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The role of makerspaces in innovation processes: an exploratory study

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Makerspaces democratize technology access and therefore improve the chances for innovation and entrepreneurship. Nevertheless, we know little about how innovation happens in collaborative innovation spaces like makerspaces. To unleash the full potential of makerspaces, it is essential to understand what resources and environments support innovation for makerspace users. Against this background, this research study aims to explore how different makerspace user groups leverage makerspace resources during their innovation process. To achieve this, we use the resource-based view in combination with an open innovation perspective and examine the relevance of makerspace resources (knowledge, technology, social, and financial) during the different stages of the innovation journey (ideation, development and prototyping, commercialization and diffusion). In contrast to prior work, we focus on different makerspace user groups within an industry-specific makerspace and investigate how open innovation strategies (inbound, outbound, and coupled) are used to leverage the makerspace resources to develop innovation projects. Since the object of investigation is broadly unexplored and complex, we use an embedded single case study approach to explore 10 different projects within a makerspace with a specific focus on photonics. Photonics is described as a so-called enabling technology that carries a considerable potential for cross-industry innovation. The qualitative content analysis revealed that professional and hobby users differ in their makerspace resource use and their modes of openness across the innovation journey. Furthermore, we find that makerspaces can take the role of a facilitator or incubator depending on who uses the makerspace to innovate.

1. Introduction

In recent years, makerspaces have evolved worldwide and made digital fabrication tools available to a broad range of people. This development is described under the term maker movement, which emerged from the do-it-yourself and hacker

cultures (e.g., Rosa et al., 2017; van Holm, 2017). Makerspaces, sometimes also described as fablabs or hackerspaces, are physical spaces that offer access to shared fabrication tools, for example, 3D printers, laser cutters, wood and metal workshops, or micro-controllers. The users of such facilities are called makers. The maker community is characterized by

intrinsic motivation, sharing culture, and a trial-and-error approach (Hatch, 2014). By developing innovative products, makers repeatedly demonstrate that they are a creative and capable community. For example, makers developed the first consumer 3D printer (West and Kuk, 2016) and led the way in developing smartphone-based payment devices (Hatch, 2014). Additionally, during the early stages of the COVID-19 pandemic, makers addressed the urgent need for medical supplies (Corsini et al., 2021). Due to the creative innovation potential, the maker community has attracted increasing attention from different research streams in the fields of innovation and entrepreneurship (Browder et al., 2019). Recent studies argue that makerspace users are more innovative than other people (Halbinger, 2018) and that makerspaces can foster innovation, entrepreneurial activities (Aldrich, 2014; Mortara and Parisot, 2016, 2018; Mauroner, 2017; van Holm, 2017; Browder et al., 2019), and local economic development and growth (van Holm, 2017; Wolf-Powers et al., 2017). Initial exploratory quantitative research has shown that startup foundation positively correlates with the longevity of makerspace existence in a region (Cuntz and Peuckert, 2023). Nevertheless, the maker movement research is still in its infancy (Gantert et al., 2022), and so far, little is known about how makerspace users leverage the resources and tools provided by makerspaces in their individual innovation process (Mauroner, 2017; Mortara and Parisot, 2018; Beltagui et al., 2021). Based on the sharing culture of the makers, the projects that evolve in such spaces benefit from knowledge inflows, outflows, and coupled development processes between makerspace users. In this sense, a makerspace could be described as an open innovation space where makerspace users with different backgrounds help each other develop their ideas by sharing knowledge and other resources.

Although we know that makerspace users highly value openness and sharing (West and Kuk, 2016; Langley et al., 2017; Li et al., 2021; Saari et al., 2021), until recently, only a few studies have linked maker community research to the concept of open innovation (Mauroner, 2017; Browder et al., 2019, 2022; Zakoth and Mauroner, 2020; Beltagui et al., 2021; Saari et al., 2021). Nevertheless, these studies mainly focus on the aspect that maker communities are another external resource to be leveraged by companies to increase their innovation capabilities. While this is a valid perspective, open innovation research has neglected to investigate maker innovation processes under the lens of open innovation. Thus, we know little about how makerspace users innovate and use the resources provided.

At the same time, open innovation scholars who mainly have studied open innovation processes in the context of corporate innovation processes call for open innovation studies in new contexts like communities to advance open innovation theory development and increase its validity (West and Lakhani, 2008; Bogers et al., 2017; Sims et al., 2019). Previous research describes open innovation as an effective strategy for resource-constrained innovators like entrepreneurs or small and medium-sized enterprises to leverage external resources (Eftekhari and Bogers, 2015), but has so far mostly neglected the above-average creative and innovative group of makerspace users (Halbinger, 2018).

Makerspaces provide a diverse pool of resources that resource-constrained innovators can leverage. From the resource-based view in the context of companies, we have learned that tangible and intangible resources with specific characteristics contribute to innovation and sustained competitive advantage (Barney, 1991). The conceptual model of Browder et al. (2019) theoretically links makerspace resources (technology, knowledge, social) to innovation in the form of entrepreneurial outcomes. However, the mechanisms of how makerspace resources are leveraged in individual innovation processes are still hidden. Consequently, our understanding of how makerspaces foster innovation and entrepreneurship is still limited.

Therefore, our research aims to close this gap by exploring the innovation journey of makerspace users regarding their application of open innovation strategies to leverage makerspace resources. Against this background, our study aims to answer the following research question: How do resource-constrained innovators use open innovation to leverage makerspace resources during their innovation journey?

To answer our research question, we study the innovation process and resource use of different makerspace users (hobby and professional) using the theoretical lens of the resource-based view combined with an open innovation perspective. Therefore, we conduct a longitudinal embedded single case study design by examining 10 innovation projects within a makerspace specialized in photonics technologies. We apply a theory elaboration approach (Fisher and Aguinis, 2017) that uses both contrasting and specification tactics. Contrasting is applied in the sense that the open innovation approach is transferred from a corporate context to a new context, namely makers. The specification takes place by deepening and expanding the resource dimensions proposed by Browder et al. (2019). Combining a resource-based view with the open innovation concept in the context of maker community research allows us to

advance theory development in these fields and delivers a better understanding of how makerspace users integrate and leverage different resources along their innovation journey. We find that the different user groups engage differently with the makerspace while innovating. The main differences pertain to the duration of makerspace use, the strategies to leverage makerspace resources (active and passive openness), and the general role the makerspace takes during the innovation journey. Besides extending and refining theories in a new context, our findings provide implications for designing more user-focused makerspaces. Therefore, our findings contribute to an improved understanding of how physical spaces and cultural environments contribute to innovation and entrepreneurship (Peschl, 2012).

In the next section, we develop the conceptual framework of our explorative study by combining the theoretical lenses of the resource-based view with the open innovation perspective in the context of innovation processes within makerspaces. Subsequently, we present our methodology and describe our case and the embedded makerspace projects (units of analysis) in more detail. After that, the research question will be answered in the findings section. In the following discussion, we draw implications for research and practice and show limitations and future research directions. The final section presents the derived conclusions of our exploratory study.

2. Theoretical background

2.1. *Makerspaces as innovation enablers – a resource-based view*

From the perspective of the resource-based view, tangible and intangible resources in possession and control of a company, startup, or individual determine the ability to innovate. To innovate and create a competitive advantage, the resources must be rare, valuable, and durable (Barney, 1991). This perspective fits well with the closed innovation framework, where innovation relies mainly on internal resources in exclusive control of the innovator (Vanhaverbeke and Cloudt, 2014). However, the focus on exclusive resources stays in contrast to the makerspace phenomenon, where the users of such spaces, like hobbyists, entrepreneurs, and companies share resource access to enable collaborative innovation (Browder et al., 2019). In that sense, makerspaces are increasing the resources at hand for the broader public by providing access to shared tools like 3D printers, laser cutters, or shared space for knowledge exchange between the users of such spaces (Halbinger, 2018).

From entrepreneurship research, we know that individuals who discover opportunities within the range of resources they control are described as being more likely to take entrepreneurial action compared to potential entrepreneurs that identify an opportunity based on a market analysis outside of their resource base (Fisher, 2012).

Halbinger (2018) has shown that makerspace users are a highly creative and innovative community. In general, makerspaces provide access to different resources encouraging users to test, experiment, exchange, build ideas, and innovate. Therefore, makerspaces, with their resources, contribute to the democratization of invention and innovation (von Hippel, 2005; Browder et al., 2019). In their theoretical work, Browder et al. (2019) describe three dimensions of resources provided by makerspaces to support innovation and turn simple projects into entrepreneurial ventures. The social dimension describes the possibility of exchange and interaction with a supportive community with diverse backgrounds within a makerspace. The technology dimension includes access to various software and hardware tools, enabling the creation of different artifacts. Finally, the knowledge dimension entails creating and exchanging specific knowledge within the shared makerspace.

Additionally, earlier research in innovation and entrepreneurship describes the lack of financial resources as a significant challenge for innovators and entrepreneurs (Stinchcombe, 1965; Heirman and Clarysse, 2004; Colombo and Piva, 2008; Rayna and Striukova, 2021). Therefore, the financial support provided by a makerspace (e.g., the financing of project-specific consumables) could lower the barrier for makerspace users to start an innovation project. Table 1 describes the primary resources shared within makerspaces based on Browder et al. (2019) and extended by financial resources described by earlier innovation and entrepreneurship research as a potential barrier for innovators and entrepreneurs.

Although numerous startups exist within the maker movement (Browder et al., 2019), little is known about how resources are used during innovation processes within makerspaces (Mortara and Parisot, 2018). Therefore, one of the study goals is to investigate how makerspace resources are used in the context of different innovation projects.

2.2. *Innovation processes in makerspaces – an open innovation perspective*

Chesbrough (2003) describes two fundamental approaches to innovation, the closed and the open

Table 1. Overview makerspace resources

Makerspace resources	Description
Technological	Standard makerspace equipment provided to every user of the makerspace consisting of different software and hardware, e.g., 3D printers, laser cutters, and microcontrollers
Social	Social in-person or online community interactions while using the shared space, e.g., with other makerspace users like hobbyists, researchers, students, startups, or companies
Knowledge	Knowledge provided by staff members of the makerspaces, e.g., on how to use tools or experiences about prototyping material and designs
Financial	Investments made by the makerspace for project-specific purposes, such as special filament for 3D printing, or project-specific tools, such as camera systems or sensors needed for experimentation, prototyping, and testing

innovation model. In research studies, makerspace users are described as a community that highly values the culture of openness and sharing (Mauroner, 2017; Browder et al., 2019; Hausberg and Spaeth, 2020; Beltagui et al., 2021) which connects to the idea of open innovation (Mauroner, 2017). The concept of open innovation is described as ‘a distributed innovation process based on purposively managed knowledge flows across organizational boundaries’ (Chesbrough and Bogers, 2014, p. 17). In the past, the phenomenon of open innovation has attracted much attention from innovation research (Huizingh, 2011). However, open innovation has mainly been studied in the context of companies, and there is a need to strengthen the connection between open innovation research and other contexts like communities (Bogers et al., 2017). The present study follows this idea by investigating open innovation in the context of the maker community.

Besides closed innovation strategies that do not include external knowledge in their innovation process, current open innovation research differentiates between three open innovation strategies depending on the direction of the knowledge flow. Inbound strategies integrate external knowledge into a company’s innovation process (e.g., user integration). In contrast, outbound strategies are open innovation modes where knowledge circulates to partners outside the company (e.g., IP licensing). The coupled open innovation mode is applied for joint idea development and marketing of constant partners (e.g., cooperation with other industries) (Gassmann and

Table 2. Overview of innovation strategies

Innovation strategies	Description
Inbound	Knowledge and resources flow from the outside to the inside of the innovation process, e.g., customer integration
Outbound	Knowledge and resources flow from the inside to the outside of the innovation project, e.g., licensing
Coupled	Development and marketing of the innovation project are carried out jointly with a partner, e.g., a joint venture
Closed	Closed innovation process without knowledge inflows or outflows. There is no exchange of knowledge with external parties

Enkel, 2004). Table 2 contrasts the open and closed innovation approaches.

Given the prevalent culture of open sharing and collaboration in makerspaces (Mauroner, 2017; Browder et al., 2019; Hausberg and Spaeth, 2020; Beltagui et al., 2021), the theoretical lens of open innovation seems well suited to study the innovation process of makerspace users. Drawing on earlier research about innovation processes (Brem, 2011; Cooper, 2011), Mortara and Parisot (2018) describe the innovation process of entrepreneurial makerspace users as a three-phase process. The first stage is described as ‘ideation’, where makers develop ideas and concepts. The second stage, ‘development production’, involves developing a product design and confirming manufacturability through prototyping. The third stage is described as ‘commercialization’, meaning maker entrepreneurs worked on small batch production, scaled-up production, and marketing-related topics. Even though this research provides valuable insights into how entrepreneurs integrate makerspaces into their innovation process, it leaves open questions about how other user groups might benefit from shared makerspace resources while innovating.

This research gap is interesting to investigate since Halbinger (2018) has shown that hobbyist makerspace users have tremendous innovation potential and might become accidental entrepreneurs (Shah and Tripsas, 2007). Additionally, it seems interesting to see how other makerspace user groups from the industry, like established companies or research institutes, integrate makerspace resources into their innovation process (Beltagui et al., 2021; Browder et al., 2022) to better understand the impact of makerspaces on the innovation processes of different users.

Another aspect not captured by previous research on innovation processes within makerspaces is that not all makerspace users monetize their project outcomes and instead diffuse them for free into the market. Langley et al. (2017), who investigated the potential trajectories of makerspace projects, described this tension between free sharing and commercialization. In that sense, the openness of makerspace projects is also reflected in how they share and diffuse their project outcomes. Even though many projects are introduced into the market with an open-source (Troxler and Wolf, 2017; Li et al., 2021) approach, we also see strategy shifts where former open-source projects turn into a closed-source model after a while (West and Kuk, 2016) or follow a completely closed source approach during commercialization (Mauroner, 2017; Mortara and Parisot, 2018). In the open innovation research stream, completely or partially free sharing is discussed under the terms ‘free revealing’ and ‘selective revealing’ (Harhoff et al., 2003; Henkel et al., 2014). Even though the innovation literature emphasizes the benefits of intellectual property protection (Schankerman, 1998; Lerner, 2002), Li et al. (2021) also identified advantages inherent in open-source commercialization, like reduced time-to-market, lowered R&D, and lowered customer support costs.

Although makerspace users seem to prefer openness and sharing (Browder et al., 2019; Beltagui et

al., 2021; Li et al., 2021) it is unclear if that is also reflected in their innovation process. Thus, a central goal of this study is to learn more about what open or closed innovation strategies are applied by makerspace users during their innovation journey to leverage makerspace resources.

2.3. Conceptual framework

In contrast to earlier studies, this research focuses on a project-level analysis of makerspace users to uncover how makerspace users innovate. Based on the literature review, we developed the framework for our qualitative research instrument by combining a simplified three-stage maker innovation process inspired by earlier research (Brem, 2011; Cooper, 2011; Bogers and Horst, 2014; Stock et al., 2016; Mortara and Parisot, 2018) with the above-described resource dimensions of makerspaces (Browder et al., 2019) extended with financial resources. Accordingly, our conceptual framework combines four dimensions of resources provided by a makerspace (social, technology, knowledge, financial) with a simplified three-stage innovation process (ideation, development and prototyping, commercialization, and diffusion). The framework enables investigation into what resources innovators use and what innovation strategies they apply during their innovation journey in the makerspace. Figure 1 illustrates the derived framework.

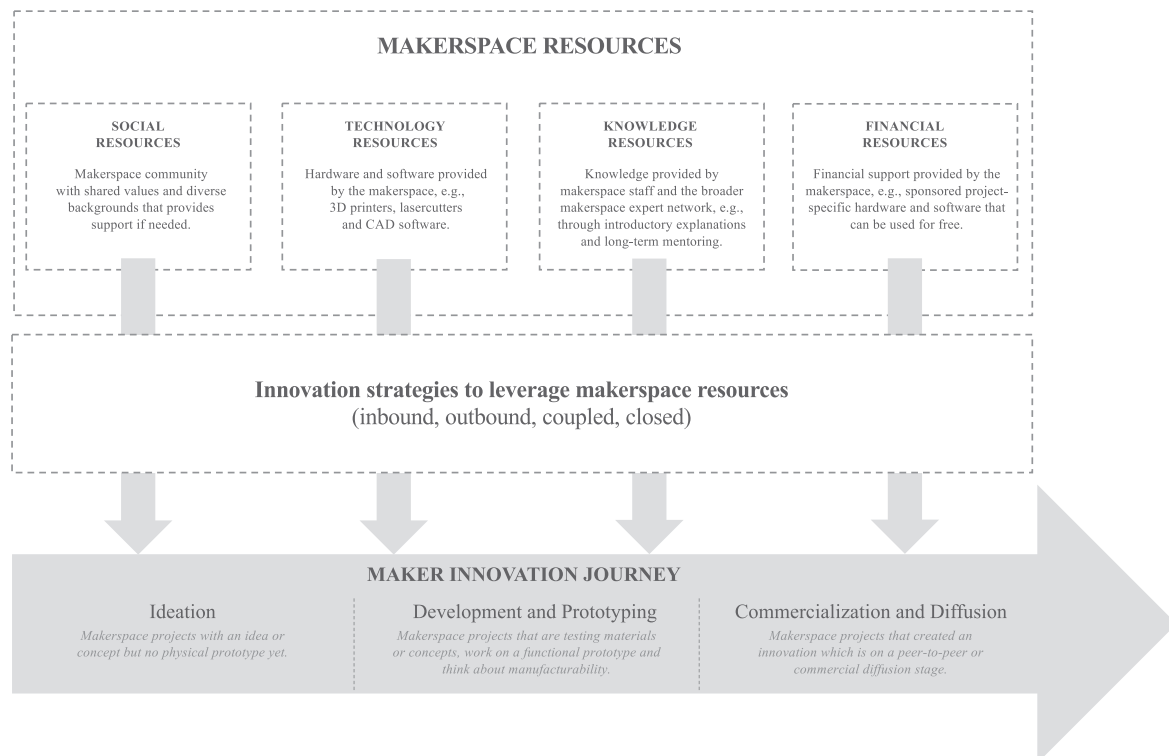


Figure 1. Conceptual framework.

3. Methodology

3.1. Data collection and analysis

In our research, we look deeper into the innovation processes and innovation strategies of makerspace users. Since the object of investigation is broadly unexplored and complex, a case study research design is applied (Yin, 2018). Case study designs are largely accepted in the fields of open innovation and maker movement research since this methodology generated valuable insights in the past (Mauroner, 2017; Mortara and Parisot, 2018; Sims et al., 2019; Bertello et al., 2021; Corsini et al., 2021; Abbassi et al., 2022). Our study follows an embedded single case study design (Yin, 2018), which allows multi-case theory building (Eisenhardt, 2021). We selected our units of analysis by a two-step approach. In the first step, we used the two authors' access to different makerspaces and purposefully selected a makerspace that gave us access to diverse makerspace user groups to compare their innovation processes regarding innovation strategies and resource use. In this way, we were able to study different innovation projects embedded in the same environment and thus obtain information-rich data. In the second step, we purposefully selected 10 makerspace projects out of the available ones based on three criteria. The first selection requirement was that the projects interact with makerspace over a longer period of time (>6 months). The long-term use criterium allowed us to gain an in-depth understanding of the resource interactions during their innovation journey. Second, all selected projects needed to have the ambition to diffuse their project results. The third selection aspect was the willingness of the project initiators to be observed and interviewed during their innovation process (Patton, 1990). We collected and analyzed data from different sources to enable triangulation and thereby increase internal and construct validity (Eisenhardt, 1989; Yin, 2018; Goffin et al., 2019). Our data sources consist of interviews with makerspace users at two different points in their innovation process, observations (makerspace user observation, public talks, workshops, hackathons, and crowd challenges), and archival data (websites, social media postings, project documentation files, scientific publications, and media reports). The available data sources per project are summarized in Table 3.

Based on prior research (e.g., Halbinger, 2018; Mortara and Parisot, 2018; Browder et al., 2019; Sims et al., 2019) we developed two complementary interview guidelines to investigate how innovation

strategies and makerspace resources (social, knowledge, technology, and financial) are used in different phases of an innovation process (ideation, development and prototyping, commercialization, and diffusion) (Appendix: Tables A and B, Figure A).

In the periods of 08/2019–01/2020 and 08/2022–09/2022, we conducted, in total, 20 semi-structured interviews with 10 initiators of innovation projects within the industry-specific makerspace. We focused on the initiators of the makerspace innovation projects since they were often present in the makerspace and had the best understanding of how the makerspace resources were integrated into the innovation process. Each of the interviews in the first round took around 1–1.5 hr, with one exception, which took around 4 hr. The second round of interviews took about 1.5–2 hr per interview, and this round allowed the participants to extend and refine the answers given in the first round. All interviews were transcribed, and analysis was conducted with the qualitative data analysis tool MaxQDA. We conducted a qualitative content analysis to analyze the data in a structured way. The first coding step was deductive coding based on the developed framework from the theoretical background that was reflected in the interview guidelines. The second step was inductive coding identifying emerging topics within our data (Miles et al., 2013). To increase intercoder reliability, the third researcher, not involved in the coding process, carefully cross-examined the developed codes. Conflicting codes were discussed by all three researchers and refined if necessary. For example, the following quote was deductively coded as 'financial resources', and it belonged to the theme 'Makerspace resources' (generic theme): '*Financially would definitely also be super useful – even in small quantities, smaller things that can be obtained quickly.*' (G). An example of an emerging inductive code is the following quote '[...] makerspaces [...] take in my opinion often the role of facilitators [...] they [...] help to lower barriers without actively intervening, for example, by establishing these infrastructures, just already remove certain hurdles.' (G) that was coded as 'Facilitator' under the generic theme 'Makerspace role'. Table 4 provides additional insights into our data coding.

Observational data were collected by two of the authors that had convenient access to the makerspace and visited the makerspace on average at least four times per month during the observation period. The observations and informal interactions with the users within the makerspace and during the different events allowed the authors to develop

Table 3. Overview of data sources

Case	Project ideas	Interviews 08/2019–01/2020 08/2022–09/2022	Observation 06/2019–12/2022				Archival data 03/2017–12/2022					
			Makerspace user observation	Public talks	Workshops	Hackathons (12–24 hr)	Crowd challenges (1 week–3 months)	Website	Social media post- ings	Project docu- mentation files (e.g., status re- ports, presenta- tion slides, and business plans)	Scientific publications	Press reports
A	Medical drone	2, Hobbyist (project initiator)	✓	✓				✓	✓	✓		✓
B	360° topography drone	2, Hobbyist (project initiator)	✓					✓		✓		
C	Meteor camera network	2, Hobbyist (project initiator)	✓			✓		✓				✓
D	Robotics platform for kids	2, Hobbyist (1 × project initiator, 1 × successor)	✓		✓			✓	✓	✓		✓
E	6D gaming device	2, Founder (project initiator)	✓					✓				
F	Gesture-controlled speaker lamp	2, Entrepreneur (project initiator)	✓			✓	✓	✓	✓	✓		✓
G	Contactless vital sign monitoring system	2, Co-founder (project initiator and COO)	✓	✓		✓	✓	✓	✓	✓	✓	✓
H	3D printed microscopy toolbox	2, Co-founder (project initiator and CTO)	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
I	Forensic microscopy system	2, CEO (project initiator)	✓				✓	✓		✓		
J	Smartphone 3D capturing device	2, Group leader (project owner)	✓	✓			✓	✓	✓	✓	✓	✓

Table 4. Data coding

First-order nodes		Coded themes	Coded generic themes
157	61	Inbound	Open innovation mechanisms
	31	Outbound	
	40	Coupled	
	25	Temporary closed	
357	78	Social resources	Makerspace resources
	113	Technological resources	
	96	Knowledge resources	
	70	Financial resources	
514	193	Ideation	Makerspace use
	236	Development and prototyping	
	85	Commercialization and diffusion	
75	59	Active openness	Community involvement
	16	Passive openness	
58	37	Free revealing	IP strategies
	21	Selective revealing	
<i>Representative codes</i>			
Short use, primary selective revealing, early partnerships, dominantly active openness, specific technology, and primary financial consumables		Facilitator	Makerspace role
Long use, primary free revealing, late partnerships, passive and active openness, basic technology, and primary financial tool acquisitions		Incubator	

a detailed understanding of the innovation projects and innovation processes of the different makerspace users. The interactions were summarized in brief field notes and later used for triangulation purposes with the other data sources to improve the reliability of the analysis.

To further increase the reliability of our analysis and our understanding of the innovation projects, extended archival data has been collected and analyzed. The analyzed archival data comprised websites about the projects, social media postings, project documentation files (e.g., status reports, presentation slides, and business plans), scientific publications, and available media reports (Table 3).

3.2. Case description: photonics makerspace

This study focuses on a makerspace with a focus on photonics, which is considered as enabling technology for downstream innovations (National Research Council, 2013). Furthermore, the advantage of focusing on such a specific makerspace is that all investigated projects have access to the same resource base making the innovation journeys more comparable.

The industry-specific makerspace we investigated, located at a university in Germany, was established in 2017 and receives funding from the German Federal Ministry of Education and Research to discover new ways of innovation in the photonics industry (Zakoth et al., 2019). In addition to providing access to more standard technologies like 3D printers, laser cutters, and microcontrollers, this makerspace provides access to equipment like pulsed lasers, optic tables, and high-end microscopes that cannot be found in other makerspaces. The makerspace maintains an open culture, but access is partially restricted by institute-specific access requirements like completing training on how to use lasers and laboratory equipment safely. The region surrounding this makerspace is often described as the German photonics cluster (Mauroner and Zorn, 2017), with around 187 companies and over 16,000 jobs connected to that industry sector (OptoNet, 2019). To empower the community to innovate, the makerspace provides different resources (Zakoth et al., 2019), summarized in Table 5.

The maker community of this makerspace consists primarily of highly educated and tech-savvy

Table 5. Photonics makerspace resources

Social	Technical	Knowledge	Financial
Community interaction e.g., unplanned interactions with other community members in the makerspace	General tools e.g., 3D printers (FDM, SLA), laser cutters, basic electronics (e.g., microcontrollers), and standard sensors (e.g., ultrasonic), soldering stations, CAD software, and wood and metal workshop	Introductory explanations by makerspace staff e.g., how to use introductions to different technologies provided in the makerspace, such as 3D printing or laser-cutting	Project-specific consumables e.g., small project-specific investments in the form of special 3D-printing filament or laser cutting materials for development and prototyping or material testing
Event formats e.g., planned interactions through event formats public talks, workshops, hackathons (12–24 hr), and crowd challenges (1 week–3 months)	Optics tools e.g., lasers with different wavelengths, optomechanical components (e.g., lenses, filters, microscopes, objectives), optic tables, optics design, and simulation software	Mentoring by makerspace staff e.g., long-term knowledge exchange with staff members that guide the projects with their expertise about materials and technologies Access to experts e.g., active introduction to experts with in-depth knowledge, e.g., in the field of optics and photonics	Project-specific tool acquisitions e.g., significant project-specific investments into technology like cameras, lasers, sensors, or other equipment needed to realize a specific project

people like researchers and students of natural sciences. Additionally, curious citizens and professionals from nearby research institutes, photonics companies, and startups use the makerspace. Out of that diverse community, many different projects have evolved. Some projects are primarily recreational, but others aim to build a business from their makerspace projects. Among all the different ongoing projects within the makerspace, we selected 10 different makerspace innovation projects (units of analysis). All the selected projects use the makerspace for a longer period (>6 months) to build their idea and plan to diffuse them into the market. The innovation projects vary from a contactless vital sign monitoring system to a modular open-source microscope toolbox. The sample consists of hobby, entrepreneurship, and industry innovation projects to investigate how different makerspace user groups integrate makerspace resources into their innovation process. Projects fall into the category of ‘hobby’ if individuals are working on a project that is not necessarily commercial, but they are exploring the idea of creating a startup, even though that is not the main purpose of working on the project. ‘Entrepreneurship’ projects reflect the makerspace users that are nascent entrepreneurs or entrepreneurs working on their first commercial product with the clear goal of bringing it to market and founding a startup. The category ‘industry’ reflects innovation projects initiated by established companies and research institutes with more than

10 years of industry experience and the clear goal to commercialize their project outcome. Table 6 gives an overview of the 10 selected makerspace projects and the backgrounds of the project initiators.

4. Findings

4.1. The innovation journeys of makerspace users

In the following, we look deeper into the innovation journey of the 10 selected innovation projects to explore how they used open innovation strategies to leverage the makerspace during their innovation process.

The analysis of the collected data revealed that the innovation process of makerspace users is iterative, meaning that the stages identified in the theoretical background are purposive, allowing makerspace users to go back and forth between the different stages. Only two of the project ideas originated within the makerspace (C, D), meaning the locus of ideas usually lies outside the innovation space. Furthermore, we found that hobby and professional makerspace users differ in the timing and length of makerspace use. Hobby projects use the makerspace across all phases from ideation to diffusion. In contrast, professional makerspace users leverage the makerspace resources at very specific stages, especially during ideation and the initial development and

Table 6. Project descriptions and background information

Project	Project idea	Initial project idea	Category	Personal background	Project description
A	Medical drone	2018	Hobby projects	Hobby	Student in the field of medical photonics with many years of experience as a volunteer firefighter
B	360° topography drone	2018	Hobby	Hobby	Open-source search and rescue medical drone project that enables communication and first aid, especially in hard-to-reach areas such as the mountains or during natural disasters This makerspace project uses a drone with a 360° camera system to capture landscapes and conduct topographical measurements
C	Meteor camera network	2018	Hobby	Hobby	The aim of the award-winning project is to design a meteor camera telescope that meets all practical requirements and can be easily recreated to establish a meteor observation network in terms of Citizen Science
D	Robotics platform for kids	2017	Hobby	Hobby	Driving robot platform that helps to educate children in programming and usage of various sensors
E	6D gaming device	2017	Professional projects	Entrepreneurship	Consultant and product manager in the software industry with a professional background in computer science and business administration (MBA) The goal of this project is to develop and market a 6D mouse . This product is relevant for the growing market of human-machine interaction because it helps humans to navigate and interact more intuitively in a VR environment
F	Gesture-controlled speaker lamp	2016	Entrepreneurship	Entrepreneurship	Design lamp with speakers and gesture recognition to control, e.g., music services or smart home devices via gestures
G	Contactless vital sign monitoring system	2018	Entrepreneurship	Entrepreneurship	This project allows contactless measurement of vital parameters like heart rate, blood oxygen, or temperature through a highly sensitive camera system
H	3D printed microscopy copy toolbox	2016	Entrepreneurship	Entrepreneurship	Open-source modular toolbox for rapid prototyping in the field of optics . The 3D printed cubes are magnetic and could be used, e.g., to easily build a low-cost but accurate microscope
I	Forensic microscopy system	2017	Industry	Industry	A company project that experiments with the makerspace equipment and tests an innovative product idea in the field of forensic material processing using a green laser
J	Smartphone 3D capturing device	2015	Industry	Industry	The goal is the development of a cost-effective 3D case for smartphones (hardware) that enables 3D scanning with the smartphone camera and an app that creates a printable 3D model from the captured images (software)

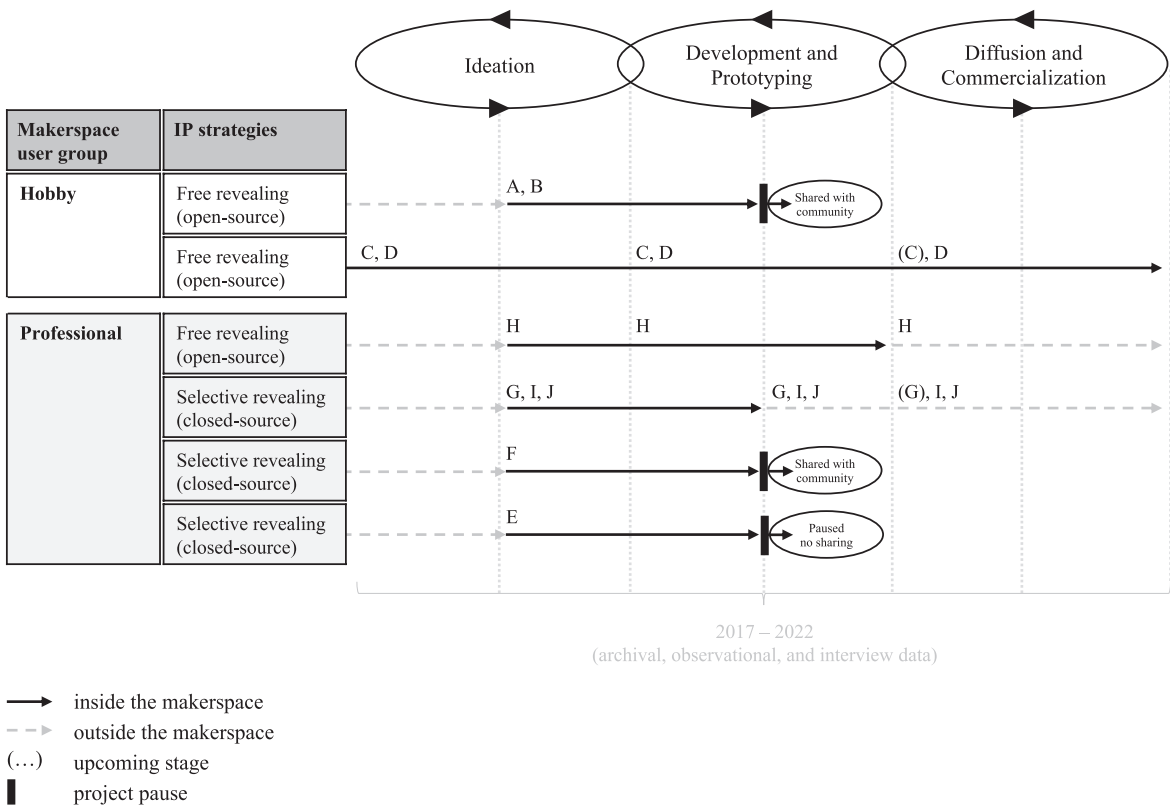


Figure 2. Innovation journey overview.

prototyping before collaborating with external partners and leaving the makerspace. For example, one of the industries makerspace innovators explained the usage approach of the provided optics equipment the following way.

We have used [the makerspace] ... to optimize the 'proof of principle' assembly, or to recognize and eliminate flaws in thinking and deficiencies ... We left [the makerspace] with the finished concept, which was then implemented in prototypes (...) [and] shipped to the U.S., because the distributors are located in Chicago and they were absolutely happy with it. (I, industry project)

Another interesting difference between a hobby and professional users lies in how they apply openness and manage intellectual property during their innovation process. All hobby projects followed an open-source approach (A, B, C, D), meaning the core aspects of the projects are shared with the public, for example, by freely revealing software source code, material lists, and construction plans on websites and publicly available databases. In contrast, only one professional project (H) decided to commercialize with an open-source approach. The other five professional projects (E, F, G, I, J) committed to a closed-source approach when

diffusing their projects into the market. They used a more targeted approach and selectively revealed parts of their intellectual property during event formats (e.g., hackathons). Figure 2 summarizes the different innovation journeys.

Nevertheless, our longitudinal investigation revealed that not all projects reached the diffusion and commercialization stage. Two hobbyists mentioned that changes in their private lives or new interests caused time constraints which led to pausing or transferring their projects to other makerspace users (A, B). Also, some entrepreneurship and industry projects were paused due to time constraints (E) and the discovery of blocking patents (F). The generated knowledge from the paused projects (B, F) was diffused within the makerspace community, for example, by hackathon participation or sharing project documentation. Only one of the paused projects did not share project details (E) with the broader community. In this sense, most makerspace innovation projects generate valuable societal and economic outcomes either by knowledge diffusion to the community and broader public (sharing) or by introducing new products into the market (commercialization).

The main advantage of using the makerspace was access to commonly shared resources resulting in faster development time and cost reduction.

Table 7. Makerspace projects insights

Case	Project idea	Category	Type	Initial project idea	Locus of idea	Current innovation stage	Innovativeness	Number of makerspaces used	Status 2022
A	Medical drone	Hobby	Open-source	2018	Outside	Development and prototyping	Partially new approach	1	Project is handed over to another member of the makerspace community due to time constraints (transferred)
B	360° topography drone	Hobby	Open-source	2018	Outside	Development and prototyping	Partially new approach	2	Project is on pause due to other interests and time constraints. Might be continued later (paused)
C	Meteor camera network	Hobby	Open-source	2018	Inside	Commercialization and diffusion	Not a new approach	2	Project is starting to collaborate with institutional partners to build the network (ongoing)
D	Robotics platform for kids	Hobby	Open-source	2017	Inside	Commercialization and diffusion	Not a new approach	2	Workshops are organized to teach programming skills (ongoing)
E	6D gaming device	Entrepreneurship	Closed-source	2017	Outside	Development and prototyping	Partially new approach	1	Project is on pause due to time constraints and other interests. Might be continued later (paused)
F	Gesture-controlled speaker lamp	Entrepreneurship	Closed-source	2016	Outside	Development and prototyping	Radical new approach	2	Project is paused due to the discovery of a blocking patent. Results are shared within the makerspace community (paused)
G	Contactless vital sign monitoring system	Entrepreneurship	Closed-source	2018	Outside	Development and prototyping	Radically new approach	1	Startup company founded in 2021 to commercialize the idea (ongoing)
H	3D printed microscopy toolbox	Entrepreneurship	Open-source	2016	Outside	Commercialization and diffusion	Partially new approach	2	Startup company founded in 2022 to commercialize the idea. Exploration of open-source commercialization with professional partners. First products are introduced into the market (ongoing)
I	Forensic microcopy system	Industry	Closed-source	2017	Outside	Commercialization and diffusion	Radical new approach	1	Project is finished and introduced into the market. Makerspace for reaching proof-of-principle of other ideas (ongoing)
J	Smartphone 3D capturing device ¹	Industry	Closed-source	2015	Outside	Commercialization and diffusion	Radically new approach	3	Project results are commercialized in a follow-up project. Results are diffused through scientific publications (transferred)

¹Closed-source software to protect intellectual property and open-source hardware.

Interestingly, six of the makerspace innovators mentioned that they were using other nearby, non-specialized makerspaces within the same city. Table 7 summarizes the main differences between the innovation journey of hobby and professional makerspace innovators.

In the subsequent sections, we explore how the different makerspace innovators used open innovation mechanisms to leverage the makerspace resources during their innovation journey.

4.2. How makerspace innovators leverage the provided resources

Three things became apparent when we analyzed the collected data. First, the duration of makerspace use differs between hobby and professional makerspace users. Second, we found differences in how open innovation is applied by hobby and professional innovation to leverage makerspace resources. The third aspect we found was that all makerspace users rarely mentioned episodes during their innovation journey where they were completely closed off and did not use any form of open innovation.

4.2.1. Social resources

For leveraging the social resources of the makerspace, the innovators followed different approaches. These differences became apparent by mapping the interaction activities of the innovation projects with the makerspace community. Through the analysis of archival data consisting of a website and social media postings, project documentation files (e.g., status reports and presentation slides), and press reports, we were able to trace back the events to 2017, when the makerspace opened. We focused only on events that were linked to the makerspace and its community. Table 8 summarizes how hobby and professional makerspace innovators used social resources (for more details see Appendix Table C).

Although we know from our observational data that all projects had some interactions with other makerspace users while working in the makerspace, the data analysis revealed that hobby innovators seem to use way less targeted event-driven approaches for social interactions. Nevertheless, all hobby projects followed an open-source approach and made, for example, source code or instructions publicly available. In this sense, they were following a free revealing outbound open innovation approach, not trying to protect their intellectual property. Due to the lack of targeted interactions with the community, we inductively coded this

behavior as ‘passive openness’. The passive openness approach was used in all stages of the innovation journey.

In contrast, the professional users all followed a closed-source approach and selectively revealed specific parts of their projects to the makerspace community. One exception in the pool of professional projects was project H, which also actively interacted with the makerspace community but followed an open-source approach, practicing open innovation by freely revealing project outcomes along the innovation journey. Only project E did not show any interaction with the broader makerspace community to activate the social resources. All other professional makerspace innovators used workshop, hackathon, and crowd challenge event formats to leverage social makerspace resources. One of the innovators (F) described the effect of the crowd innovation events as follows.

(...) the crowd innovation challenge was really something terrific, (...) because there were five people who were top experts, I took them by the hand, showed them everything and then they implemented things, namely we produced prototypes. (...) we worked on an idea, tightened it up and did tests (...) that was really great. (F, entrepreneurial project)

Based on the active and targeted involvement of the maker community we inductively coded this behavior as ‘active openness’. Since most professional makerspace projects left the makerspace in the early development and prototyping stage, the activation of the social resources happened mainly in the ideation and development stages.

4.2.2. Technological resources

Unsurprisingly, all investigated makerspace projects integrated the technological resources into their open innovation process by applying inbound open innovation. However, we found some minor differences in what kind of technological resources the different makerspace users use. Table 9 summarizes what and how the technological resources were leveraged.

The technology inflows of the hobby makerspace users (A, B, C, D) focused on general technologies available in most makerspaces, like 3D printers, laser cutters, or basic electronics. The hobbyists leveraged these tools during their innovation journey for testing materials and building different functional prototypes. Figures 3 and 4 show examples of prototypes developed by hobby and professional innovators within the industry-specific makerspace.

Table 8. Leveraging social makerspace resources (active openness)

Event format	Duration	Description	Hobby users						Professional users						Open innovation mechanisms
			A	B	C	D	E	F	G	H	I	J			
Public talk	Few hours	In this format, the project initiators present the project idea to the makerspace community or the broader public. It is used to get attention for the project	✓ (3)	✓				✓ (2)	✓ (8)			✓ (8)		✓ (1)	Outbound
Workshop	Few hours	In this format, the project outcomes are used to work hands-on with the product. This helps to test the own product with the makerspace community. It creates valuable feedback for the project initiators				✓ (11)			✓ (5)					✓ (1)	Outbound, inbound
Hackathon	12–24 hr	In this format, participants develop solutions to relevant problems within a short period of time (12–24 hr). The outcome could be, e.g., how a microscope design could be improved using digital fabrication technologies like 3D printing or laser cutting. The outcome of this time-pressured format is usually early-stage concepts and demonstrators		✓ (1)			✓ (2)	✓ (1)	✓ (4)					✓ (1)	Outbound, inbound, (coupled)
Crowd challenge	1 week–3 months	An intense co-creation format where the makerspace community works for at least 1 week up to 3 months on a specific innovation challenge given by one of the makerspace projects. The goal of this format is to bring a project significantly closer to the market, e.g., by producing a functional prototype					✓ (2)	✓ (1)	✓ (2)	✓ (1)				✓ (1)	Coupled
			Σ17						Σ40						

[Correction added on 11 May 2023, after first online publication: The last row of this table has been updated in this version.]

Table 9. Leveraging technological makerspace resources

Technical resources	Hobby users				Professional users						Open innovation mechanism
	A	B	C	D	E	F	G	H	I	J	
General tools e.g., 3D printers (FDM and SLA), laser cutters, basic electronics (e.g., microcontrollers) and standard sensors (e.g., ultrasonic), soldering stations, CAD software, and wood and metal workshop	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	Inbound
Optics-specific tools e.g., lasers with different wavelengths, optomechanical components (e.g., lenses, filters, microscopes, and objectives), optic tables, optics design, and simulation software						✓	✓	✓	✓	✓	Inbound



Figure 3. Prototypes of hobby innovation projects developed in the industry-specific makerspace. Left: Robotics platform for kids (Project D, © Photonics Makerspace). Right: 360° topography drone (Project B, © Photonics Makerspace). [Colour figure can be viewed at wileyonlinelibrary.com]

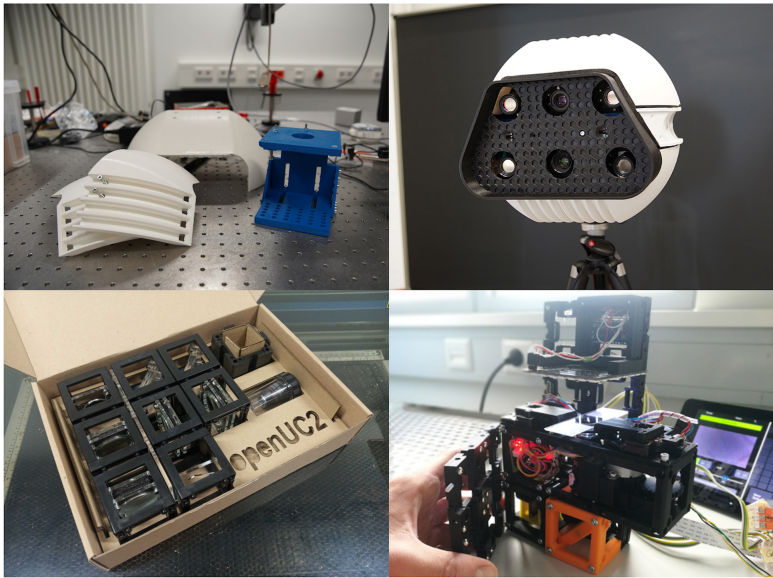


Figure 4. Prototypes of professional innovation projects developed in the industry-specific makerspace. Top: contactless vital sign monitoring system (Project G, © Photonics Makerspace). Bottom: 3D printed microscopy toolbox (Project H, © openUC2, CC-BY-ND 4.0). [Colour figure can be viewed at wileyonlinelibrary.com]

The professional makerspace users (F, G, H, I, J) leveraged general and, in contrast to hobbyists, high-tech photonics-specific resources like lasers, optical lenses and filters, mirrors, wafers, optic tables, or optics design software available in the innovation space. From

the professional users, only the gaming device project (E) focused on more standard technology inbound by primarily using the metal workshop for prototyping.

The strong use of photonics-specific technologies within professional projects might hint that

more complex projects are attracted to the makerspace specifically to use this kind of equipment. This assumption is encapsulated by one of the entrepreneurial makerspace users (F), who used multiple makerspaces and traveled long distances to access the photonics-specific resources.

Another noteworthy aspect discovered during our cross-case analysis regarding the different resource usage was how long the makerspace users stayed within the makerspace while innovating. The hobby projects stayed longer in the makerspace, leveraging the makerspace resources with an open innovation inbound strategy. In contrast, the professional makerspace innovators started jointly developing their projects with professional partners in the development and prototyping stage. They switched from a purely inbound strategy to a coupled development process with partners outside the makerspace community. One example of this behavior is the open-source microscopy toolbox project (H) that switched from 3D-printed lens holders to injection-molded ones. Since injection molding requires the production of specific tools, they had to collaborate and jointly adapt their former design with a professional manufacturer outside the makerspace. The other professional makerspace projects described similar early collaboration behaviors. While project H partially uses the makerspace during diffusion and commercialization for prototyping new product generations, the other professional makerspace projects either moved entirely toward coupled activities with professional designers, manufacturers, and marketers (G, I, J) or paused the project (F, E) when they had finished the early development and prototyping stage. This behavior could hint that professional makerspace users are better aware of the growth limits within a makerspace environment and, therefore, use it more targeted until they have finished the early stages of their innovation process.

4.2.3. Knowledge resources

The knowledge resources provided by the makerspace were leveraged from all innovation projects by purposively seeking out knowledge inflows into their innovation process (inbound open innovation). One exception is the medical drone project (A) where the innovator had an engineering background and was already experienced with the rapid prototyping technologies provided in the makerspace. Knowledge resources in the form of introductory workshops and mentoring by makerspace staff members were most relevant at the beginning of the ideation and development stage and became less relevant over time when the makerspace users had built up the relevant know-how to use the makerspace equipment. Table 10 summarizes what knowledge resources the hobby and professional makers used throughout their innovation journey.

One difference between the innovators is that some of the professional projects (F, I) also used the makerspace expert network to generate additional and more specific knowledge inflows. This is exemplified by the following quote where one of the entrepreneurial makerspace users described the access to photonics-specific knowledge as highly relevant for his project.

The cool thing about the makerspace in Jena is that I gained expertise in fiber optics and had a contact person there that I didn't have [at the makerspace in Dresden] – the expertise that exists in Jena doesn't exist at all in Dresden. [The project] would simply not have been possible without the makerspace [...].
(F, entrepreneurial project)

The quote highlights that the infrastructure of an industry-specific makerspace can complement the benefits of a non-specific makerspace by offering access to specialists and experts that mentor the makerspace projects.

Table 10. Leveraging knowledge makerspace resources

Knowledge resources	Hobby users				Professional users						Open innovation mechanism
	A	B	C	D	E	F	G	H	I	J	
Introductory explanations by makerspace staff e.g., introduction to different technologies such as 3D printing or laser cutting		✓	✓	✓	✓	✓	✓	✓	✓	✓	Inbound
Mentoring by makerspace staff e.g., long-term knowledge exchange with staff members that guide the projects with their expertise about materials and technologies		✓	✓	✓	✓	✓	✓	✓	✓	✓	Inbound
Access to experts e.g., active introduction to experts with in-depth knowledge for example in the field of optics and photonics						✓			✓		Inbound

Table 11. Leveraging financial makerspace resources

Financial resources	Hobby users				Professional users						Open innovation mechanism
	A	B	C	D	E	F	G	H	I	J	
Project-specific consumables e.g., small project-specific investments in the form of special 3D-printing filament or laser cutting materials for development and prototyping or material testing	✓	✓	✓	✓		✓		✓			Inbound
Project-specific tool acquisitions e.g., significant project-specific investments into technology like cameras, lasers, sensors, or other equipment needed to realize a specific project	✓	✓	✓	✓							Inbound

4.2.4. Financial resources

The financial resources provided by the makerspace were used differently by the hobby and professional makerspace innovators. Early financial support through project-specific investments was highly relevant for most hobby projects to kickstart (A, B, C), test, and further develop (D) their ideas. Investments supported by the makerspace were, for example, a heavy payload drone (A), special drone parts (B), specific camera systems (C), and a set of programmable educational robots. The financial resources of the makerspace stayed relevant for the hobby makerspace users even when they reached the diffusion and commercialization stage to support the project result diffusion, for example, by providing free infrastructure for workshops and other events. Table 11 captures the main differences in how hobby and professional users leveraged their financial resources.

Interestingly, unlike the hobby projects, none of the professional projects used the project-specific financial resources provided by the makerspace during the ideation phase. Also, most of the professional projects just used the tools and equipment already available at the makerspace (E, G, I, J), during the development and prototyping, without requiring further project-specific investments. Exceptions were the gesture-controlled speaker lamp project (F) and the 3D printed microscopy toolbox (H) that got financially supported by the makerspace through the procurement of project-specific consumables in the form of specific 3D printing filament for design and material tests. In summary, the professional projects did not rely on the financial resources of the makerspace and perceived it more as a technical facilitator during the early stages of their innovation process. This perspective is captured well by the following quote describing the facilitator role the makerspace takes during the innovation process.

The very extensive construction kit, [...] made it possible to realize very different proofs of principles [...] I actually don't expect to see such not-quite-cheap things as we have for the scanner, the light source, and the camera. That's not the job of a 'makerspace' to provide that kind of thing. [...] But the experience [...] how to quickly set something up optically plus the many possibilities to actually make it, that's what we used.
(I, industry project)

In a nutshell, the main differences between a hobby and professional makerspace innovators lie in the timing of when they leave the makerspace environment and their approaches to leverage social, technological, knowledge, and financial resources. In summary, the data analysis revealed three interesting aspects.

First, hobby makerspace innovators stay in the makerspace during their commercialization and diffusion phase to disseminate their project results within the makerspace community. In contrast, professional makerspace users mostly leave the makerspace before the commercialization and diffusion phase and cooperate with professional partners outside the makerspace community to support the market launch and commercialization.

Second, regarding the applied innovation strategies to leverage the social resources, we found that hobby makerspace users prefer passively sharing the first project progress (free revealing and outbound) to attract fellow contributors starting in the late ideation and early development and prototyping phase. In contrast, professional projects focus on active openness by selectively revealing intellectual property during event formats. Both user groups benefit from the provided technological resources, while the professional makerspace users specifically leverage the photonics-specific tools. Regarding the provided knowledge resources, we found that all innovators use them, while some of the professional innovators also used access to experts within the makerspace network.

Financial resources seem to play an important role for hobbyists to kickstart their projects. Thereby, the financial resources lower general innovation barriers.

Third, we found that both groups of innovators never follow long-term a closed innovation approach, which indicates that resource constraints force all makerspace users to open up and collaborate with partners close to the makerspace community (hobby innovators) or professional partners (professional innovators).

4.3. The role of makerspaces for hobby and professional innovators

In addition, our data reveals two main pathways for how users integrate makerspaces into their innovation process. The two prominent roles makerspaces can take are (1) makerspace as a facilitator and (2) makerspace as an incubator. Figure 5 summarizes the two main pathways of makerspace users during their innovation journey.

The makerspace users that use the makerspace as facilitators (E, F, G, H, I, J) spend less time in the makerspace, knowing the limitations of what the

makerspace can provide for their innovation project. The following quote captures this well:

[...] makerspaces [...] take in my opinion often the role of facilitators [...] they [...] help to lower barriers without actively intervening, for example, by establishing these infrastructures, just already remove certain hurdles. (G, entrepreneurial project)

Another characteristic of this user group is that they primarily work on closed-source projects where project success is defined by an outcome that can be commercially exploited. Interestingly, this group of users seeks professional partners outside the makerspace early in the ideation and development stage to overcome resource constraints concerning product design, functionality, manufacturing, and distribution (coupled innovation strategy).

The makerspace users that use the makerspace as an incubator (A, B, C, D) tend and plan to stay longer in the makerspace. In contrast to the other user group, they primarily work on open-source projects where the project outcomes are openly shared with the makerspace community and the broader public to attract fellow contributors and diffuse their outcomes into society (outbound innovation strategy).

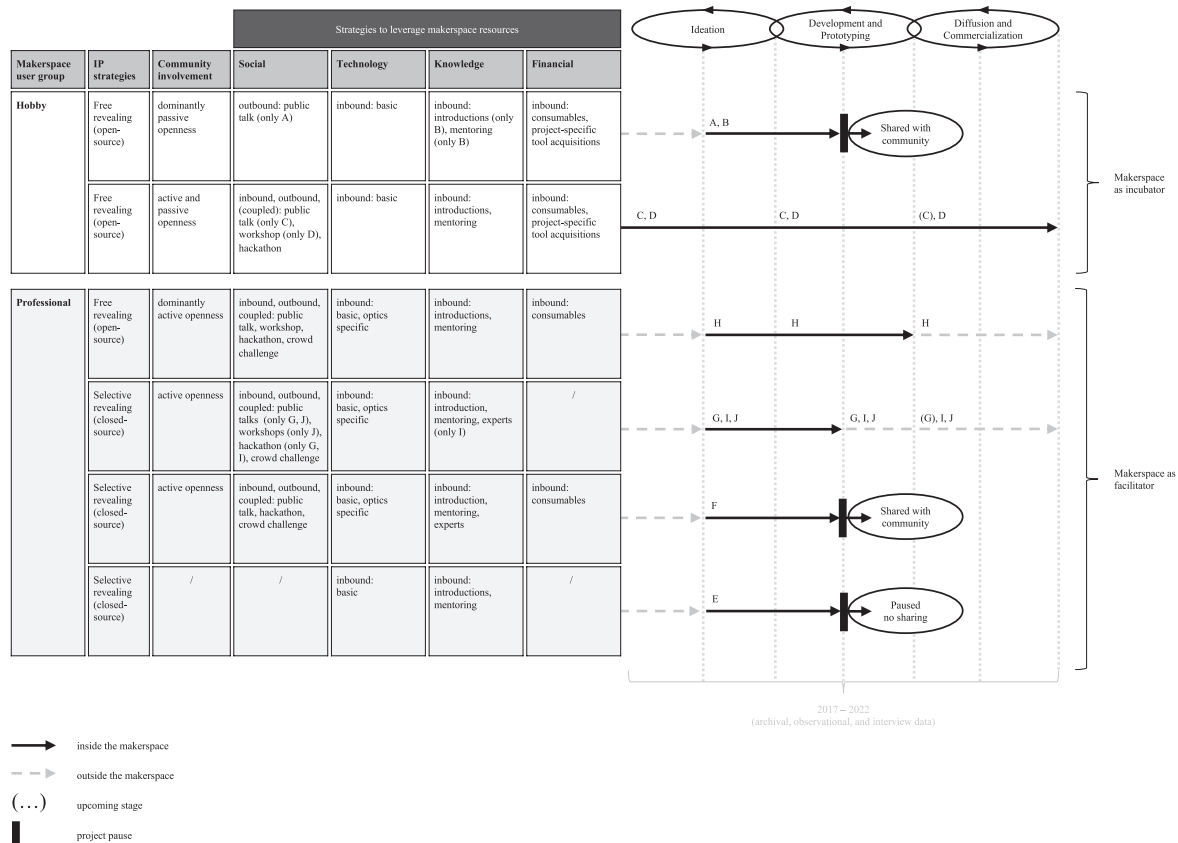


Figure 5. The different roles of makerspaces during innovation processes.

This user group tries to overcome resource constraints through the makerspace and with the help of its broader community or partners with close cultural proximity, like citizen science initiatives. The collaboration with professional manufacturing and distribution partners starts later or is not considered at all.

From the perspective of innovation outcome, it can be concluded that makerspaces support different kinds of innovations by providing access to shared resources. The outcomes are diverse, and we found both incremental and more radical innovations that were freely shared or commercialized. Even if projects were paused or stopped, the results were usually made available to the makerspace community. However, we find no evidence that makerspaces promote an increase in startup foundation *per se*, as none of the hobby innovators that explored the idea of becoming an entrepreneur at the beginning of their journey converted the innovation project into a startup. The theoretical and practical implications of these findings are the subject of the following section.

5. Discussion and implications

5.1. Implications for theory and practice

Scholarly, we extend and connect the maker community and open innovation research streams. Our empirical study contributes to the understanding of innovation processes within makerspaces, which resources are needed, and what innovation strategies are applied.

First, we contribute to the maker community research stream by combining a simplified innovation process with the theoretical makerspace resource model of Browder et al. (2019) and derive a more detailed understanding of innovation processes within makerspaces. Thereby, we contribute to the discussion on how makerspaces foster innovation and how different makerspace users leverage innovation space resources in their innovation process (Mauroner, 2017; van Holm, 2017; Halbinger, 2018; Mortara and Parisot, 2018; Svensson and Hartmann, 2018; Browder et al., 2019; Beltagui et al., 2021). Earlier research by Mauroner (2017) and Beltagui et al. (2021) connected the innovation process of makerspace users with the concept of bricolage (Levi-Strauss, 1966; Baker and Nelson, 2005; Stinchfield et al., 2013). In this sense, makers can be seen as constant problem solvers with access to shared resources provided by the makerspace environment. During their

innovation process, they can use the makerspace resources at hand to solve their innovation problems. Our findings indicate that hobby makerspace users, in particular, seem to act like bricoleurs using the resources at hand. For this user group, the makerspace acts as an incubator that is used long-term. In contrast, professional makerspace users seek external partnerships early to extend their resources. They tend to leave the makerspace sooner and see its role more as a facilitator during early project development. This finding expands our understanding of how makerspaces are used.

Second, empirical research about how makers innovate and what resources they use has mainly focused on non-specialized makerspaces. At the same time, we can observe the phenomenon that research institutes, universities, and private companies establish more specialized makerspaces to foster user innovation in know-how intense environments, such as biotechnology (Kera, 2012; Vuylsteke et al., 2022), healthcare (Svensson and Hartmann, 2018), physics (Fonda and Canessa, 2016), or quantum technologies (Ritter et al., 2021). Our study shows that specialized makerspaces can be complementary resource providers for hobby and professional innovators. Hence, this study contributes to understanding the relevance of different places and spaces for innovation and entrepreneurship (Peschl, 2012; Caccamo, 2020).

Third, we elaborate on the theoretical contribution of Browder et al. (2019) by specifying and expanding the resources relevant to makerspace innovators during their innovation journey. We refine the social, technological, and knowledge resources and thereby contribute to a better understanding of what resources are relevant for innovators in makerspace environments and how they are leveraged. Moreover, we demonstrate the importance of financial support as a relevant additional makerspace resource that can positively influence the innovation journey of makerspace users. Interestingly, financial resources provided by the makerspace seem to be especially relevant to open-source hobby innovation projects, which might be connected to the finding that most hobby innovators mentioned a lack of business-related knowledge. This seems to make it difficult for them to develop a solid financial plan or a viable business model in the early development stages. This might explain why our dataset did not provide examples of hobby innovators becoming accidental entrepreneurs (Shah and Tripsas, 2007; van Holm, 2017).

Fourth, our study extends the open innovation research stream by connecting it with a new context, namely the maker movement. Thereby, we follow the call of Bogers et al. (2017) to explore the open innovation phenomenon in different contexts

apart from the commonly studied area of companies. Our findings suggest that makers intuitively use different open-innovation modes and rarely peruse a closed innovation strategy. Hobby makerspace innovators use the strategy of free revealing (Henkel et al., 2014) mainly to attract fellow contributors to their projects. In contrast, professional makerspace users tend to apply selective revealing (Henkel et al., 2014) to keep better control over their intellectual property. Furthermore, we find in the context of makerspaces, that selective revealing always goes along with active openness (e.g., hackathons), whereas free revealing is associated with both active and passive openness (e.g., source code publication) to involve the community. With these findings, we deepen the understanding of IP strategies in a new context and add to open innovation theory development (Harhoff et al., 2003; Henkel et al., 2014).

For policymakers, the funding or support of industry-specific makerspaces might be helpful to push innovation in future-relevant technology fields like biotechnology, artificial intelligence, robotics, or quantum computing. Through our case study, we revealed that the innovation outcome of makerspaces is manifold and can lead to both incremental and radical innovation based on closed or open-source approaches. For fostering technology transition and making innovations more accessible, open-source projects are especially valuable for society and wealth. The social value became evident, for example, during the global COVID-19 pandemic when local maker communities openly shared designs of clinical care equipment with the global maker community and incumbent manufacturers to enable an immediate crisis response (Corsini et al., 2020, 2021; Bertello et al., 2021).

5.2. Limitations and future research

In general, maker community research is still evolving and offers enormous potential for additional research. Since we use a qualitative single-case study design, our study allows for explorative insights but has implied limitations in broader generalizability. Therefore, we encourage researchers to conduct quantitative studies to examine the relevance of the described makerspace resource dimensions (social, technology, knowledge, financial) in different makerspace environments and at different stages of the innovation process. Additionally, examining the innovation motives of hobby and professional makerspace innovators could contribute to entrepreneurship research and improve understanding of why hobby makerspace users seem to not transform into entrepreneurs. Furthermore, our study focused on young innovation projects to better understand the influence of makerspaces on the innovation process.

Therefore, one limitation of our study lies in the selected projects. Future studies could focus on understanding long-term innovation success by collecting data on more mature makerspace projects already established in the market. Another limitation of our study is the retrospective character of our dataset. Future longitudinal studies could try to increase the amount of real-time data to better grasp the process character of the innovation journey, for example, by interviewing the makerspace innovators about the ideation stage when they are actually in it to avoid a retro perspective bias. Future longitudinal maker community research could also explore why makerspace innovation projects are discontinued. Moreover, investigating how companies can benefit from internal makerspace initiatives or collaboration with external makerspaces is an additional direction for future research.

6. Conclusion

Our research sheds light on the innovation process of hobby and professional makerspace users by investigating an industry-specific makerspace with a focus on photonics. In contrast to non-specialized makerspaces, those with an industry focus grant access to advanced technologies and specific know-how. The results show that industry-specific makerspaces can be a complementary infrastructure to drive innovation in very specific technology fields.

Through our research, we contribute to the understanding of how the innovation processes within makerspaces look, which resources are needed, and what innovation strategies are applied during the journey from ideation to commercialization and diffusion. Our results reveal that hobby innovators and professional makerspace users leverage makerspace resources differently and that makerspace users intuitively apply different open innovation strategies throughout their innovation journey. Moreover, we find that professional makerspace innovators use the makerspace more as a facilitator. In contrast, hobby innovators use it as an incubator, meaning they stay longer and leverage available financial resources to kickstart their projects. Interestingly, in our data, no hobby makerspace user eventually founded a business, indicating that the original project motivation did not change over time. Nonetheless, we see that most makerspace projects generate different types of outcomes that are disseminated, either by sharing or by commercializing the project results. This insight leads us to conclude that the societal value of makerspaces is not only about turning every hobbyist into a potential entrepreneur.

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Data availability statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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APPENDIX

Table A. Interview guideline first interview

Stage	Theme	Questions	Additional material ¹
General information	Personal and project background (e.g., Mauroner, 2017; Mortara and Parisot, 2018)	<ul style="list-style-type: none"> • Can you start by saying a little about yourself and your professional background? • What project are you pursuing in the makerspace and how did you come up with the idea? • Are more than one person involved? Where did you meet each other? • When did you get the idea and when did you start working on it for the first time? • Did you come to the Makerspace with the idea or did the idea originate in the makerspace? • What motivates you to work on the idea? (intrinsic vs. extrinsic) • Is your idea a product or a service? • How do you rate the novelty of your idea? (regional, national, worldwide market novelty, radical vs. incremental...) • In which phase of the product development process are you currently (ideation, development and prototyping, commercialization, and diffusion)? • For whom are you developing the product? What are your motives? (to start-up, self-realization, maker community...) • Do you intend to commercialize the product/service (open source and closed source)? 	A
Impact of the makerspace on the innovation process	General use and used formats (e.g., Mauroner, 2017; Mortara and Parisot, 2018)	<ul style="list-style-type: none"> • How did the makerspace support you in the innovation process or what were the challenges/problems as well? • What formats of the makerspace did you use? (lectures, workshops, hackathons, innovation camps, open lab day, mentoring, makers, other makerspaces, other). • At what stage of your innovation process (ideation, development and prototyping, commercialization and diffusion) did you use which formats? • How regularly do you use the makerspace? • Have other makers helped you with implementation? • Did you use other makerspaces or how did you deal with problems during the process? 	B
	Resource dimensions (e.g., Stinchcombe, 1965; Heirman and Clarysse, 2004; Browder et al., 2019; Rayna and Striukova, 2021)	<ul style="list-style-type: none"> • How important do you consider these four resources in relation to your innovation project (social, technology, knowledge, and financial resources)? • How important were they in the different innovation phases of your project? • If you were to rate on a scale of 1–7 how helpful the 4 different dimensions were in the three innovation phases, how would you rate them? Where 1 means not relevant at all and 7 means very relevant. 	C
	Innovation strategy (e.g., Chesbrough, 2003; Gassmann and Enkel, 2004; Appleyard and Chesbrough, 2017; Sims et al., 2019)	<ul style="list-style-type: none"> • Does your product/service build on existing products/services? • Is it an open source or closed source product/service? • How open were you in the ideation, development and prototyping, commercialization, and diffusion phases in terms of your knowledge sharing? How did you go about it/what strategy did you use? Why? • Did the openness level of the product change over time? If so, why? • Why did you choose an open model, why a closed one? (IP, speed...) • In academia, different open innovation strategies are distinguished. There is a distinction between inbound, outbound, coupled, and closed innovation. Which strategy did you use in which phase of your innovation process and why? 	D

Stage	Theme	Questions	Additional material ¹
Main challenges	Main challenges (e.g., Giusti et al., 2020; Mortara and Parisot, 2018; Browder et al., 2019)	<ul style="list-style-type: none"> • What are your main challenges in product development? • Which of the following resource dimensions are currently causing you the most problems (social, technology, knowledge, and financial resources)? • Have the challenges changed during the innovation process? Why? • Can you assign the biggest challenges and benefits of the makerspace to each stage of the innovation process? • Thinking about different types of knowledge, what knowledge are you still missing the most currently? (e.g., technological, market, management, industry-specific knowledge, financial knowledge, and institutional knowledge) 	
Business model	Business model (e.g., Osterwalder and Pigneur, 2010; Chesbrough et al., 2018)	<ul style="list-style-type: none"> • How do you envision benefiting personally from your idea? (monetary vs. non-monetary reward; recognition in the community...) • How do you currently benefit from it? • Have you thought about a business model? (value proposition, how to create, deliver, and capture value) 	
Demographics	Demographics	<ul style="list-style-type: none"> • Where are you from? • Your gender • Your age • Education • Profession 	
Final remarks	Additional information	<ul style="list-style-type: none"> • Is there anything else you would like to tell me? 	

¹Letters indicate at what point in the interview respondents were given an additional sheet to visualize their answers and make it easier to answer (see Appendix Figure A).

Table B. Interview guideline second interview

Theme	Questions	Additional material ¹
Introductory questions	<p><i>This follow-up interview is about understanding the innovation process of makerspace users better. We had already talked about your Makerspace project in 2019/20</i></p> <ul style="list-style-type: none"> • What is the current status? Does the project still exist? What stage of the innovation process are you in? (ideation, prototyping and development, diffusion, and commercialization) • Do you use the project output personally and therefore work on the project (user), or is it a company project or did you want to start with it from the beginning? • Did the Covid pandemic have an impact on the development of the project? If yes, which ones? • Do you still use makerspace today? Why yes/no? 	A
Innovation process	<p><i>The following questions are about understanding your innovation process in more detail</i></p> <ul style="list-style-type: none"> • Can you briefly describe how you went about the innovation process? What was the starting point? How did you make decisions? <p><i>Last time we talked about how the resources of makerspace are relevant to the innovation process of your project</i></p> <ul style="list-style-type: none"> • Could you briefly describe again which resources were particularly relevant in which phases? • Did you use resources outside of makerspace to develop your project? If so, which ones and why? <p><i>Specifically, last time we talked about: technological, social, knowledge, and financial resources</i></p> <ul style="list-style-type: none"> • Could you briefly describe again when which of these dimensions were relevant in the innovation process? Has this changed? <p><i>The following questions are about understanding your innovation process in more detail</i></p> <p><i>Innovativeness</i></p> <ul style="list-style-type: none"> • How important was it for you to develop something new as part of your project? • How do you rate the degree of innovation of your project? <p><i>Proactiveness</i></p> <ul style="list-style-type: none"> • How important was it for you to be the first to implement this idea? • Have you looked if something like this already exists on the market or have you screened the market/other maker projects in a structured way? <p><i>Risk taking</i></p> <ul style="list-style-type: none"> • How many resources do you invest in the project? How much time do you invest in the project? Is it your main job? • Would you like to start up with this idea or market it? • Do you invest private money or what is the invested budget of the company? <p><i>Passion</i></p> <ul style="list-style-type: none"> • What motivates you or has motivated you to work on the project? • Do you see the project as a hobby or work? <p><i>Perseverance</i></p> <ul style="list-style-type: none"> • How long have you been working on the project or how long have you been working on the project? • Where do you want the project to go in the future? (if the person is still working on the project) 	C
Innovation strategies	<p><i>Last time we also talked about the extent to which the innovation process of the project is open and in which phases</i></p> <ul style="list-style-type: none"> • Could you retrospectively describe again in which phases you were open or closed? Did this change? <p><i>Specifically, last time we had talked about: inbound, outbound, coupled, or closed innovation practices/strategies</i></p> <ul style="list-style-type: none"> • Could you briefly describe again when which practice/strategy was relevant in the innovation process? 	D
Final remarks	<ul style="list-style-type: none"> • Is there anything else you would like to share with me? 	

¹Letters indicate at what point in the interview respondents were given an additional sheet to visualize their answers and make it easier to answer (see Appendix Figure A).

Table C. Event overview 03/2017–12/2022

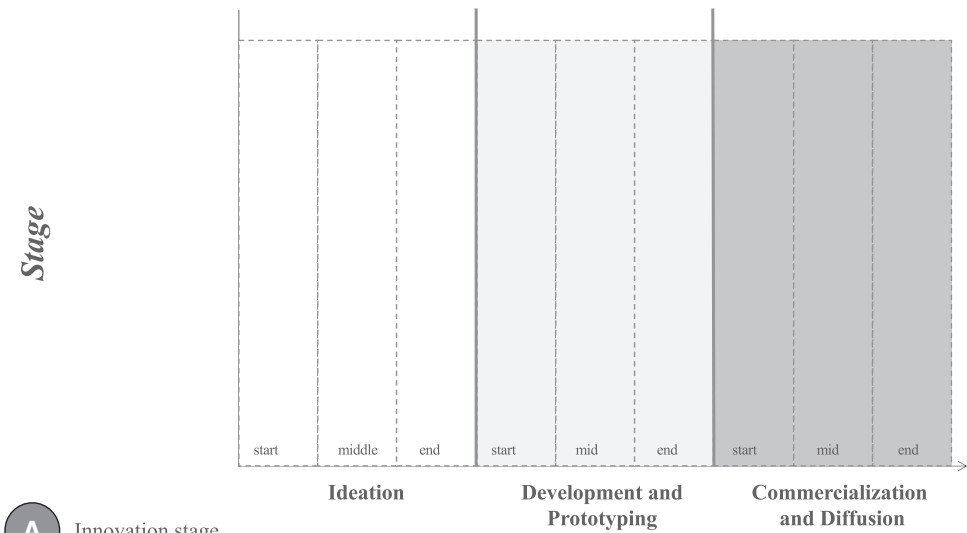
Year	Event overview ¹	Date	Hobby users			Professional users										Target group	Open innovation mechanisms
			A	B	C	D	E	F	G	H	I	J					
2017	Opening photonics makerspace	03/2017															
2018	Hackathon	04/2018				✓									Maker community	Outbound, inbound, (coupled)	
	Workshop	07/2018										✓			Maker community	Outbound, inbound	
	Workshop	09/2018				✓									Public and maker community	Outbound, inbound	
	Public talk	09/2018	✓												Investors, public, and maker community	Outbound	
	Public talk	10/2018	✓												Investors, public, and maker community	Outbound	
	Workshop	10/2018							✓						Maker community	Outbound, inbound	
2019	Public talk	11/2018							✓						Public, industry, and maker community	Outbound	
	Public talk	03/2019													Public, industry, and maker community	Outbound	
	Hackathon	05/2019				✓				✓					Maker community	Outbound and inbound	
	Workshop	06/2019								✓					Maker community and users	Outbound and inbound	
	Public talk	06/2019						✓		✓		✓			Industry and maker community	Outbound	
	Crowd challenge	07/2019						✓		✓		✓			Maker community	Coupled	
	Workshop	09/2019								✓		✓			Maker community and users	Outbound and inbound	
	Hackathon	09/2019						✓		✓		✓			Maker community	Outbound, inbound, and (coupled)	
	Public talk	09/2019							✓						Investors, public, and maker community	Outbound	
	Workshop	10/2019								✓					Maker community and users	Outbound and inbound	
2020	Workshop	11/2019													Maker community and users	Outbound and inbound	
	Public talk	11/2019				✓				✓					Public, industry, and maker community	Outbound	
	Workshop	12/2019				✓									Maker community and users	Outbound and inbound	
	Start Covid-19 pandemic	01/2020															
	Public talk	01/2020							✓						Industry	Outbound	
	Public talk	04/2020							✓						Maker community and industry	Outbound	
2021	Public talk	07/2020	✓												Public, industry, and maker community	Outbound	
	Hackathon	09/2020			✓			✓		✓					Maker community	Outbound, inbound, and (coupled)	
	Public talk	11/2020						✓							Maker community	Outbound	
	Public talks	06/2021						✓							Maker community	Outbound	
	Public talks	06/2021							✓						Investors, public, and maker community	Outbound	

Year	Event overview ¹	Date	Hobby users		Professional users							Target group	Open innovation mechanisms
			A	B	C	D	E	F	G	H	I	J	
2022	Crowd challenge	04/2021–07/2021						✓		✓		Maker community	Coupled
	Company formation	09/2021							*				
	Public talk	01/2022								✓		Maker community	Outbound
	Workshop	03/2022				✓						Maker community and users	Outbound and inbound
	Public talk	04/2022								✓			Outbound
	Public talk	06/2022							✓			Maker community	Outbound
	Crowd challenge	04/2022–07/2022							✓			Maker community	Coupled
	Company formation	08/2022								*			
	Public talk	11/2022								✓		Public, industry, and maker community	Outbound
	Hackathon	10/2022								✓		Maker community	Inbound and coupled
	Workshop	11/2022								✓		Maker community and users	Outbound and inbound
	Workshop	11/2022				✓	(4)					Maker community and users	Outbound and inbound
	Public talk	11/2022								✓		Public, industry, and maker community	Outbound
	Workshop	12/2022				✓	(3)			✓		Maker community and users	Outbound and inbound

¹Data sources: interviews (08/2019 – 01/2020 and 08/2022 – 09/2022), observation (06/2019 – 12/2022), and archival data (03/2017 – 12/2022).

Question:

In which phase of the product development process are you currently?



Question:

What formats of the makerspace did you use? (talks, workshops, hackathons, innovation camps, open lab day, mentoring, makers, other makerspaces, other)

Formats

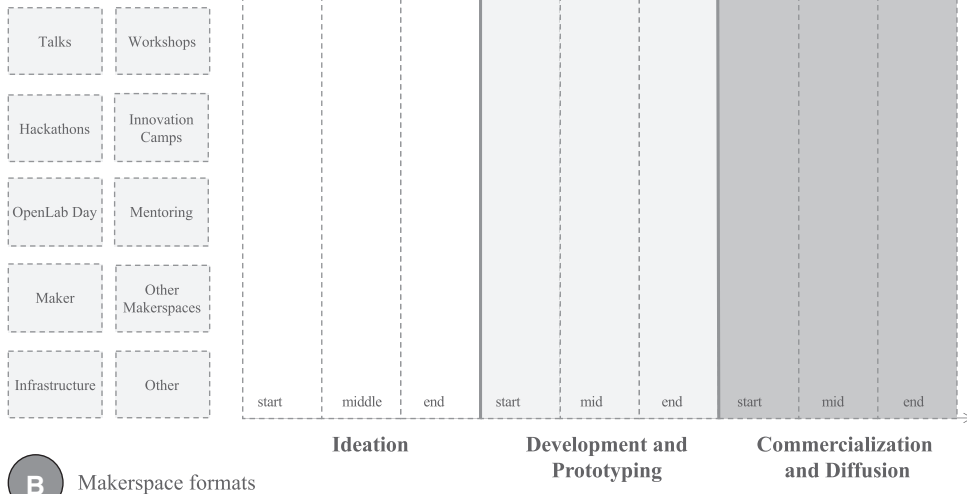




Figure A. Interview support material.