Research Paper

Circular Entrepreneurship via Makerspaces Towards Fostering Sustainable Cities: A Mixed-Method Approach with Case Studies

N. Premyanov[1], E. Roma-Athanasiadou[1], Julie Metta[2], N. Tsoniotis[3,4], M. Angelidou[1], and A.C. Tsolakis[1,*]

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Abstract

This paper discusses the role of makerspaces in supporting circular entrepreneurship and their potential contribution to urban regeneration. Urban regeneration addresses urban challenges through sustainable and inclusive transformations. Circular makerspaces can support this direction by providing resources for makers and promoting a circular economy, while potentially acting as hubs for circular social innovation. However, to unlock makers' full sustainability potential, makerspaces require business support services that foster entrepreneurial mindsets towards a circular economy. This study uses a mixed-method approach, including action research, surveys, observations and case studies, to analyse the design and implementation of a circular accelerator programme in makerspaces across seven cities in Europe and Türkiye, supported with data gathered from 105 makers and 40 projects in circular entrepreneurship. The research suggests potential benefits such as the improvement of entrepreneurial skills, environmental impact awareness, and the enhanced network and collaborations, fostering further opportunities for the development of circular economy. The paper suggests that acceleration programmes via makerspaces focused on circular economy can have multiple benefits for both the makers and their urban context. These findings could support administrators, municipalities, urban planners and policy makers to examine additional ways to support urban regeneration and sustainability.

Keywords: Circular Economy · Maker Movement · Social Innovation · Citizen Participation · Innovation Ecosystem · Urban Regeneration

1. INTRODUCTION

By the end of the 21st century, cities are expected to accommodate a staggering 85% of the predicted 10 billion global population (Cheshire and Batty, 2022). However, the rapid influx of people in urban areas has outpaced urban planning and adaptation efforts, resulting in overcrowding in some areas and vacant spaces in others, accompanied by different quality of life and socio-economic growth. Recent global events, such as pandemics, conflicts, and natural disasters, highlight the need for efficient urban planning and the adoption of inclusive and sustainable approaches. These events have also emphasised the urgency for transformative changes in urban development, highlighting the need to address inclusivity, sustainability, and resilience, key concepts for sustainable cities (Paes et al., 2023).

Urban regeneration has become a comprehensive solution to address these challenges, focusing on the sustainable and inclusive transformation of physical, economic, social, and environmental dimensions (Roberts and Sykes, 1999; Evans and Jones, 2008). It can catalyse the creation of sustainable cities by fostering inclusive practices and empowering communities to actively participate in shaping the future of their urban environments. In recent years, there has been a notable shift towards bottom-up approaches in urban regeneration, driven by citizen-led initiatives, especially in marginalised urban areas where official efforts for change have been limited. Coupled with the adoption of social innovation, which emphasizes the importance of collaboration (dos Santos

[1] Q-Plan International Advisors PC, Thessaloniki, Greece
[2] Research Group Sustainable Development, HIVA, KU Leuven, Belgium
[3] Ideas Forward, Thessaloniki, Greece
[4] Municipality of Thessaloniki, Thessaloniki, Greece
[*] Corresponding author: tsolakis@qplan-intl.gr

Figueiredo et al., 2022), citizens and public administrations have started to interact and collaborate more effectively to transform cities into sustainable, inclusive ecosystems that provide high standards of living for all citizens (Pradel-Miquel, 2021).

According to recent literature, an entrepreneurial dimension may contribute to realizing circular impact and urban regeneration (Suchek et al., 2022; UN, 2023). Circular entrepreneurship involves business models and practices that prioritize the reduction, reuse, and recycling of materials to create sustainable value chains (Cullen and De Angelis, 2021). This entrepreneurial approach may drive circular initiatives within urban settings by creating economic incentives and business models that support sustainable practices. Circular entrepreneurship involves the continuous loop of production processes, minimizing waste, and promoting the sustainable use of resources (Rimmer, 2021). This can contribute to urban regeneration by stimulating local economies, creating jobs, and promoting the sustainable development of urban areas (Coskun, 2024). The maker movement, driven by engaged individuals who go beyond consumption to engage with production in creative ways, exemplifies the spirit of citizen-led urban regeneration and social innovation (Dougherty, 2012). This global phenomenon has gained momentum in recent years, attracting diverse talents and skills in various locations, fostering creativity and community collaboration (Metta and Bachus, 2020). These locations are known as fablabs, tech shops, hackerspaces, repair-cafes, or makerspaces[5].

Makerspaces, generally defined as collaborative workspaces equipped with tools and materials for various creative and productive activities, offer potential for circularity (Metta and Bachus, 2020). They support open, distributed production and democratize entrepreneurship by providing access to resources and knowledge. The European Union currently hosts over 800 makerspaces, which holds a potential in fostering innovation and sustainability (JRC, 2023). Makerspaces can affect cities by contributing to the circular economy, with data suggesting their contribution towards circular economy and sustainability in Europe to amount to millions of euros (approx. 26) annually (JRC, 2023; Probst et al., 2015). This can be attributed partially to the fact that circular economy principles of 'reduce-reuse-recycle' are aligned with makerspaces (Elwakil et al., 2024), actively supporting circular urban production and strengthening social engagement.

Makerspaces, serving as urban hubs of social inclusion and sustainability, offer more than just physical resources, providing opportunities for networking, training, and social services to empower makers and foster productivity (Van Holm, 2015). However, unlocking their full social innovation potential and driving sustainability and socio-economic growth requires a supportive environment that prioritizes the development of an entrepreneurial mindset, along with business knowledge and soft skills (Rayna and Striukova, 2021; Coskun et al., 2022). In developing cities, makerspaces promoting a circular economy can foster sustainable urban development, accelerating their evolution and making tangible contributions to circular supply chains, value chains, and the adoption of a circular mindset (Angelidou et al., 2018; Kruger and Steyn, 2021; Coskun et al., 2022).

By fostering circular social innovation, these inclusive and sustainable makerspaces can influence technological, economic, and environmental impacts on cities, potentially supporting urban regeneration efforts (Tsui et al., 2020; Elwakil et al., 2024). While makerspaces are often celebrated for their inclusivity and sustainability, their outcomes can vary widely depending on the specific practices and resources of each makerspace (Coskun et al., 2022). Studies have demonstrated positive impacts, such as increased community engagement and the development of sustainable products (Van Holm, 2015; Tsui et al., 2020), but challenges remain in consistently achieving these outcomes across different settings (Coskun et al., 2022).

Despite the potential and ambitions of makerspaces, there is a research gap regarding their actual impact on circular entrepreneurship, urban regeneration and their intercept. This paper addresses this gap by providing empirical evidence on the effectiveness of makerspaces in fostering circular entrepreneurship and their role in urban sustainability via their nurtured circular mindsets and ventures. The present work aims to shed light on the following research questions:

- How can circular makerspaces breed circular entrepreneurship?
- How can circular entrepreneurship through makerspaces support urban regeneration and sustainability?

To address these research questions, this study employs a mixed-methods approach, including action research, surveys and case study methodologies, to gather data on the impact of the circular accelerator

[5] Hereafter all referred as makerspaces — more information can be found on https://www.makerspaces.com/what-is-a-makerspace/

programme within makerspaces. This approach, presented in Section 3, allows for an analysis of both qualitative and quantitative aspects (Jefferson et al., 2014), providing an understanding of the programme's effectiveness and the broader implications for urban regeneration and sustainability. The novelty of this research lies in its hands-on evaluation of a circular accelerator programme within makerspaces across multiple cities, highlighting both successes and challenges.

The present study aims to address the various dimensions outlined above while considering the principles of the New European Bauhaus (i.e., Enriching, Sustainable, Inclusive) and the United Nations' Sustainable Development Goals for cities. To do so, it reports and discusses on the activities performed and data collected during the Pop-Machina Circular Maker Accelerator (PCMA) programme, implemented within a network of makerspaces in seven municipalities across Europe and Türkiye, part of the European H2020 Pop-Machina[6] project. The manuscript extends the authors' previous work (Premyanov et al., 2022), that was published early in the deployment of the accelerator programme (after the induction training) and focused on the challenges and mitigation measures during the first steps, towards collecting valuable feedback for the upcoming stages.

The results, presented in Section 4, show that makerspaces, as collaborative workspaces equipped with know-how, tools and materials for various creative and productive activities, may be used as platforms for fostering circular entrepreneurship. These spaces, often by design, support the principles of the circular economy by promoting the reduction, reuse, and recycling of materials, thereby fostering sustainable value chains. The results suggest that makerspaces could enhance entrepreneurial skills, environmental impact awareness, and networking. By providing access to resources, knowledge, and a community of like-minded individuals, makerspaces democratize circular entrepreneurship and empower makers to develop innovative solutions that could contribute to urban regeneration and sustainability.

2. RELATED WORK

2.1 Entrepreneurship as a Driver for Urban Regeneration

By revitalizing urban areas, upgrading infrastructure, and promoting circular and sustainable practices, urban regeneration initiatives contribute to the creation of cities that prioritize environmental sustainability and social inclusivity. Through the integration of innovative technologies, data-driven decision-making, and participatory approaches, urban regeneration could foster economic development, enhance quality of life, and reduce environmental impact while supporting the transition to a circular economy (Girard and Nocca, 2022).

Moreover, urban regeneration projects can focus on enhancing social inclusion by improving accessibility, promoting public spaces for community engagement, and ensuring equitable access to services and amenities. Therefore, urban regeneration acts as a catalyst for the transformation of cities, making them more sustainable, inclusive, and of course technologically advanced. However, this relationship can be bidirectional, with network and collaboration being the most common elements (dos Santos Figueiredo, Prim, and Dandolini 2022). Numerous studies have analysed the relationship between entrepreneurship and urban regeneration, resulting in a spectrum of terminologies and paradigms (Levoso et al., 2020; Ghisellini and Ulgiati, 2020; Gupta, Kumar and Wasan, 2021).

On the one hand, the intersection of the two concepts, entrepreneurial urbanism has been exploring cases of business-driven urban "renaissance" for several decades (Prifti and Jaupi, 2020). Business Improvement Districts, a compelling example of entrepreneurial urbanism, originated in Toronto in 1971 and spread to the UK in 2001 (Ward, 2005). The adoption of entrepreneurial initiatives at district levels has been driving cities' planning policies using both bottom-up and top-down approaches, to assist struggling urban areas in growing. Local businesses have become more involved with local governance, city development funding has become more accessible, and districts have been able to attract and retain a promising workforce, ultimately leading to the overall transformation of the district. Nowadays, the concept of entrepreneurial urbanism has even extended to the recent trend of Smart Cities, creating a stronger connection between technological innovation and urban transformation (Kummitha, 2018).

On the other hand, focusing mainly on the cities' habitats, entrepreneurial citizenship has been (re)defined as driven by the need for (social) change in the immediate living environment. In the Netherlands, emerging initiatives creating entrepreneurial citizens have been discovered to cover both top-down and bottom-up developments, actively supporting urban regeneration in deprived neighbourhoods (Al Sader, Kleinhans and Van Ham, 2019).

[6] https://cordis.europa.eu/project/id/821479

Over the past decade, the highly dependent and productive symbiosis between entrepreneurship and urban regeneration (or transformation), where either side can be a driving force for the other, has gained a lot of ground (Luederitz et al., 2023). Researchers have started to shift their focus towards the correlation with other domains and industries. For instance, in a recent study, the idea of creative placemaking was introduced as the convergence point of entrepreneurship, urban transformation, and the creative and cultural industries (Wise, Özdemir and Fillis, 2022). One of their key findings suggests that micro-level developments can have economic and social impacts on urban transformation. Similarly, coupling with other initiatives and movements, such as the maker movement, can fuel further the effects of such collaboration while acting as a multiplier within the urban fabric at the local, municipal or metropolitan level. Focusing more on circular entrepreneurship may help prioritize even more ecological and social value creation, which are inherent elements of circular business models (Cullen and De Angelis, 2021).

2.2 Circular Makerspaces as Entrepreneurship Platforms for Sustainable Cities

According to the UN (2017) sustainable cities are urban areas designed to balance economic growth, social inclusion, and environmental protection. They ensure access to affordable housing, public services, and participatory decision-making, while building resilient infrastructure to withstand natural disasters and climate change. By promoting efficient resource use through sustainable transportation, waste management, and energy practices, these cities aim to reduce environmental impact. Ultimately, sustainable cities strive to enhance quality of life for current and future generations.

Makerspaces, as physical spaces where makers gather, have the potential to foster circularity and sustainability within urban environments (Coskun et al., 2022). By emphasizing creativity, resourcefulness, community engagement, and sustainable practices, the maker movement aligns with the principles of sustainable cities, working towards the creation of environmentally responsible and socially inclusive urban environments (Javidroozi et al., 2023). Certain maker groups have been recognised to have high potential of being activated as sustainability advocates via their activities in makerspaces (Rahman and Best, 2024). Makerspaces have the potential to support hardware innovation, open distributed production, and democratize entrepreneurship (Saari et al., 2021; Bergman and McMullen, 2020; Ramella and Manzo, 2018). For example, makerspaces have facilitated the development of prototypes for new products, from electronic devices to sustainable materials (Dougherty, 2012). Specific instances include the creation of low-cost medical devices and environmental monitoring tools (Rimmer, 2023), showcasing their impact on innovation. Therefore, they can empower makers in urban contexts by providing circular entrepreneurial tools, skills and knowledge (Maravilhas and Martins, 2018; Rayna and Striukova, 2021; Doussard et al., 2018; Geissdoerfer et al., 2018), thereby contributing to urban sustainability, planning, and resilience at various levels, from municipal to citizen (Millard et al., 2018; Galuppo et al., 2019).

By offering access to infrastructure and resources (most often of secondary use), makerspaces facilitate the development of sustainable products, thus contributing to the achievement of circular economy objectives (Doyle, 2019) and the advancement to zero-carbon and zero-waste sustainable cities. This is also supported by the fact that hardware innovation can support the design, development, operation and maintenance of sustainable cities.

From a municipality's perspective, the implementation of circular makerspaces raises local awareness and increases the likelihood of circular and collaborative ideas reaching the market. This enriches the socio-economic production ecosystem in a sustainable and democratized manner, aligning with municipal circular economy strategies and UN Sustainable Development Goals (Millard et al., 2018; Galuppo et al., 2019). Municipal makerspaces also serve as communication channels, enabling dialogue between the municipality, citizens, and makers. This facilitates bottom-up needs shaping local decision-making and policy development, fostering a participatory approach (Millard et al., 2018; Doussard et al., 2018). Engaging citizens as makers cultivates a range of circular and green skills, including entrepreneurship and environmental impact awareness. This engagement also promotes a better understanding of local circular value chains and their potential, enhancing the viability, scalability, and sustainability of supported business endeavours and contributing to the transition to a circular and sustainable economy (Doussard et al., 2018; Rayna and Striukova, 2021).

Hence, makerspaces could serve as platforms for sustainable entrepreneurship, empowering makers with circular entrepreneurial skills and knowledge. However, unlocking their potential is challenging and requires dedicated entrepreneurial training and research focusing on governance structures and business-related aspects (Browder, Aldrich and Bradley, 2019; Mersand, 2021; Coskun et al., 2022). In particular, makers that are trying to monetise their ideas, often encounter a series of challenges, particularly in areas related to business models

and scalability (Geissdoerfer et al., 2018; Doyle, 2019; Doussard et al., 2018). Therefore, equipping makers with both hard and soft skills would mostly allow them to overcome these challenges to increase their propensity towards making a circular impact in their living urban environment leading ultimately to its regeneration.

Even though there are already a lot of circular acceleration programmes - and many more are being created at this point - the literature to study them is very scarce (Bank, Fichter and Klofsten, 2017), and there are very few executed targeting makers via makerspaces. In Europe, very few makerspaces are interested in entrepreneurship (Rosa et al., 2017), with even fewer having organised and deployed acceleration processes for makers. While the EU-27 together with the UK, count over 800 makerspaces - 822 according to JRC (2023), only 4% (i.e., 34) expressed an interest in entrepreneurship). Evidently, besides a few exceptions, the majority of makerspaces is still focused on (circular) educational and collaborative activities, that do not extend to entrepreneurship.

3. MATERIALS AND METHODS

This section describes both the set-up of the circular accelerator programme and the approach taken to answer the research questions. To address the research questions, we employed a mixed-methods approach, including action research, surveys, and case study methodologies. This approach allowed us to gather qualitative and quantitative data, providing an understanding of the programme's effectiveness and the broader implications for urban regeneration and sustainability.

3.1 Circular Accelerator Programme Set Up

A circular accelerator specifically targeting makers has been developed in the context of the Pop-Machina project, following the important components as presented in Pauwels et al. (2016), i.e., a portfolio of training, mentoring, and coaching aimed at imparting critical skills to makers. The Pop-Machina Circular Maker Accelerator (PCMA) programme was designed to provide business support to makers, with a focus on fostering circular entrepreneurship. The programme was deployed in seven cities: Istanbul (Türkiye), Kaunas (Lithuania), Leuven (Belgium), Piraeus (Greece), Santander (Spain), Thessaloniki (Greece), and Venlo (the Netherlands). The main goal of the PCMA was to encourage innovation and business opportunities from collaborative circular production projects within makerspaces and help these projects find a path to market and secure funding. With this goal in mind, the design of the PCMA also incorporated values such as inclusiveness, sustainability, creativity, know-how, collaboration, and openness.

Considering the above scope, objectives, and values, the PCMA programme consists of three stages: (1) induction training, (2) extended mentoring, and (3) focused business modelling and planning. The programme supported 105 makers and 40 projects across the seven cities. The initial selection of participants was based on a non-competitive application process, ensuring inclusivity and broad participation from the local maker communities. In between the three stages, two screenings were conducted to select the most promising "makepreneurs" (Figure 1). This allowed the programme to focus resources on projects with the highest potential for success and impact. Further details on the programme set-up and replication advice, including the specific training modules, mentoring approaches, and business support mechanisms, can be found in the "POP-MACHINA Circular Maker Accelerator Handbook" (Tsolakis et al., 2023).

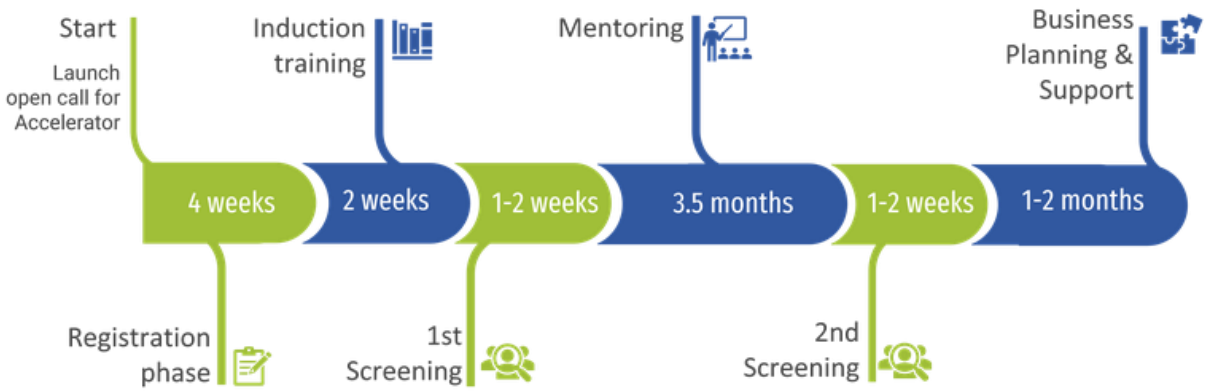

Figure 1. The Pop-Machina Circular Maker Accelerator Deployment Process

The PCMA was designed to equip makers with tools and knowledge to navigate the challenges of circular entrepreneurship, supporting them to transform their ideas into profitable and sustainable businesses. By delivering the programme through makerspaces, the programme expanded upon existing technical training and facilitated access to equipment for rapid prototyping and testing. The broader objective was to not only encourage economic growth but also contribute to the local urban transformation towards a more sustainable, inclusive and circular urban environment (Hallen, Cohen and Bingham, 2020).

The PCMA was piloted in 2022 across the seven Pop-Machina pilot cities (see above), each with a unique ecosystem, which required a diverse timeline to cater to the needs and challenges of the local community. In fact, the most compact delivery of the PCMA programme followed the original timeline, delivering all results within five (5) months (original plan); whereas the most extended delivery lasted almost a year, delivering the final business plans in early 2023.

3.1.1 Induction Training

The first stage is designed to support all interested makers with a comprehensive introduction to the basic terms, fundamental skills, and knowledge needed to succeed in business. As the maker audience is quite diverse, it is beneficial to instil the grassroots, in terms of circular business knowledge and skills. Therefore, a set of ten courses (openly available on the Pop-Machina Open Knowledge Tool[7]) was designed to offer basic business knowledge, circular and environmental elements, and finally access to funding and financing aspects (the ten courses are: Business Strategy, Business Model, Business Plan, Financial Plan, Design Thinking, Assumption Mapping and Experimentation Design, KPI management, Effective Collaboration, Environmental Management, and Access to Funding Opportunities).

This training was (and still is) accessible to all makers to ensure lasting effects on the wider maker community, regardless of their participation in the subsequent phases. By the end of this stage, 105 makers have been registered and trained.

3.1.2 Mentoring

A screening process is employed to select the most promising projects that are offered the opportunity to closely interact with experienced mentors, either through focused masterclasses or through one-to-one sessions. The screening process included a set of questions that aimed to evaluate:

(i) the concept and innovativeness of the proposed solution; evaluating the clarity and feasibility of the proposed solution, as well as its innovation and circularity (current and potential).
(ii) its environmental and societal (scalable) impact; extending to environmental and societal benefits, while also assessing whether the solution proposed is scalable or not.
(iii) its market uptake potential; covering the viability of the business idea and the market uptake potential.

The answers from the makers were evaluated by the mentors and coaches in each makerspace, considering additional aspects such as the business maturity of each team, as well as their background as makers (since they may not be accustomed with business grassroots).

[7] https://okt.pop-machina.eu/

While going through this stage of mentoring and coaching, the makers had also the opportunity to actively participate in other makerspace activities, which included training on equipment, technical workshops, networking, etc. As a result, it was made evident to the local ecosystem that makerspaces can function as multifaceted collaborative arenas, facilitating concurrent technical and entrepreneurial development while empowering the overall community. In total, 40 projects have been mentored consisting of 53 makers.

3.1.3 Business Modelling and Planning

During the third and final stage of the programme, the emphasis was placed on enhancing the business model and business plan of the most market-ready projects. This was based on a second more elaborate screening process which re-evaluated the aspects from the first screening (concept and innovativeness, impact, and market uptake) but also went further by asking questions related to:

(iv) implementation and team capacity; assessing the skills and experience of the team members as well as the timeline and financial needs or the project, and
(v) motivation and future plans/commitment; checking the dedication of the team and the post-PCMA activities envisioned.

This stage provided focused training on pitching, access to funding and financing, etc. The participants involved in these projects were afforded a concentrated coaching process that provided them with exclusive guidance and support in refining their business vision and aligning it with market requirements. In total, 8 projects participated in this stage, consisting of 18 makers.

To leverage the power of the network created, the makerspaces interacted more at this stage, organising joint events for pitching and knowledge transfer, including success stories and lessons learned.

More information on the structure of the PCMA, as finalised after its completion, of the business support provided, the organization of the programme, and the number of participants can be found either in the open access survey and data on Zenodo (Q-Plan International 2023) or in the PMCA Handbook (Tsolakis et al. 2023).

3.2 Methodological Approach

To ensure the robustness of our findings, the mixed-methods approach allowed us to gather sufficient data to answer our research questions (Jefferson et al., 2014; Leech et al., 2010, Dawadi et al., 2021). The approach incorporates action research, surveys and case study methodologies on seven different cities. It allows to capture data on the skills development, business creation, and innovative practices fostered by the programme. It provides a framework for evaluating the PCMA programme and to assess physical and social changes in the makerspaces and surrounding communities. This methodology ensured that we could offer insights into the role of circular makerspaces in fostering entrepreneurship and supporting urban sustainability.

3.2.1 Satisfaction Surveys

The data collection process involved distributing a detailed satisfaction survey to all participants. The data were collected through bilateral communication with the makerspaces and online surveys completed by both the makerspaces' personnel (i.e., 13 responses) and the makers (i.e., 20 responses) themselves. Related data (including the survey questions) are openly available through Zenodo (Q-Plan International, 2023). The survey included sections on demographic information, satisfaction with the programme, perceived and actual impacts on entrepreneurial skills, sustainability awareness, circularity and business improvements, as well as suggestions for improvement. All participants were invited (through e-mails, joint virtual and physical meetings) to participate in the surveys in an anonymized way. Non-response bias was mitigated by following up with non-respondents and encouraging completion through reminders.

The satisfaction survey was one of the primary methods used to collect data on participant experiences and outcomes. It allows the understanding of participant satisfaction and the gathering of feedback on specific aspects of the programme. As the first empirical data collected about a circular accelerator programme deployed in circular makerspaces, it provides baseline information on how these spaces are perceived and used by their participants. The survey method allows for the collection of standardized data, making it easier to compare responses and identify common themes and areas for improvement. Additionally, the structured format of the survey ensures that all participants are asked the same questions, promoting consistency in the data collected. This approach is particularly useful for capturing immediate reactions and short-term impacts, and thus allows the assessment of the initial effectiveness of the programme.

The survey results address the research questions by providing empirical data on the effectiveness of the PCMA within makerspaces. By collecting feedback from both makerspaces' personnel and makers, the surveys

offer insights into the participants' experiences, satisfaction levels, and perceived impacts on their entrepreneurial skills, environmental awareness, and networking capabilities. This data helps to evaluate how well the programme fosters circular entrepreneurship and supports urban regeneration and sustainability. The qualitative and quantitative analysis of the survey responses allows for an understanding of the programme's outcomes, suggesting areas of success and identifying potential improvements, grounded in real-world experiences.

Due to the limited number of responses, we focused on a qualitative thematic analysis of the responses, driven by the need to explore both the depth and breadth of participant experiences (Dawadi et al., 2021). However, we acknowledge that the self-reported nature of the data and potential biases in participant responses may influence the validity of the findings. Self-reported data can suffer from biases like social desirability and recall bias, affecting the accuracy of responses. Sampling bias may occur if respondents are not representative of all participants, and non-response bias could skew results if non-respondents have different views.

Relying solely on self-reporting satisfaction surveys has other limitations as well. The opinions expressed may not fully capture the long-term impacts or broader systemic changes facilitated by the programme. Acknowledging these limitations highlights the need for ongoing research to better understand how circular makerspace and acceleration programmes can support circular entrepreneurship and urban regeneration. Future research should include longitudinal studies to track progress over time and case studies to assess community engagement and environmental practices. These methods would complement our findings, providing a more comprehensive evaluation of the PCMA programme's effectiveness.

Additionally, the findings are based on observations from seven pilots, which, while heterogeneous, cannot fully capture the broader diversity of European makerspaces. This limitation reduces the ability to generalize the results across different contexts and regions, as the unique characteristics of makerspaces in other locations may yield different outcomes.

3.2.2 Action Research

While the survey results are key data for the study, they are only one piece of the information used to answer the research questions. The researchers involved in this study closely followed the makerspaces over a four-year period, providing a detailed understanding of how projects evolved and interacted within their local contexts. This long-term observation allowed the researchers to document the challenges, successes (both perceived and observed), and behaviours of the participants, offering insights that would not have been captured through surveys alone.

We conducted an action research approach while setting up and implementing the PCMA. Action research involves iterative cycles of planning, acting, observing, and reflecting, which allowed us to adapt and refine the programme based on real-time feedback and observations (Cornish et al., 2023). This approach is beneficial as it actively involves participants and stakeholders, promoting practical problem-solving and continuous improvement (Cornish et al., 2023).

Observations of the makers, entrepreneurs and of the makerspaces were conducted over several months, and in some cases several years, allowing us to follow up on the internalization and comprehension of circular economy principles by the both the entrepreneurs, makers and makerspaces (often through close collaboration with them). Data collected through action research included detailed observations of participant interactions, feedback from mentoring sessions (including success stories), evolution and attendance of the makerspaces and the outcomes of various training activities. These insights supported the understanding of the practical challenges and successes of the programme, enabling us to make informed adjustments and gather comprehensive data on the effectiveness of the PCMA within makerspaces. This method provided a dynamic framework that complemented the survey data, capturing more immediate and practical insights from the participants' experiences. However, it also has limitations, such as potential bias from researcher involvement and the challenge of maintaining objectivity (Cornish et al., 2023; De Oliveira, 2023).

The mixed-methods approach, combining action research, surveys, and case studies, was particularly advantageous for this study. The action research enabled the researchers to observe real-time changes, such as how certain makers who were unfamiliar with circular practices gradually adopted these principles within the makerspaces—something that self-reported surveys might not have revealed. Case studies provided examinations of specific projects highlighting how the programme supported vulnerable groups and contributed to local circular economies. Meanwhile, the surveys quantified aspects such as participant satisfaction, skill acquisition, and knowledge improvement, offering a quantitative view of the programme's impact.

4. RESULTS

While positive statistics on the accelerator programme have been presented in a previous publication (Premyanov et al., 2022), this section will focus on the aggregated results after its completion, based on satisfaction surveys deployed. The whole survey and data collected are openly available through Zenodo (Q-Plan International, 2023).

In total, the PCMA supported 105 makers, with 40 projects proceeding to the mentoring stage. The value chains supported by each makerspace were diverse and covered six out of the seven value chains identified in the EU Circular Economy Action Plan (CEAP) (European Commission, 2020), showcasing the potential in transforming various secondary materials into new products, that would otherwise end up as urban waste. Figure 2 illustrates the distribution per city and the diversity of value chains supported per makerspace.

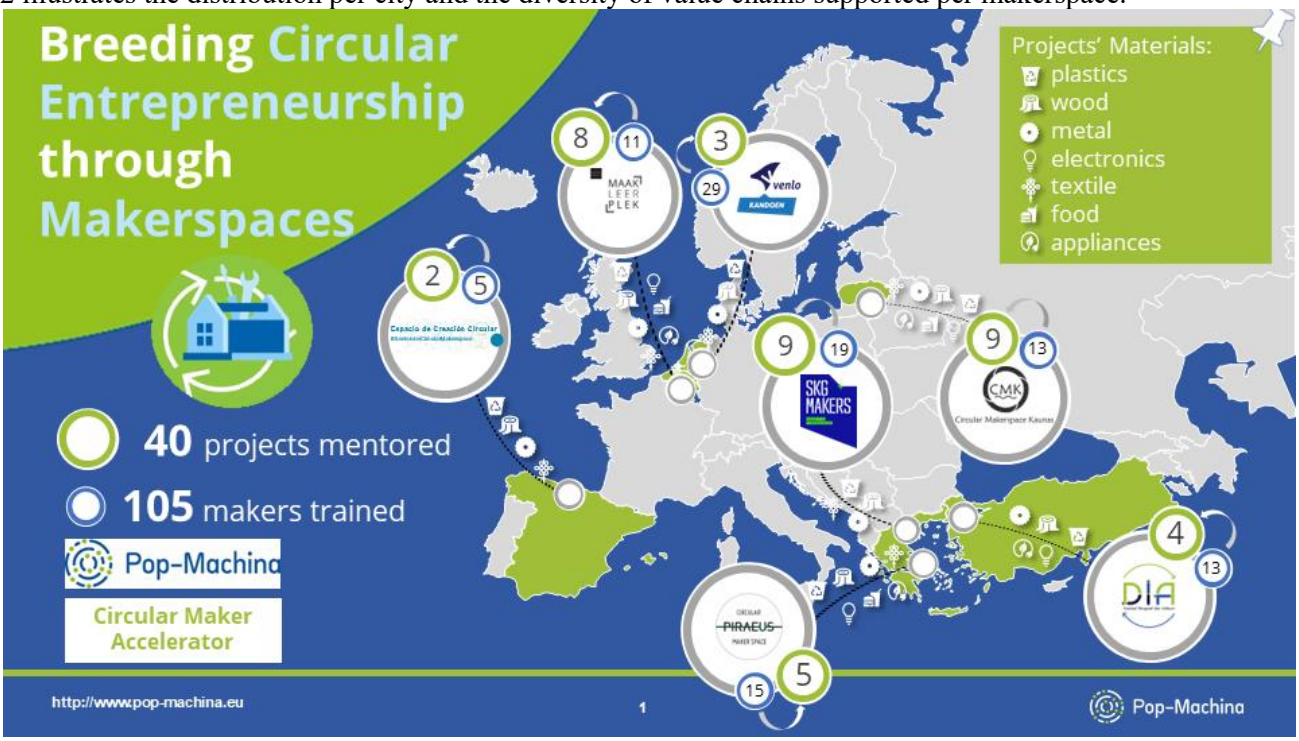

Figure 2. Makers Trained (i.e., 105), Projects Mentored (i.e., 40) and Value Chains Covered (i.e., 7) Per City

Following the completion of the mentoring phase, only 8 of the projects progressed to the subsequent stage, working together with market experts to further refine their business models and plans. The selection was based on several factors, such as maturity, commitment, market potential and envisioned impact (circular, sustainable, etc.), as elaborated in Section 3.1.2, as well as willingness to proceed further. A limited number of projects (i.e., 8) wanted and were mature enough to proceed to the third stage of the PCMA programme, leading to the selection of one project per city, with the exception of one makerspace that had two very mature teams. Hence, the limitations introduced are inherent to the realistic conditions of the case studies, under which, not all makers want to become business owners.

Currently, at least two ventures have emerged from the programme, whereas seven managed to increase their revenue or personnel, all focusing on the creation of products made mainly or entirely out of secondary raw materials.

While working on their business plans, the weight of secondary raw materials reported as consumed reached a little over 1.1 tons of secondary raw materials (mainly plastic, followed by wood, metal, textile, electronics, and food). This finding suggests a capability to reduce urban waste from only a limited number of makers and their projects.

4.1 Makerspaces' Personnel Perspective

Thirteen trainers actively involved in the PCMA responded to the satisfaction survey, including mentors, coaches, consultants and makerspace admin personnel. Their responses are summarised in Table 1 (see Annex 1). In general, the makerspaces perceived in a positive light the deployment of the accelerator, with 38.46% (n=5/13) expressing strong satisfaction with their overall experience, with the rest (61.54%, n=8/13) also

expressing a positive experience (Figure 3). It is noteworthy that none of the participants had previous experience in delivering an acceleration programme through a makerspace. The satisfaction expressed by the makerspaces suggests that the programme has potential to support cities through urban regeneration towards sustainability, by actively engaging citizens and makers in circular practices.

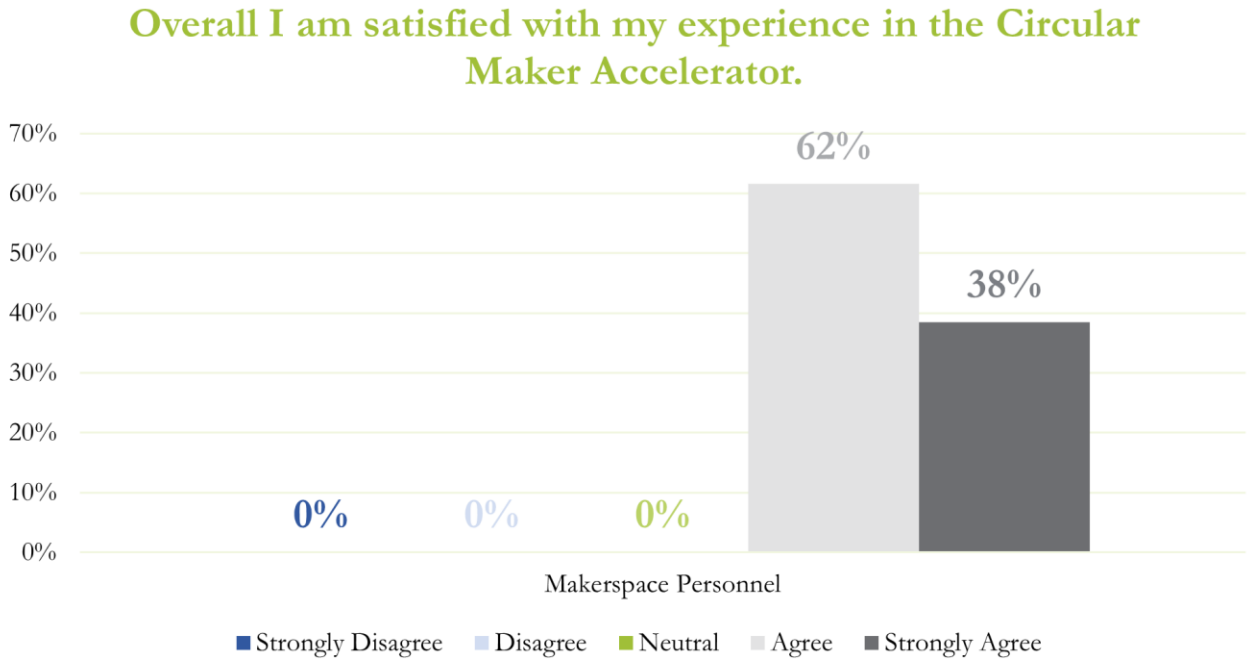

Figure 3. Makerspaces' Personnel's Overall Satisfaction with the Pop-Machina Circular Maker Accelerator

The survey results also showed that the makerspaces placed emphasis on the support provided to makers in accessing funding and/or financing. Among respondents, 38.46% (n=5/13) stated that they managed to *moderately* support their makers in this regard, whereas another 38.46% (n=5/13) answered that the programme allowed them to support them *very* well. Similarly, 46.15% (n=6/13) of the respondents *moderately* agreed that they have supported makers in contacting investors, whereas only 23.08% (n=3/13) responded that they were *very* positive about the said support. Interestingly, 53.85% (n=7/13) believe that the makers have been supported a lot to increase their revenue, followed by 30.77% (n=4/13) who responded *moderately*.

Focusing more on the improvement of knowledge and skills, 46.15% (n=6/13) of respondents had a positive perception that the makers also managed to improve their knowledge of the circular economy, and even further 15.38% (n=2/13) responded *extremely*, followed by 38.46% (n=5/13) who responded *moderately*. The same 46.15% (n=6/13) of respondents also had a positive perception that the makers have been effectively supported to improve not only their entrepreneurial skill set but also their understanding of environmental impact. Half of the makerspace respondents, therefore, perceived a quite positive outcome from the execution of the accelerator.

In terms of networking, 61.54% (n=8/13) of respondents believed that their makers were supported in expanding their network and collaborations, followed by 30.77% (n=4/13) of respondents who *moderately* believed so. 69.23% (n=9/13) of respondents also indicated that their makers created jobs, the number of which varies.

The survey results suggest that the makerspaces perceived the deployment of the PCMA as a positive experience, with satisfactory outcomes in terms of the support provided to makers in accessing funding, improving knowledge and skills, and expanding their network and collaborations. Hence, according to their viewpoint, the PMCA has positively contributed to the development of the circular maker movement and sustainable entrepreneurship in the seven cities.

4.2 Makers' Perspective

The makers' satisfaction survey results, together with the analysis of the insights from the seven pilots, reveal the programme's success in providing valuable support, guidance, and resources to the participating makers, resulting in the enhancement of their skills, knowledge, and network.

A total of 20 makers, across all seven makerspaces, responded to the satisfaction survey distributed upon the completion of the PCMA. The overall results collected are introduced in Table 2 in Annex 1 (whereas all the results are available on Zenodo). In terms of age, the majority of the respondents were between 26 and 35 years old, accounting for 45% (n=9/20) of the total respondents. This is followed by 25% (n=5/20) between 18 and 25, 25% (n=5/20) between 36 and 45, and only 5% (n=1/20) in the range between 46 to 55. In terms of gender, 55% (n=11/20) were female, 30% (n=6/20) male, and the remaining 15% (n=3/20) preferred not to disclose their gender. In terms of education, half of the respondents had a Master's degree. One respondent (5%) held a doctorate degree, and another one (5%) had a High School education. This indicates that most of the respondents were young adults and had higher education degrees, which could have influenced their overall experience in the programme. This is line with other observations in the makerspaces, where mostly young makers, being university students or graduates, have been participating in makerspace activities. Of course, this varies from makerspace to makerspace. However, this profile has also been found to be more prone to entrepreneurial activities (Andrews et al. 2021). Finally, from the authors engagement with the makers participating in the PCMA (as part of the action research), and therefore the respondents as well, participants were mostly white.

Overall, the makers reported a high level of satisfaction with the business support offered by the makerspaces (i.e., support in accessing funding and financing, enhancing their knowledge and skills, and expanding their network and collaborations, and more) with 80% (n=16/20) of the respondents confirming that the support was satisfactory as a whole (Figure 4). Additionally, 18 out of 20 respondents were satisfied with the mentoring received, suggesting the effectiveness of the 2nd stage of the PCMA. However, as presented above not all respondents (10-15%) were satisfied with the support provided. From the comments through the open-ended questions, several individual opinions were expressed. A respondent that agreed being satisfied requested "*to focus more on individual challenges and peer-to-peer working, while having a longer period of coaching but less intense"*. A respondent that disagreed emphasised the need *"for more qualified staff (in terms of technical support, use of machinery and safety protocols), and increased support for makers"*. The second respondent that disagreed expressed that they *"had hoped for more support in terms of business development, including access to funding and resources for growing their business"*. Finally, the respondent that strongly disagreed and the respondent that was neutral did not provide any feedback on what could be improved. Interestingly, the first respondent that disagreed also reported that they *"managed to increase revenue slightly through the machines provided in the makerspace"*, whereas the neutral respondent was one of the few that had managed to access funding through the PCMA, also increasing their revenue.

This suggests that while the programme was mostly successful, improvements could be made in ensuring more tailored access to resources and opportunities across all participants. Considering that all the unsatisfied participants (20%) had a university degree (either bachelor or master) and half had quite positive outcomes, it can be assumed that their expectations were higher or that the training did not meet their advanced needs.
This general feedback, aligns with the opinion of the makerspaces (see Section 4.1), suggesting that makerspaces employing programmes such as the PCMA can aid in breeding circular entrepreneurship.

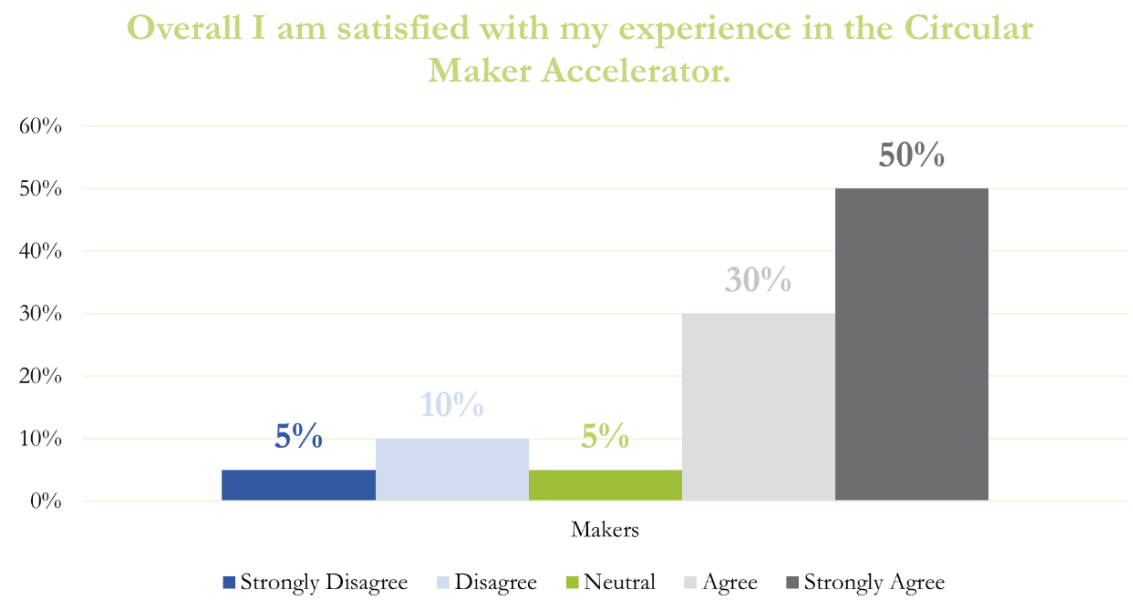

Figure 4. Makers' Overall Satisfaction with the Pop-Machina Circular Maker Accelerator

In terms of support on funding and financing, 15% (n=3/20) have reported that they have managed to access funding or financing. Another 30% (n=6/20) claimed to have contacted investors and increased their revenue. Additionally, 15% (n=3/20) of the makers reported that they had increased their personnel during the programme, indicating the potential for job creation through the accelerator programme. However, these percentages do not necessarily represent the same respondents. In overall, we can see (Figure 5) that a limited number of makers has reported to have achieved business growth in terms of increasing their personnel and their revenue or getting in touch with investors and securing additional funds. This suggests that while most makers were satisfied with the support received, this has not materialized in tangible business outcomes. Hence, improvements could be made in ensuring more consistent access to resources and opportunities across all participants.

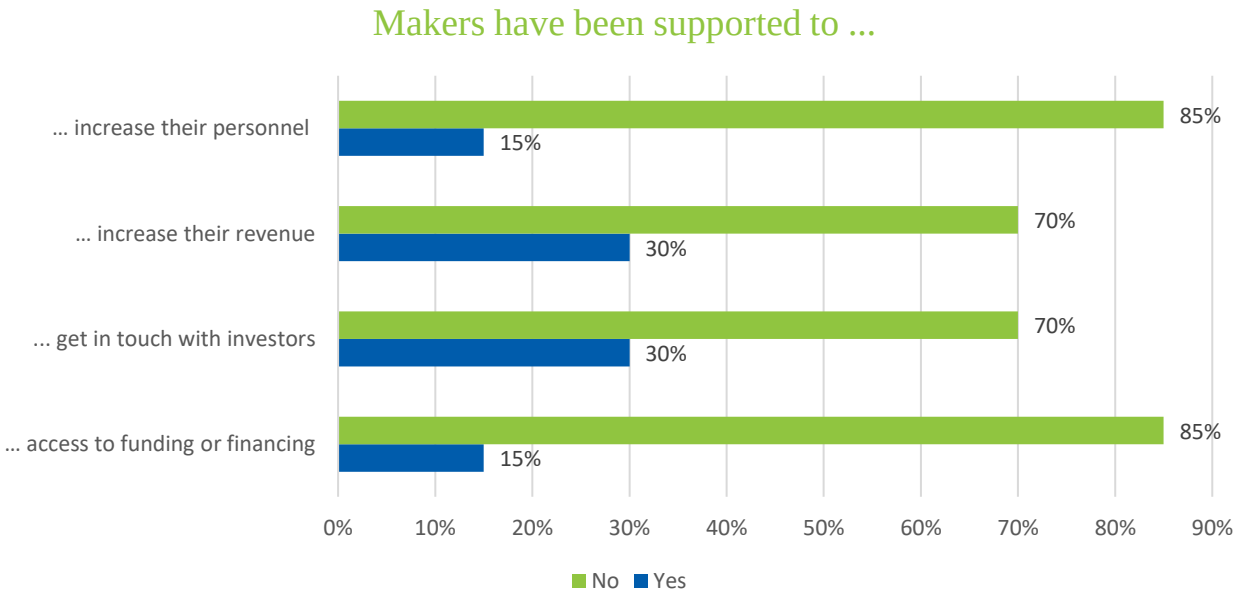

Figure 5. Makers' Reported Business Growth Support Received From the Pop-Machina Circular Maker Accelerator

Regarding skills and knowledge improvement (Figure 6), as the PCMA involved hands-on experience within the makerspace, more than half of the makers (55%, n=11/20) reported that they have *moderately* improved

their technical skills and knowledge, while 30% reported *significant* improvement. In fact, 25% (n=5/20) of the respondents claimed to have learned a new technical skill. In terms of business knowledge, 60% (n=12/20) of the respondents believed that they have improved their business knowledge *significantly*, followed by 35% (n=7/20) that believe to have done so *moderately*. Half of the respondents (50%, n=10/20) reported having acquired new soft skills, including business modelling, effective communication, pitching, and more, skills needed for their business development.

Extending more specifically to the knowledge of circular economy, 45% (n=9/20) of the makers responded positively, indicating that they had improved their overall knowledge of the domain *very* much or *extremely*. Another 35% (n=7/20) of the makers reported *moderate* improvement, while 15% reported only *slight* improvement. Similarly, when asked about their understanding of their environmental impact, a reasonable portion of the makers (45%, n=9/20) reported *moderate* improvement, 30% (n=6/20) reported *very significant* improvement, with one responder (5%) reporting *extremely significant* improvement. However, when asked how much they believe they have improved their knowledge of entrepreneurship, 55% (n=11/20) of the makers reported *very significant* improvement, 10% (n=2/20) reported *extremely significant* improvement, 20% (n=4/20) reported moderate improvement, and an additional 15% (n=3/20) reported slight improvement.

Contrary to the above results related to business growth, in terms of capacity building we see that the reported improvements are aligned with the overall satisfaction of the programme.

Figure 6. Makers' Knowledge and Skills Perceived Improvement

In terms of networking, 85% (n=17/20) of the makers reported that they had engaged more in makerspace activities, out of which 80% (n=16/20) had engaged more with their local community. In more detail, 30% (n=6/20) responded that they have significantly expanded their professional network, 60% (n=12/20) reported a moderate expansion, whereas a responder (5%) reported a slight expansion.

Finally, 85% (n=17/20) expressed their desire to extend the support received from the makerspace (including also access to equipment) after the end of the accelerator (offering also valuable feedback on the overall process for making improvements). The desire to extend the support received from the makerspace after the end of the programme also suggests that the makers found the programme to be valuable and impactful.

Overall, the analysis of the responses collected suggests that the PCMA provided valuable support, guidance, and resources to the makers, positively impacting their skills, knowledge, and networks, while also fostering a circular entrepreneurial mindset. However, the sample size is relatively small, and further research is needed to confirm these findings and assess the generalisability of the programme's impact.

The positive experience that makers had through their participation in the PCMA programme, and its effects on their activities, has also been captured through a series of case studies that can were considered as success stories (i.e., the Maker Stories[8]), complementing the action research performed.

For instance, “Studio Blai”, which specializes in upcycled plastic materials, and “Denim Diaries”, which makes new products from recycled jeans and other textiles, reported valuable benefits in both technical (via design thinking and access to equipment) and business (via business management related activities) skills. This was also the case for the “Material Bank” at “Atelier Circuler”, the makers of which reported that the PCMA facilitated their upscaling trajectory.

Furthermore, “House of Confetti”, known for its sustainable fashion, and “Wambo”, a social reuse and repair hub, leveraged the networking opportunities provided by the programme to forge new partnerships and increase their supply chains and market reach.

Additionally, the insights gained from “Vres ftera” and “Drewcereceda” emphasize the importance of personalized support to carefully assess revenue streams and the economic feasibility of their circular projects. The practical success stories from these case studies highlight the broader impact that circular maker accelerators can have, showcasing the potential for makerspaces to foster sustainable business growth while contributing to the circular economy.

[8] https://pop-machina.eu/makers-stories/

4.3 Action Research

Beyond the data collected from the makers, action research revealed additional insights from the seven case studies across Europe and Türkiye.

4.3.1 Citizen Engagement and Circular Practices

Our observations while running the PMCA programme allowed us to see progress in citizens engagement towards circular practices. Even citizens with a traditionally linear mindset were able to engage in circular practices when involved in the makerspaces and the PCMA. Makers started collecting recyclables (e.g., almost all makers started bringing plastic bottle caps to be recycled within the makerspace), engaging in textile upcycling, refurbishing old furniture and equipment (e.g., especially during workshops and festivals makers engaged in such activities).

An interesting example of adopting said practices in a real-life setting is the case of a renovation worker who began collecting, refurbishing and selling old furniture online, showcasing a shift from a linear to a circular business model.

4.3.2 Urban Regeneration Potential

The PCMA showed potential to contribute to local urban regeneration. By providing opportunities for citizens to engage in circular production, the programme enabled makers to play an active role in driving positive change in their living environments. Furthermore, through the increased networking and collaborations, the makerspaces attracted more actors from the regional business ecosystem into the makerspaces providing additional opportunities for the district, starting with an increase in the clientele of local shops and businesses.

Urban regeneration efforts were also aided by the endeavour to diversify the local economies in the seven cities by creating new sources of income and employment while also supporting circular innovations. By supporting small-scale entrepreneurship while promoting circular economy and sustainability, the PCMA results suggest a potential initiative for stimulate economic growth.

In addition, this involvement in circular business practices can lead to a step towards urban regeneration, encouraging more inclusive and sustainable growth in these areas. Despite the previously mentioned limitation regarding the lack of diversity among participants, the projects developed through the PCMA were inclusive, not only in their selection but also in their business model. For example, initiatives like “Atelier Circular” in Belgium and “Vres ftera” in Greece specifically engaged and supported vulnerable communities. Finally, a clear, yet very small-scale, connection has been established between the PCMA and municipal waste streams. Several makerspaces used secondary raw materials that would otherwise be characterised as waste from municipal warehouses or collection points. For instance, the makerspaces in Thessaloniki and Istanbul that extracted on several occasions wooden and metallic discarded items (barrels, shutters and blinds, tables, etc.) to support makers’ creations.

4.3.3 Social and Economic Impact

From a socio-economic perspective, the PCMA supported the growth of makerspaces and local businesses. In fact, some projects and local businesses continued their production in the makerspaces, creating economic traction and expanding collaboration with municipal actors. Coupled with the business-oriented capacity building of both the makerspaces’ personnel and the makers, the PCMA has introduced valuable socio-economic benefits to the local communities. Even though this already reflected in the satisfaction surveys, this outcome has been observed in a larger scale during the activities and events of the PCMA. We observed improvements in both soft and technical skills. For instance, supported makers became accustomed in handling specialised equipment like 3D printers or CNC routers, while also improving their presentation / pitching skills and becoming better in financial estimations and projections.

Furthermore, the training provided by the PCMA in circular economy and environmental topics was designed to have a lasting impact on the makers’ business mentality and decision-making processes. As these circular businesses grow, their demand for secondary raw materials are expected to increase, creating opportunities to source these materials from urban waste streams. This could help address some of the challenges faced by urban areas in managing their waste, creating a closed-loop system that benefits both businesses and municipalities. For instance, in Leuven the “Material Bank” allows for companies to get supply in secondary construction materials at scale.

Finally, fundraising events such as bazaars, fairs and demo days with investors, although not always directly part of the PCMA, supported the revenue growth of makers by attracting resources to local neighbourhoods.

These events can help to raise awareness of the circular economy and sustainability, and thus may contribute to social and economic growth. In Thessaloniki, for instance, the makerspace hosted events (including bazaars, festivals and investor presentation days) that brought together makers, local businesses, investors, and other business and innovation actors, fostering economic collaboration.

5. DISCUSSION

The study presents the results of a circular accelerator programme (i.e., PCMA) that aimed to foster circular entrepreneurship to makers, via makerspaces, in seven cities in Europe and Türkiye. There are very few programmes in Europe currently supporting circular entrepreneurship through makerspaces, and even less research exploring their impact in entrepreneurship, as well as their effects on the urban spaces in which they are located. This discussion aims to establish an empirical connection between the PCMA's accomplishments and its potential impact on urban regeneration and sustainability (addressing the second research question), while shedding more light on how such spaces can breed circular entrepreneurship (addressing the first research question).

5.1 Breeding Circular Entrepreneurship

The positive feedback and data extracted from both makerspaces and makers, along the observations from the action research over several case studies, suggest the PCMA's potential to engage and include citizens and makers in circular entrepreneurial practices, addressing the research question of whether makerspaces can breed circular entrepreneurship. By providing hands-on technical and business training in circular economy principles and viable business management (from planning to accessing funding), most of the makers supported reported improvements in entrepreneurial skills, environmental awareness, and networking capabilities, demonstrating an established circular entrepreneurial mindset. In fact, the study reveals that even makers without prior experience in circular practices were able to adapt and integrate these principles within the makerspace environment and into existing or new businesses.

This is mainly based on observations deriving from the action research and the interaction between the makers and the makerspace personnel. Makers that did not follow circular practices in their lives outside the makerspace, did not encounter difficulties to follow a more circular way within the makerspaces, which ultimately led to either small changes in their lives outside the makerspace (e.g., collecting bottle caps for the plastics recycling, or bringing old clothes for the textile projects, etc.) or business opportunities within previously linear processes. For instance, the case of the renovation worker who transitioned from discarding old furniture to refurbishing and selling it online illustrates this adaptive mindset. However, while these instances are noteworthy, the broader impact of these behavioural shifts on long-term circularity practices remains underexplored.

5.2 Supporting Urban Regeneration and Sustainability

On the other hand, in terms of urban regeneration, the study suggests a positive correlation between makerspaces and urban transformation, as discussed through the lens of Evans and Jones (2008), addressing the social and economic dimensions of urban regeneration.

From the social perspective, the PCMA was designed to be socially inclusive, providing equal opportunities for any maker to participate, regardless of gender, age, culture or business experience, as long as they had a promising idea and the willingness to learn. This not only extends to the supported projects, but also to their offerings. For instance, “Atelier Circular” in Belgium, “House of Confetti” in the Netherlands and “Vres ftera” in Greece were by-design engaging and benefiting vulnerable communities.

In contrast to many established acceleration programmes, the focus was on the development of circular products, with an emphasis on fast hands-on prototyping (with equipment and materials provided by the makerspaces in many cases). This approach provided citizen-led initiatives with the necessary skills and knowledge to drive change in their living environment, potentially increasing the number of entrepreneurial citizens, as introduced in Al Sader, Kleinhans and Van Ham (2019). By providing access to such opportunities, the PCMA has the potential to impact local urban regeneration, by allowing citizens to play an active role in driving positive change. However, these conclusions are drawn primarily from participant perceptions, and there is a need for more longitudinal and comprehensive studies to robustly capture the programme's effects on the urban fabric.

Furthermore, presented findings suggest that makerspaces can play a significant role in leveraging circular social innovation to foster circular entrepreneurship. The evidence suggests that makerspaces offering business

support through an acceleration programme can empower local maker communities and have a socio-economic impact on both the makers and their living environments. As makers develop their circular entrepreneurial aspirations and mindset, their activities and sustainable products, which are integral to the urban fabric, support the transition to an all-inclusive circular economy. This, in turn, contributes to urban regeneration and sustainability. The positive experiences and entrepreneurial development of the makers demonstrate the potential of circular entrepreneurship through makerspaces to drive sustainable practices and contribute to the goals of urban regeneration in inclusive and sustainable cities.

From the economic perspective, the PCMA may have boosted revenue not only for the makerspaces (where applicable), but also for small local businesses, contributing to economic growth in their urban context. Some of the businesses established or supported through the PCMA (i.e., both participants to the programme but also other local businesses that engaged in PCMA open/public activities) continued their small-scale production in the makerspaces, creating even more economic traction and engaging more actors, while positively affecting public authorities, such as the municipalities. Others, have created their own workshops in the vicinity of the makerspaces (or in the municipality in general), also joining in the urban regeneration process.

Additionally, locally organized fundraising events (such as bazaars and fairs) supported makers to raise their revenue, even if they did not participate in the PCMA directly. These instances attracted extra resources (e.g., money, materials, and personnel) to the neighbourhood, promoting training, social impact, and economic growth, while also raising awareness of topics such as circular economy and environmental footprint. While this diversification of local economic activities is promising, these outcomes are based on initial observations and need further verification through longitudinal studies.

The PCMA predominantly supported circular business ideas delivering products or services that align (to a certain degree) with the principles of sustainability and circularity, and with the targets of the EU Green Deal and in particular with the EU CEAP. Furthermore, the entrepreneurs' training, in both circular economy and environmental topics, is expected to have lasting impacts on their business mentality and decision-making processes. This effect can impact the urban space where these businesses are located, as they become more responsible and make more informed decisions about their resource and waste management. Moreover, as these circular businesses grow and scale up, they are expected to require more secondary raw materials, which can be sourced from urban waste streams, potentially ameliorating the challenges most urban spaces have in terms of waste management. However, the implementation of circular business practices will differ in each region and may face unique challenges. Nonetheless, regional variations need further exploration beyond the scope of this work.

Summarising, the results (both qualitative and quantitative) reveal that circular entrepreneurship through makerspaces can support urban regeneration and sustainability by stimulating local economies, creating jobs, enhancing collaborations and promoting sustainable practices. Further research and evaluation are needed to validate these findings and explore the broader implications of such acceleration programmes for urban regeneration, sustainability and a circular economy.

5.3 Limitations

While the PCMA has several benefits, it also has limitations that warrant discussion to enhance the transparency and validity of our findings. These limitations pertain to the scale of our research, the sample size of participating teams, the limited number of cohorts, the representativeness of respondents, and potential bias in project selection.

Most of the businesses supported have a very small production capability, resulting in limited use of secondary raw materials and economic growth. However, it is interesting to note that the final 8 supported projects, in their business plans, declared a consumption of 930 kg of secondary raw materials within a year. Measuring the impact of the PCMA on the local urban fabric and established businesses will require a longer period, even though up- and re-skilling and new job creation have already been observed.

Another limitation of the study is the sample size. As this was the first accelerator of its kind, the PCMA did not support a substantial number of projects, nor was there enough time to run multiple cohorts. Moreover, not all supported projects completed the programme or responded to feedback questionnaires (only 19% of makers provided feedback). Therefore, more iterations (cohorts) are needed to determine if the foreseen results will be achieved. Nevertheless, this issue remains a challenge beyond this study's programme (Bank, Fichter and Klofsten, 2017).

Another limitation observed in the survey results is that the respondents may not be representative, as the majority were young, highly educated, and mostly male. This is also supported by the action research related to the engagement of makers in the PCMA, complementing it with the fact that most participants were also white.

Although this agrees with most makers in general (Marotta, 2021), it also means that the perspectives and experiences of individuals from different racial or ethnic backgrounds, educational levels, or socioeconomic statuses may not have been fully captured. This limitation could impact the generalisability of the findings to the broader population of makers who are interested in participating in accelerator programmes and highlights the need for more targeted outreach to underrepresented groups.

The limitations of the respondent profile may also affect the types of businesses or projects that were selected for the PCMA. Nevertheless, given the diversity of the countries and their ecosystems, including participants' backgrounds, experiences, and motivations, the range and nature of circular projects that were pursued were rather broad in terms of circular value chains, products, services, and markets (Gregori et al., 2019).

These limitations should be kept in mind when interpreting the survey results and when considering the implications for future accelerator programmes. To ensure that these programmes are accessible and beneficial to a diverse range of makers, it may be necessary to actively seek out and include individuals from different backgrounds and with different levels of experience and resources.

In addition, future studies could also focus on tracking the economic growth and development of supported businesses. This would offer a clearer understanding of their financial impact and scalability, while also enriching the diversity of circular projects but also provide a better understanding of how circular entrepreneurship can contribute to inclusive and sustainable urban development.

5.4 Practical implications

The findings of this study hold several practical implications for several stakeholders, including policymakers, makerspaces, and the makers themselves.

Policymakers interested in fostering circular economies and supporting urban regeneration should consider the value of municipal-led makerspaces as potential hubs for citizen-driven innovation and entrepreneurship. The PCMA's success in engaging citizens in circular practices, even those with previously linear mindsets, highlights the potential for such programmes to drive sustainability at the grassroots level. However, the inclusivity of these spaces remains a challenge. The current results of this study do not fully support the claim that makerspaces can contribute to a "just transition" or inclusivity goals, as they predominantly attract highly educated elites. This disparity between the programme's aims and its actual demographic reach calls for tailored policy interventions aimed at expanding accessibility to diverse socioeconomic groups.

This presents an opportunity to craft policies that actively encourage broader participation in makerspaces, particularly from marginalized communities. Such policies might include targeted funding for underrepresented groups, subsidized access to makerspaces, or partnerships with educational institutions to engage a wider audience. Additionally, the socio-economic impact of circular entrepreneurship could be amplified by providing makers with more robust business support services, potentially in collaboration with local governments or private sector partners. Ensuring the scalability of these circular businesses and fostering stronger connections with local markets could help integrate circular practices more deeply into urban economies.

Makerspaces themselves also stand to benefit from these insights. While the PCMA demonstrated potential for economic growth within local ecosystems, the long-term success of makerspaces in supporting circular entrepreneurship will depend on their ability to provide sustained business development support. Furthermore, makerspaces should take a proactive approach to enhancing inclusivity by offering accessible resources (materials, equipment, trained staff, etc.), fostering diverse collaborations, and creating mentorship programmes tailored to a broader range of makers. The findings suggest that although makerspaces have begun to contribute to urban regeneration, these contributions are uneven, and makerspaces could play a more significant role by intentionally fostering more inclusive entrepreneurial ecosystems.

For makers, the PCMA underscores the importance of adopting circular principles not only within the confines of makerspaces but also in broader business practices. The entrepreneurial activities fostered by the PCMA illustrate how circular entrepreneurship can create both environmental and economic benefits, albeit on a smaller scale. Makers who engage in circular business models contribute to the wider goal of transitioning toward a sustainable, circular economy. However, the challenges of scaling up and sourcing secondary raw materials locally remain critical issues that individual makers must navigate. Collaboration between makers, businesses, and local governments will be crucial in overcoming these hurdles, with makerspaces acting as significant facilitators.

The socio-economic exclusivity of makerspaces also raises important considerations for makers themselves. As actors within the broader circular economy, makers should be aware of the potential exclusionary nature of their spaces and work towards fostering inclusivity in both their entrepreneurial practices and community engagement. By recognizing the limits of the current demographic reach of makerspaces, makers can actively seek to involve individuals from diverse backgrounds, thereby enriching the entrepreneurial ecosystem and ensuring that the benefits of circular innovation are shared more equitably.

6. CONCLUSION

Makerspaces, as collaborative workspaces, have the potential to provide a conducive environment for makers to develop innovative ideas and transform them into viable circular business ventures. These spaces have the potential to foster a culture of creativity, collaboration, and knowledge sharing, allowing makers to explore and experiment with circular economy principles. However, the success of circular ventures, originating from the maker movement, hinges on the availability of appropriate resources and support systems that can nurture their entrepreneurial skills and help convert their ideas into successful circular businesses.

To address this issue, this paper introduces the results of a replicable circular accelerator programme (PCMA) that can be adopted by makerspaces to function as sustainable entrepreneurship platforms that empower makers to transform their projects into viable circular business ventures. The approach focuses on providing technical and business-related training, mentoring, and coaching to makers, with the ultimate goal of fostering circular social innovation and promoting sustainable and inclusive cities. The PCMA results offer meaningful contributions to the growing body of research on circular entrepreneurship, demonstrating the potential of makerspaces to breed circular entrepreneurship and support urban regeneration. However, the study also identifies significant limitations, including the demographic homogeneity of participants, the scale of supported businesses, and the short-term nature of the observed impacts.

To test the effectiveness of this approach, the PCMA was executed across seven pilot cities, each with a unique ecosystem. The PCMA followed a fair and inclusive three-stage approach that catered to the local context of each of the seven pilot cities' ecosystems. A total of 105 makers received training in technical and business-related topics, and 40 projects underwent more elaborate mentoring and coaching to expand their entrepreneurial skills. At least one project per city (8 projects in total) had concluded the third and final stage, presenting a comprehensive business plan for the next three years.

Feedback from both makerspaces' personnel and makers suggested that the PCMA was beneficial for the local community, outlining social, economic, and environmental benefits for the citizens involved. The programme's physical implications in the local urban fabric suggest that it could contribute to local urban regeneration and sustainability while promoting effective circular social innovation. Therefore, makerspaces deploying such innovation support initiatives have the potential to become a focal point for sustainable cities and support their circular economy strategy.

The PCMA’s impact appears to extend beyond the direct creation of start-ups. It has supported the development of a circular ecosystem in each of the seven pilot cities, providing opportunities for makers and entrepreneurs to collaborate and exchange knowledge, ideas, and resources. The programme's focus on circular social innovation has also aimed to generate positive social and environmental benefits, such as job creation, waste reduction, and the promotion of sustainable lifestyles.

By providing access to mentoring, networking, and funding opportunities, accelerator programmes like the PCMA aim to facilitate the growth and development of circular entrepreneurs, potentially enabling them to contribute to the sustainable and inclusive transformation of cities. Future research could focus on scaling up the accelerator programme and evaluating its long-term impact on local urban regeneration and the circular economy.

This study suggests that makerspaces that deploy circular acceleration processes can act as sustainable entrepreneurship platforms, potentially promoting the creation of viable circular business ventures from makers and fostering inclusivity within the maker community and their living urban environment. By providing access to resources, mentorship, and networking opportunities, makerspaces can enable a diverse range of individuals, including underrepresented groups (even though in this study not directly supported but indirectly involved), to participate in the circular economy. Through the implementation of the PCMA, makers are able to get trainings on technical and business-related skills and knowledge to develop innovative ideas into successful (circular) businesses, enhancing their capacity for economic self-sufficiency and empowerment. By creating an inclusive and supportive environment, entrepreneurship programmes based in makerspaces have the potential to

contribute to building resilient and inclusive communities and advancing the goals of sustainability, social equity, and economic development.

To maximize the impact of makerspaces on circular entrepreneurship, several conditions and recommendations are essential. Firstly, makerspaces should offer comprehensive hands-on technical and business support services, including training in circular economy principles. The PCMA programme highlighted the importance of mentoring and coaching in improving makers' entrepreneurial skills and environmental awareness for the circular economy. Secondly, fostering a collaborative environment that encourages networking and knowledge sharing among makers can enhance innovation and the development of sustainable products. Additionally, partnerships with local governments, businesses, and educational institutions can provide the necessary support and resources for makerspaces to thrive. By implementing these recommendations, makerspaces can become hubs for circular entrepreneurship, driving sustainable urban regeneration and contributing to the creation of resilient, inclusive, and environmentally responsible cities.

The practical implications of these findings suggest that policymakers, makerspaces, and makers each have a role to play in supporting the transition to a circular economy. Policymakers who which to play a role in the development of circular entrepreneurship should focus on creating inclusive and supportive frameworks for circular entrepreneurship, while makerspaces may want to focus on providing more accessible and sustained support for diverse groups of makers. Makers, in turn, would gain in embracing their role as agents of change, actively seeking to expand the reach of circular practices within and beyond the makerspace environment.

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AUTHOR CONTRIBUTIONS

Nikolay Premyanov: Conceptualization, Data Curation, Investigation, Methodology, Validation, Writing – original draft
Elli Roma-Athanasiadou: Conceptualization, Methodology, Data Curation, Investigation, Validation, Visualization, Writing – original draft
Julie Metta: Conceptualization, Methodology, Validation, Writing – original draft, Writing – review & editing
Nikos Tsoniotis: Conceptualization, Validation, Writing – review & editing
Margarita Angelidou: Conceptualization, Methodology, Project Administration, Validation, Writing – review & editing
Apostolos C. Tsolakis: Conceptualization, Data Curation, Investigation, Methodology, Project Administration, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing

DECLARATIONS

Competing interests: The authors declare no competing interests.

ANNEX 1

Table 1. Makerspaces' Answers per Satisfaction Survey Question

Options	No of Responses
Age	
26 - 35	3
36 - 45	7
46 - 55	2
> 55	1
Gender	
Female	4
Male	6
Prefer Not to Say	3
Education	
Bachelor's Degree	3
Master's Degree	6
Doctorate Degree	4
Makerspace Role	
Administrator	6
Consultant	6
Maker Champion	3
Volunteer	1
Other	1
The communication channels available in the context of the accelerator were satisfactory.	
Strongly Agree	2
Agree	10
Neutral	1
The range of business support services designed was useful.	
Strongly Agree	3
Agree	9
Neutral	1
I benefited from the business support services material offered.	
Strongly Agree	3
Agree	7
Neutral	3
Overall, I am satisfied with my experience in the Circular Maker Accelerator.	
Strongly Agree	5
Agree	8
I am satisfied with the business support services my makerspace delivered.	
Strongly Agree	2
Agree	10
Neutral	1
The makers have been supported to access funding / financing opportunities.	
Not at all	1
Slightly	2
Moderately	5
Very	5
The makers have been supported to contact investors.	
Not at all	3
Slightly	1

Options	No of Responses
Moderately	6
Very	3
The makers have been supported to raise their revenue.	
Not at all	1
Slightly	1
Moderately	4
Very	7
The makers have been supported to bring their product closer to the market.	
Moderately	4
Very	2
How much did you improve your soft skills?	
Slightly	1
Moderately	4
Very	1
How much did you improve your business knowledge?	
Slightly	2
Moderately	2
Very	2
How much do you believe the soft skills of your makers has been improved?	
Moderately	5
Very	1
How much do you believe the business knowledge of your makers has been improved?	
Moderately	3
Very	3
How much do you believe the makers' knowledge on circular economy has been improved?	
Slightly	2
Moderately	5
Very	4
Extremely	2
How much do you believe the makers' knowledge on entrepreneurship has been improved?	
Moderately	7
Very	5
Extremely	1
How much do you believe the makers' understanding about environmental impact (in terms of resource use and CO2 footprint) has improved?	
Slightly	4
Moderately	3
Very	5
Extremely	1
Did you engage in more activities with your local maker community?	
Slightly	2
Moderately	6
Very	5
Did the number of makers in the makerspace increase?	
Not at all	1
Slightly	4
Moderately	6

Options	No of Responses
Very	2
How much did you expand your makerspace's network?	
Slightly	2
Moderately	6
Very	4
Extremely	1
What type of stakeholders did you establish collaborations with?	
Universities	2
Industries	1
Public Bodies	2
SMEs	2
Accelerators / Incubators	2
Other Makerspaces / Fablabs	5
How much do you believe the makers were supported in expanding their network and collaborations?	
Slightly	1
Moderately	4
Very	7
Extremely	1
How many jobs did your makers create?	
None	4
1-5	7
5-10	1
>50	1
How many jobs did your makerspace create?	
None	5
1-5	6
5-10	1
20-50	1

Table 2. Makers' Answers per Satisfaction Survey Question

Options	No of Responses
Age	
18 - 25	5
26 - 35	9
36 - 45	5
46 - 55	1
Gender	
Female	11
Male	6
Prefer Not to Say	3
Education	
High School	1
Bachelor's Degree	8
Master's Degree	10
Doctorate Degree	1
The communication channels available in the context of the accelerator were satisfactory.	
Strongly Agree	9
Agree	6

Options	No of Responses
Neutral	4
Strongly Disagree	1
My local makerspace provides a useful range of business support services.	
Strongly Agree	9
Agree	7
Neutral	3
Disagree	1
I benefited from the business support services offered.	
Strongly Agree	7
Agree	9
Neutral	2
Disagree	2
Overall, I am satisfied with my experience in the Circular Maker Accelerator.	
Strongly Agree	10
Agree	6
Neutral	1
Disagree	2
Strongly Disagree	1
Did you manage to access any funding or financing?	
Yes	3 (15k – 20k)
No	17
Did you manage to get in touch with investors (one or more)?	
Yes	6
No	14
Did you increase your revenue?	
Yes	6 (10-500%)
No	14
Are you satisfied with the training / mentoring received?	
Totally Satisfied	7
Satisfied	11
Unsatisfied	2
Have you improved your technical skills & knowledge	
Not at all	1
Slightly	2
Moderately	11
Very	5
Extremely	1
Have you acquired any new technical skills?	
Yes	5
No	15
Have you improved your soft skills & business knowledge?	
Slightly	1
Moderately	7
Very	9
Extremely	3
Have you acquired any new soft skills or business knowledge?	
Yes	10
No	10

Options	No of Responses
How much do you believe you've improved your knowledge on circular economy?	
Not at all	1
Slightly	3
Moderately	7
Very	8
Extremely	1
How much do you believe you've improved your knowledge on entrepreneurship?	
Slightly	3
Moderately	4
Very	11
Extremely	2
How much did your understanding about your environmental impact (in terms of resource use and CO2 footprint) improve?	
Not at all	4
Moderately	9
Very	6
Extremely	1
Did you engage in more makerspace activities?	
Not at all	3
Slightly	3
Moderately	6
Very	7
Extremely	1
Did you engage in more activities with your local maker community?	
Not at all	4
Slightly	3
Moderately	7
Very	6
How much did you expand your personal network?	
Not at all	1
Slightly	2
Moderately	10
Very	6
Extremely	1
How much did you expand your professional network?	
Not at all	1
Slightly	1
Moderately	12
Very	6
How did the accelerator help you in your employment?	
I had my own small company and I managed to increase our revenue	4
I had my own small company and I managed to increase our personnel	3
I was employed in another company, and I managed to start a secondary business	2
I am seriously thinking of opening my own company	6
Nothing changed	6

Options	No of Responses
I had my own small company and I am now ready to make growth happen	1
Would you like to extend the support received from the makerspace?	
Yes	17
No	3

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