Additive Construction Operations

Constructing scalable EABs in less time

by Capt Bradley Abell

In the next quarter century, the Marine Corps will improve the tempo and scope of its expeditionary operations. Support to our forces will need to maintain speed and efficiency to preserve combat effectiveness. In the *Marine Corps Operating Concept* (MOC), operations will be conducted using seabasing, ship-to-shore movements, and forward staging areas known as expeditionary advanced bases (EABs).[1] Unlike the past decade, where forward operating bases took months to establish, EABs will need to be operational in a matter of days or hours to adequately support the forces at the forward line of troops. Current engineering techniques and materials in the Marine Corps cannot meet the time and efficiency requirements outlined in MOC. However, if the Marine Corps continues to incorporate modern, commercial construction practices, then the force will be able to support the EABs of the future.

The commercial construction industry already leverages advancements in drone technology, three-dimensional (3D) printing in the field, and innovations in material sciences. Unmanned technology is being applied to earth-moving equipment around the world to provide efficient and precise project scheduling. The additive manufacturing concepts developed in laboratories with small 3D printers have been extrapolated to construction sites and used to develop methods for printing permanent structures with concrete. Material science has developed breakthroughs in cement formulas and the rapid curing of cementitious materials with carbon dioxide.[2] The Marine Corps writ large can capitalize on these advancements to swiftly develop EABs in accordance with the MOC.

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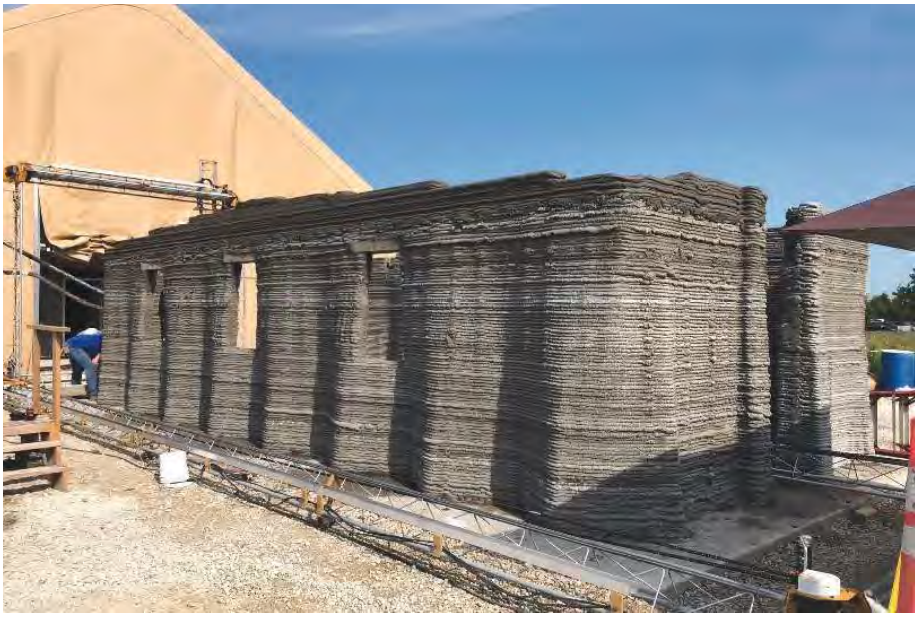
EAB Construction Concept

EABs are a critical element in the MOC. EABs can provide staging areas, sea-denial posts, forward operating bases, and logistic hubs. In size, EABs could range in size from small outposts to large logistic nodes, requiring the need for scalable engineering systems. The rapid evolution of current and future conflicts requires the expedient construction of bases to effectively impact the fight. Using additive construction advancements, hardened EABs could be constructed in less than 72 hours.



EABs will need to be operational in a matter of days or hours to adequately support the forces at the forward line of troops. *(USMC courtesy photo, August 2018.)*

Unmanned Equipment

Survey and earthmoving equipment has advanced in precision and efficiency by using cutting-edge software and GPS-enabled sensors to enable unmanned operations. These "drones" have the ability to measure grade and elevation, identify key locations, and propose possible building layouts. Furthermore, many of the commercial heavy equipment manufacturers produce systems able to receive, send, and execute a construction plan utilizing only the raw data collected by the drone. Komatsu, for example, has developed a smart construction program which combines drone-scanning technology with earthmoving operations.[3] The program sends small drones to conduct site scans, which are developed into digital three-dimensional models in building information modeling (BIM) software. Once the model is developed, the program calculates the most efficient methods to accomplish a project. After the program completes its analysis, autonomous earthmoving equipment works in concert according to the priorities of work determined by the program. Autonomy and synchronization of survey and earthmoving operations allows for better precision, eliminates unnecessary movements, and completes a project's layout and foundations in an efficient and timely manner.

Site analysis and preparation are the first requirements before any construction of an EAB can begin. Small unmanned drones will effectively complete surveys in a timely and covert manner; this is similar to Komatsu's 3D scanning smart construction program.[4] Drones will launch from vessels near the shore, transit to the location, and capture 3D scans of the site, providing instant feedback to the ship. A special model drone will land to test dirt samples and determine the dirt's properties and composition for compaction, moisture content, and suitability for a 3D printed slurry mix. These samples inform the engineering team on which additional materials to prepare and determine the additional steps needed to print. This analysis and site preparation can take a matter of hours using drones vice the days or weeks it would take using traditional reconnaissance and survey teams.

A couple hours before the unmanned earthmoving equipment begins, the 3D scans and dirt samples are analyzed by engineers. Next, the engineers rapidly complete the EAB layout using predesigned structures in BIM or alternative computer-aided design programs. Engineers choose designs from a digital library based on the site layout and requirements of the EAB. For example, engineers would be able to select scaled combat operations centers, aid stations, bunkers, and numerous force protection barriers. Although atypical, the designs are primarily dome shaped to provide maximum protection, concealment, and efficiency. Dome-shaped structures provide greater protection because slanted walls are thicker and create deflection from direct fire weapons. The dome shape also creates lower-profile buildings that will only rise a few feet above the grade when earthen materials are used. Further, building domes is more efficient because a 3D printer can complete an entire building in one print. If we were to build concrete structures with standard vertical walls and a horizontal ceiling, the formwork alone would take 24 hours to prepare, a minimum of one day to cure, and an additional day of stripping the formwork. Thus, in the time it takes to build one structure using traditional construction techniques, the Marine Corps could build three separate, safer structures using additive construction.

... 3D printing technology has advanced from laboratories to construction projects ...

Once the layout is finalized with pre-engineered dome-shaped buildings, a team of small unmanned heavy equipment and self-mobile concrete 3D printers, similar in size to commercially available ride-along excavators, can be lifted by CH-53, MV-22, or C-130 to the site. If there is not a suitable landing zone, the equipment is both small and light enough that it will be air dropped into the site via parachute. Once on the deck, the unmanned earthmoving equipment begins its priorities of work. The team simultaneously starts berming the perimeter and preparing the construction site, maximizing its time on the objective. Site security is provided by remotely operated armed drones dropped with the earthmoving equipment, but it is less of a concern because the site is not yet physically occupied by any Marines.

Traditional heavy equipment operations only use one or two pieces of gear, creating a single point of failure. If a part breaks or is damaged by our adversaries, the sole piece of earthmoving equipment is out of the fight. By using additive construction, we would have fire team to squad-sized teams of small unmanned earthmoving equipment that are mutually supportable.

The equipment preparing the site for the structures would have the task of stockpiling the earth in a preprogrammed location while the 3D printers would move into place to begin.

3D Concrete Printing Technology

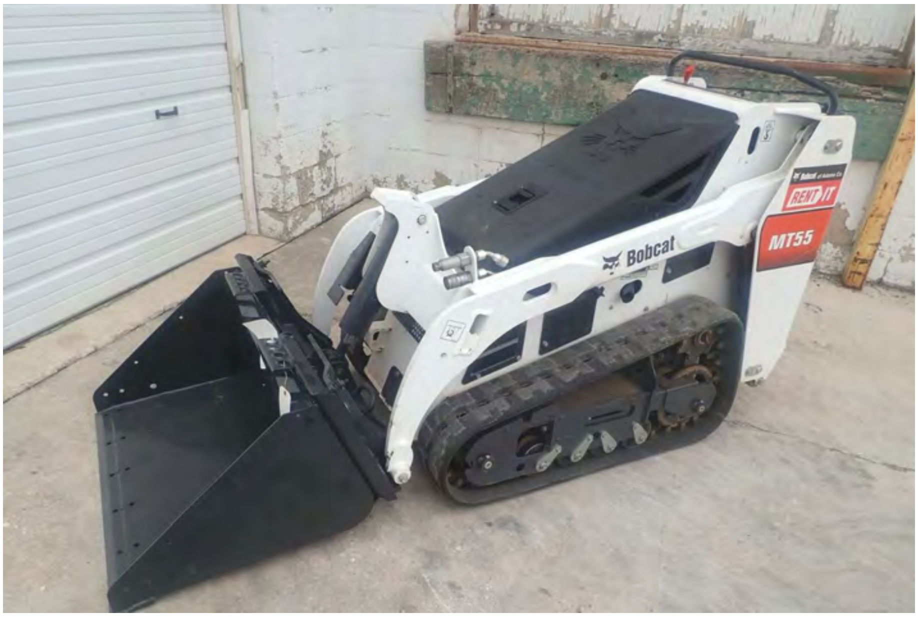
In recent years, 3D printing technology has advanced from laboratories to construction projects across the globe. Using the latest technology, the Chinese firm, HuaShange, successfully printed an entire 400-square meter two-story house in just a few days.[5] There are two types of commercial construction printers currently in use today. One is Gantry Systems, in which the printer nozzle is guided by vertical and horizontal beams, similar to popular small-scale 3D printers; the other is CyBe construction printers, in which the printer nozzle is guided by a robotic manufacturing arm.

A gantry style printer called the Automated Construction of Expeditionary Structures system is currently in development with the U.S. Army Engineer Research and Development Center—Construction Engineering Research Laboratory at Champaign, IL.[6] In its current form, the Expeditionary Structures system can be transported via C-130 or logistics vehicle system replacement and is assembled and employed on the bed of a vehicle. Next-generation ACES systems will be MV-22 lift capable, allowing for rapid employment. This printer just underwent final testing and development in Illinois during the summer of 2017.

Another system in development is the CyBe Construction CyBe RC 3DP.[7] RC 3DP utilizes an industrial robotic manufacturing arm on a set of tracks and stilts. The tracks and stilts enable the printer to become self-mobile and print structures up to 4.5 meters tall. This system is remotely operated using BIM software to upload the building design and program the printer. A two-in-one mixer and pumper networked to the printer is connected to feed material to the nozzle at the appropriate rate. This system is currently available as a commercial off-the-shelf piece of equipment and is being used in Dubai to construct the new Dubai Electrical and Water Authority facility.[8]

A different approach to efficient construction methods and materials, such as 3D printers, is compressed block machines and masonry robots. Compressed block machines utilize local earth material, roughly four to eight percent in weight of Portland™ cement or an equivalent binder, and water.[9] Completed blocks have a minimum compressive strength of 1900 pounds per square inch, which is equivalent to standard concrete masonry unit block.[10] Compressed block machines reduce the amount of water and cement required in comparison to concrete mixes. Standard concrete mixes are 35 percent water and 20 percent cement, whereas compressed blocks are 20 percent water and 8 percent cement. With lower water and cement requirements, compressed block construction drastically reduces the requirements on class IV supply. Unmanned machines can also be used to build with compressed blocks, increasing productivity by up to three times of a typical masonry crew.[11]

At the EAB, the printers can use local earthen material from the foundation as the aggregate with a cementitious binder created onsite or delivered in a second wave for its concrete slurry mix. The equipment digs the foundation below the grade and stockpile the excess earth—the same earth that will soon form the exterior of the structure. Each 3D printer has a support machine in tow, with water and cementitious material pre-loaded into hoppers for each specific building type while the earthmoving equipment loads the earth material into the support machine. The support machine then sifts and mixes the aggregate, cement, and water together before finally pumping the concrete slurry over to the printer as the building is printed.



The MT 55. *(Photo provided by author.)*

Emerging Concrete Technologies

Concrete is the most abundant construction material in the world. To be sure, cement and mix plants are in all corners of the globe. It is simple and inexpensive but has many beneficial properties including strength in compression, flexure, shear, durability, and water tightness. Concrete is composed of three basic ingredients: cement, water, and aggregate. Cement acts as the binder of the aggregate when mixed with water during its hardening process, known as hydration. Aggregate is a mix of fines (sand) and coarse material (gravel). Basic mix design is one-part cement, two-parts fines, three-parts coarse gravel, and one-half part water (parts in terms of weight where 1 Cubic Foot is about 143 pounds).

Concrete strength is directly related to the water-cement ratio of the design: the lower the water-cement ratio, the stronger the concrete. Concrete strength slowly increases as the hydration process takes place and does not meet full strength for 28 days. Advances in admixtures may decrease the duration to full strength or improve workability, high early strength, and air entrainment; slow or speed up the curing process; and increase the bonding properties between old and new concrete, or even the addition of polymer reinforcements. Between the mix design and admixtures, cementitious materials have a wide variety of uses and can meet engineering requirements in nearly

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any environment around the world and make suitable 3D printer slurry mix.

Even with new admixtures, there are still developments in technology which are advantageous to the expeditionary use of concrete. Rutgers University with Solidia Technologies developed a process and a type of cement mixture known as Carbonate Cement.[12] Using a process called “reactive hydrothermal liquid phase densification,” only the amount of water necessary to maintain workability and begin the reaction is used. Rather than a 35 percent water-cement ratio, a ratio of 10 percent will work. Water is not needed for the hydration curing process as the primary reaction involves carbon dioxide (CO2) reacting with calcium to form bonds between the aggregate. This technology is already being used in laboratories and facilities for pre-cast concrete. Currently, the concrete needs a pressurized CO2 environment to cure in less than 24 hours (reaching close to full strength in 24 hours rather than 28 days). Locally produced carbonate cement using local earth materials and a curing period of 72 hours or less can become a new reality in an expeditionary environment while constructing EABs with 3D printers.

Utilizing drones, BIM software, and pre-engineered non-standard structures, specifically tailored digital layouts can be completed in a matter of hours. Once completed, the engineers armed with small unmanned equipment and concrete 3D printers would be able to successfully construct scalable EABs within 72 hours, dependent on the quantity of printers available. The current and future advances and accomplishments of material sciences will make expeditionary cementitious material a reality for these 3D printers, which are available now. By implementing the additive construction techniques through incorporating modern commercial construction practices, the Marine Corps can enable the timely and efficient construction of scalable EABs in order to support the MOC.

Concrete is composed of three basic ingredients: cement, water, and aggregate. ***(Photo by LCpl Jesus McCloud.)***

Notes

1. Headquarters Marine Corps, *Marine Corps Operating Concept: How an Expeditionary Force Operates in the 21st century*, (Washington, DC: September 2016).

2. Department of Materials Science and Engineering, “A Disruptive Technology for CO2 Utilization and the Construction Business,” (Piscataway, NJ: Solidia Technologies, Rutgers University, November 2013). See also Richard E. Riman, Nick DeCristofaro, and Kevin Blinn, “Carbonate Cement and Concrete: A Disruptive Technology for CO2 Utilization and the Construction Business,” Department of Materials Science and Engineering, (Piscataway, NJ: Solidia Technologies, Rutgers University, November 2013).

3. Kendall Jones, “Entering the Age of Self-Driving Construction Equipment,” *Construction Connect*, (July 2016), available at https://www.constructconnect.com.

4. Ibid.

5. Clare Scott, “Chinese Construction Company 3D Prints an Entire Two-Story House On-Site in 45 Days,” *3dprint,* (June 2016), available at https://3dprint.com.

6. Michael Case, John Fikes, and Eric Reiners, “Building Structures on Demand,” *The Military Engineer*, (Alexandria, VA: Society of American Military Engineers, November–December 2016).

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8. Ibid.

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10. Ibid.

11. Julia Sklar, “Robots Lay Three Times as Many Bricks as Construction Workers,” *MIT Technology Review*, (Cambridge, MA: Elizabeth Bramson-Boudreau, September, 2015).

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