Swarm 3D Printing and Assembly for Autonomous Manufacturing

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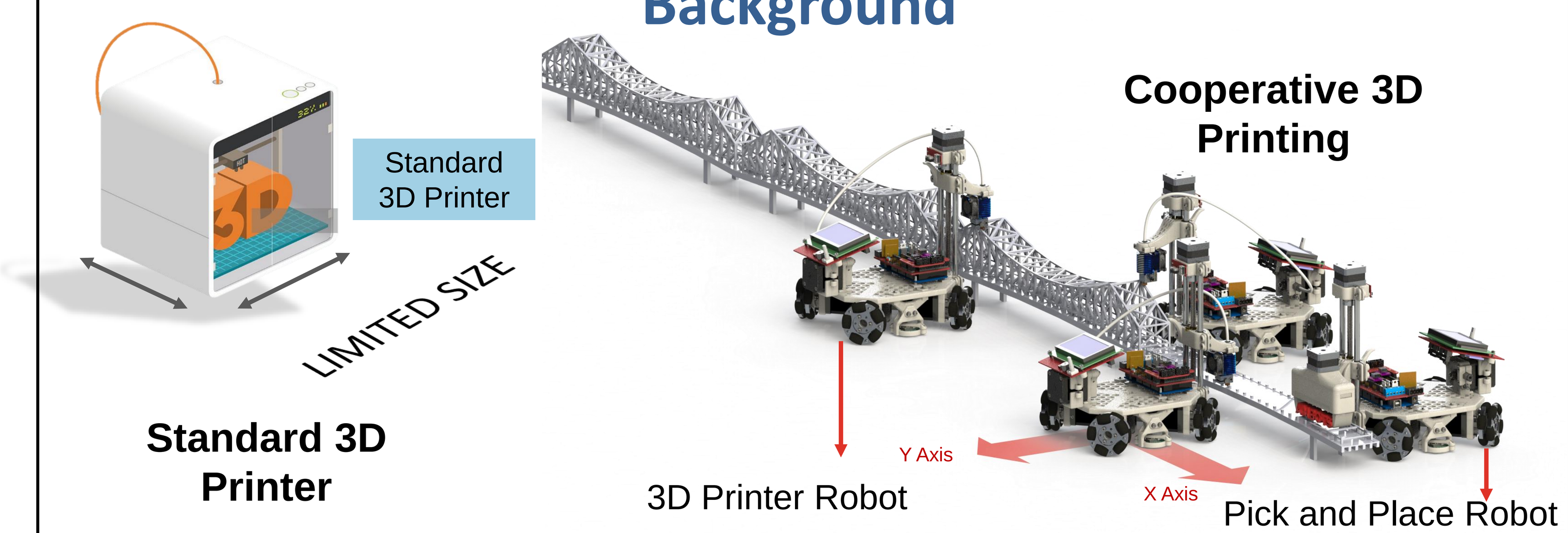
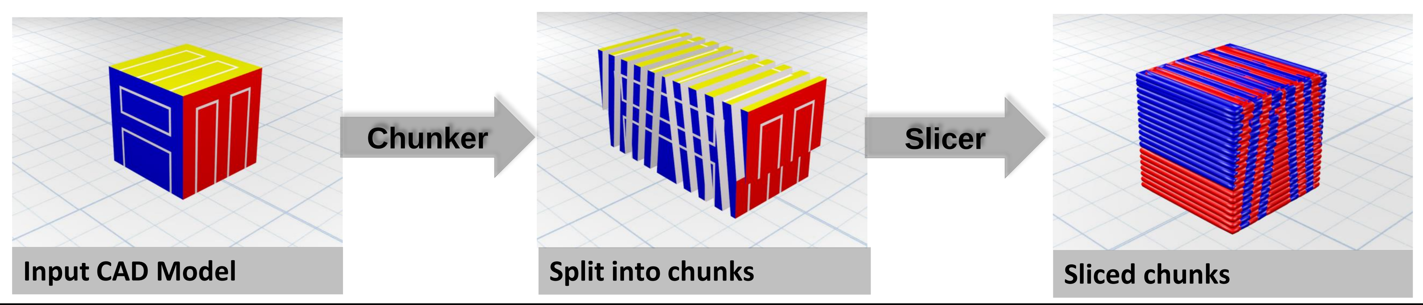
Background



Limitation of conventional 3D Printer: Scale and Speed

Cooperative 3D Printing (C3DP) is a novel concept that integrates multi-robot system with 3D printing. It envisions large number of 3D printing robots along with assembly robots, working together to complete a print job. Cooperative 3D Printing mitigates the prominent issues of conventional 3D printing system without compromising the quality of the part.



Project Objective and Goals

1. To find chunking strategy that can be used to divide a part into smaller chunks so that no post processing is required after C3DP

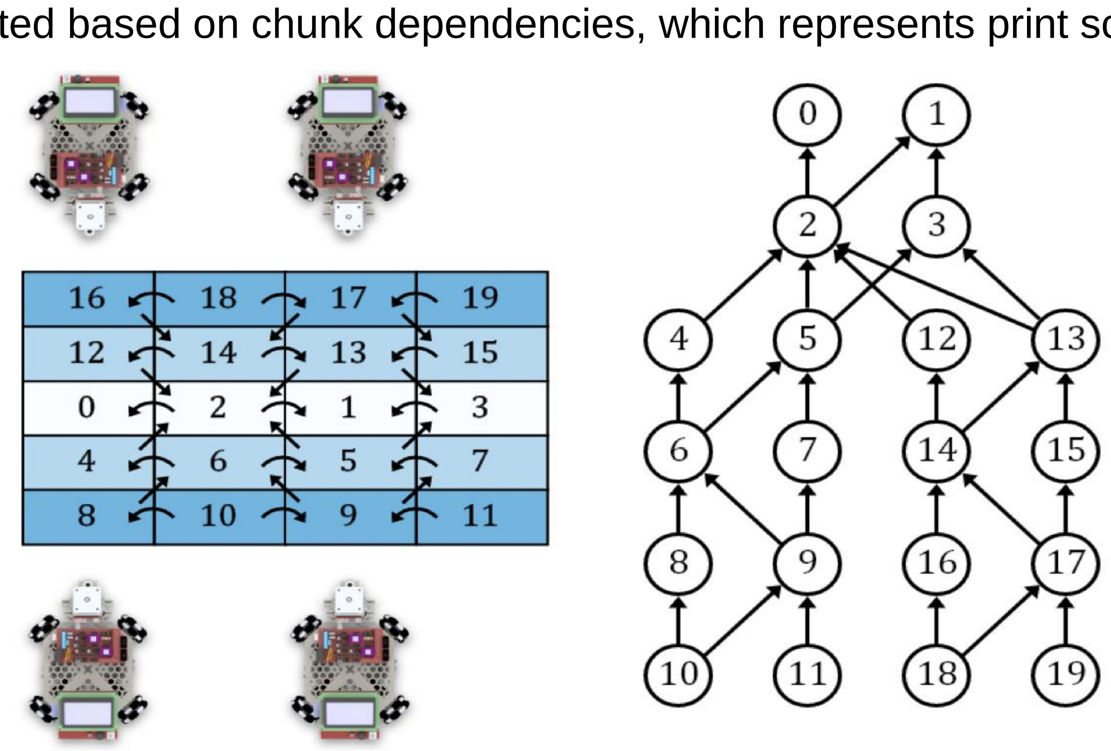
2. To determine the mechanical strength of chunk-based printed parts and compare it with the conventional 3D printed part

3. Identify the constraints (geometric, chunking and, scheduling) that must to be satisfied in order to enable cooperative 3D printing

4. To find out what approaches can be taken to integrate different stages of C3DP in robust way

Scheduling

- **Scheduling** is process of creating print sequence upon the completion of chunking.
- After chunking, the chunks are assigned to individual robots and **DDT** is generated based on chunk dependencies, which represents print schedule



Geometric constraints are the required in order to weed out print scheduling strategies that are physically impossible. We implement geometric constraints so that there is no collision between either the printing robots (**GC-1**) or between the printing robots and the printed part (**GC-2**) . A collision free printing schedule must be geometric constraints satisficing

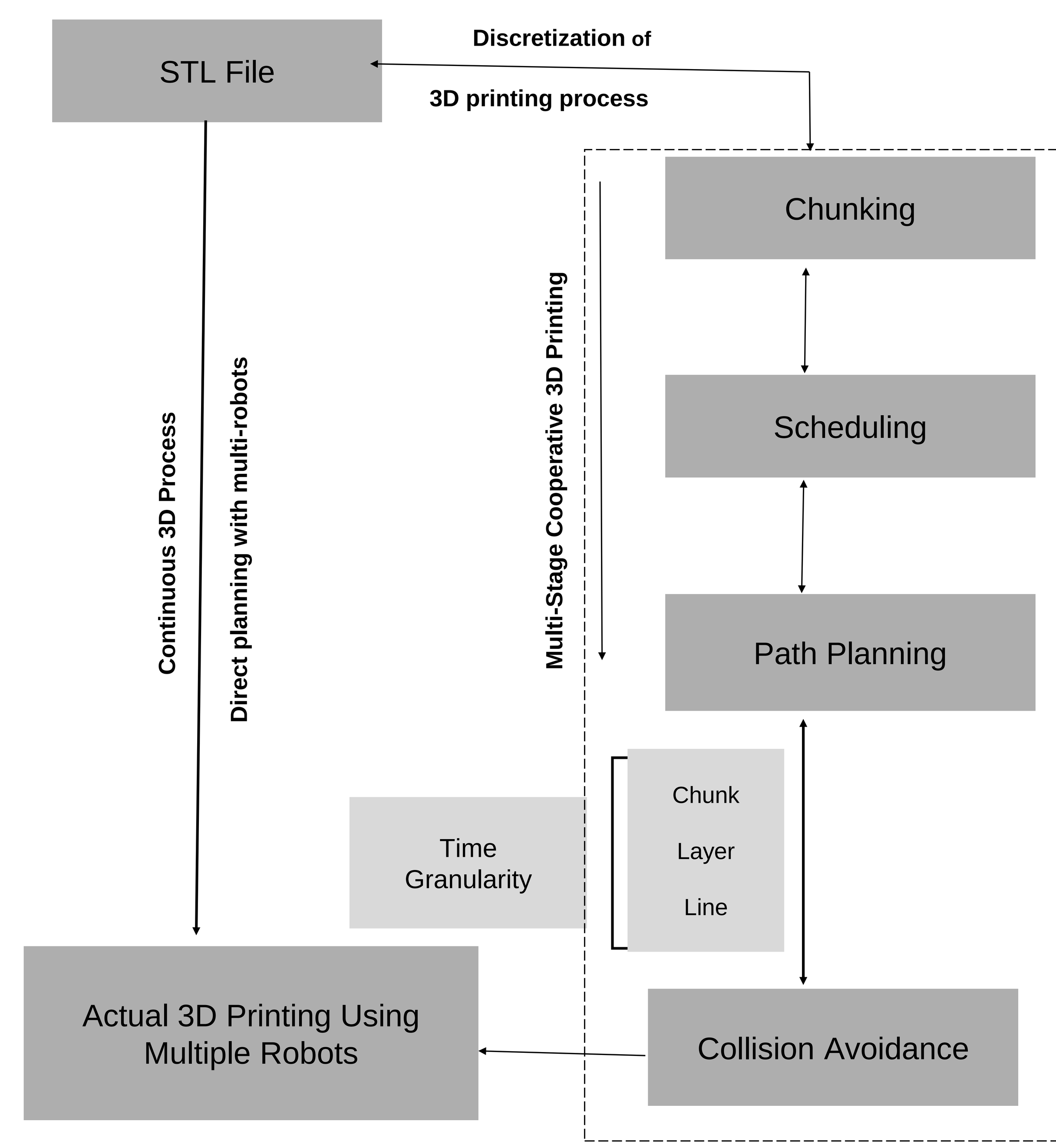
- **GC-1**: $SV_{r,i}(t) \cap SV_{r,j}(t) = \emptyset,\ i = 1,2,..n; j = 1,2,..n; j \neq i$
- **GC-2**: $AS_{r,i}(t) \cap AS_c(t) = \emptyset,\ i = 1,2,..n$

Time Evaluation: DDT is used to calculate the total print time of a printing schedule using the following equation:

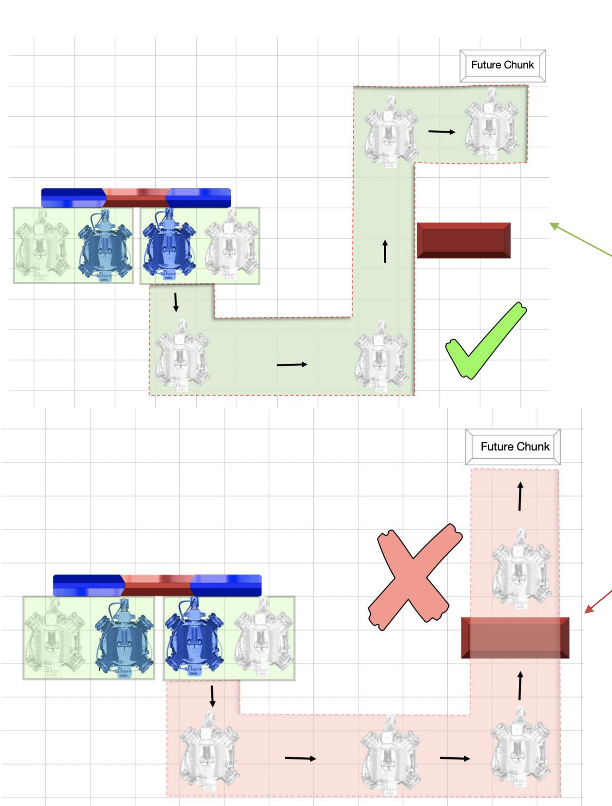
$$T_{total} = max(\{T(D, c_m) \mid m \in [0, n-1]\})$$

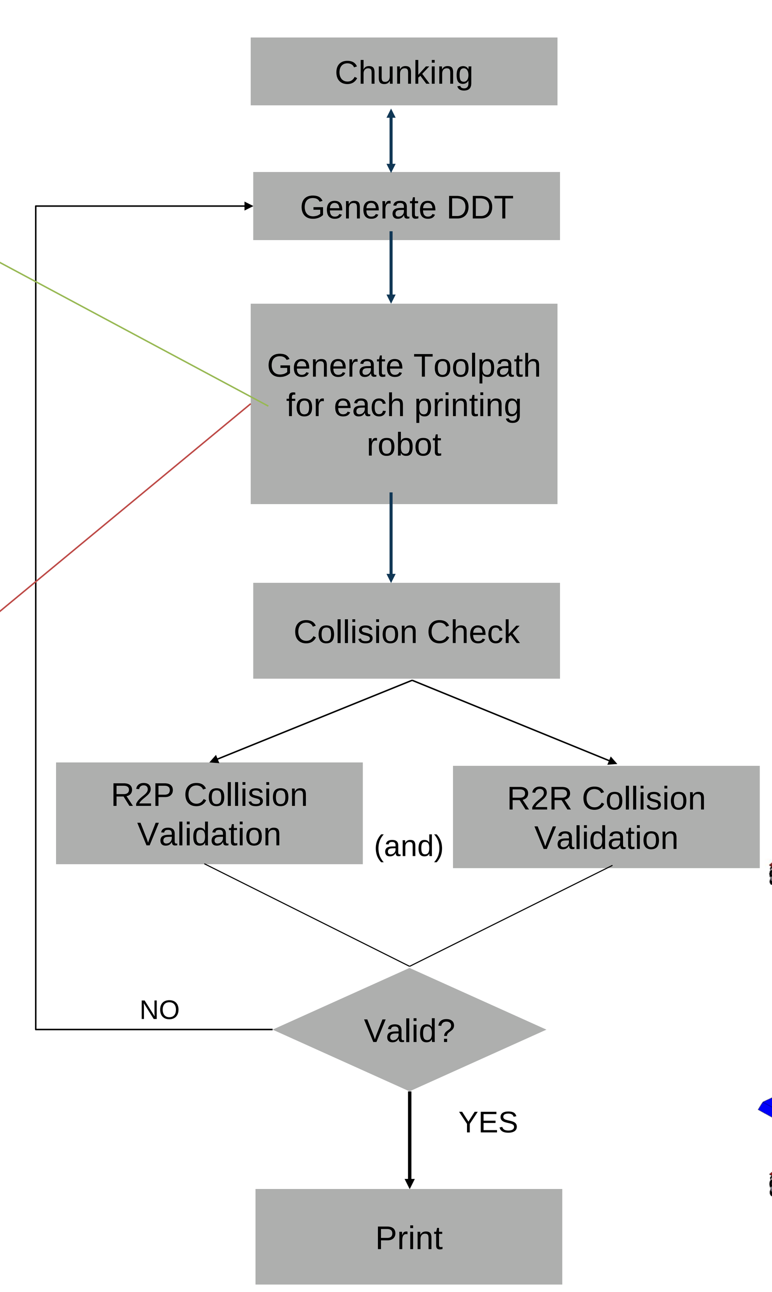
Design Setup :Discretization of 3D Printing Process

3D printing is a **continuous process** where material gets deposited continuously over time until the part is complete. **C3DP discretizes** the continuous 3D printing process in discrete inter-coupled stages as shown on the flowchart on the right.



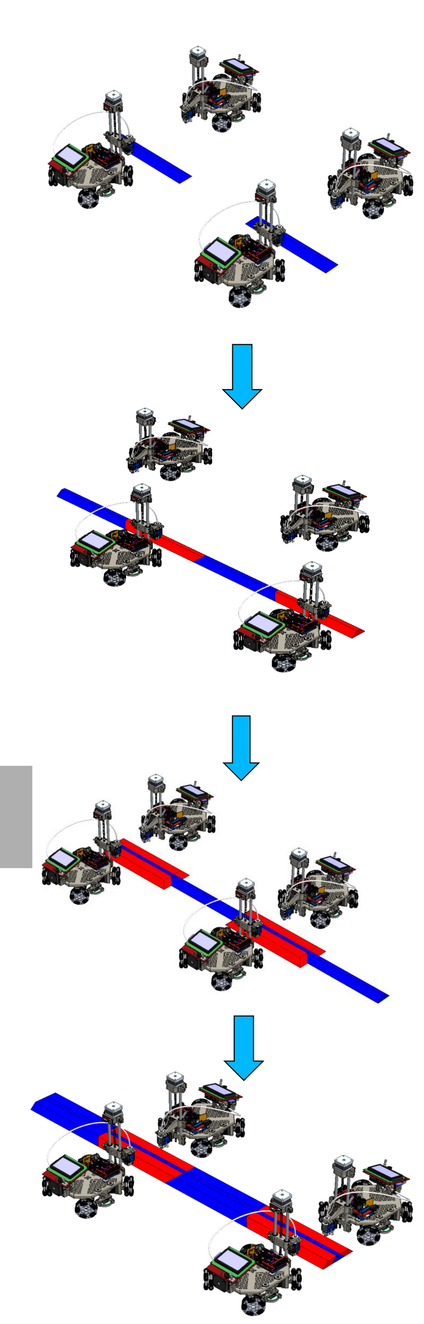
Generative Framework to Integrate Chunking and Scheduling





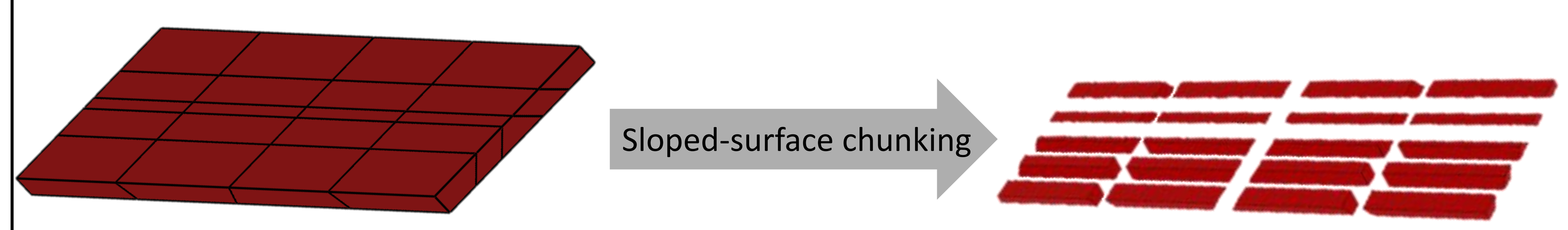
- Based on the number of chunks, either **A*** algorithm or **Conflict-based search** for multi-agent path planning can be used to find optimal path for robots

Print Simulation Result

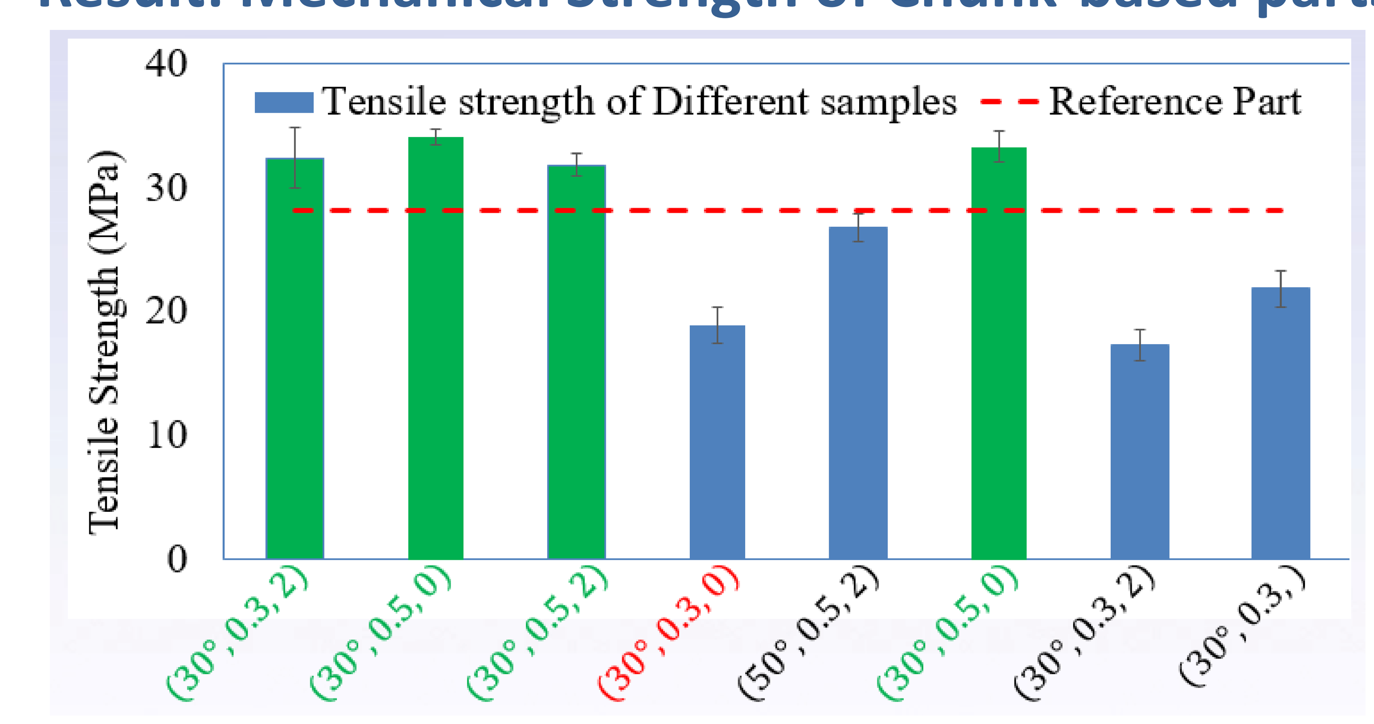


Chunking

- **Chunking** is dividing a part into smaller chunks using a developed chunking strategy. These individual chunks are later assigned to individual 3D printing robots during scheduling.
- Different chunking strategy can be used. Some of the potential approaches **are sloped surface chunking strategy** (figure shown), striping chunking (similar approach used by project Escher, Autodesk), Divide and conquer etc.



Result: Mechanical Strength of Chunk-based parts



Tensile strength of the part is plotted against the parameters combination: (**Slope Angle**, **Chunk Overlapping**, **Number of Shells**)

❖ Conclusion

1. **Sloped-surface chunking strategy** (SSCS) can be used to **divide a large part** into smaller chunk for printing **without requiring post processing**.
2. SSCS can result in part that is **as strong as** the traditional 3D printed part.
3. **Generative framework** approach can **integrate** chunking and scheduling in robust way.

❖ Future Studies

1. Development of self sustaining software platform that can take a 3D model, generate chunks, search though design space to generate optimal print schedule for specified number of robots
2. Develop a digital manufacturing system containing a team of 3D printing robots and multi-assembly robots working together

❖ Publications

1. L. Poudel, Z. Sha, W. Zhou, *Mechanical Strength of Chunk-Based 3D Printed Parts for Cooperative 3D Printing*, 46th SME North American Manufacturing Research Conference, College Station, TX, Jun. 18-22, 2019
2. L. Poudel, W. Zhou, Z. Sha, *Computational Designs of Scheduling Strategies For Multi- Robot Cooperative 3D Printing*, 39th IDETC/CIE Conference, Anaheim, CA, USA, Aug 2019.
3. L. Poudel, C. Blair, J. McPherson, Z. Sha, W. Zhou, *A Heuristic Scaling Strategy for Multi-Robot Cooperative 3D Printing.* Journal of Computing and Information Science in Engineering, *October, 2019*.
4. Zhang, Ziyang, Laxmi Poudel, Zhenghui Sha, Wenchao Zhou, and Dazhong Wu. *Data-Driven Predictive Modeling of Tensile Behavior of Parts Fabricated by Cooperative 3D Printing*. Journal of Computing and Information Science in Engineering. *October, 2019*.

❖ Acknowledgement

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❖ References

1. J. McPherson, W. Zhou, *A Chunk-based Slicer for Cooperative 3D Printing.* Rapid Prototyping Journal, Vol. 24 Issue: 9, pp.1436-1446.
2. L. J. Love. "*Utility of big area additive manufacturing (BAAM) for the rapid manufacture of customized electric vehicles*." No. ORNL/TM-2014/607. Oak Ridge National Lab.(ORNL), Oak Ridge, TN (United States). Manufacturing Demonstration Facility (MDF), 2015.