Abstract

Recent innovations in construction feature the use of robotic 3D printers to build walls with greater speed, efficiency, and affordability than conventional methods However, these robots are often installed on a large gantry system, limiting the scale of the project being built to what the gantry can reach. Additionally, the sheer scale of the gantry systems make them difficult to move easily and limit their effectiveness. I am particularly interested in the use of these robots for building affordable housing in developing countries. A solution should be lightweight, robust, and mobile, everything a gantry system is not.

One proposal by Zhang et al suggests using a system of two mobile robots instead of a gantry. The authors show that with such a system, the workspace available to the total system is greater than each robot's individual workspace. My aim in this research project would be to replicate aspects of this paper through simulation in Python Bullet. My emphasis would be on writing a path planning algorithm that, upon execution, would show robots constructing a geometric object without colliding.

Description and motivation

The use of 3D printing robots in construction is rapidly approaching inflection point. The advantages of these robots in construction make them quite desirable, especially since they carry the promise of more affordable, sustainable, and less-time consuming final products. The use of 3D printing robots, or the broader category of additive manufacturing has already taken off in other industries, such as .. and … Particularly in the construction industry, additive manufacturing will allow greater control over products? And reduce waste?

There are a number of research and design firms that have already to begun to seriously examine and implement methods for 3D printing such as Printhuset,[[1]](#endnote-1) Crane WASP[[2]](#endnote-2), and ICON[[3]](#endnote-3). Description of the specific methods they use (historical analysis?) Description of the methods they use

Unfortunately, current methods of 3D printing in construction might hinder the widespread adoption of the process by construction firms. Many methods [sources again] involve a large gantry. A gantry is a … The use of the gantry places significant limits on the size of the building that can actually constructed, as it must be less than the size of the gantry itself[[4]](#endnote-4). This means that the starting height of these 3D printing systems is at least 10 feet tall. This massive external framework[[5]](#endnote-5)makes these systems them to transport and severely limits the sites where they might be used. Additionally, these systems often feature only one print head, limiting the efficiency of printing.

It is particularly important that these systems are refined and (made better?) because of the enormous promise they hold in solving the global intractable problem of affordable housing. The world is urbanizing rapidly[[6]](#endnote-6), creating a massive demand for housing that in many places goes unmet due to lack of efficeny in home construction, which leads to an increase of house prices. In many of the world’s largest cities, housing costs range from 200 to 3000 percent of incomes, pushing many to the periphery.[[7]](#endnote-7) Currently 25 percent of the world’s urban populace live in informal settlements, which are characterized by uncertainty and lack of economic opportunity[[8]](#endnote-8).

Systems for 3D printing homes, if made widely available and affordable for use by construction firms might create a large dent in this problem. However, in order for this to happen, it is critical to move away from gantry based systems, and towards more scalable solutions. Zhang et al offer one such solution. They have explored a proposal for concrurrent 3D printing by a team of mobile robots. They argue that their system, taking advantage of “localization, collision avoidance, and efficient coordinated printing through optimal robot placement” demonstrates the needed scalability by allowing the individual robots to print “single piece structures of arbitrary sizes” [[9]](#endnote-9). This is a particularly interesting method, that takes advantage of many concepts in robotics to create a nessecary advancement in 3D printing technology.

The remainder of this paper is organized in the following way. In Section 2, I explain the algorithms I considered when implementing this project. In Section 3, I describe the implementation process and explain the results. In Section 4, I present my reflections and analysis.

Thoriugh intro and motivation

Also known as Additive Manufacturing) carries the promise of faster, safer, more customizable, and less labour-intensive operations in multiple segments of the Building and Construction (B&C) industry [1]. Recent years have seen rapid developments in 3D-printing for B&C, from the formulation of printable materials [2–4], to the design of new printing systems [5–9], to commercialization [10,11].

A major hurdle to the widespread adoption of 3D-printing in B&C is the limitation on the sizes of the printed structures. As reviewed in detail in Section 2, most existing 3D-printing systems for B&C are based on a gantry, which can only print structures whose sizes are at most as large as that of the gantry itself. Some arm-based systems have been demonstrated, but the sizes of the printed structures in this case are limited by the reach of the robotic arm. One workaround consists in printing smaller pieces, which can then be assembled together. This workaround generates however additional design and process com- plexities, as well as creates potential weaknesses at the assembly in- terfaces.

To overcome this scalability issue, we propose in this paper a 3D- printing system based on a team of multiple mobile robots. Such a system can potentially print single-piece structures of arbitrary sizes, depending on the number of deployed robots. We demonstrate, for the first time to our knowledge, the actual printing of a single-piece con- crete structure by two mobile robots operating concurrently (see Fig. nd video at https://youtu.be/p\_jcG25tUoo). The size of structure is 1.86 m × 0.46 m × 0.13 m (length, width, height), which is larger than the reach of each robot arm taken separately (1.74 m), highlighting the need for multi-robot deployment. According to the classification method proposed in [12], where concrete 3D-printing techniques are classified based on object scale (xo), extrusion scale (xe), environment (e), assembly strategies (a) and support (s), our system of collaborative printing is categorized as xo1xe1e0a0s0 with robotic complexity of r6, which is higher than all state-of-the-art techniques as recorded in [12]. Note that concurrent printing is important to guarantee good bonding properties at the junctions: sequential printing would lead to fresh concrete adjoining hardened concrete at the junctions, weakening thereby the bonding strength [3,13].

Concurrent 3D printing by multiple mobile robots is difficult for several reasons. First, the robot motions must be carefully planned and coordinated to optimize material delivery while avoiding mutual col- lisions. Second, robot localization must be highly precise to ensure that the pieces printed by different robots are perfectly aligned. Finally, the mixing and pumping systems of the robots must be coordinated to de- liver materials in a synchronized manner.

The remainder of the article is organized as follows. In Section 2, we review existing 3D-printing systems for B&C. In Section 3, we present in detail our system based on a team of mobile robots. In Section 4, we report the results of the multi-robot printing experiment. In Section 5, we discuss the advantages and limitations of the proposed system. Fi- nally, in Section 5.1, we conclude and sketch some directions for future

Sources

1. Printhuset [↑](#endnote-ref-1)
2. Crane WASP [↑](#endnote-ref-2)
3. ICON [↑](#endnote-ref-3)
4. Zhang et al [↑](#endnote-ref-4)
5. Zhange et al [↑](#endnote-ref-5)
6. Source about world urbanizing rapidly [↑](#endnote-ref-6)
7. The Global Housing Crisis, Citylab, 2018 [↑](#endnote-ref-7)
8. The Global Housing Crisis, Citylab, 2018 [↑](#endnote-ref-8)
9. Zhang et al [↑](#endnote-ref-9)