a significant challenge: ensuring diversity within these spaces (Kye, 2020). Encouraging participation from rural areas, artisan communities, and women is an ongoing endeavor for many makerspaces. However, these spaces are actively pursuing various strategies to become more inclusive and accessible. These efforts are aimed at not only broadening the demographic reach of makerspaces but also enriching the innovation ecosystem by incorporating a wider range of perspectives and skill sets.

6. Conclusion

The study explored the emergence of makerspaces and fablabs in India, aiming to understand their operational mechanisms and their roles within the broader innovation landscape of the country. The research identified two primary motivations behind the establishment of these spaces: firstly, to provide a prototyping infrastructure essential for startups, and secondly, to foster learning, creativity, and technical skills within communities. The analysis revealed that makerspaces in India manifest in three distinct categories. The first category includes those supported by state-level funding, designed to boost regional startup initiatives. The second category comprises community makerspaces and fablabs established by private individuals. The third category consists of academic makerspaces and fablabs, increasingly integral to higher education institutions, contributing to student learning and skill development. The study concludes that the Indian maker movement reflects the country's startup culture. In contrast to the Western maker culture, which was initially deeply rooted in technology-based activism, the Indian counterpart has primarily served as an incubator for entrepreneurial endeavors from its inception.

The paper presents significant implications for theory and policy. The existing literature on makerspaces and fablabs has predominantly focused on experiences in the global north, with much of the discourse shaped by the activities and functions of these spaces in those regions. This study introduces a global south perspective to the understanding of maker culture, particularly drawing insights from the Indian context. From a policy perspective, the paper offers several recommendations grounded in its findings. Firstly, while maker culture was originally conceived to democratize innovation and product development within communities, the participation of the public in India, especially those without entrepreneurial aspirations, remains notably low. Policies should aim to increase the popularity of these

spaces among general hobbyists and the creative community. Secondly, people running some of these spaces have expressed a noticeable lack of diversity among participants in terms of gender, as well as in occupational and educational backgrounds. Policies should strive to make these spaces more inclusive and appealing to women and individuals from non-technical disciplines. Thirdly, these spaces hold substantial potential to enhance the skills and knowledge of grassroots innovators. There is a need for policy initiatives to increase awareness among these innovators about the benefits and opportunities offered by makerspaces and fablabs.

The paper acknowledges certain limitations. The first pertains to its qualitative methodology, which restricts the findings to insights gathered solely from interviews with managers, founders, employees, and users of these spaces. This approach may not fully capture the diversity of experiences and perspectives associated with makerspaces and fablabs. Due to time constraints, the study was unable to incorporate viewpoints from policymakers at the state, regional, and national levels. This exclusion limits the understanding of how these spaces are integrated into broader national innovation policies. Another significant limitation is the analytical technique employed in the study, which involves the researcher's subjective judgments and interpretations of the data. This method may introduce biases or limit the generalizability of the findings. Future research in this area could address these limitations by incorporating quantitative studies. These could focus on the users of these spaces, examining their perceptions and the impact of these environments on their skill development. Moreover, future studies might offer in-depth case studies of select makerspaces in India, providing a more comprehensive understanding of their operations and contributions to the innovation ecosystem.

As India advances in its position on the global innovation index, the relevance of makerspaces and fablabs is poised to increase significantly. It will be interesting to observe how these spaces are assimilated into the fabric of Indian innovation and entrepreneurship. As they continue to expand, it is anticipated that new dimensions and dynamics will emerge, potentially offering novel insights and contributions to the global discourse on innovation ecosystems. The evolution of these spaces in the Indian context could provide valuable lessons and models for other countries especially in the global south looking to strengthen their own makerspace infrastructure.

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Appendices

Appendix A: Interview Participant Details

S.No.	Interviewee position	Makerspace ID	Respondent ID	Type of Organization	Interview Duration and Location
1.	Manager	MS-01	R1	Independent makerspace within a coworking space	48 minutes (Both interviews done together) In person at the makerspace
2.	Employee	MS-01	R2	Independent makerspace within a coworking space	
3.	Co-founder	MS-02	R3	Independent makerspace	78 minutes (Both interviews done together) online
4.	Co-founder	MS-02	R4	Independent makerspace	
5.	Founder	MS-03	R5	Social enterprise related to makerspaces	43 minutes online
6.	Employee	MS-04	R6	State funded makerspace/fablab	29 minutes in person at the makerspace
7.	Co-founder	MS-05	R7	Community makerspace	25 minutes online
8.	Co-founder	MS-05	R8	Community makerspace	70 minutes in person at the makerspace
9.	Employee	MS-05	R9	Community makerspace	18 minutes in person at the makerspace
10.	Manager	MS-06	R10	Community makerspace/fablab	90 minutes in person at the makerspace
11.	Maker	MS-06	R11	Community makerspace/fablab	23 minutes (Both interviews done together) in person at the makerspace
12.	Maker	MS-06	R12	Community makerspace/fablab	
13.	In-charge	MS-07	R13	Academic makerspace	33 minutes online
14.	In-charge	MS-08	R14	Academic Makerspace	60 minutes online
15.	In-charge	MS-09	R15	State funded makerspace/fablab	41 minutes in person at the makerspace
16.	Employee	MS-09	R16	State funded makerspace/fablab	30 minutes (Both interviews done together) at
17.	Employee	MS-09	R17	State funded makerspace/fablab	

					the makerspace
18.	Employee	MS-10	R18	State funded makerspace	20 minutes in person at the makerspace
19.	Founder	MS-11	R19	Independent Makerspace	43 minutes in person at the makerspace
20.	Incharge/Employee	MS-12	R20	Academic makerspace	48 minutes online

Appendix B: Data Structure for the Study

Aggregate theme	Sub-theme	Description	Representational quotes
Foundational purpose	Lack of prototyping facility	Makerspaces aim to fill the infrastructure gap for prototyping facilities in India which can be utilized by startups	*"India lags a little bit on the hardware front. I mean, we have large scale industries which can do it, but if you want to go there, you have to at least have a few hundred or thousand units and a huge capital to invest in it, right? The challenge when we started this place was to solve for that - engineering people could easily prototype, build products, and test them"*
	Reducing dependence on China	Without makerspaces there was a dependence on China for prototyping requirements for people looking to design their ideas	*"we needed to depend a lot on China even for prototyping, but to some extent, that has changed because we have technologies like 3D printing, VMCs, CNCs, and other general machining tools which allow any hobbyist, entrepreneur, or innovator to come here and try out their ideas."*
	Lack of DIY culture	The public lacks a DIY skill as compared to western nations because services in India are very cheap and people avail them.	*"In India, the inherent skill of building and manufacturing is not as widespread as it is in countries like the US, where people often create their own doors or equipment due to a strong DIY culture."*
	Support the learning of the students	Makerspaces in higher education institutions in India started to provide practical education to students	*"A majority of what we learn revolves around electronics, various mechanisms, and creating different products. The aim is to educate students about smart, integrated products, or in other words, anything they want to customise with sensors, controllers, LEDs, and technologies like advanced Bluetooth — these are some of the elements we introduce to the students. They're very eager to learn about this, and these introductions catalyse their progression in their academic pursuits."*

	Missing the open innovation culture in India	There is no space which is open for the public in India who are creative and want to experiment with digital tools.	*"I couldn't just go to the university and start using a tool. That culture was missing – a culture of being around similar people, learning from each other, openly sharing – that open source culture, which is also very important."*
	Initial funding and support	Makerspaces were started with the initial funding from the savings and finds of their founders.	*"It was completely bootstrapped with our own funds, and not supported by any government organization, like the maker spaces you may have seen in libraries, maker spaces, and colleges in cities."*
Primary users	Startups as the main clients	Some of the makerspaces are being primarily used by the companies and startups in the region.	*"Our clientele is primarily made up of startups based in the … region. A large number of our clients operate in hardware domains."*
	Prototyping as a service	Makerspaces also serve clients who have an idea but are not skilled enough to create products.	*"we are on the vendor list of quite a few institutes. When you're on the vendor list, it makes things easier. If the institute wants a service, they can take it directly."*
	Open to all	Makerspaces which are rooted in the communities are open for all the people from different walks of life.	*"So, our central idea was always to bring people from various walks of life into this space, place the tools directly in their midst, allow them unrestricted access, and observe what they could construct using these machines. That's when the truly beautiful creations began to emerge."*
	Disciplinary background of academic makerspace users	Some academic makerspaces are used by students from diverse disciplines while some are used only by technical field students.	*"Some of them are from architecture, management, pharmacy, and dentistry. Engineering students mainly use the Makerspace due to the opportunities available for interacting with students from different disciplines, as all the colleges and institutes are nearby."*
	Student community	Makerspaces in academic institutions are open to the student and faculty of the institutes.	*"Students and faculty members alike can have access to our facilities at designated times. We run very exclusive, integrated courses that cater to diverse disciplines."*
Learning and knowledge sharing	Attracting people online	The potential users of the makerspaces learn about the spaces using online forums and social media.	*"The other route is nowadays we see a lot of digital presence helping us. We were not very active on the digital space earlier, but now we have started digital marketing, and that is getting a lot of walking and stuff."*
	Collaborations and workshops	There are lot of workshops which are collaboratively organized by the makerspaces which are used for imparting knowledge and learning.	*"There have been people from different companies cross-pollinating, trying to help each other because I know there's a company called (name removed), the founder is one of the geniuses in electronics. And there are other teams who are very good at bio,*

			and they needed help in electronics, and this guy would give consultation".
	Knowledge sharing	The ways in which knowledge is shared within the makerspaces.	*"Knowledge sharing takes place through three main modes. The first one is obviously the Fab Academy program, a six-month program conducted under the Global Fab Foundation. In addition to this, we conduct short-term workshops for individuals within …, as well as those from outside the region. In these workshops, we deliver sessions on various digital fabrication technologies, such as 3D printing and laser cutting."*
	IP issues	How are issues related to intellectual property handled and whether there is a need to apply for patents.	*"If you think of a maker lab as a place to come and create a product that you want to sell, then you have a whole IP issue to deal with. However, if you think of a maker lab as a place where you learn to create things, so you're not actually creating a solution or a real product but just learning how to design anything, then there are no IP issues at all."*
	Open-source ideas	The role of open source for the innovations that are developed inside the community makerspaces.	*"open source can be beneficial in many ways, but it doesn't necessarily aid in raising investment for sustainable businesses. While it fosters innovation, quick failure, and rapid iteration, it doesn't encourage the development of entrepreneurial startups or business institution. This is because anyone can build upon open-source technology, which may make your offering less investable."*
Innovation and creativity	Space for frugal innovation	Makerspaces advocate the use of frugal approaches to innovation to ensure less wastage.	*"Frugality does play a big role, and that's what we suggest to everyone that comes in: use everything at your disposal first to make your product. We have another rural innovator who made a seed sowing tool. He used scrap metal to make his proof of concept, and even the design was inspired by walking sticks. There's quite a lot of inspiration that we draw and plenty of available materials that we use to build or showcase that our concept or design actually works. That's when we go about sourcing the correct materials."*
	Jugaad in makerspaces	The quick fix solutions and their role in the makerspaces.	*"people start with a makeshift solution and then transition to more sophisticated ones as they gain access to better facilities and resources. If someone is building a temporary*

			solution, we don't stop them, nor do we have the right to do so. However, as professionals with strong engineering and science backgrounds, we encourage the adoption of proven technologies and innovations, rather than relying solely on makeshift approaches."
	Citizen science initiatives	Community makerspaces also have citizen science initiatives for data collection and analysis.	*"Currently, we are working on a project to map water pollution in the rivers of …. Okay. So, if you think about it, in India, we barely have any information about our rivers and their pollution levels. When these tests are conducted, they are typically carried out by specific universities, often by a lone PhD student. This results in sparse data, especially in … where the data is outdated by four years and is quite limited. However, this situation presents a perfect opportunity to involve the community. We've been working with fishermen, taking water samples when they're out fishing, and collaborating with a lab in … that's doing the same testing."*
	Innovations in the makerspaces	Innovations which happen in the makerspaces.	*"From the makerspace perspective, I've seen numerous innovations, like the development of drones using our 3D printing and machining services."*
	More Entrepreneurial, less makers	Makerspaces are used by people who are more entrepreneurial but less of makers so they are looking for people who can help them in prototyping their ideas.	*"The culture of innovation and frugality was high, but people were more entrepreneurial than hands-on makers. We were contacted more by startups who had just incorporated and already had products or ideas they wanted to develop. They would ask us to help them make their ideas more professional before seeking seed investments."*
Diversity and inclusion	Gender disparity	The gender disparity in the makerspaces are a reflection of the way boys and girls are raised.	*"There's a reason for that. Because we tell our girls very early on that some of these things are for boys, whether we like it or not. Movies, TV, and even home discussions reinforce the idea that boys are the ones who create all these things. What the girl hears is that only boys can create these things, and that creates a limitation in her thinking that she can do exactly the same things as others."*
	Artisan and rural community	Community makerspaces in different ways collaborate and work with the rural and artisan communities.	*"we actually established a textile lab for woman artisans in Jaipur, in partnership with the French government. The French funded this initiative, and the lab is a physical*

			space equipped with modern tools. It's an exciting model that invites students from all over the world, who are involved in textile work, to collaborate with female artisans and learn from each other. This lab exists and we have been working on it. It has been a beautiful learning journey, even though the pandemic has disrupted many aspects of our operations."
	Male: female ration	The gender disparity in makerspaces are also reflected in the workforce of these spaces.	*"We don't have great diversity at the moment; our team is entirely male. However, this wasn't a conscious decision. It's more indicative of the issue with STEM education in …. Recently, we posted job openings for three technical officer positions and, disappointingly, we didn't receive a single application from a woman."*
	Mostly tech background	Academic makerspaces are mostly used by students from technical or science backgrounds who wants to work on their projects.	*"The majority of them are engineers. We have a few PhDs - when I say PhDs, or Masters in Science converted into PhDs."*
	Women participation	There is an increased participation from the women now in the makerspaces as it used to be initially when these places were first setup.	*"we've observed an increase in female representation in these areas. I recall that when this movement first started, there were only a couple of women involved in creating significant projects."*
Future prospects	Government support	The government approach currently towards supporting the makerspaces is more towards building the space and providing tools but not in building the community.	*"I do believe that the government's approach lacks the cultural aspect of these spaces. I've visited many of the makerspaces that the government is setting up. I was even invited by Niti Aayog to advise them on the tools that should be included, among other things, before this initiative began. Nonetheless, I believe these spaces should not merely provide tools, but should also inspire students to think creatively and construct things. For that, students need exposure to this culture and access to a community."*
	Promising future	The policy approach currently favours setting up of new spaces in the country.	*"I think the future of makerspaces is very promising because there is a growth of STEM in education. The government is venturing into ATLs, and now they're even providing proper infrastructure in each and every college, which is under process after the budget."*
	Challenges with academic makerspaces	The challenges which are faced by the makerspaces in their current	*"One of the main challenges we face managing the Makerspace is related to student integrity and pacing.*

		operationalization in academic institutions.	*Sometimes students come in at the very last moment, which makes it difficult to manage and engage them effectively. This aspect is not entirely under our control and depends significantly on student behavior and their commitment to their work."*
	Policy approach	The education policy of the government has been supportive of building these spaces in the country especially within academic institutions.	*"The National Education Policy (NEP) has brought a lot of attention to this, which is great. However, they don't know how to deal with the NEP or what to teach to meet its requirements. A maker program would be a wonderful way to address this, as it provides hands-on experience and practical knowledge that aligns with the goals of the NEP."*