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Additive Manufacturing with Residues: Binder Jetting Applications in the SAMSax Living Lab

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Abstract

The Living Lab SAMSax (Sustainable Additive Manufacturing in Saxony) aims to advance sustainable manufacturing practices by utilising organic and inorganic residues in additive manufacturing (AM), with a particular focus on Binder Jetting technology (BJT). This innovative approach provides an alternative to fossil-based raw materials by upcycling residual materials in powder or dust form, e.g. of agricultural origin such as wood, grass, kernels, shells (e.g. hazelnut), or residues from industrial processes such as glass grinding or textile production, and a variety of other materials. The integration of these residues into the manufacturing process reduces CO_2 emissions and optimises the utilisation of natural resources. To date, more than 50 different residual materials have been identified and analysed. Furthermore, SAMSax extends the application of renewable resources beyond powder materials to the binder itself, thereby ensuring a fully eco-friendly system. The lab places a strong emphasis on the use of local industrial and agricultural residues, particularly from small and medium-sized enterprises (SMEs), supporting a circular economy. The additive nature of AM enables the creation of complex geometries and customised solutions. Binder Jetting at SAMSax facilitates the relatively precise fabrication of components from these residues, thereby transforming them into functional and valuable products. A new machine was set up to foster research into BTJ with multiple binders and flexible parameter setting. The paper presents first data on achievable resolution using the new two-printhead BJT setup.

Living Lab; additive manufacturing (AM); Binder Jetting; sustainability

1. Introduction

Sustainability has become a matter of increasing concern in the field of product development, due to challenges such as climate change, resource scarcity, and environmental degradation. Industries and consumers are increasingly demanding resource-efficient production methods and materials [1-3].

Additive Manufacturing (AM) has emerged as a highly adaptable production technology with significant potential. It facilitates not only the creation of complex structures but also the efficient manufacturing of customised products. By providing increased flexibility, reduced production cycles, and decreased manufacturing costs, AM plays a pivotal role in accelerating progress across various industries [2, 4, 5]. Particularly, Binder Jetting (BJT) is an advanced AM process whereby powdered material is applied in layers, and then selectively bound with a liquid binder, thus forming a three-dimensional object [6]. In recent years, this technology has seen significant advancements, expanding the range of material options and enhancing its ability to meet diverse industrial demands [4, 7].

Previous studies have highlighted the potential of additive manufacturing to utilize renewable and recycled materials [8, 9, 10]. For example, [1] provide in their review a comprehensive overview of waste materials such as eggshells, seashells, fish residues, and agricultural biomass that can be transformed into biomaterials for bone tissue engineering applications. Agricultural bio-wastes, including wood, fish, and algae cultivation residues, have also been identified by [11] as suitable materials for AM processes. Additionally, [12] and [13] demonstrate that wood residues from conventional wood processing can be successfully utilized in 3D printing, thereby upgrading these materials, which are often used as fuel or disposed of in landfills. However, integrating diverse residual materials into AM processes, while ensuring optimal performance, remains a significant challenge [1, 4, 6]. The challenge lies in adapting the physical and chemical properties of waste materials to meet the requirements of additive manufacturing.

As a research project involving the three technical universities of Saxony (TU Bergakademie Freiberg, Chemnitz University of Technology, and Dresden University of Technology), the simul$^+$ Living Lab SAMSax adopts an interdisciplinary approach to developing sustainable manufacturing processes. The objective of the Lab is to function as a collaborative and experimental space where bio-based, natural, and industrial residues are transformed into new industrial applications for small and medium-sized enterprises (SMEs). SAMSax is guided by the principles of the circular economy, with a focus on reducing material consumption, minimising waste, and enhancing the recyclability and biodegradability of products [14].

This paper underlines SAMSax's interdisciplinary methodology, which integrates the Living Lab approach as a method for transforming waste residues into new applications using Binder Jetting. The research further emphasises the investigation of innovative materials and the advancements in machine design, presenting several implemented examples that demonstrate the practical application of sustainable additive manufacturing (AM).

This paper is structured as follows: Section 2 discusses the interdisciplinary methodology employed in SAMSax. Section 3 presents the results, including examples of implemented applications. Section 4 explores the broader implications of these findings and outlines future directions for sustainable additive manufacturing.

2. Methodology – Living Lab SAMSax

SAMSax focuses on regional, organic, and inorganic residues, integrating them into the Binder Jetting process to promote sustainability and reduce reliance on fossil-based raw materials. Residual materials are subjected to rigorous testing for properties such as particle size distribution, bulk density, tap density, Hausner ratio, and Carr index to assess their suitability for additive manufacturing. The lab categorizes these materials into three primary groups:

Agricultural Residues: These include materials of plant origin, such as wood (e.g., beech and birch sawdust), grasses like Miscanthus, and shells or kernels (e.g., hazelnut).

Industrial By-products: These consist of residues from manufacturing processes, such as glass grinding dust, textile fibers (e.g., recycled cotton and denim fiber dust), and chromate-free sanding residues.

Specialized Organic-Inorganic Mixtures: Hybrid materials, such as mineral-wood composites, pyrolysis coke, and cellulose-sand mixtures, bridge the gap between organic and inorganic properties, enabling tailored applications in additive manufacturing.

To date, SAMSax has analyzed over 50 materials, including unconventional residues like potato peels, coffee grounds, paper fibers, and carbon fiber dust. These materials are optimized for binder jetting through adjustments to particle size and distribution, ensuring flowability and print fidelity.

The SAMSax Living Lab prioritises the use of renewable resources, not only for powdered base materials but also for the essential binding agents. Currently, SAMSax employs polymer-based binders such as polyvinyl alcohol (PVA), while simultaneously exploring and developing alternatives like gelatin and resin-based binders derived from natural sources such as tree rosin. The utilisation of bio-based binders not only fosters the production of components that are fully bio-based, but also frequently leads to the result of products that are biodegradable. Moreover, these binders offer the advantage of being recyclable, allowing for repeated use and contributing to sustainability. The primary focus is the development and implementation of advanced machine designs that are compatible with the specific characteristics of residual materials.

SAMSax focuses at the intersection of material science, mechanical engineering, and technology on applications that require good biodegradability and, consequently, a limited functional lifespan.

2.1. Binder Jetting Technology at SAMSax

In the SAMSax Living Lab, two Binder Jetting printers have been utilized and specifically adapted for processing sustainable materials. The ZPrinter 310, with a build volume of 200x250x200 mm, has been modified to accommodate the use of bio-based and recycled materials. Similarly, the Concr3de Armadillo White, featuring a build volume of 420x420x250 mm, has been tailored to meet the requirements of sustainable material utilization in Binder Jetting processes.

The SAMSax Living Lab has undergone an expansion in which a large-scale Binder Jetting system has been integrated with a smaller experimental unit. This dual-system arrangement has been designed to enable advanced research and development in the field of additive manufacturing, with a focus on bio-based materials and industrial residues, such as powders derived from grasses and wood. The experimental unit functions as a platform for conducting laboratory-scale trials, facilitating the determination of fundamental process parameters that can be directly transferred to the production system.

Both systems have been specifically engineered to process sustainable materials, with the large-scale Binder Jetting system (see Figure 1) and the experimental unit working in combination to explore and implement innovative manufacturing approaches. These include the application of multiple inks, the development of novel environmentally friendly binders, and the integration of additional functionalities directly into the printed components. To ensure the seamless transferability of results, the experimental unit is equipped with an ink system that is identical to that of the production system. This alignment facilitates the targeted development of new powder-binder combinations that can be directly applied to the larger production system.

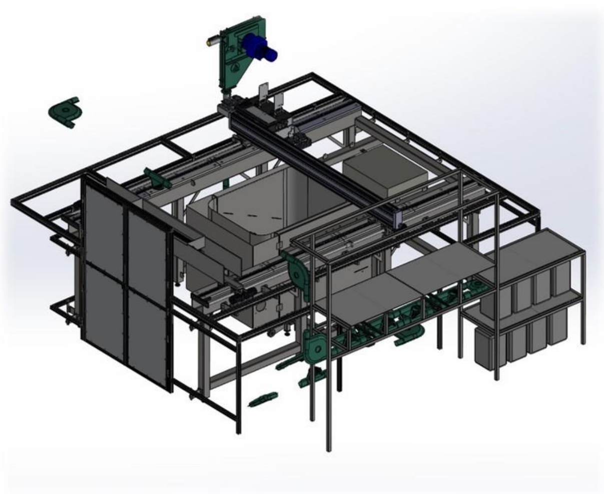

Figure 1. Design Phase of the Binder Jetting Printer (production system)

The production system has been designed to support a broad range of applications and materials. It is adaptable to various printheads from different manufacturers and supports inks that are water-based or solvent-based. The system features an advanced recirculating ink supply system, equipped with integrated temperature control, degassing, filtration technologies, and sensors for monitoring flow rates, vacuum, and overpressure. The system is prepared for the simultaneous use of up to eight printheads, with two printheads per ink supply unit, enabling the implementation of complex multi-ink applications. Furthermore, the production system is capable of accommodating a wide range of materials with adjustable process parameters, allowing for particle sizes ranging from 5 to 1000 µm and bulk densities from 0.1 to 4.5 g/cm³. The system's 1 m³ build volume facilitates the production of large-scale components, thus expanding the range of potential applications.

It is evident that the experimental unit and the production system (see Figure 2), when considered as a whole, establish a comprehensive foundation for the development and realisation of innovative and sustainable manufacturing technologies. This configuration facilitates the refinement of process parameters and the optimisation of powder-binder combinations within the experimental environment, thereby ensuring that these advancements can be seamlessly scaled and applied in the production system.

Figure 2. Experimental setup on the front left and production system on the right

3. Results

At SAMSax, six applications have been successfully implemented using BJT. However, due to confidentiality requirements, the disclosure of two of these applications is prohibited. Consequently, this paper presents four case studies that exemplify the utilisation of residual materials processed through Binder Jetting technology. These case studies illustrate the potential of this innovative approach to transform waste materials into functional and sustainable components, emphasising the versatility and environmental benefits of Binder Jetting in additive manufacturing.

For the production of stage elements for the AIDA performance at the Chemnitz Theater, five identical column capitals were required. The design specifications emphasized the use of sustainable materials while maintaining high detail resolution and ensuring rapid production. To meet these requirements, the capitals were fabricated using Binder Jetting technology with Miscanthus as the primary material (see Figure 3).

The composition consisted of powdered Miscanthus combined with 15 wt.% polyvinyl alcohol (PVA) as the binder, along with a water-based ink. The printing process employed a layer thickness of 250 µm, using the Concr3de Armadillo White printer.

Figure 3. Column capital made of Miscanthus

In collaboration with INTOPLAN GmbH Bauchemie, a company specialising in construction materials for flooring, tile, and plaster systems, two applications—a bust (see Figure 4) and a gargoyle (see Figure 5)—were successfully produced using BJT. The objective of this project was to adapt mortar for use in Binder Jetting and to explore its potential applications, with a particular focus on restoration, where high precision and material compatibility are critical.

Figure 4. Bust of Abraham Gottlob Werner

The material requirements included water insolubility, cost efficiency, high strength, and the ability to create fine surface details. To meet these specifications, the printing process was carried out with a layer thickness of 0.1 mm and a saturation level of 120%. The ZPrinter 310 was employed for the production, demonstrating the feasibility of using mortar in additive manufacturing and paving the way for innovative applications in restoration.

Figure 5. Gargoyle

In the context of the mineral exhibition "terra mineralia," a solution was devised for the purpose of displaying minerals in a manner that would both showcase their aesthetic qualities and ensure their safety. This solution entailed the production of specialized trays, utilising BJT. The requirement for tailored solutions for museum exhibits in movable drawers is driven by the need to ensure the safety and stability of the objects when handled by visitors. Consequently, custom-fitted "beds" were developed to securely hold the minerals during display.

The fabrication of these trays was accomplished through the utilisation of the Concr3de Armadillo White printer, employing Miscanthus as the primary material. To enhance durability and aesthetics, the printed components underwent post-processing, which included infiltration with a colophony resin solution followed by a black lacquer coating (see Figure 6).

Figure 6. Trays with minerals in the exhibition

The new production system has not yet been utilised for these specific applications. However, following its full implementation, it is expected to enable the implementation of scalable solutions for similar use cases, offering expanded opportunities for sustainable and efficient AM processes.

4. Summary and Outlook

Sustainability challenges, such as resource scarcity and environmental degradation, are driving the need for innovative production technologies. Binder Jetting (BJT), an additive manufacturing method, enables the efficient transformation of renewable and recycled materials into functional products. However, adapting the diverse properties of residual materials to meet the performance requirements of AM processes remains a critical challenge.

The SAMSax Living Lab, a collaborative initiative involving three technical universities in Saxony, addresses these challenges by integrating bio-based, natural, and industrial residues into sustainable manufacturing processes using BJT. Guided by the principles of circular economy, SAMSax focuses on reducing material consumption, minimizing waste, and improving the recyclability and biodegradability of products.

The lab has successfully demonstrated the potential of BJT to transform residual materials, such as Miscanthus, mortar, and wood-based residues, into functional components for industries ranging from theater set design to museum exhibitions and restoration.

SAMSax's research underscores the transformative capacity of binder jetting in upcycling a diverse variety of residual materials into functional and scalable products. The new multi-printhead BJT setup, integrating an experimental unit and a large-scale production printer, provides a foundation for the testing and scaling of innovative material-binder combinations, while exploring complex geometries and tailored solutions for various industries.

Future research at SAMSax will concentrate on the expansion of the material library and the optimisation of formulations for enhanced printability and performance. In addition, industrial applications of sustainable binder jetting will be investigated, with an emphasis on scaling processes to meet real-world production demands.

The Living Lab exemplifies how interdisciplinary collaboration and technological innovation can address pressing sustainability challenges, setting a benchmark for future AM research.

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References

[1] Putra, N. E., Zhou, J., and Zadpoor, A. A., “Sustainable Sources of Raw Materials for Additive Manufacturing of Bone-Substituting Biomaterials,” *Adv. Healthc. Mater.*, **13**(1), p. 2301837, Jan. 2024, doi: 10.1002/adhm.202301837.

[2] Colorado, H. A., Velásquez, E. I. G., and Monteiro, S. N., “Sustainability of additive manufacturing: the circular economy of materials and environmental perspectives,” *J. Mater. Res. Technol.*, **9**(4), pp. 8221–8234, Jul. 2020, doi: 10.1016/j.jmrt.2020.04.062.

[3] Zeidler, H., Micke, L., Kühnel, L., Lamottke, M., and Denker, M., “Material extrusion printer for pastes based on a commercial desktop filament printer for plastics,” *1 Open Source Hardw. Konf. 2024*, Nov. 2024.

[4] Jiang, H., Yang, X., and Wang, H., “Preparation and characterization of starch-based binders for binder jetting,” *RSC Adv.*, **14**(44), pp. 32506–32516, 2024, doi: 10.1039/D4RA05411C.

[5] Javaid, M., Haleem, A., Singh, R. P., Suman, R., and Rab, S., “Role of additive manufacturing applications towards environmental sustainability,” *Adv. Ind. Eng. Polym. Res.*, **4**(4), pp. 312–322, Oct. 2021, doi: 10.1016/j.aiepr.2021.07.005.

[6] Holland, S., Tuck, C., and Foster, T., “Selective recrystallization of cellulose composite powders and microstructure creation through 3D binder jetting,” *Carbohydr. Polym.*, **200**, pp. 229–238, Nov. 2018, doi: 10.1016/j.carbpol.2018.07.064.

[7] Ziaee, M., and Crane, N. B., “Binder jetting: A review of process, materials, and methods,” *Addit. Manuf.*, **28**, pp. 781–801, Aug. 2019, doi: 10.1016/j.addma.2019.05.031.

[8] Jerman, M., Krinke, S., Kühnel, L., Müller, M., Valentinčič, J., and Zeidler, H., “Additive manufacturing using renewable materials: concept of upcycling peach kernels for use in Binder Jetting and FFF,” 2020.

[9] Singamneni, S., Behera, M., Guen, M., and Zeidler, H., “Mechanism of Bonding in Seashell Powder Based Ceramic Composites Used for Binder-Jet 3D Printing,” *Bioceram. Dev. Appl.*, **8**, Jan. 2018, doi: 10.4172/2090-5025.1000108.

[10] Zeidler, H., Klemm, D., Böttger-Hiller, F., Fritsch, S., Le Guen, M. J., and Singamneni, S., “3D printing of biodegradable parts using renewable biobased materials,” *Procedia Manuf.*, **21**, pp. 117–124, 2018, doi: 10.1016/j.promfg.2018.02.101.

[11] Rahman, A. M., Rahman, T. T., Pei, Z., Ufodike, C. O., Lee, J., and Elwany, A., “Additive Manufacturing Using Agriculturally Derived Biowastes: A Systematic Literature Review,” *Bioengineering*, **10**(7), p. 845, Jul. 2023, doi: 10.3390/bioengineering10070845.

[12] Krapež Tomec, D., and Kariž, M., “Use of Wood in Additive Manufacturing: Review and Future Prospects,” *Polymers*, **14**(6), p. 1174, Mar. 2022, doi: 10.3390/polym14061174.

[13] Buschmann, B., Henke, K., Talke, D., Saile, B., Asshoff, C., and Bunzel, F., “Additive Manufacturing of Wood Composite Panels for Individual Layer Fabrication (ILF),” *Polymers*, **13**(19), p. 3423, Oct. 2021, doi: 10.3390/polym13193423.

[14] Berkemeier, A., et al., “SAMSax—An Innovative Living Lab for the Advancement of a Circular Economy through Additive Manufacturing Technologies,” *Sustainability*, **16**(2), p. 823, Jan. 2024, doi: 10.3390/su16020823.