

Airborne Microplastic Generation and Transport from 3D Printing Activities in a University Setting

Peyton Thompson

University of Florida

Sungyoon Jung

sungyoon.jung@ufl.edu

University of Florida

Research Article

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Abstract

Plastics are everywhere in our daily lives. Smaller plastics, known as microplastics (ranging in size between 5 mm and 1 μm), can either be intentionally manufactured or formed through the degradation of larger plastics by factors such as UV radiation and mechanical abrasion. Indoor air quality is crucial, as people spend more than 80% of their time indoors, and poor air quality can directly impact human health and productivity. Due to their small size, microplastics can be inhaled and potentially reach the respiratory tract, raising concerns about potential health effects. 3D printers have become increasingly common in indoor environments, and recent studies reported that they may serve as a potential source of microplastic emissions. This study aimed to investigate the microplastic release from 3D printing activities in a university setting. Fallout microplastics were collected from various locations within and outside a makerspace where students and staff fabricate products using filament-extrusion 3D printers and fabric items. The physicochemical properties of microplastics were characterized using a stereomicroscope and pyrolysis-gas chromatography/mass spectrometry (Py-GC/MS). Our results confirmed the presence of microplastics throughout the makerspace and in areas outside it, indicating potential particle transport beyond the printing space. The major polymer type was identified as polymethyl methacrylate, one of the common materials for 3D printing. These findings highlight that 3D printers can be a significant source of microplastics in indoor environments and underscore the need for a better understanding of their potential impacts on individuals in higher education settings where 3D printing activities frequently occur.

1. Introduction

Plastics are everywhere, and their wide range of applications dramatically increases their production and consumption. The global plastic market is expected to grow, reaching a value of around 1.05 trillion USD by 2033 (sensXPERT 2024). Smaller plastics, known as microplastics (MPs), can either be manufactured intentionally or formed through the degradation of larger plastics by environmental factors such as UV radiation. Although there is still ongoing debate, MPs are generally defined as particles between 5 mm and 1 μm in size. Recent studies have reported the potential of their adverse environmental and human health impacts. For example, environmental pollutants such as heavy metals and per- and polyfluoroalkyl substances (PFAS) can be adsorbed on the surface of MPs, altering their transport mechanisms (Mao, Lang et al. 2020, Gao, Fu et al. 2021, Cai, Gu et al. 2023, Shi, Almuhtaram and Andrews 2023). Moreover, humans can be exposed to MPs through inhalation and ingestion (Karbalaeei, Hanachi et al. 2018). Once inside the human body, they may cause harm. For example, inhaled MPs can penetrate deep into the lungs and further result in respiratory issues. A previous study highlighted increased respiratory symptoms among individuals frequently working with 3D printers (Chan, Rajaram et al. 2017). Although much research has identified the presence of MPs in the environment and highlighted their potential hazards, there still remains limited information.

People spend more than 80% of their time indoors, and thereby, indoor air quality is considered a critical factor for human health (González-Martín, Kraakman et al. 2021). Recent studies have shown that MP

concentrations are often higher indoors compared to outdoors (Choi, Lee et al. 2022, Boakes, Patmore et al. 2023, Nandi, Kumar et al. 2024). For example, Boakes et al. reported the highest MP concentrations in an indoor residential setting, while the lowest concentration was observed in a rural outdoor environment (Boakes, Patmore et al. 2023). This is partly due to the dilution of MPs in the outdoor environment, as well as the higher intensity of human activities indoors. Different indoor environments also exhibit distinct chemical compositions of MPs. For instance, fragment MPs dominated by polymer, such as polyethylene terephthalate (PET) and polypropylene (PP), prevailed in surgical settings due to the use of hospital-related tools, devices, and consumables (Field, Green et al. 2022), whereas acrylic and rubber fragment MPs were prominent in nail salons (Chen, Lin et al. 2022). Indoor ventilation has also been an essential factor affecting MP concentrations (Choi, Lee et al. 2022). These findings emphasize the need to identify the sources and conditions that influence the occurrence and characteristics of MPs in indoor environment.

Three-dimensional (3D) printing has become a common indoor activity, with the United States 3D printing market size currently valued at 24.61 billion USD and expected to grow to 134.58 billion USD at a growth rate of 19.18% (2025). This technology has been widely utilized due to its easy operation in fabricating 3D objects by heating and extruding a filament of thermoplastics (Zhang and Black 2023). In higher education, including universities and research institutions, 3D printing has increasingly been incorporated into engineering, architecture, and medical departments' curricula, enabling students to develop the ability to design and make 3D models for specific applications required in each field (Thiong'o, Bernstein and Drake 2021, Pearson and Dubé 2022). Therefore, students at universities or research institutes have easy access to laboratories, makerspaces, or classrooms containing various types of 3D printers. However, previous studies have reported the release of harmful contaminants from 3D printing activities (Afshar-Mohajer, Wu et al. 2015, Väisänen, Alonen et al. 2022, Felici, Lachowicz et al. 2023, Zhang and Black 2023). Typically, particulate matter (PM) and volatile organic compounds (VOCs) have been reported to be released from 3D printing activity, with varying concentrations and types of VOCs depending on the 3D printing device. For instance, approximately $480 \mu\text{g m}^{-3}$ of PM_{10} , $350 \mu\text{g m}^{-3}$ of $\text{PM}_{2.5}$, and $1725 \mu\text{g m}^{-3}$ of total VOC (TVOC) were reported with the operation of a binder jetting 3D printer (Afshar-Mohajer, Wu et al. 2015), while $20 \mu\text{g m}^{-3}$ of PM_{10} , $2.0 \mu\text{g m}^{-3}$ of $\text{PM}_{2.5}$, and $60 \mu\text{g m}^{-3}$ of TVOC were obtained during filament extrusion (Väisänen, Alonen et al. 2022). PM_{10} and $\text{PM}_{2.5}$, and VOCs are criteria air pollutants under the Clean Air Act, and their concentrations are regulated by National Ambient Air Quality Standards (NAAQS). These findings have clearly revealed evidence of creating air pollutants from 3D printing activities, indicating the potential negative impact on students at universities and research institutes. Although some previous studies have reported the existence of MPs released from 3D printing activities in the workspace (Chan, Rajaram et al. 2017, Murashov, Geraci et al. 2021), there is a dearth of information related to MP release by 3D printing activities in higher education settings.

This study aimed to investigate the occurrence and characteristics of MPs released from 3D printing activities in an educational setting by collecting fallout MPs from a makerspace with 3D printing

capabilities at the University of Florida. Multiple locations within the makerspace were considered to understand the distribution of MPs across the space and their potential transportation throughout the facility. The physicochemical properties of collected MPs were identified using a stereomicroscope and pyrolysis-gas chromatography/mass spectrometry (Py-GC/MS). This study provides the first preliminary dataset on MP release from an educational setting and its transportation, offering insights into this previously understudied area.

2. Materials and methods

2.1 Sample area and collection

The University of Florida hosts multiple facilities that offer 3D printing services. We collected fallout atmospheric MP samples from a makerspace in March 2024. The floor configuration of the space is shown in Fig. 1. For sampling, we used pre-cleaned 600 mL beakers. These beakers were pre-rinsed with ultrapure water (18.2 MΩ·cm at 25°C) and completely dried in a biosafety cabinet (Axiom Class II) prior to sampling. After then, the beakers were covered with aluminum foil and carried in cardboard boxes. At the sampling sites, the beakers were placed at various locations for a duration of one week. During sampling, the aluminum foil was removed to allow exposure. After one week, the beakers were re-covered with aluminum foil and carefully transported back to the laboratory. Then, the samples were stored in the biosafety cabinet until analysis. Multiple sampling sites were selected based on location to investigate the transportation of MPs generated from 3D printing devices, as well as the impact of human activity in the space.

At the makerspace, there are twelve filament-extrusion 3D printers (ten of them are functional). The space is open to students from 2 PM to 7 PM and is air-conditioned, containing various other devices for fabricating clothing and other items. The typical number of users ranges from six to eight, with a maximum of twelve throughout the working hours. For sampling, we selected five locations inside the space, one outside location, and blank sample. These samples are denoted as S followed by a number (e.g., S1, S2, etc.), with the blank sample denoted as B1 in Fig. 1. S1 and S2 represent samples taken inside and outside the 3D printer, respectively. As depicted in the photos of Fig. 1, each 3D printer is housed in a black casing. Six of these functional printers are equipped with filters (the specific details unknown) to capture generated particles, represented in red in the schematic. The remaining four printers, lacking filters, are denoted by dark blue boxes. The comparison between S1 and S2 samples highlights the difference in particle abundance generated by 3D printing devices with and without filtration.

2.2 Sample preparation

All samples underwent a double filtration process using a glass vacuum filtration system. The first filtration used a regenerated cellulose membrane filter (Cytiva Whatman™ Regenerated Cellulose Membrane, Grade RC60, 47 mm diameter, 1 μm pore size) to separate larger MPs. The second filtration

employed a glass fiber filter (GF/F, Cytiva Whatman™ Binder-Free Glass Microfiber Filter, 47 mm diameter, 0.7 µm pore size) to concentrate smaller MPs. Larger, noticeable MPs were manually separated at this stage using the stereomicroscopy and tweezers. Smaller MPs were concentrated onto the GF/F filter during the second filtration. The MPs collected on the RC membrane filter were transferred to a pre-rinsed beaker and further concentrated onto the GF/F filter. The filter was then trimmed to a diameter of less than 8 mm to fit into a pyrolysis sample cup (approximately 80 µL volume) for further analysis using Py-GC/MS.

2.3 Analysis of plastics

The physicochemical properties of MPs were investigated using analytical instruments. The stereomicroscope (Motic SMZ 171-TLED) with a Moticam BT110 digital camera, providing up to 5x magnification, will be utilized to analyze the morphology, color, and size of plastics. Additionally, the number of plastics was counted using this instrument. Py-GC/MS, employing a multi-shot pyrolyzer (EGA/PY-3030D, Frontier Laboratories) coupled with an Agilent 8890 GC and an Agilent 5977C MS, analyzed the chemical composition of plastics. For analyzing samples, a single-shot mode was employed. Each sample was loaded in a small pyrolysis cup and loaded in the pyrolyzer, which was then heated to 650°C to generate pyrolysis gas products from the plastics. The generated pyrolysis gas products were subsequently transferred into the GC column for separation. The GC oven was heated from 40°C to 320°C at 10°C min⁻¹. Due to the limit of detection of the microscope, plastics less than approximately 10 µm was not visually counted.

2.4 Quality control

Appropriate PPE was worn by all personnel while handling samples to avoid any cross-contamination. All samples and filters were stored in glass containers, which were covered with aluminum foil. All samples and filters were then placed in a biosafety cabinet before further analysis. The filtration process took place in a fume hood, while drying or storage of samples occurred within the biosafety cabinet. Prior to each experiment, liquids and chemicals were pre-filtrated using a 0.02 µm membrane filter (Cytiva Whatman™ Anotop™ 10 Sterile Syringe Filter with 0.02 µm), and all glassware and tools underwent multiple rinses with ultrapure water. For the analysis using Py-GC/MS, an empty pyrolysis cup was run at least twice to ensure there was no residue from previous samples. To ensure no or negligible cross-contamination, we performed sampling and procedural blank tests. The sampling blank showed 3 black particles and 2 fibers, while the procedural blank during the filtration showed 3 fibers, 6 black particles (chemical composition was not characterized due to the very small mass of the particles). We conducted multiple recovery tests to ensure the experimental procedure achieves reliable recovery rates without significant loss. Different types of standard MPs were tested and their recovery rates during the sample preparation were obtained: 90.0 ± 0% (20 beads of 900 µm polystyrene (PS, Goodfellow)), 77.5 ± 3.5% (20 beads of 600 µm polymethyl methacrylate (PMMA, Goodfellow)), and 73.5 ± 15.0% (70 µg of 5 µm PS (Nanobead NIST traceable particle size standard, Polysciences)).

3. Results

The physicochemical properties of prepared samples were evaluated using the stereomicroscope and Py-GC/MS, and their results are addressed following.

3.1. Physical properties of MPs generated from 3D printing

Different types of particles were observed from all sampling locations (S1-S6), as shown in Fig. 2. However, their physical properties and abundance are varied among locations. In the case of S1 inside the box where only 3D printer is placed, the majority of particles have irregular black shapes with various size range between 10 μm and 100 μm . The inset image which is magnified version of one single black particle clearly shows the sharp edge, which could be the evidence of artificial process to create these particles. Since there are negligible human activity occurred inside the box and only 3D printing process mainly occurred, these black particles can be assumed to be the generated 3D printing-related MPs. We focused on these black particles among different locations to better understand how they transport throughout the makerspace and also outside space through the small door. Except for the image from S1, other images showed lots of microfibers or large fibers with different colors and lengths. This observation could be due to the clothes people wearing in space and their activities. Many recent studies have reported that the major shape of MPs in the atmosphere indoors and outdoors is fiber (Shruti, Kutralam-Muniasamy et al. 2022, Abad-López, Orozco-Pérez et al. 2024, Nandi, Kumar et al. 2024), and our finding is consistent with these studies. Rather than the fibers, small black particles were also observed from all the locations despite their varied abundance.

Given that the red-highlighted boxes have filters (no details available), we investigated the efficiency of capturing any created MPs from 3D printing machines. We assumed that the black particles were probably generated from 3D printing machines, and thereby, the filter's efficiency can be evaluated by comparing the size fraction distribution (bar) and cumulative fraction size distribution (line) of those particles from S1, S2, and S3 (Fig. 3). We counted more than 100 black particles in the microscopic images using ImageJ software and measured their longest dimension, as shown in Fig. 2. It should be noted that around 40 particles were counted from the microscopic images of S2 due to its much lower concentration compared with the other cases. As can be seen in Fig. 3, the size fraction and cumulative size distributions of S1 and S3 were similar, displaying a broader range with a median value of around 25 μm . However, S2 showed a much higher fraction of smaller particles with a median value of approximately 15 μm . These results indicate that the filter is efficient at capturing larger particles, whereas smaller particles (less than 15 μm) may penetrate through the filter and disperse throughout the space. Also, given that the microscope has a detection limit of around 10 μm , the actual trend may be more pronounced for smaller particles, such as inhalable ranges (< 10 μm), potentially posing a greater health risk to students.

3.2. Chemical properties of MPs generated from 3D printing

The chemical compositions of all samples were evaluated using Py-GC/MS, and the results are shown in Figs. 4 and 6. The microscopic images identified the black particles as the most suspicious, likely generated by 3D printing activities, given their high abundance inside the 3D printing box. Total ion chromatograms (TICs) of S1, S2, and S3 exhibited a common peak at 3 min, which corresponds to methyl methacrylate (MMA) (Fig. 4). MMA is a monomer of polymethyl methacrylate (PMMA) and is found as a major pyrolysis product of PMMA (Jung, Raghavendra and Patri 2023). PMMA has been used as one of the filament materials that can be melted and extruded via fused deposition modeling (FDM) in additive manufacturing technology (Hata, Ikeda et al. 2021, Dutta, Veeman and Vellaisamy 2024, Hu, Li and Jia 2025). The MMA peaks overlaid in the inset of Fig. 4, revealing the intensity of S1, S3, and S2 in order. This trend aligns with the microscopic images that show fewer black particles in S2 and S3 than in S1. These results confirm that PMMA MPs were generated from 3D printing activities in the makerspace.

To understand the distribution of MPs generated from 3D printing activities, the MMA peak was analyzed from all TICs, and the deposition rate with the unit of $\mu\text{g m}^{-2} \text{ day}^{-1}$ in all sampling locations were obtained and are shown in Fig. 5. MP deposition rate varied depending on sampling location. The MP deposition rate of S1 (inside the 3D printing box) showed the highest value of $898.26 \mu\text{g m}^{-2} \text{ day}^{-1}$, then S3 (outside the 3D printing box without a filter, $507.72 \mu\text{g m}^{-2} \text{ day}^{-1}$) in order. This finding indicates that a certain amount of MPs may be retained within the box even without a filter. The deposition rates at S2 (outside the 3D printing box with a filter), S4 (workbench), and S6 (outside the room) were lower than those at S1 and S3 ($60.52 \mu\text{g m}^{-2} \text{ day}^{-1}$, $50.20 \mu\text{g m}^{-2} \text{ day}^{-1}$, and $51.65 \mu\text{g m}^{-2} \text{ day}^{-1}$, respectively). The MP deposition rate at S6 indicates that MPs can be transported outside the space, potentially resulting in students inhaling those MPs in the library. The lowest deposition rate was detected at S5 (counter, $21.27 \mu\text{g m}^{-2} \text{ day}^{-1}$), the farthest location from the 3D printing boxes.

Chemical composition of other MPs was also identified (Fig. 6), although their abundances were not compared, as the primary goal of this study was to investigate the generation of MPs from 3D printing activities and their transport throughout the space. In the case of S4, an intense peak appeared at 10.9 min, corresponding to caprolactam ($\text{C}_6\text{H}_{11}\text{NO}$), a major pyrolysis product of nylon 6 (PA 6) (Jung, Raghavendra and Patri 2023). Students were actively working at the workbench to manufacture fabric items such as shirts or bags, suggesting that PA6 may be a major polymer type observed in S4. In addition to these intense peaks (MMA and caprolactam), other polymer types were identified by extracting characteristic mass-to-charge (m/z) ratios representing unique pyrolysis products. For polyethylene (PE), the m/z of 140 at 6.8 min was used as an indicator peak for 1-decene ($\text{C}_{10}\text{H}_{20}$), a major pyrolysis product. For polypropylene (PP), the m/z of 70 at 4.5 min was selected as an indicator for 2,4-dimethyl-1-heptene (C_7H_{14}). For polyvinyl chloride (PVC), the m/z of 104 at 5.4 min (styrene, C_8H_8) and 128 at 10 min (naphthalene, C_{10}H_8) were used as major products. For PA 6, the m/z of 113 at 10.9 min was chosen for caprolactam (Hotaling and Jung 2026). S4 showed intense peaks corresponding to PVC and PA 6, along with a minor peak corresponding to PE (Fig. 6a). S6 exhibited distinct peaks corresponding to PP and PVC, with a minor peak corresponding to PE (Fig. 6b). It should be noted that the extraction ion chromatography (EIC) at m/z 140 for PE is not shown in Fig. 6 due to its

low peak intensity. S5 did not show distinct MPs other than PMMA. Our observation indicates the generation of MPs from on-site activities by users, such as their backpacks, cups, and clothing, consistent with previous studies reporting that clothing, textiles, and stationery are dominant sources of indoor MPs (Ageel, Harrad and Abdallah 2022, Bhat 2024).

4. Discussion

Previous studies have reported fine-particle emissions from 3D printing activities and demonstrated that emission rates vary depending on operating conditions, including filament type and extrusion temperature (Azimi, Zhao et al. 2016, Steinle 2016, Mendes, Kangas et al. 2017, Zhang, Pardo et al. 2019, Byrley, Wallace et al. 2020, Lewis, Byrley et al. 2026). For example, Byrley et al. (Byrley, Wallace et al. 2020) used a 2 m³ chamber to evaluate particle emissions from a twin-screw 3D printing filament extruder and reported higher particle number concentrations for acrylonitrile butadiene styrene (ABS) than for polylactic acid (PLA) using a scanning mobility particle sizer (SMPS). Zhang et al. (Zhang, Pardo et al. 2019) similarly reported higher particle emissions from ABS than PLA, while Lewis et al. (Lewis, Byrley et al. 2026) observed the highest emission rate for ABS among 17 tested filament types. In another study, Azimi et al. (Azimi, Zhao et al. 2016) reported fine-particle emission rates of up to 9×10^{10} particles·min⁻¹ using a condensation particle counter (CPC) and SMPS in a controlled 3.6 m³ stainless-steel chamber equipped with a desktop 3D printer. Emission rates varied substantially among filament types, with ABS producing the highest and PLA the lowest emissions like other studies. The authors also found that the chemical composition of the emitted particles was predominantly associated with the filament material. Mendes et al. (Mendes, Kangas et al. 2017) similarly reported substantially higher particle emissions from ABS, with concentrations reaching 1.4×10^9 particles·s⁻¹, and demonstrated that extrusion temperature significantly affected particle emission rates.

Although these studies provide clear evidence of fine- and ultrafine-particle emissions from 3D printing activities, relatively little attention has been given to particle emissions in occupied indoor environments, particularly university settings. A few studies have investigated MP occurrence in different university settings (Zhang, Zhao et al. 2020, Chaithra 2026). For example, approximately 5–10 particles·m⁻³ were detected in various facilities at a residential educational institute using a low-volume active air sampler, including a 3D printing facility, waste segregation area, and ball mill unit (Chaithra 2026). Among these facilities, the 3D printing facility was a relatively compact indoor space containing large 3D printers and occupied by 5–7 individuals. Approximately 6 particles·m⁻³ were detected in this facility, with fibers predominantly smaller than 100 µm and polyolefin polymers, consistent with the use of polymeric printing filaments (Chaithra 2026). However, the spatial distribution and potential transport of MPs generated by 3D printing activities remain poorly understood.

Furthermore, 3D printing has become increasingly integrated into higher education environments through engineering courses, makerspaces, and student projects. These settings provide students with hands-on opportunities to design, operate, and use 3D printers to fabricate objects. For example,

universities such as the University of Florida have multiple 3D printing laboratories equipped with numerous 3D printers that may be operated repeatedly as part of coursework and student projects. This increasing use of 3D printing in higher education settings highlights the potential importance of universities as indoor environments where MP emissions from 3D printing activities may occur.

Our study provides further evidence of particle generation associated with 3D printing activities, consistent with previous findings. In addition, we investigated their spatial distribution and observed potential transport throughout the makerspace and beyond the immediate printing area, suggesting that particles generated during 3D printing may be transported to other indoor environments.

We also observed a high fraction of smaller MPs ($< 10\ \mu\text{m}$) in the samples collected from the system with the filter during 3D printing activities. The predominance of smaller particles suggests that these particles may not have been efficiently retained by the system and may therefore have greater potential for transport throughout the indoor environments. The size-dependent behavior is particularly relevant to indoor air quality because smaller particles, especially those $< 10\ \mu\text{m}$, can remain airborne for longer periods and may have greater potential for inhalation and subsequent health effects. These findings highlight the need for further studies on the transport and exposure of smaller MPs generated during 3D printing activities and developing effective strategies for their capture and control.

5. Limitations and suggestions for future studies

The current study primarily investigated fallout MPs in a makerspace within a higher education setting. The atmospheric transport of MPs can vary depending on their physicochemical properties, including polymer type, density, size, and morphology. For example, PS has a density of $0.6\text{--}1.1\ \text{g}\cdot\text{cm}^{-3}$, while PVC has a density of $1.3\text{--}1.4\ \text{g}\cdot\text{cm}^{-3}$. Lower density and elongated MPs may remain suspended for longer periods and potentially undergo greater atmospheric transport than denser particles. Recent studies have reported differences in the concentrations and characteristics of fallout and suspended MPs, potentially due to differences in their aerodynamic behavior (Kernchen, Löder et al. 2022, Coşgun, Gündoğdu et al. 2025). For example, a study conducted across the Weser River Catchment in Northwest Germany employed both active and passive sampling techniques to collect aerosol (suspended) and fallout MPs. The results showed distinct differences in polymer types: PE was dominant in aerosol samples, whereas PP, PE, PET, PVC, and PS were more prevalent in fallout samples probably due to the source and polymer density (Kernchen, Löder et al. 2022). These findings emphasize the importance of considering both suspended and fallout MPs to obtain a more comprehensive understanding of MP pollution.

In addition to MPs, 3D printing activities can generate other air pollutants, including VOCs and PM (Afshar-Mohajer, Wu et al. 2015, Azimi, Zhao et al. 2016, Steinle 2016, Mendes, Kangas et al. 2017, Zhang, Pardo et al. 2019, Byrley, Wallace et al. 2020, Väisänen, Alonen et al. 2022, Felici, Lachowicz et al. 2023, Zhang and Black 2023, Lewis, Byrley et al. 2026). Because of their relatively large specific surface area and diverse surface chemistries, MPs may also interact with and potentially transport co-occurring

pollutants. Previous studies have demonstrated that MPs adsorb contaminants such as polycyclic aromatic hydrocarbons (PAHs) (Sørensen, Rogers et al. 2020, Hou, Zhao et al. 2023), PFAS (Bhagwat, Tran et al. 2021, Meng, Tian et al. 2023), and heavy metals (Mao, Lang et al. 2020, Gao, Fu et al. 2021) and that adsorption efficiency varies with polymer type, particle size, and surface characteristics. These findings suggest that MPs may influence the environmental transport and fate of other pollutants. The present study and previous research have identified polymers such as PMMA, PLA, and ABS as relatively prominent polymer types associated with 3D printing activities, while these polymers are generally reported at lower abundances in outdoor atmospheric MP studies. Consequently, their environmental behavior, including interactions with co-occurring pollutants in indoor environments, remains relatively poorly understood. Further investigation of the relationships between MPs and other pollutants, such as VOCs, could provide additional insight into the potential environmental significance of MP emissions during 3D printing activities.

Indoor air quality is strongly influenced by building characteristics, operating conditions, ventilation, and occupant activities. The present study provides preliminary evidence of MP generation and spatial distribution associated with 3D printing activities in a higher education setting. Our observations further suggest that MPs generated during 3D printing may be transported beyond the immediate printing area and potentially distributed throughout indoor environments. However, universities, makerspaces, and laboratories can differ substantially in their operating conditions, including the number, type, and brand of 3D printers, filament materials, printing frequency, number of occupants, ventilation characteristics, and building configuration. Therefore, additional measurements across diverse university environments are needed to establish a more comprehensive understanding of MP generation, transport, and transformation associated with 3D printing activities. Such information would help identify factors controlling MP emissions and distribution ultimately support the development of effective strategies to reduce MP release and potential exposure among students and staff.

6. Conclusions

In this study, we investigated the occurrence and transport of MPs generated 3D printing activities in a higher education setting. Fallout MP samples were collected from six locations within and outside a makerspace where students actively fabricate products using filament-extrusion 3D printers, as well as clothing and other fabric items. MPs were detected in all samples, with PMMA identified as the predominant polymer type regarding black fragments detected throughout space and in locations outside it. Deposition rates varied among sampling locations, indicating that MPs generated within the makerspace can be transported throughout the space and potentially beyond it. Given that the location is regularly occupied by students and staff, these airborne MPs may contribute to inhalation exposure.

We also observed a substantial reduction in MP deposition associated with the use of a filter on the 3D printing machine. However, smaller particles ($< \sim 15 \mu\text{m}$) were not efficiently captured, which is of particular concern because their small size may facilitate airborne transport and inhalation. Overall, our findings demonstrate the generation and spatial transport of MPs associated with 3D printing activities

in a higher education environment and highlight the potential importance of these emissions for occupational and indoor exposure assessment.

Declarations

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Ethics Declaration

Not applicable

Consent to Participate Declaration

Not applicable

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Author Contribution

P.T.: Sampling, data acquisition, data analysis, and manuscript writing. S.J.: Conceptualization, funding acquisition, supervision, guidance, project administration, writing, review, and revision.

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Figures

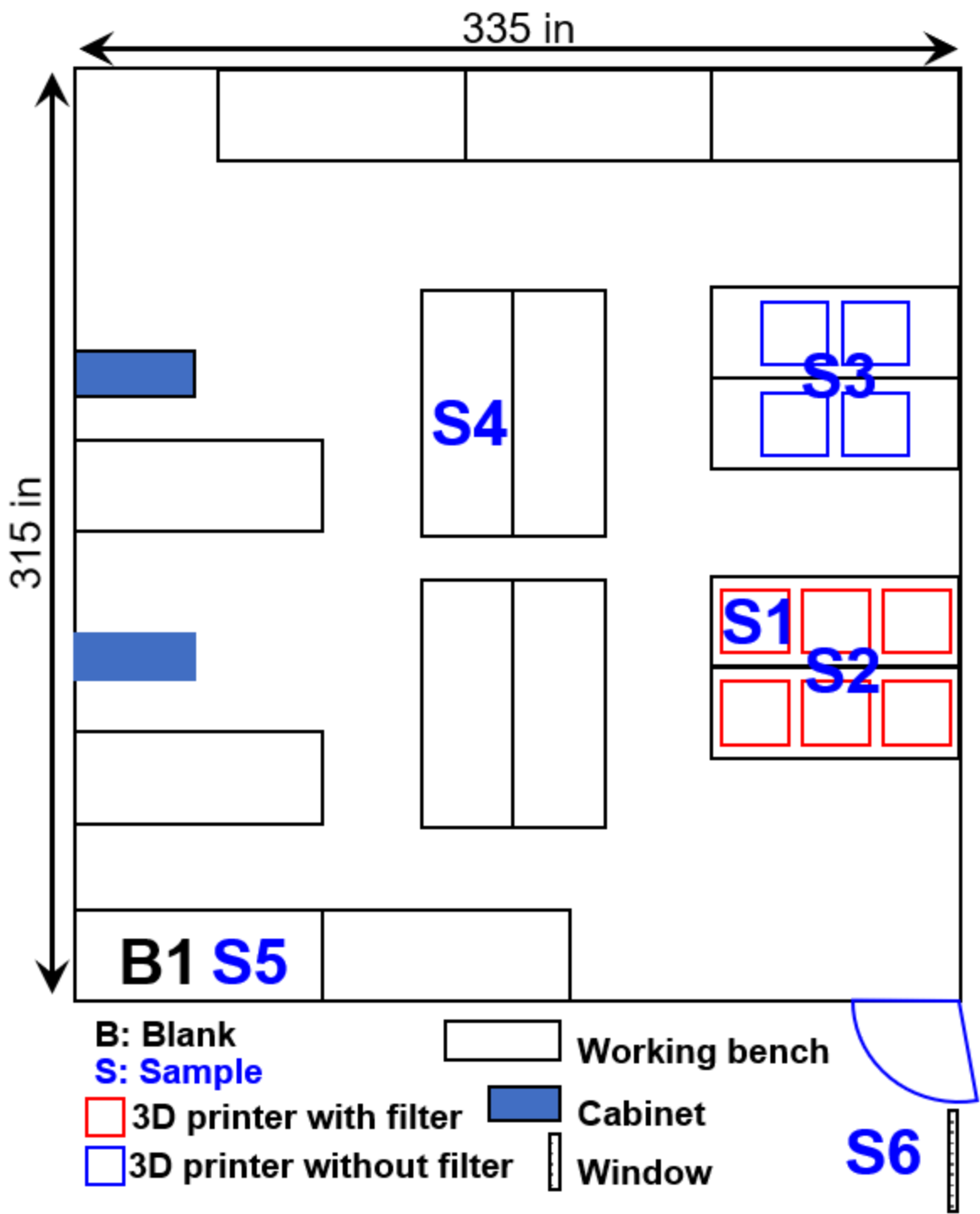


Figure 1

Layout of the makerspace.

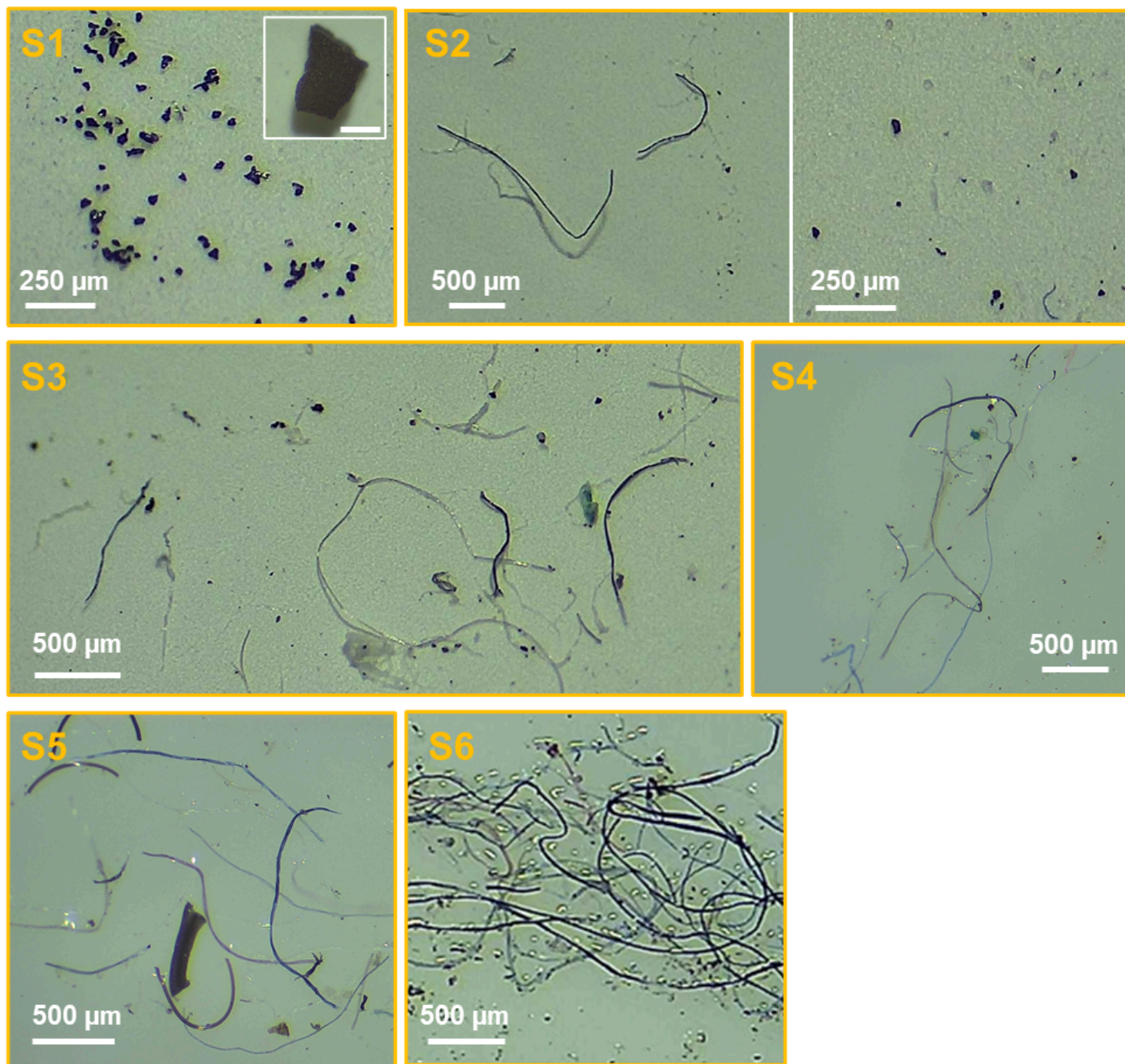


Figure 2

Microscopic images of collected samples from different sampling locations, labeled as S followed by the corresponding number.

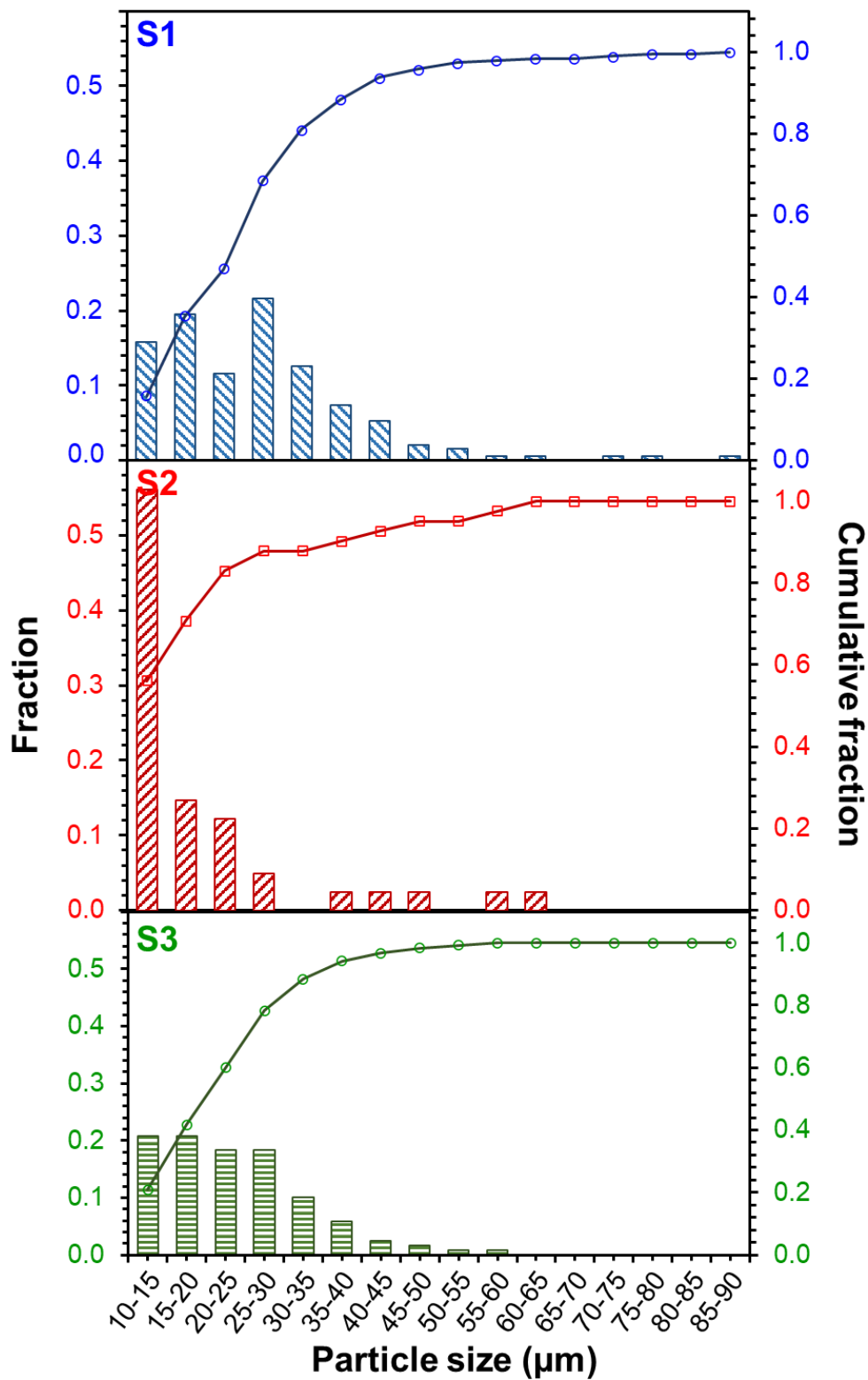


Figure 3

Particle size distribution. The left y-axis represents the size fraction distribution, while the right y-axis shows the cumulative fraction distribution.

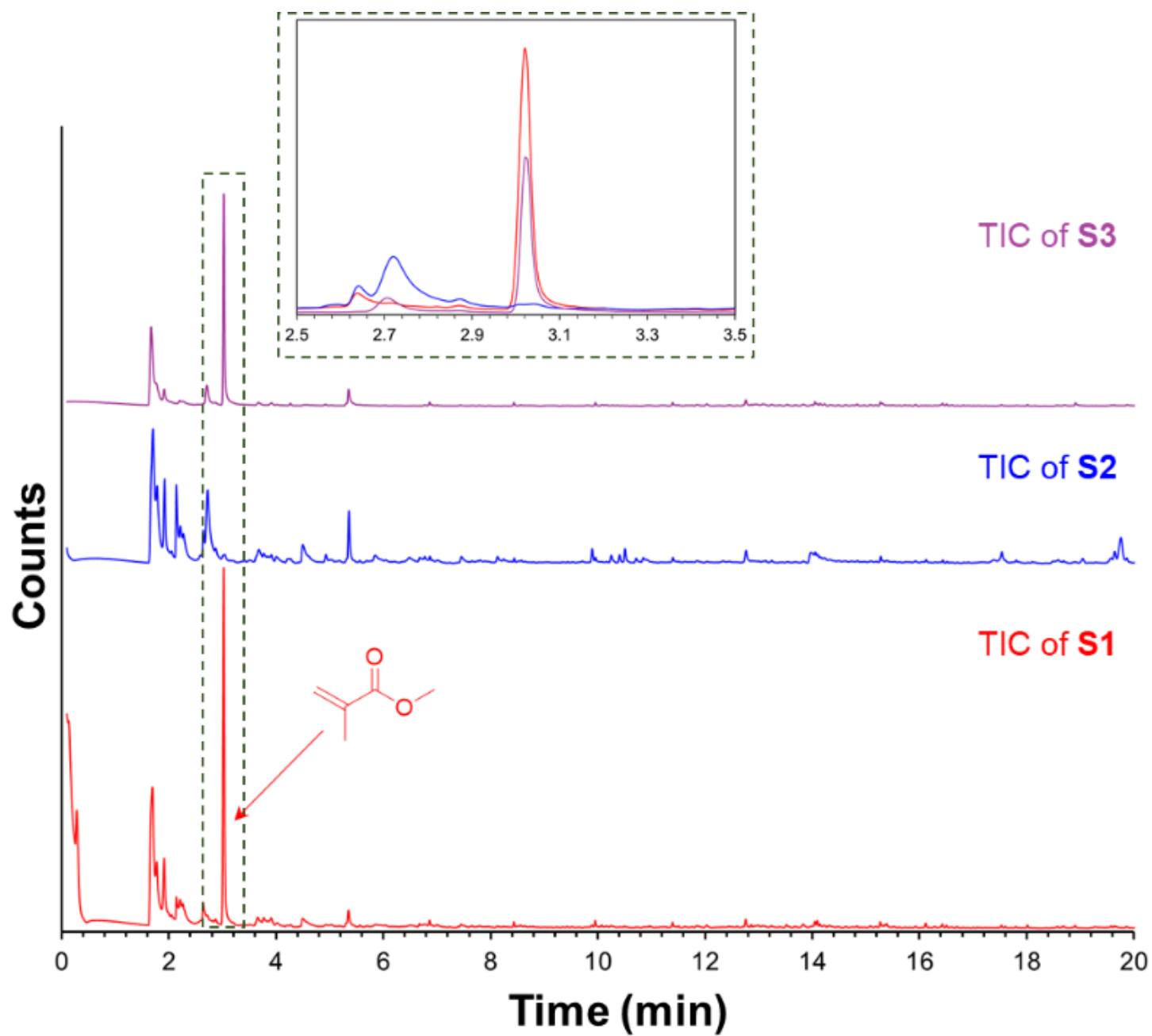


Figure 4

Total ion chromatography (TIC) of samples S1, S2, and S3.

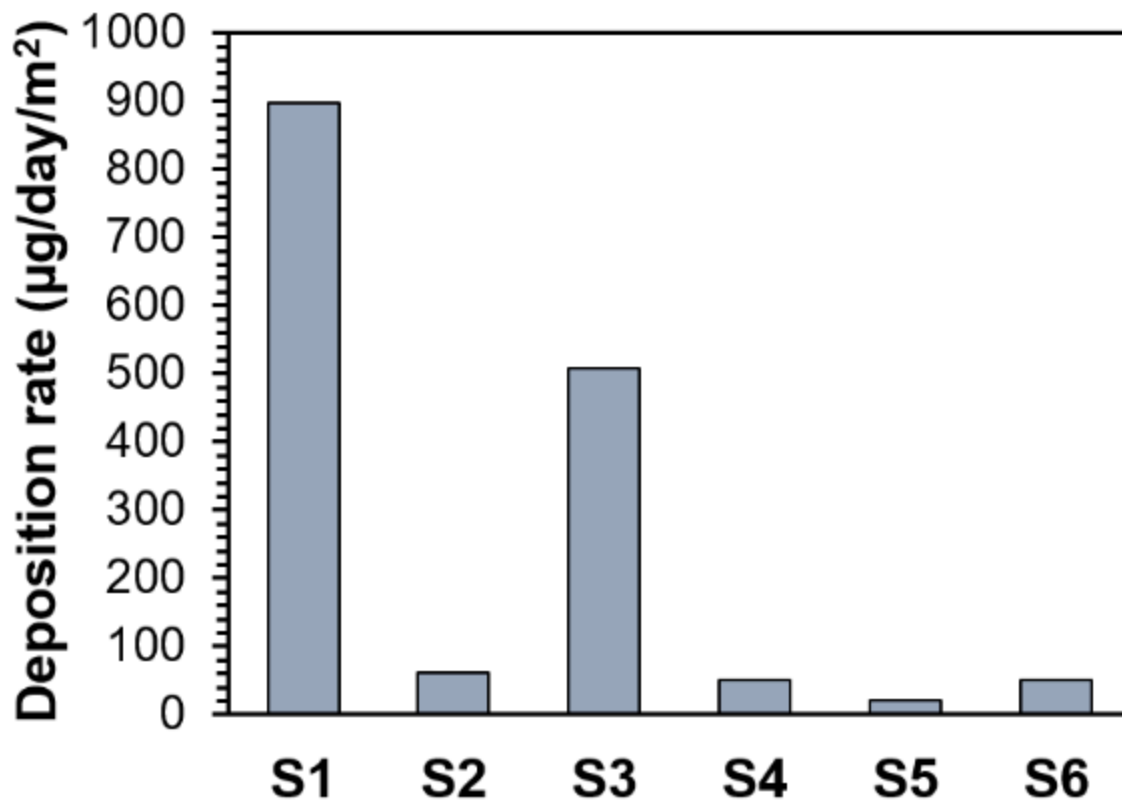
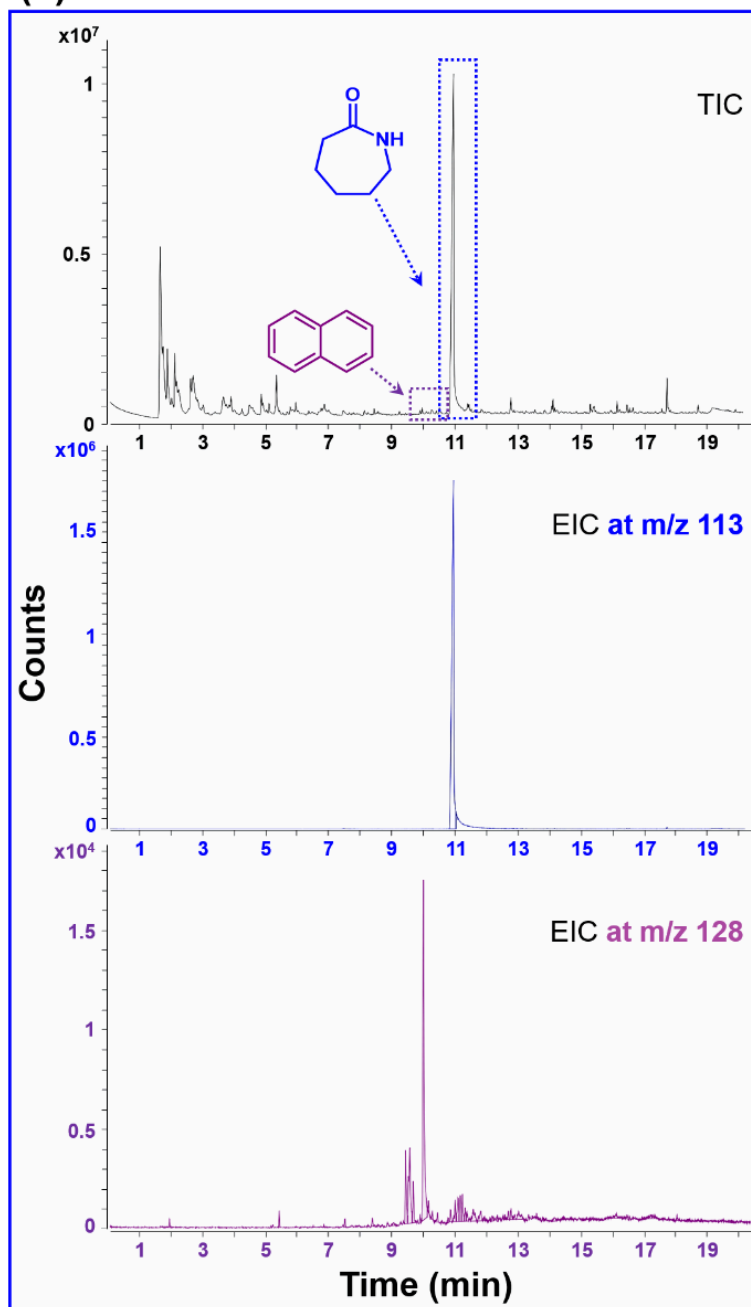
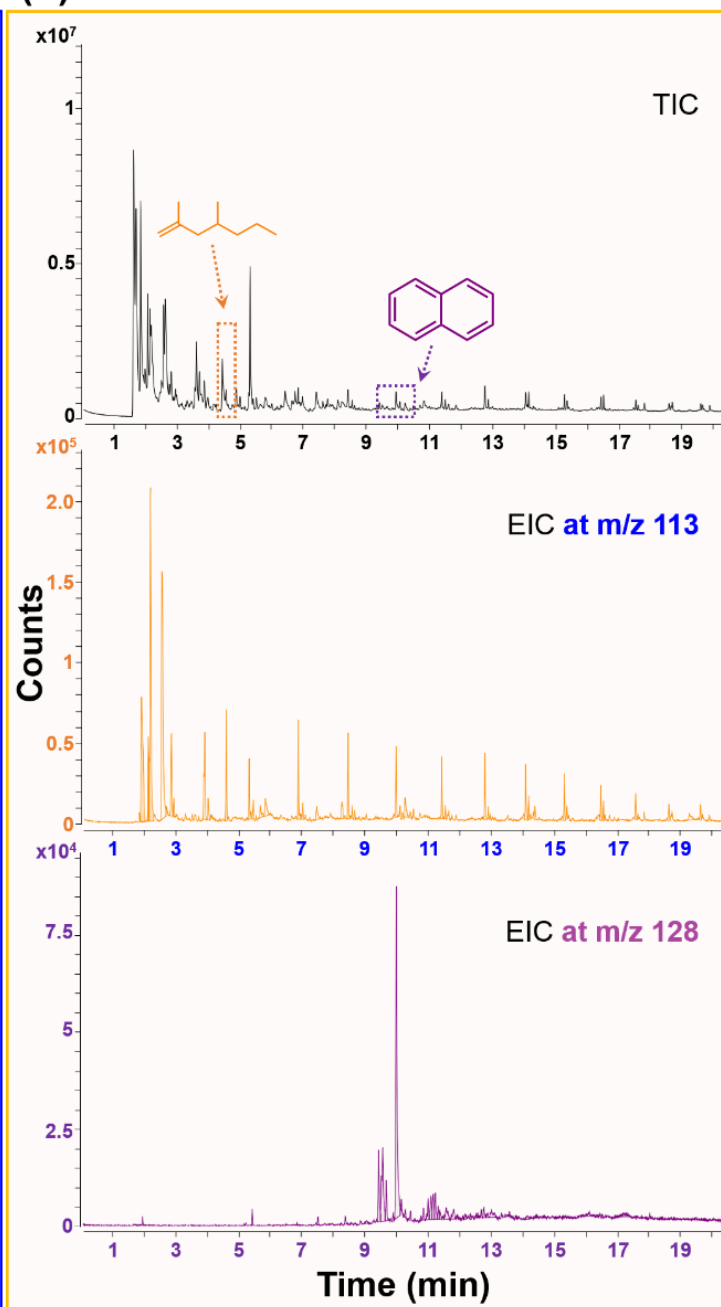


Figure 5

Generated MP from 3D printing activity distribution throughout space.

(a) S4**(b) S6****Figure 6**

Total ion chromatograms (TICs) and extracted ion chromatograms (EICs) for (a) S4 and (b) S6.