Contract No:

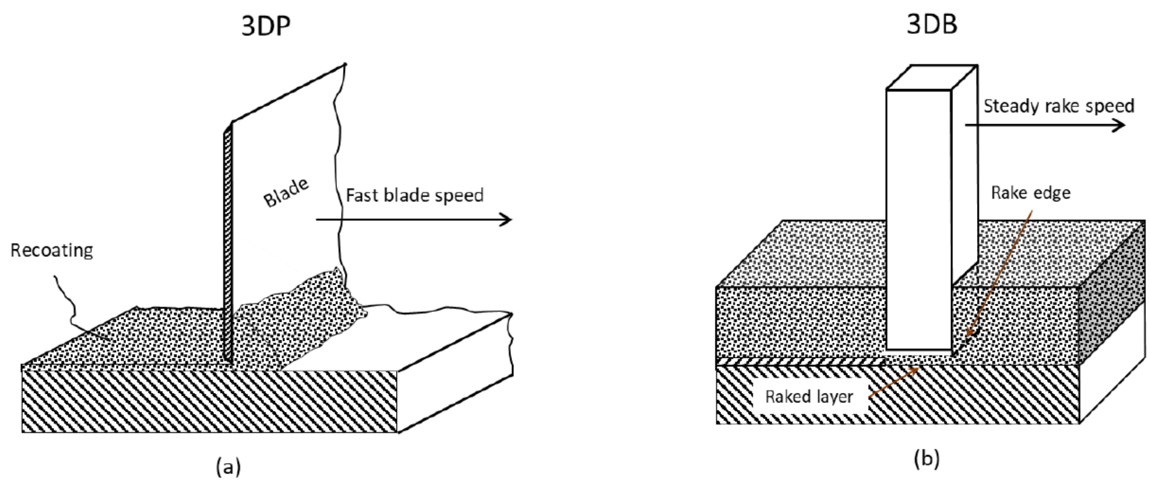
This document was prepared in conjunction with work accomplished under Contract No. 89303321CEM000080 with the U.S. Department of Energy (DOE) Office of Environmental Management (EM).

Title of Project
Develop Direct 3D Building as a Transformation of 3D Printing

Project Start and End Dates
Project Start Date: 04/15/2021
Project End Date: 09/20/2021

Project Highlight

3D building transforms 3D printing, the most state-of-the-art manufacturing technology so far developed, to make another step change in manufacturing performance concerning process unrepeatability, material defects, and powder cost, which have become the barrier to further additive manufacturing applications in the key industries of national interest including national nuclear security, spacecraft, aerospace, and energy.



Difference in powder layer creation between 3DB and 3DP

Project Team
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External Collaborators (all external collaborators and their respective organizations that participated in this project:

Abstract
Phase 1 of this project recognizes the key advantages of direct 3D building (3DB) by literature research, initial experiments, and analyses. The fundamental enhancement in powder density, layer thickness, and their uniformities are attributed to the independence from high blade speed and powder flowability. The increase in layer quality, before selective fusion, is found qualitatively significant for a step change in process robustness when the unrepeatability of 3D printing (3DP) remains a challenge in serial volume production. The reduced challenge of powder flowability should not only entail improvement in build quality but also reduce powder cost from the strict morphology and size specs. The concurrent selective fusion and powder surface preparation eliminate the need for frequent recoating pauses to increase build speed. On-going experiments include density cup measurements by

X-ray scanning and recoating performance evaluation by a rotating disk system to verify some of the results.

Objectives

- Establish the science of real direct digital manufacturing and lay down the theoretical foundation for 3DB by publishing technical papers.
- Develop proposals to more sustainable funding sources including NA-22, EM/LM, NNSA, PDRD, and LDRD – grand challenge.
- Collect data and experiences for future equipment development and build up licensing case for relevant patents.

Introduction

Direct 3DB is proposed to transform 3DP, the most dominant modality of additive manufacturing, to make another significant leap in system manufacturability. 3DB and 3DP belong to laser powder bed fusion (PBF) for metallic, polymetric, and ceramic materials. The LDRD seedling project with limited funding enables comprehensive literature search, data analysis, in-depth discussion, and various off-line experiments prior to machine development. The pilot project will lead to more sustainable and substantial funding adequate for the system prototyping of hardware and software. Just like any other fundamental paradigm shift, the technology readiness level (TRL) is rather low (< 1) with many good questions to be addressed.

This initial phase of the seedling project covers 4 months of R&D work conducted by a team of 4 researchers among others in various supporting roles. We investigated the details of the original 3DB system, which has not been envisioned until now. The structural relevance between 3DP and 3DB is established by appropriate powder mechanics to leverage the available data from recoating research in 3DP. The difference between 3DP and 3DB is analyzed to identify the advantages of 3DB as far as the layer quality is concerned prior to selective fusion.

Among others, the technical challenges of the new paradigm including the interaction of the submerged ram with its surrounding powder mass are recognized but no feasibility risk is identified. Specific countermeasures are conceived to address the challenges systematically. The interaction between ram and powder bulk is also found advantageous with respect to powder compression before layer separation.

Approach

Instead of the ordinary thinking of coming up with an idea and then figuring out how to make it work, we took an unusual approach of reverse thinking by first determining what the idea can achieve while assuming it would work even before the feasibility study. The approach is inspired by the recent proposal guidance of NA-22, which asks the key question of “so what” if you can do it. In the R&D project, we first recognized the qualitatively significant benefits of 3DB over 3DP while putting aside the questions concerning technology readiness level.

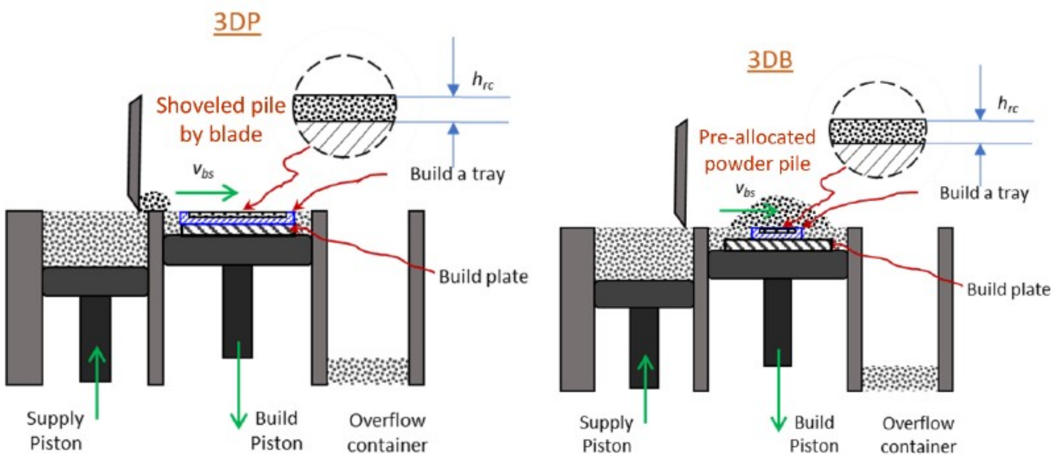
- Establish the structural and process relevance between 3DB and 3DP.
  – For instance, both prepare a powder level for subsequent selective fusion.
- Leverage the available 3DP data to derive general mechanics correlations applicable to 3DB.
  – One of such key correlations is the dependence of recoating quality on machine and material parameters, such as tool speed and particle diameter etc.
  – The metrics for layer quality include height ratio, ratio variation, packing fraction, and fraction variation.
- Consider the structural and process difference between 3DB and 3DP to reveal the advantages and challenges of 3DB in terms of the quality and productivity in generating the powder layer.

Accomplishments

Our literature search and investigation are focused on the quality of the powder layer, prepared for laser selective fusion. The layer quality is often overlooked while most research interests target the active laser fusion process. However, the laser cannot resolve any deficiency in powder packing density and layer thickness variation since it is a fundamental material problem. 75 reports were identified concerning powder mechanics, 3DP recoating, experiments, and simulation. Qualitative mechanic analyses have been conducted to correlate the similarities and to identify the performance differences between 3DB and 3DP. Powder density measurements by CT scanning have been started with relevant data. We worked with Mercury Scientific to leverage their instrument for process characterization. Specific activities and accomplishments include:

- Identified 4 mechanical advantages that contribute to the better layer quality created in 3DB.
  – Powder in front of tool edge is compressed by tool pressure and powder gravity to increase the local packing density.
  – The pre-allocated powder in front of tool edge relieves the challenge of powder flowability, which leads to critical height and density variation in 3DP.
  – Without the frequent recoating pauses, 3DB can afford much lower tool speed which entails the higher quality of powder layer to be fused.
  – The shorter tool length of 3DB ram reduces tool deflection, vibration, and damage to tool edge and build.
    - Larger machine has more challenge from tool length.
- Identified 4 processing steps in 3DP which can be saved in 3DB to shorten cycle time for 3DB.
  – Piston moves up in supply tank to prepare powder to be shoveled to build tank
  – Blade or roller translates from supply tank to overflow tank to recoat the entire surface.
  – Blade or roller returns to supply tank from overflow tank to prepare for the next cycle.
  – Recoating large blank surfaces, not selected for laser fusion
    - The area of blank surface increases as the ratio of part cross section over total machine build area decreases.
- Identified 3 opportunities to improve build quality and reduce material cost at the same time.
  – Below the tight material spec for 3DP, the smaller particles, which undercuts powder flowability, can become admissible in 3DB to increase compaction density and to lower material cost since there is no need to remove the smaller ones.
  – Used powder can be recycled more times to increase material life since 3DB isn't as critical as 3DP to powder flowability. Mercury Scientific have a lot of data to indicate the declining flowability of recycled powder.
  – Fibrous powder, well known for its poor flowability, can become admissible in 3DB to exploit the excellent packing density and build quality by the micro fibrous stock.
- Addressed 2 major potential feasibility challenges among others
  – The ram in 3DB isn't driven to translate at the high laser scanning speed. High ram speed can significantly disturb the powder in tank and lead to poor layer quality. Inside the hollow ram, laser beam oscillates at very high frequency to hatch the build surface in a desirable checkerboard format.
  – Nylon powder heated to near melting point can adhere to the ram surface to powder snowballing. Solutions include special side coating and lower tank temperature etc. Also, we can leverage the technology of roller in staying clean in the adhesive environment.
- Density cup measurements by X-ray scanning – 9 samples have been prepared and are being scanned.
- Recoating performance evaluation by a rotating disk system – Materials including Nylon 6 and Ti64 powders have been sent to Mercury Scientific to test the effects of tool speed and set height etc.

Future Directions



- Continue the experimental verification of identified mechanical advantages of 3DB using 3DP as a baseline.
- Evaluate other system properties including the characteristics of heat transfer, thermal stresses, and atmospheric interferences.
- Continue system level research leading to more innovations.

FY 2021 Peer-reviewed/Non-peer reviewed Publications
N/A

Intellectual Property
The provisional patent application #63/169,430 is filed with USPTO on 04/01/2021. The invention is entitled "Direct 3D Building Submerged in Powder Tank - An Alternative to 3D Printing," SRS-21-007.

Total Number of Post-Doctoral Researchers
3

Total Number of Student Researchers
N/A