

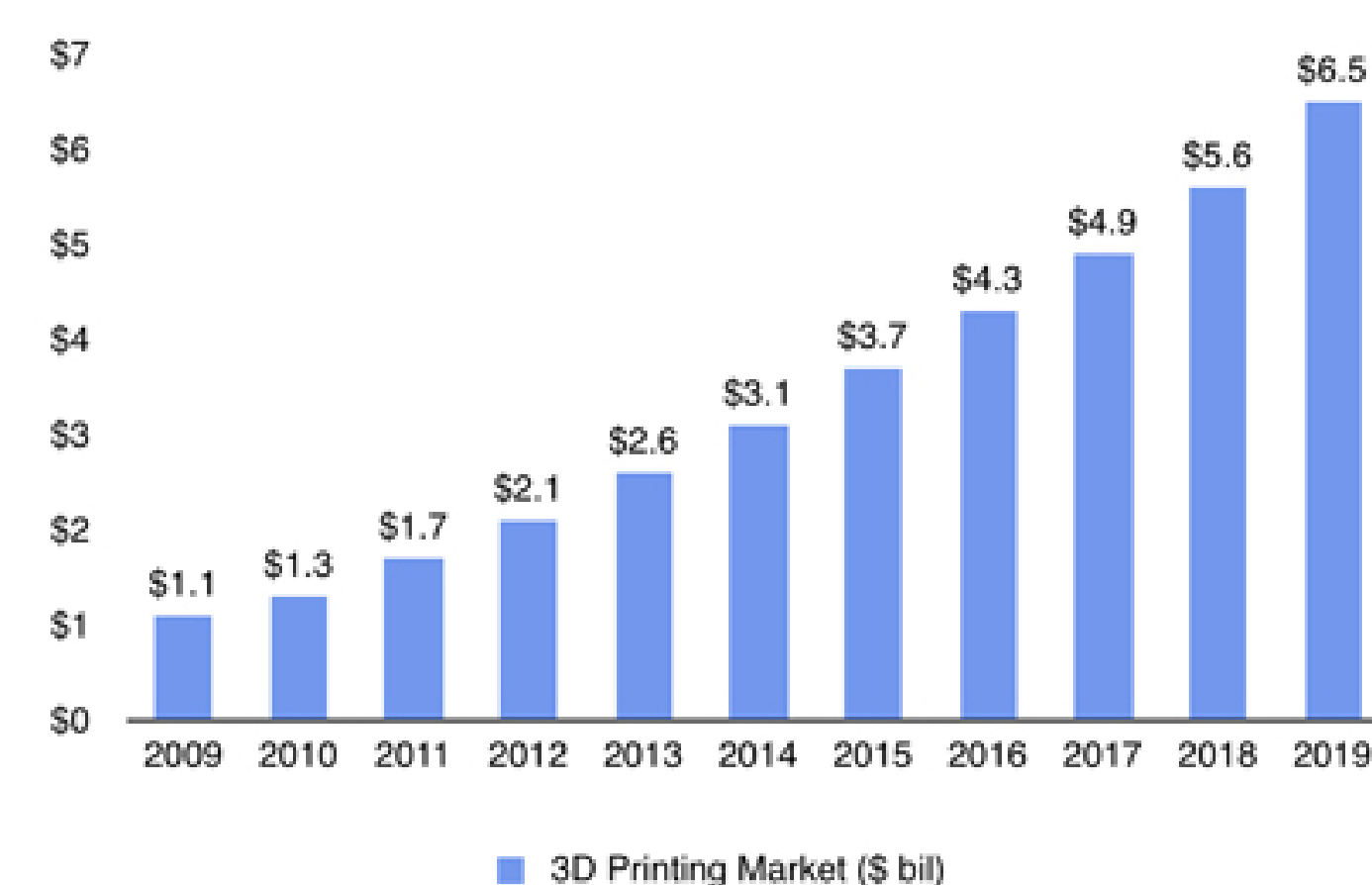
Three-Dimensional Cement Printing Technology Development

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INTRODUCTION

- The purpose of this research is to build an effective system that allows the fabrication of cement-based structures by three-dimensional (3D) printing of cement.
- The technology involves layer-by-layer deposition of a thixotropic cement slurry without a mold, so that the shape of the slurry is maintained afterward, akin to the squeezing out of toothpaste.
- 3-D Printing is a rapidly growing field of technology business.

3D PRINTING MARKET¹



Source: Citl, Wohlers Associates.

WORK PLAN

- Identify and modify a printer design for 3D cement printing.
- Design method of cement deposition
 - Utilize a piston that pushes the cement out of its vessel.
- Select location of vessel so that the movement of the printer nozzle will not be hindered.
 - Place the vessel on top and have a tube that feeds the cement down to the moving printer nozzle.
- Fabricating and testing the modified printer.
 - Performing testing at various printing speeds and various elapse times (i.e., the time between the printing of the same point in successive layers).
- Testing the mechanical properties of the printed structure
 - Comparing the printed structures with conventionally cast cement structures
 - Conduct mechanical testing on the printed structures after curing.

ADVANTAGES AND SIGNIFICANCE

- No need of molding or demolding
- Intricate structural shapes can be achieved
- Produce cement structures quickly
- Easily produce curved edges
 - Allowing more artistic designs in buildings
- Lower drying shrinkage than conventional material
- Reduced labor cost
- Less waste material
- Suitable for printing large objects

CHALLENGES FACED

CONCERNING PRINTING MATERIAL⁵

- The cement used for printing must be adequately thixotropic for dimensional control
- In spite of the thixotropy, the fluidity of the cement must also be adequate for achieving good interlayer bonding.
- Curing (hydration) of cement after printing is necessary
 - Curing typically takes about a month.
 - Fluidity decreases as curing occurs.
 - Thixotropy increases as curing occurs.
- Reinforcement is required for strength under tension or flexure, but steel rebars cannot be deposited.

CONCERNING PRINTING PROCESS

- The elapse time between the printing of the same point of adjacent layers should be small enough in order for the interlayer bond to be good.
- Placement of the cement vessel for effective printing using a movable nozzle.

OTHER CONCERNS

- Scalability of the design to allow the 3D printer to transition into large-scale applications
- Maintenance (mainly cleaning) of the vessel, tube and other components to avoid hardened cement remaining on the surfaces.

DESIGN SPECIFICATIONS

- Decided on Delta Bot Printer design⁴
 - Design does not require a moving base plate allowing a structure to be built on the ground
- Cylindrical shaped slurry vessel was chosen.
 - Easier to fabricate
 - The cylindrical design allows the piston to be cylindrical
- Vessel size is large enough to contain enough cement for minimal refills.
- Cement vessel is located on top of the printer
 - This is so that the printer nozzle is not weighed down by the cement vessel, when the nozzle is in motion.
 - The changing weight of the cement vessel during printing does not affect the speed at which the printer nozzle moves.

PRINTING MATERIAL (CEMENT)

- Apart from the printer design, the cement mix formulation is crucial for this project.
- The success of 3D cement printing requires:
 - a cement mix that is sufficiently fluid for the deposition and bonding between the successive printed layers
 - but be stiff enough for the printed cement mix not to sag as it cures in the absence of a mold.
- Professor D.D.L Chung has developed a suitable cement mix for 3D printing.
- The printing material to be used is Portland cement mainly due to its material properties suitable for our project.
 - When mixed with water, the product sets in a few hours and hardens in about a month.

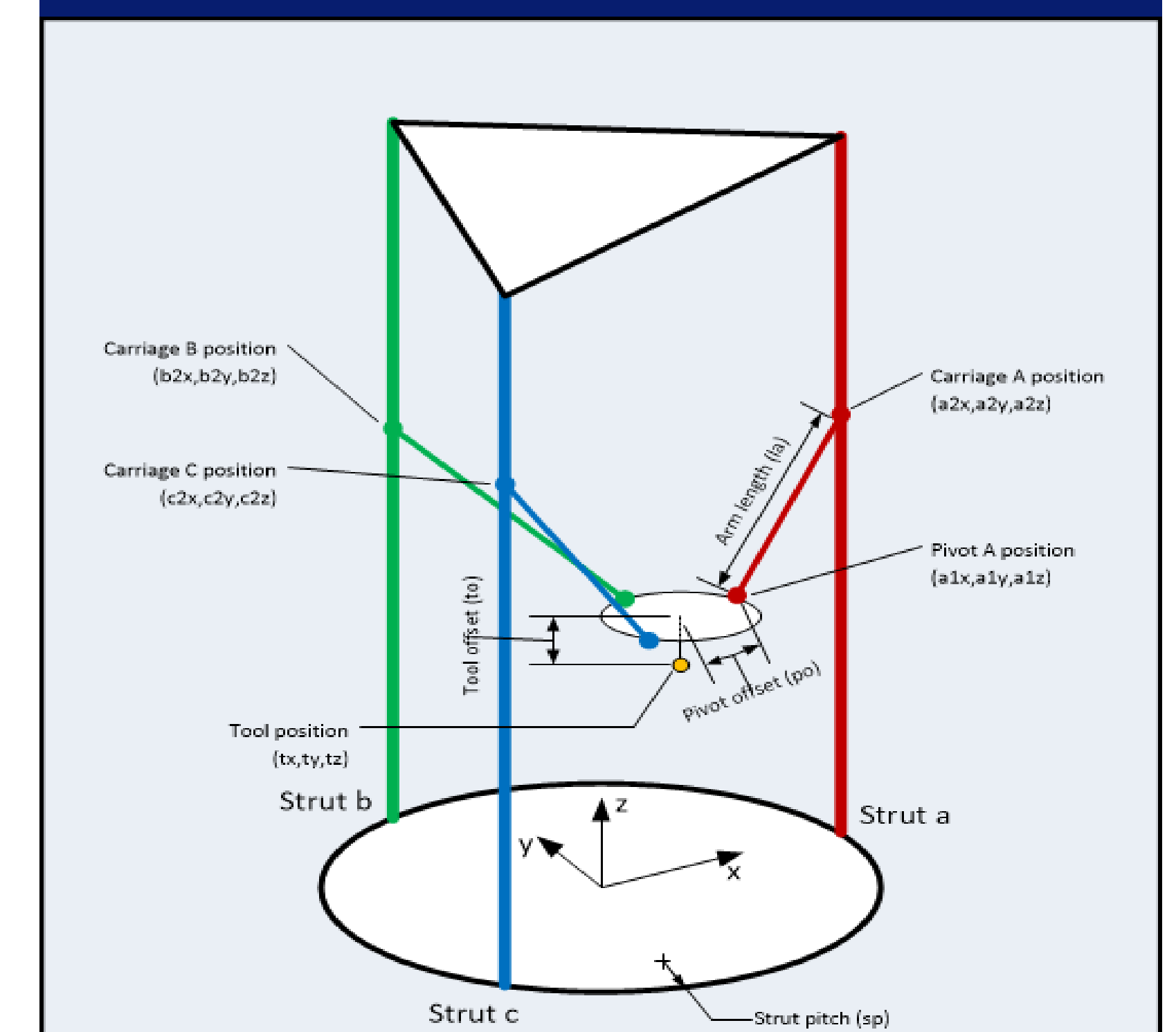
AN EXAMPLE OF A 3-D PRINTED STRUCTURE²



PRINTER DESIGN

- Delta Bot is a type of robot with three arms held by three struts (towers). It will be adapted for the printer.
 - This set up allows a completely open build space, the printer nozzle comes down from the top and does not interfere with the build plate.
- It allows curves in the printed structure.
 - The printer can make circular motion.
- The build plate does not move.
 - The z-coordinate plane is controlled by the printer nozzle moving up and down as controlled by the arms.
- The printer can be modified for large-scale applications.
 - The design is not complicated and would require minimum modification in order to be used for large-scale applications.

STRUCTURE OF THE DELTA BOT³



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