Mitigating Microplastic Emissions in Plastic Lumber Production: A Sustainable Solution for Sanding Processes in Developing Countries

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***Abstract*— Plastic pollution has emerged as a critical environmental challenge, prompting innovative recycling initiatives such as Tanzanian business Green Venture's conversion of plastic waste into plastic furniture. However, the sanding process in this production generates microplastics, which pose significant ecological and health risks. This study investigates the microplastic emissions during sanding and proposes a cost-effective solution to enhance dust collection without necessitating major equipment overhauls. By developing a vacuum attachment combined with a shield to contain airborne particles, the research aims to mitigate microplastic release and improve workplace safety. The findings highlight the importance of tailored solutions for small-scale manufacturers in low-resource settings, emphasizing the need for practical approaches that prioritize local adaptability and sustainability.**

Keywords—Plastic pollution, microplastics, recycling, dust collection, sanding process, Green Venture, environmental health, workplace safety, sustainable manufacturing, low-resource settings.

Introduction

Plastic pollution has become an important environmental issue, with a tremendous amount of plastic waste making its way into ecosystems across the world. This has consequently sparked various innovative ways of recycling as the crisis escalates. Green Venture, a Tanzanian company, has contributed to such initiatives in the form of recycling plastic waste into plastic lumber for furniture production. This initiative is a step towards a circular economy by repurposing waste materials. However, if specific aspects of manufacturing are not managed correctly, this may lead to more harm than good.

A significant concern arises during the sanding phase of plastic lumber production. This process generates microplastics, tiny plastic particles less than 5 millimeters in size. These particles are difficult to contain and filter. Microplastics have been found in oceans, freshwater systems, soils, and even the atmosphere [4]. Their pervasive presence poses substantial risks to both ecological and human health.

Research indicates that microplastics can absorb and transport toxic chemicals. This leads to potential endocrine disruption, carcinogenic effects, and developmental toxicity in organisms [2]. Due to their small size, microplastics can be ingested by a wide range of organisms, from marine life to terrestrial animals, leading to the entry of these particles into the food chain and impacting human health [4]. The inhalation of airborne microplastics is another exposure route, raising concerns about respiratory health implications [3].

This study focuses on Green Venture's manufacturing processes, especially the release of microplastics during sanding. The main objective is to suggest new ways of reducing such emissions so that the recycling process adds to environmental health rather than increasing pollution. By addressing these challenges, this research aims to enhance the sustainability of plastic recycling initiatives and contribute to broader environmental protection efforts.

Related Work

Dust collection systems have been designed and optimized primarily for wood-based manufacturing. These systems only need to remove a significant portion of larger wood particles sufficient to maintain safe air quality for workers. There is little incentive to achieve complete or near-perfect dust extraction, especially for finer particles, as wood dust is biodegradable and poses minimal environmental risks. In contrast, the emerging field of plastic “carpentry” presents a new set of challenges. Unlike wood dust, the smallest plastic particles—microplastics—pose significant risks to both human health and the environment, requiring more stringent collection methods than traditional wood sanding practices.

The most common method for dust collection in hand-held power sanders is pairing a sander that has an inbuilt vacuum with sandpaper featuring pre-drilled holes for vacuuming (Fig.1). Although sufficient for woodworking, this setup is limited in several ways in addressing Green Venture’s microplastic concern. First, even with these in-built vacuum holes, the sanders fail to capture finer plastic particles that are dispersed rapidly into the air while sanding (Fig. 2). Additionally, the efficiency of the vacuum system depends heavily on sandpaper with precisely aligned holes. Such sandpaper can be difficult to source, particularly in regions like Tanzania where sandpaper varieties are already scarce. Furthermore, this functionality requires that the sander be manufactured with these holes. Currently, Green Venture does not own any of these sanders with in-built vacuums. Completely replacing or modifying existing sanding equipment to improve microplastic collection is often unfeasible for small-scale manufacturers like Green Venture. The costs and logistical challenges of such upgrades make it impractical. Instead, any proposed solution must work with their existing sanding tools to remain cost-effective and accessible.

Fig. 1: Sandpaper with vacuum holes [1]

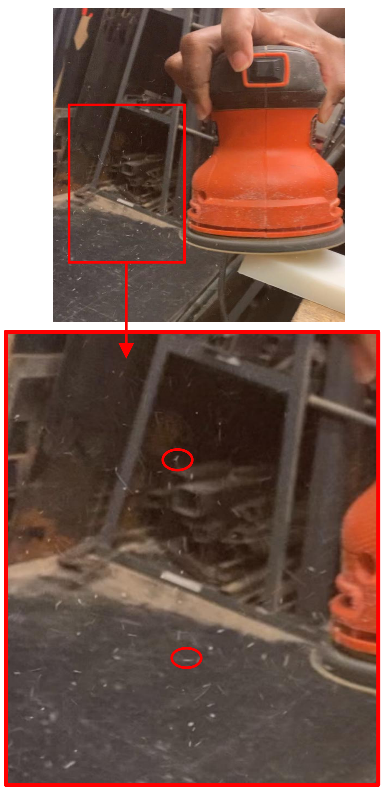

Fig. 2: Dust escaping into the room when a vacuum sander is used on a corner

Despite these challenges, one key design feature of orbital sanders is particularly promising: the placement of vacuum holes directly above the sanding surface. The proximity of the holes to the sanding surface is critical, as it maximizes suction efficiency at the point of generation. Any enhancements to dust collection systems for plastic sanding should build upon this feature and consider the proximity of the vacuum opening to sanding surface.

Interestingly, it is already common practice to augment the vacuum power of hand-held power sanders with vacuum support by attaching a shop vacuum to where the container for the in-built vacuum would have been (Fig. 3). This practice demonstrates a promising direction for enhancing dust collection without requiring significant equipment overhauls.

Fig. 3: A sander with a vacuum attachment [5]

There is limited research specifically focused on microplastic capture during plastic sanding, and existing environmental regulations often overlook emissions from such small-scale manufacturing processes. This regulatory gap highlights the need for innovative solutions tailored to plastic sanding. Drawing from woodworking practices, this study aims to adapt and improve dust collection methods to address microplastic emissions effectively. By drawing inspiration from the placement of vacuum holes in sanders with in-built vacuums and adapting the practice of using external shop vacuums, this research aims to develop a scalable and cost-effective approach to minimizing microplastic emissions during sanding. Such innovations will contribute to making small-scale plastic recycling operations both environmentally sustainable and economically viable.

METHODOLOGY

Information Gathering

The information-gathering phase began with direct engagement with the manufacturer. The first inquiry was whether any specific problems needed addressing, but no particular concerns were identified at that time. The manufacturer was then asked about the various steps in their manufacturing process, which were outlined as refining, cutting and shaping, joining/assembly, sanding and finishing, quality control, and packaging and delivery.

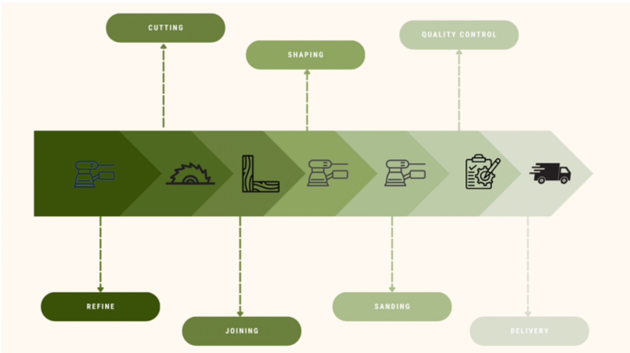

Fig. 4: An outline of the manufacturing process of Green Venture

For a deeper understanding of the workflow and challenges, a customer journey mapping approach was employed. The manufacturer was asked to describe specific elements of each step in the process, including user actions and tasks, touchpoints or tools and resources used, challenges or pain points encountered, satisfaction with each step, and potential opportunities for improvement.

Through this exercise, sanding emerged as a major concern. It was discovered that the sanding phase generates microplastic dust, which is released into the air, posing environmental and health risks. The process is manual and occurs during both the refining step and the sanding and finishing step, which extends the time required for production. Additionally, the process consumes a significant amount of sandpaper, and sourcing sandpaper in Tanzania is challenging due to an unreliable supply chain, which makes it difficult to maintain a consistent inventory.

Further details about the equipment used in the sanding process were requested, and the manufacturer provided photos and videos that documented the sanding procedure. This visual information helped to better understand the equipment and assess the scale of challenges related to microplastic emissions and the availability of sandpaper. This comprehensive information-gathering process provided the foundation for identifying areas where improvements could be made in the manufacturing process.

Fig. 5: Top plank - just extruded; bottom plank – after refinement and sanding

A key observation from the information-gathering process is that the current sanding setup lacks any form of dust collection system, such as vacuums or extraction mechanisms, leaving microplastic particles to disperse freely into the air. Additionally, much of the sanding process requires handheld tools due to the intricate and diverse shapes of the furniture pieces being refined. These unique shapes make it challenging to adopt standardized, automated sanding solutions, further highlighting the need for a tailored approach to mitigating microplastic emissions in this context.

Fig. 6: A worker at Green Venture using a sander

Ideation

During the ideation phase, multiple techniques were employed to generate potential solutions for the sanding process and its associated issues. Several ideation methods were used, including the SLIP method, a user needs assessment, and a Pugh Chart. These techniques facilitated a structured approach to brainstorming and evaluating different concepts that could address the identified problem of microplastic dust during sanding.

A range of concepts was considered, with several promising ideas emerging from the brainstorming sessions. One concept involved creating a fixture for the hand sander, which would include a box or a vacuum system to contain the dust. This would require sliding the plastic through the fixture while sanding, ensuring that the dust was contained. However, this setup would only be effective for sanding flat planks and would not accommodate the higher mobility required for sanding furniture with intricate shapes, which forms a significant part of the manufacturer’s process. Additionally, similar functions are already performed by commercial planers equipped with built-in vacuums. Developing a comparable product was deemed unfeasible within the project's design constraints, as it would not be cost-effective or practical to mass-produce a solution that matches the functionality and efficiency of a planer.

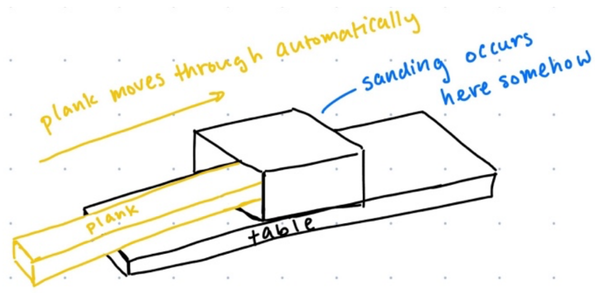

Fig. 7: A concept for using an enclosure to prevent dust escaping

Another concept involved using a water-based solution, where water would be sprayed continuously to wet the plastic and prevent dust from becoming airborne. While promising in theory, this approach was ultimately deemed impractical. The need for a constant inflow of water and specialized waterproof sanding equipment would significantly disrupt the current shop workflow and setup. Additionally, implementing this system would introduce serious challenges, such as the requirement for effective water filtration to handle the contaminated runoff, further complicating the process and increasing operational costs.

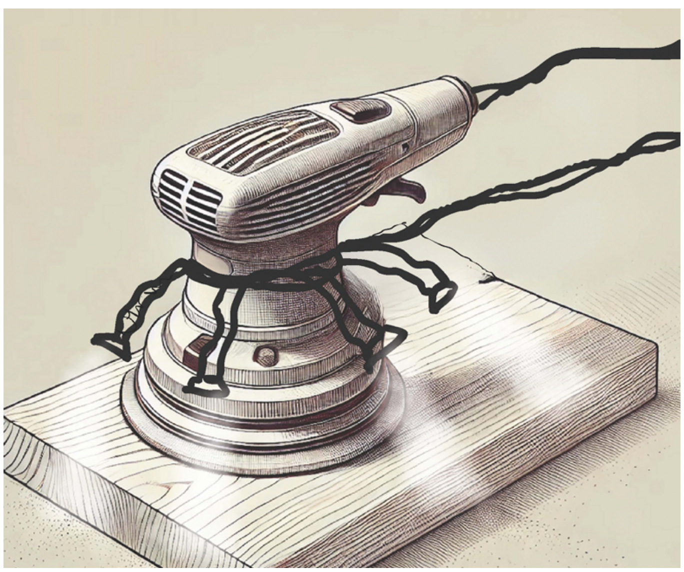

Fig. 8: A concept for using water-based dust collection

Non-sanding pathways to achieve smoother plastic surfaces were explored. One example is the implementation of hot rolling, where heated cylinders would press the planks into a smooth shape right after rolling. The team did not move forward with this concept due to the high energy needed and the fact that this concept would not affect the manual sanding process.

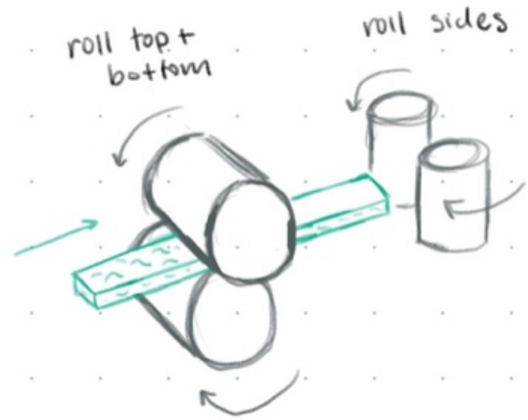

Fig. 9: A concept for hot rolling planks to eliminate sanding

Additionally, an enclosed area, such as a box with a drawer or vacuum system underneath, was considered. Another potential solution involved a portable "suction bag" designed to fit over the object being sanded, preventing dust from escaping. This concept was tested, as shown in Fig. 10, and was found to be an effective method of dust collection. However, the concept was deemed inflexible and difficult to adapt to multiple shapes of sanded objects, because quickly sticking the edges of the bag to achieve the enclosure was difficult to achieve.

Fig. 10: A concept for a bag over the sanding location being tested

Other concepts such as a vacuum table, where the table itself would be vacuuming dust away from the surface, and thermoforming were also explored, but it was decided that implementation would be too expensive and difficult, because a large amount of setup space would be required. Finally, another concept suggested purchasing a vacuum sander or developing a vacuum attachment for the existing sanders.

Prototyping

The vacuum attachment for the sander became the most promising solution. Several variations of this idea were considered, including mini vacuum tubes like straws that would point directly at the sanding surface (Fig. 12); a large shield surrounding the sander to prevent dust from escaping (Fig. 13); brushes along the perimeter of the sander to collect dust; and a vacuum attachment that would suck the dust from around the sander (**Error! Reference source not found.**). Ultimately, the vacuum attachment for the sander was selected as the focus of the project due to its feasibility and practicality. This solution could be easily integrated with the manufacturer's existing tools, requiring no changes to their manufacturing process, making it more likely to be implemented in practice.

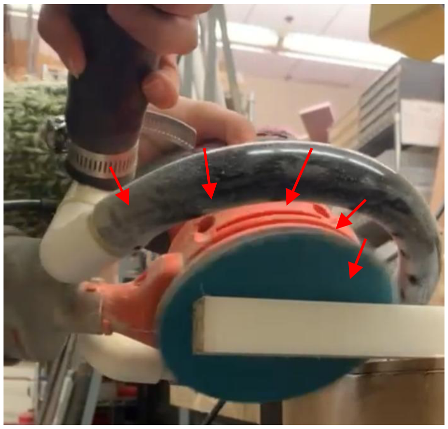

Fig. 11: A tube with vacuum holes positioned around the base of the sander

Fig. 12: A concept to use multiple straws as miniature vacuums pointed at the base of the sander

Fig. 13: A vacuum attached to a shield around the sander

To add additional protection to stop dust from getting into the air around the user, a shield was desired, that would fit over the shield. To prototype the shield concept, first a wire mesh was positioned around the sander as a framework for the shield (Fig. 14), and then clear foil was wrapped around the mesh to act as the shield (Fig. 15).

Fig. 14: A wire mesh around the vacuum tube

Fig. 15: Clear foil wrapped around the wire mesh to act as a shield

RESULTS

Design Concepts

A completed vacuum tube circuit is shown in Fig. 16, where PVC pipe segments were used to join the ends of the tube and connect it to the vacuum. Holes were drilled along the base of the tube, angled slightly inwards to aim at the base of the sander, where the dust is produced.

Fig. 16: A completed vacuum tube circuit connected to the vacuum

While determining hole size, it was discovered that if the vacuum holes were too small, as larger particles of dust were sucked into the vacuum, they would clog the holes, as seen in Fig. 17. Because this occurred during testing with piles of dust samples, and not actual sanding, it is unknown if the holes getting clogged is a real concern during the normal manufacturing process. However, hole size was increased to mitigate this risk.

Fig. 17: Dust clogging small holes in the vacuum tube

Final Concept

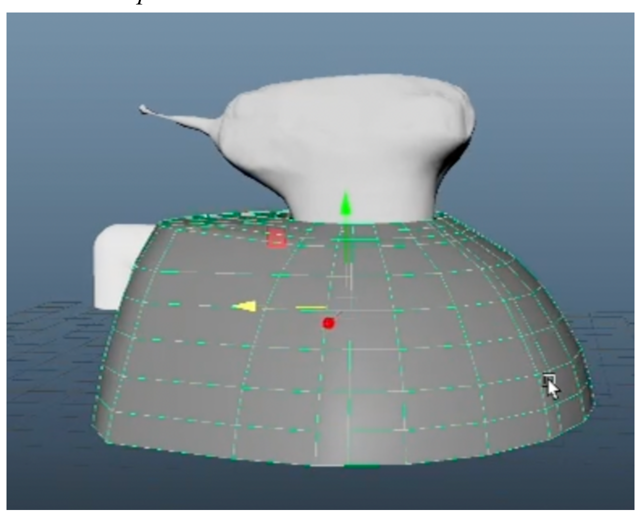

Fig. 18: A CAD model of a sander shield (1)

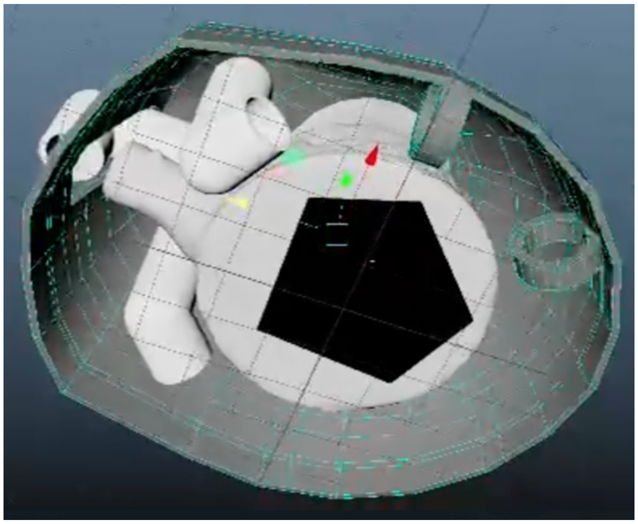

Fig. 19: A CAD model of a sander shield (2)

Fig. 18 and Fig. 19 show the final prototype that will be tested at Green Venture during the team's trip to Tanzania. As the concept is implemented, trials can be performed to quantify the effect of the sander vacuum and shield attachment on dust collection.

Discussion

Key Findings

The study highlighted a few important lessons that can be learned in the mitigation of microplastic release during plastic sanding. First, it was determined that suction or vacuum systems alone cannot contain microplastics effectively, since particles tend to escape without additional containment measures. It became clear that a shield was necessary to create a compact enclosure around the sanding area forthe capture and redirection of all particles into the vacuum system. Second, while the idea of using water sanding was promising at first, it presented a number of problems. The filtration system required to prevent contaminated water from being discharged raised the complexity of the solution to a level that is not feasible for the current manufacturing setup. Moreover, water sanding would involve changes in worker practices, which the team wanted to avoid to ensure ease of adoption.

Comparison to Similar Work

Previous research on microplastic containment has largely focused on filtration systems for waterborne microplastics or industrial air filtration in high-resource settings. For instance, studies on industrial particulate management have highlighted the efficacy of multi-layered filtration systems, but these often require costly infrastructure and specialized maintenance, making them unsuitable for low-resource environments. In contrast, the proposed shield design prioritizes simplicity and accessibility while achieving similar containment goals.

While water-based solutions have been effective in other contexts such as wet grinding, they often require robust wastewater treatment systems to prevent secondary pollution. As noted in prior studies (e.g., Horton et al., 2017), these systems are expensive and resource-intensive. By striking out water sanding and focusing on a dry containment approach, this study provides a more practical alternative for settings where infrastructure is limited.

Devices similar to the proposed shield exist in the form of dust collection shrouds and shields designed to enhance dust containment during sanding operations. For instance, GEM Industries offers shrouds that retrofit their sanders to connect with standard shop vacuums, providing an effective dust collection system. Similarly, Milwaukee produces universal surface grinding dust shrouds for grinders, which improve dust containment by enclosing the sanding area and directing particles into a vacuum system.

While these solutions demonstrate the efficacy of physical containment in managing dust emissions, they are often designed for high-resource settings and may not be accessible in Tanzania. The materials, manufacturing processes, and costs associated with these products may limit their scalability and applicability. Additionally, these shrouds do not implement the optimal vacuum placement as there is only one tube that connects the shop vacuum to the shroud, thus the suction power fails to reach all around the sander. In contrast, the shield designed in this study prioritizes cost-effectiveness, simplicity, and local adaptability. By using locally available materials and incorporating a modular design compatible with widely available shop vacuums, the proposed solution addresses both the technical challenge of microplastic containment and the economic and logistical constraints faced by manufacturers in Tanzania. This makes the shield a practical alternative that fills a critical gap in existing solutions.

Environmental Impact

The implementation of the shielded sander will significantly reduce the release of microplastics into the environment. By trapping particles at the source, the solution prevents them from dispersing into air, soil, and water systems, aligning with global efforts to curb microplastic pollution. The reduced environmental footprint of Green Venture's manufacturing process could also improve its reputation as a sustainable enterprise.

Health Benefits

The containment of microplastics also addresses potential health hazards faced by workers. Inhalation of microplastics has been linked to respiratory issues and inflammation. By reducing airborne particles, the solution improves workplace safety and could contribute to better long-term health outcomes for workers and people around them.

Economic Considerations

The solution was designed with cost-effectiveness and scalability in mind. Collaboration with Green Venture ensured that the shield and vacuum components were affordable and accessible in Tanzania. The simple design allows for local sourcing and easy integration into existing workflows, reducing the financial burden on the company. However, full economic validation requires field testing to confirm maintenance and operational costs.

Study Limitations

Several limitations constrain the study's conclusions. Field testing in Tanzania has not yet been conducted, leaving gaps in understanding how the solution performs under working conditions and its long-term durability. Maintenance requirements in Tanzanian factories are yet to be evaluated as well. Additionally, the lack of access to Green Venture's plastic lumber meant that alternative materials had to be used during testing. While these proxies were similar, they may not perfectly replicate the properties of the actual materials.

Testing was conducted in a controlled indoor environment in Boston, differing significantly from the outdoor factory conditions in Tanzania. Furthermore, while the sander and vacuum used in the study were matched to those available in Tanzania, differences in worker techniques and environmental factors may influence the results.

CONCLUSIONS

The development of a cost-effective and practical solution for microplastic containment during plastic furniture sanding represents a significant step towards more sustainable recycling practices. This study's approach, combining a vacuum attachment with a protective shield, addresses the critical need for microplastic emission reduction in small-scale manufacturing settings, particularly in resource-constrained environments like Tanzania. The solution can be integrated with existing sanding equipment, minimizing disruption to current manufacturing processes. While the study presents a promising solution, it also highlights the need for further research and development in this area. Field testing in Tanzania will be crucial to validate the design's effectiveness under real working conditions and to assess quantifiable air quality improvements.

REFERENCES

[1] C. Root, "Sandpaper Terminology Explained - 6 Terms You Need to Know," SERIOUS GRIT, Apr. 04, 2023. https://www.seriousgrit.com/blogs/sandpaper-post/sandpaper-terminology-explained-7-terms-you-need-to-know*)*

[2] E. M. F. Kallenbach, E. S. Rødland, N. T. Buenaventura, and R. Hurley, "Microplastics in Terrestrial and Freshwater Environments," *Microplastic in the Environment: Pattern and Process*, pp. 87–130, Oct. 2021, doi: https://doi.org/10.1007/978-3-030-78627-4_4.

[3] J. Gasperi *et al.*, "Microplastics in air: Are we breathing it in?," *Current Opinion in Environmental Science & Health*, vol. 1, no. 2468–5844, pp. 1–5, Feb. 2018, doi: https://doi.org/10.1016/j.coesh.2017.10.002.

[4] M. C. Rillig, A. A. de Souza Machado, A. Lehmann, and U. Klümper, "Evolutionary implications of microplastics for soil biota," *Environmental Chemistry*, vol. 16, no. 1, p. 3, 2019, doi: https://doi.org/10.1071/en18118.

[5] "RIDGID 2-1/2 in. Power Tool Adapter Accessory Shop Vac Attachment for RIDGID Wet Dry Vacuums VT1407," The Home Depot, 2024. https://www.homedepot.com/p/RIDGID-2-1-2-in-Power-Tool-Adapter-Accessory-Shop-Vac-Attachment-for-RIDGID-Wet-Dry-Vacuums-VT1407/100206293 (accessed Dec. 12, 2024).