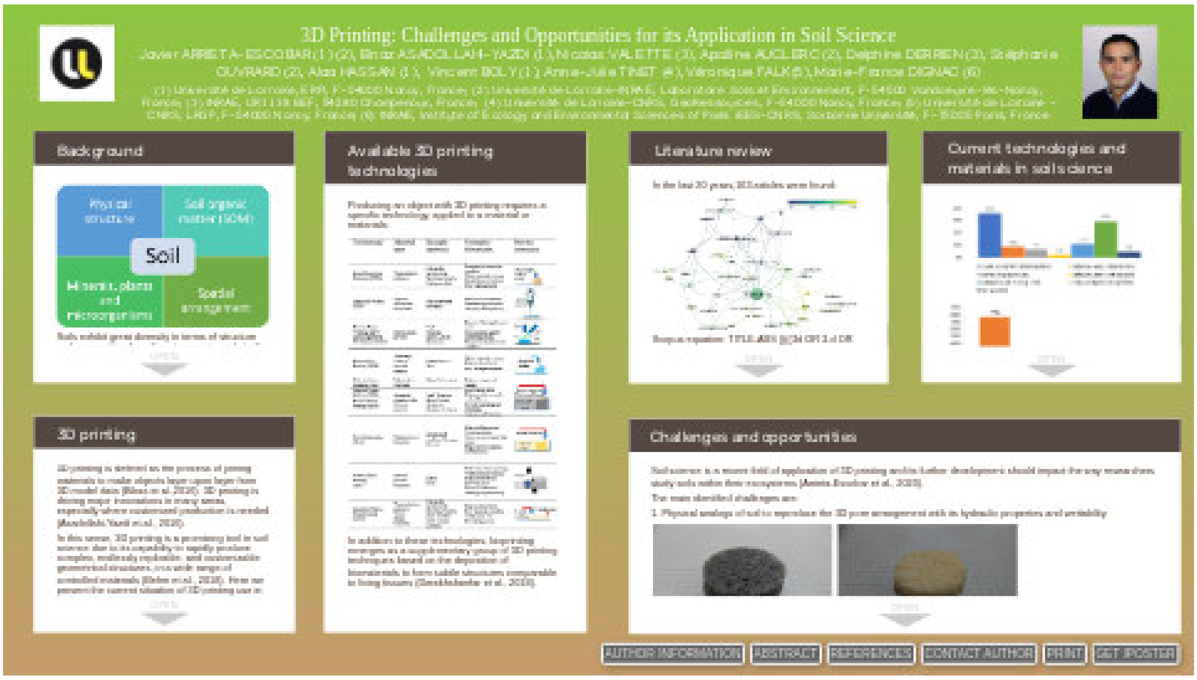
3D Printing: Challenges and Opportunities for its Application in Soil Science



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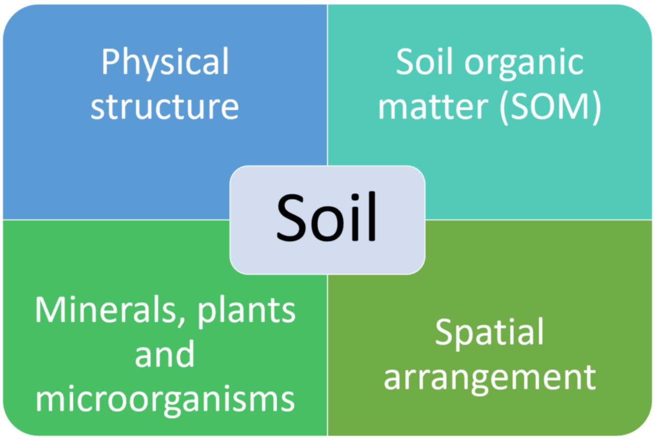
PRESENTED AT:

BACKGROUND

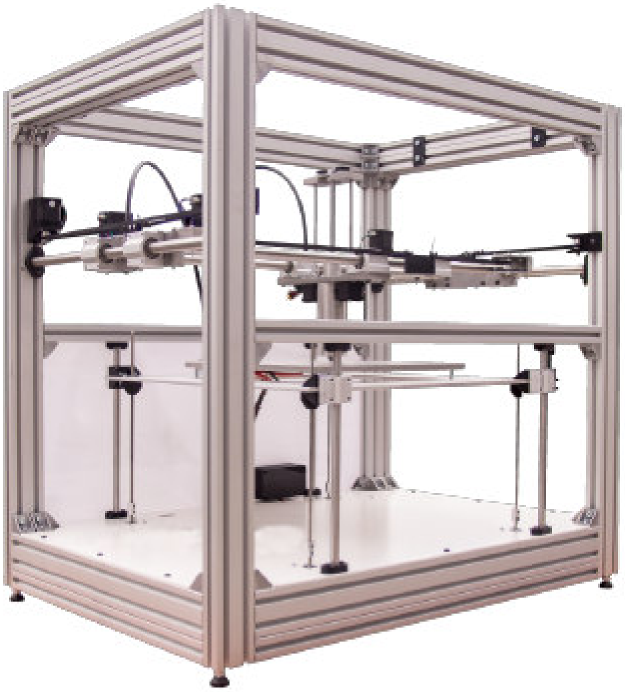


Soils exhibit great diversity in terms of structure and composition in different scales. To understand the functioning of individual soil types and to compare different soils, researchers should reach out to innovative approaches and solutions (Hu and Jiang, 2017). 3D printing is a promising technology for improving the understanding of soils.

3D PRINTING

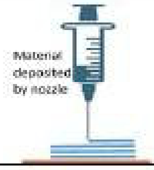
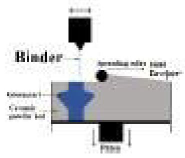
3D printing is defined as the process of joining materials to make objects layer upon layer from 3D model data (Bikas et al.,2016). 3D printing is driving major innovations in many areas, especially where customized production is needed (Asadollahi-Yazdi et al., 2016).

In this sense, with 3D printing, one can rapidly produce complex, endlessly replicable, and customizable geometrical structures, in a wide range of controlled materials (Behm et al., 2018). Here we present the current situation of 3D printing use in soil sciences.



AVAILABLE 3D PRINTING TECHNOLOGIES

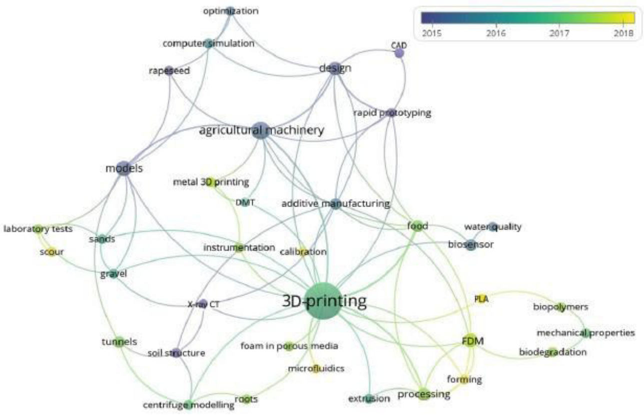
Producing an object with 3D printing requires a specific technology, applied to a single material or mix of materials:

Technology	Material type	Example materials	Strengths/ Downsides	Process schematic
Fused Deposition Modeling (FDM)	Thermoplastic polymers	Polyamide, Acrylonitrile Butadiene Styrene, Polylactic Acid	Inexpensive extrusion machine Multi-material printing Limited part resolution Poor surface finish	
Direct Ink Writing (DIW)	Aqueous slurries and dispersions	Cellulose-based hydrogels	Ideal for biomaterials Maintaining structural integrity during drying	
Electron Beam Welding (EBW) Laser Engineered Net Shaping (LENS)	Molten metal powder	Steel Titanium Alloys, Cobalt Chromium	Repair of damaged/ worn parts Functionality graded material printing Require post-processing machine	
Polyjet/Inkjet Printing (MJM)	Thermally stable or unstable plastics	Photopolymers Wax	Multi-material printing High surface finish Low strength material	
Selective Laser Sintering (SLS)	Polyamides / Polymers	Nylon, Polystyrene	High accuracy and details Fully dense parts High specific strength and stiffness Powder handling and recycling Support and structure	
Selective Laser Melting (SLM) Electron Beam Melting (EBM)	Atomized metal powder, Ceramic powder	Steel, Titanium alloys, Cobalt chromium, Alumina, Zirconia		
Stereolithography (SLA)	Photopolymers Ceramics	Epoxies and acrylates, Alumina, Zirconia	High building speed Good resolution Over-curing scanned line shape High cost for supplies and materials	
Indirect Inkjet Printing (3DP)	Polymer powder Ceramics	Plaster Resin	Full-color object printing Wide material selection High porosities on finishing parts Require infiltration during post-processing	
Laminated Object Manufacturing (LOM)	Thermoplastics polymers Wood Metals Ceramics	Polyamide, Acrylonitrile Butadiene Styrene, paper, metallic sheet, ceramic materials	High surface finish Low material, machine, and process cost De-cubing issues	

In addition to these technologies, bioprinting emerges as a supplementary group of 3D printing techniques based on the deposition of biomaterials to form subtle structures comparable to living tissues (Derakhshanfar et al., 2018).

LITERATURE REVIEW

In the last 20 years,163 articles related to soil sciences were found:

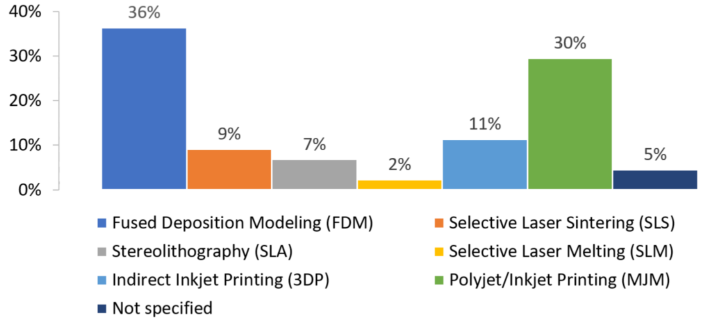


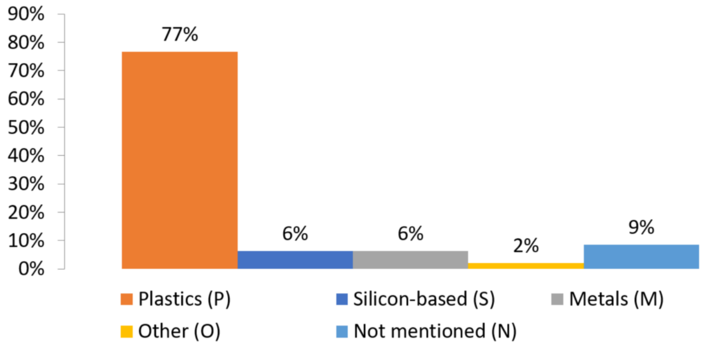
Scopus equation: TITLE-ABS ((((3d OR 3-d OR (three-dimensional)) PRE/0 print*) OR (additive PRE/0 manufactur*)) AND (soil OR agricult* OR agro*))

A total of 35 keywords had at least 2 occurrences: “Agricultural machinery” was the most frequent application of 3D printing. Its initial predominance has shifted to research topics such as biopolymers, biodegradation of printed materials, and microfluidics (i.e. fluid circulation in the soil at the microscale). In many situations, 3D printing is presented as the simplest and cheapest way to obtain objects (Rangel et al., 2013).

Soils have also been used as a cheap, easily available, and sustainable source of raw material for 3D printing (Javaid & Haleem, 2019). Printing with soil was mostly achieved in architectural (Mitterberger and Derme, 2019) or spatial applications (Bagrov et al., 2017; Ceccanti et al., 2010; Cesaretti et al., 2014; Chow et al., 2017), but none required the replication of soil characteristics.

CURRENT TECHNOLOGIES AND MATERIALS IN SOIL SCIENCE





Among 3D printing technologies, FDM (Fused Deposition Modeling) and MJM (Polyjet/Inkjet Printing) are the most common technologies in soil science applications.

In terms of materials, plastics are the most used, maybe because these materials are related to well-known 3D printing technologies (FDM, SLA, and MJM).

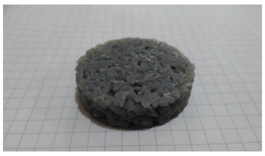
To the best of our knowledge, there is no current utilization of biobased materials for applications in soil science (Arrieta-Escobar et al. 2020b)

CHALLENGES AND OPPORTUNITIES

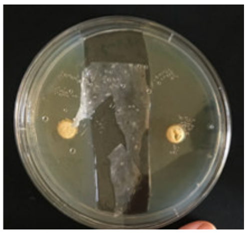
Soil science is a recent field of application of 3D printing and its further development should impact the way researchers study soils within their ecosystems (Arrieta-Escobar et al., 2020).

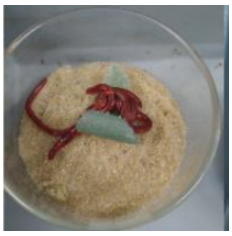
The main identified challenges and opportunities are:

1. Physical analogs of soil to reproduce the 3D pore arrangements with its hydraulic properties and wettability.

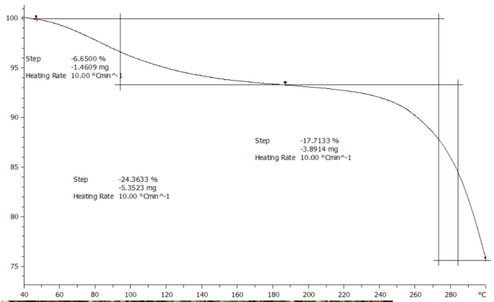


2. The interactions between living organisms and their resources in the soil imply that the printed material should not be toxic for these organisms. Biocompatibility tests are being proposed with fungi, plants, and macrofauna for innovative materials.



3. Materials respecting the dynamics of soil (biotic agents and abiotic processes) exhibiting a wide range of mechanical properties (thermal compatibility, sufficient rigidity to prevent collapse due to physical disturbances). Ongoing in-situ tests should demonstrate the utility of 3D printed objects in the degradation assessment under real conditions.




DISCLOSURES

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AUTHOR INFORMATION

Ph.D. in Chemical and Industrial Systems Engineering, I currently work as a postdoctoral researcher at the Université de Lorraine in Nancy, France. I have worked on chemical product design and formulation for 10 years (5 years in the industry), and I also have experience as a teacher (3 years at universities). I like swimming and also enjoy learning languages (I am fluent in Spanish, French, German, and Portuguese and I'm currently learning Swedish).

ABSTRACT

Being at the interface of the geosphere, the biosphere, and the atmosphere makes the soil a particularly challenging object. Nevertheless, its importance in ecological and environmental domains should encourage researchers to make use of new technologies, like 3D printing, to improve their comprehension of soils. With 3D printing we can build up objects by adding materials layer-by-layer based on a three-dimensional model, producing almost any geometrically complex shape or feature in a wide range of materials. Here we present the major challenges and opportunities of 3D printing for its application into soil science. We show that despite the remarkable achievements in 3D printing development during the past few years, it is still under-used in the field of soil science. Besides the 3D printing technology uses considering the soil as a source of mineral raw materials, or as the basis for the development of technical infrastructure, new researches highlight the functioning of the soil itself as an ecological compartment. Indeed, one of the most important challenges for the application of 3D printing in this area is the accurate modeling and replication of the soil structure and composition. This would require 3D-printed objects to be made of biocompatible yet chemically and mechanically stable materials manufactured under controlled conditions, which can mimic the many interactions occurring at this scale. Having 3D-printed objects with strict and controlled composition and structure could help academics and researchers to conduct reproducible experiments and gain a better understanding of the parameters controlling soil ecology and functioning. This opens a new way to broader utilization of 3D printing in soil science in the near future.

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