

Cases on large scale, materials saving
3D construction printing of critical
infrastructure;

Sustainable construction through 3D
printing

March 2024



▶ FOR CONCRETE CONSTRUCTION, IN-SITU FORMWORK AND PRECAST HAVE BEEN THE DOMINANT CONSTRUCTION METHODS IN THE PAST

Pre-cast concrete



Description Concrete that is cast and cured in molds in a controlled environment, such as a factory or a plant, and then transported and assembled at the construction site.

Includes molds and extrusion-based concrete.

Cast-in-place (in-situ) concrete



Concrete that is poured and cured in shuttering built at the construction site.

Includes form-work, tilt-up, and slip-forming.

▶ THE HISTORIC CONCRETING METHODS OF THE PAST, CANNOT DELIVER THE SUSTAINABLE CONSTRUCTION REQUIRED TODAY

DUE TO THE INHERENT RESTRICTIONS OF THESE METHODS FOR LOTS OF APPLICATIONS THESE METHODS CANNOT DELIVER THE MOST SUSTAINABLE AND MATERIALS SAVING SOLUTION

Inherent restriction	Restrictive details	In-situ Formwork	Precast	Consequences	Examples / cases
Transport restrictions	Typically max 4,5m diameter due to road widths and height of bridges	n.a.	X	Suboptimal solutions	- Windmill towers maxing out at 80-100m - Water sewage tanks with small diameter needs to be made much taller (instead of wider) , leading to excessive excavation activity and cost
	Must have integral reinforcement to be able to lift the concrete structure from the mold and transport it	n.a.	X	Excessive use of materials as materials are placed where really not needed	- Precast wall elements - Standard wall elements for warehouses
Mold restrictions	Cannot make too complex molds / concrete structures	X	X	Excessive additional cost and/or Excessive use of materials	- Precast seahives; coastal barriers - In situ wall elements
	Difficult to make other geometries than straight and rectangular	X	X	Excessive use of materials to compensate for weak contribution from the geometry to the strength of the construction	- Rectangular caisson, instead of caissons with rounded ends towards the water pressure - Conical bottom part of windmill tower instead of trumpet shape, which reduces the foundation from a massive foundation to a strip foundation
	Cannot vary concrete thickness in the mold	X	X	Excessive use of materials as materials are placed where really not needed	Water, biogas and other liquid tanks, with same wall thickness all the way, despite the fact that large thickness only need for bottom part

3D PRINTING UNLOCKS INTELLIGENT SOLUTIONS TO ADDRESS LIMITATIONS OF EXISTING METHODS – SUSTAINABLE CONSTRUCTION

Standardized solutions with pre-cast and in-situ concrete
Transport, mold and design restrictions leading to inefficient, suboptimal solutions and excessive use of materials

Sustainable construction – via 3D construction printing

The design freedom of 3D printing allows for designs where, there is maximum structural support from the geometry and therefore much less need for concrete and reinforcement

Leading to significant materials, co2 and cost savings

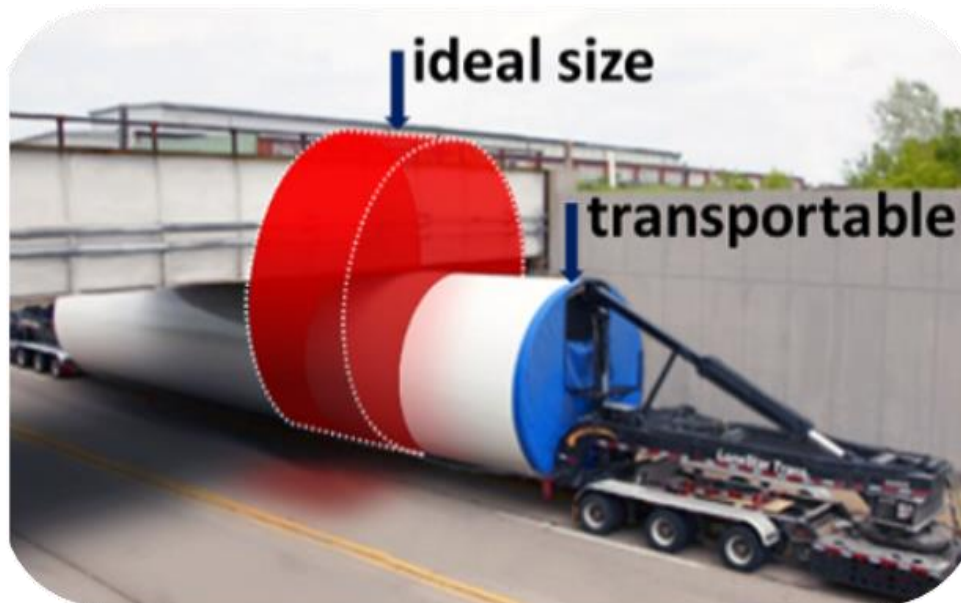


WHY 3D PRINT WIND TURBINE TOWERS ?

BECAUSE THE 3D CONSTRUCTION PRINTING TECHNOLOGY CAN DELIVER THE TOWER HEIGHTS PRESENT SOLUTIONS CANNOT

Towers are conical meaning the base is wider than the top. The taller we want to go the wider the base will be. We want to go beyond 80-100m, but impossible/too expensive now.

Present situation: Steel towers and elements
concrete towers



World's first 3D printed wind turbine tower, 2019

Scope:

- ▶ Concrete: 100 tons (hollow)
- ▶ Reinforcement: none

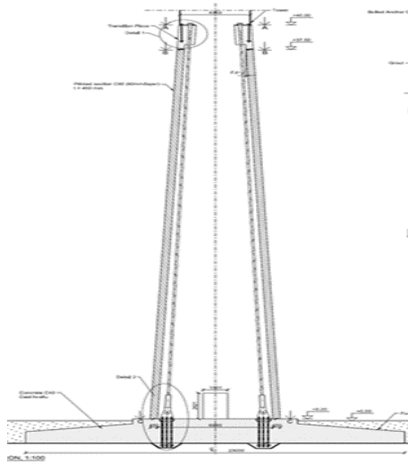
Printing time: 3 weeks;
second time: 3 days



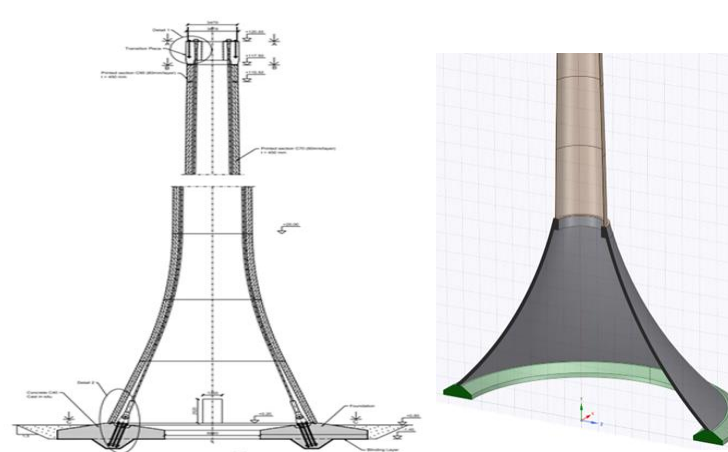
10 m

▶ NOT ONLY CAN WE PRINT TALLER TOWERS, WE CAN ALSO SAVE ON THE MATERIALS

Traditional cone-shaped design



3DCP wider trumpet-shape



40% saving on materials for foundation



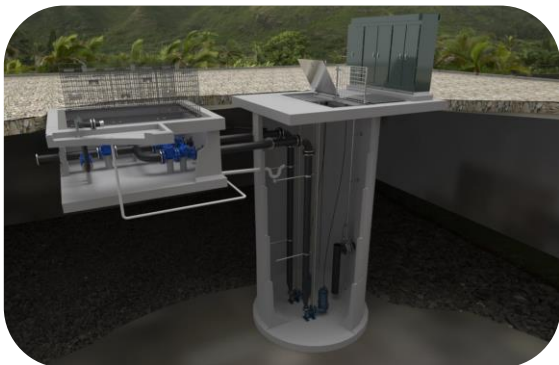
Logic

Wide diameter means that the foundation can be made as a strip foundation instead of being massive, leading to a 40% saving in the amount of concrete and reinforcement used for the foundation.

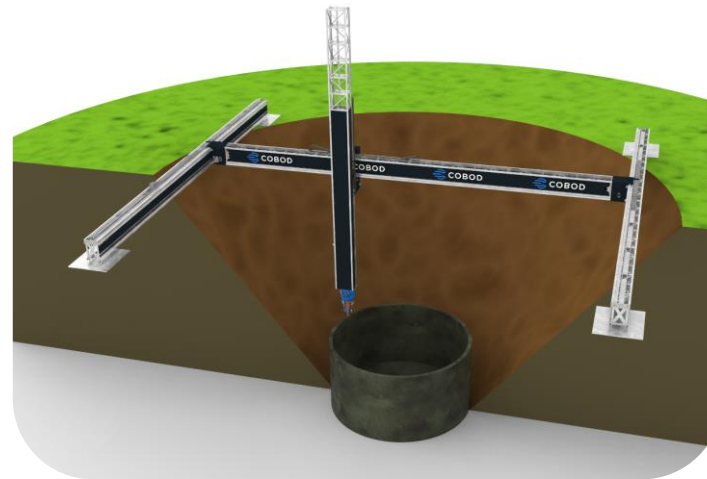
The trumpet shape cannot be made with precast and in situ casting solutions, as the mold would be too complex.

UNDERGROUND SEWAGE WATER TANKS

Traditional precasted sewage tank



3D printed sewage tank



Description

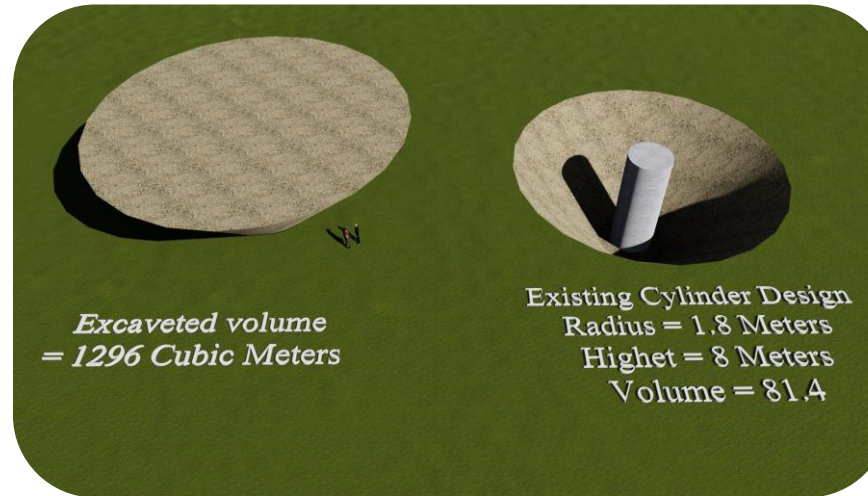
Underground sewage tanks are traditionally done as pre-cast reinforced concrete assembled on-site

Existing methods come with many limitations; elements must be transported 100s of km from the plant, and excessive excavation is the most significant cost. Expensive cranes are required, and the **maximum diameter is limited to 3.6 meters (road restrictions)**, forcing the tanks to be tall and narrow to achieve the desired volume.

The 3D printing benefit is reducing the high excavation costs by allowing for tanks with wider diameters, and eliminating transportation and craning

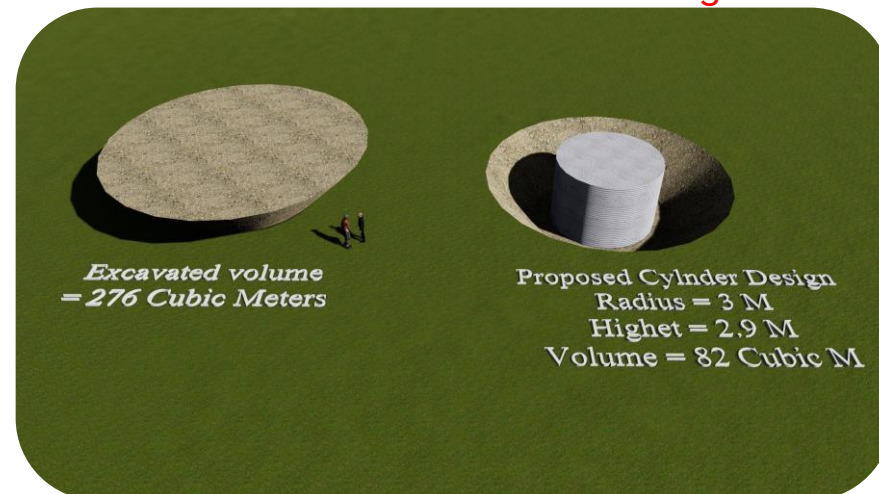
UNDERGROUND SEWAGE WATER TANKS

Traditional precast sewage tank;
tall due to limited diameter



3D printed sewage tank ;
much shorter but wider diameter

79% reduction in amount of excavation due to
the wider diameter and less height



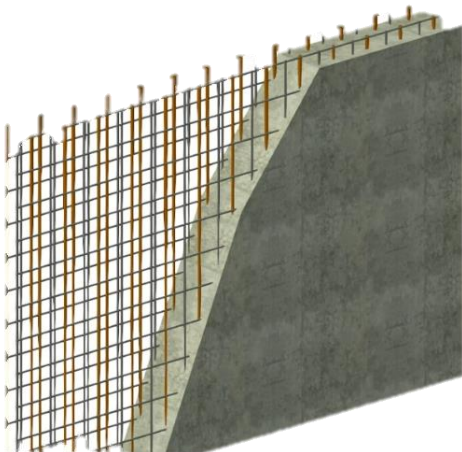
Description

The precast tank solution has a very narrow diameter (due to transport restrictions) leading to the need for a very tall tank and a very deep excavation, requiring 1.296 m³ soil to be excavated to make room for the 81 m³ tank.

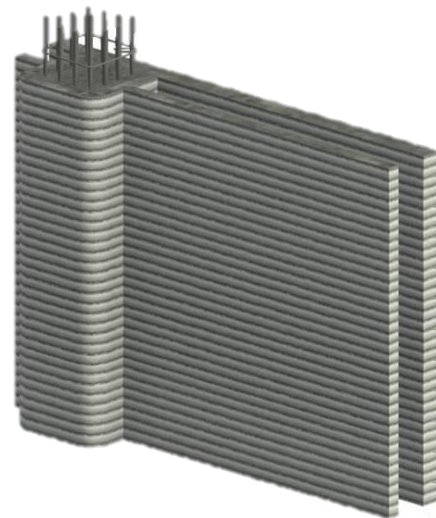
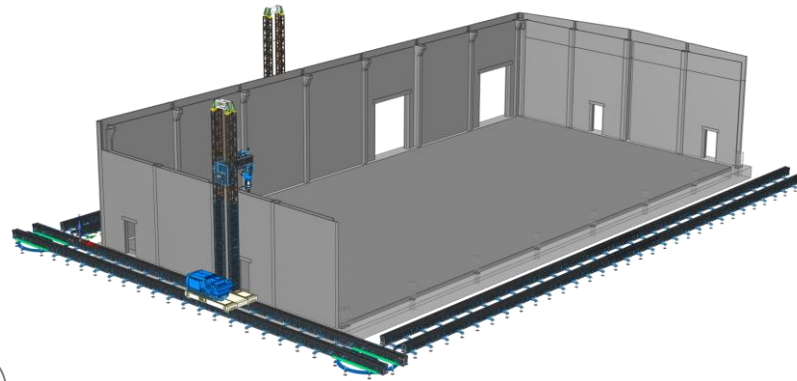
The 3D printed sewage tank because of less height and a wider diameter reduces the amount of materials needed to be excavated by 79% (276 vs 1.296 m³ with existing design)

STANDARD WALL ELEMENTS

Conventional warehouse / data center



3D printed warehouse / data center



Description

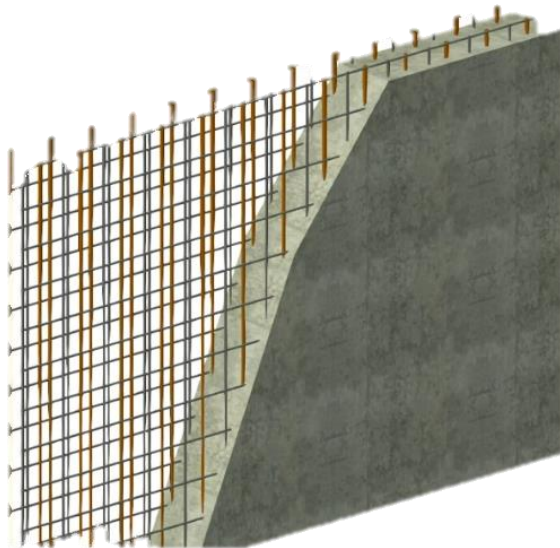
Together with Rambøll COBOD has conducted a study on a 5,000 m² 3D printed warehouse at 330 x 160 ft (100 x 50 m)..

The study concluded that 3D printing can make such large structures using unreinforced walls with reinforced columns (precast and in situ casting **cannot make such as it requires a too complex mold**)

The study also compared the materials consumptions related to the two ways of making the wall elements for the warehouse.

STANDARD WALL ELEMENTS; 31%-50% MATERIALS REDUCTION VERIFIED IN RAMBØLL STUDY FOR A 5.000 M2 WAREHOUSE

Traditional reinforced wall, e.g., pre-cast or in-situ



Concrete, m3

800 m3

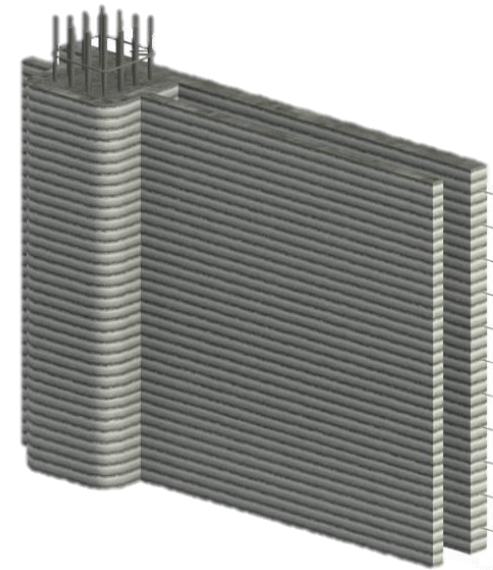
Rebar, tons

80 t



Same strength

3D construction printing wall element with columns



400 m3

55 t

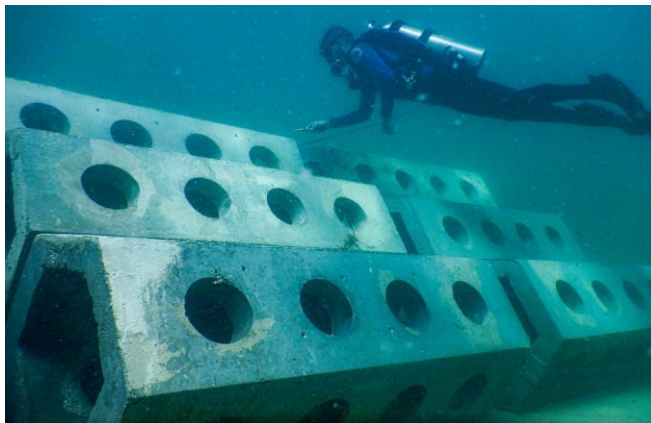
50% reduction

31% reduction

SEA HIVES; COASTAL BARRIERS



Traditional precast coastal barriers
One hexagon barrier pr cast



3D printed barriers,
Multiple hexagon barriers printed together



Description

Coastal barriers are made to make the coast more resistant to storm surges and rising sea level, at the same time as they improve marine and coral reef life. Hexagon barriers have so far been precasted one per cast, as the mold cannot cope with the complexity of casting more at the same time.

Precasted hexagon barriers require thicker concrete walls and more reinforcement to allow for the barriers to be lifted out from the mold. Excessive materials usage. Precasted hexagon barriers must all have the same size; cannot be varied in width or height to fulfill the specific needs in one installation area.

Biggest problem is the installation cost, which normally is 50% of the total cost of producing and installing the barriers.

When more barriers can be installed together, the installation cost is significantly reduced.

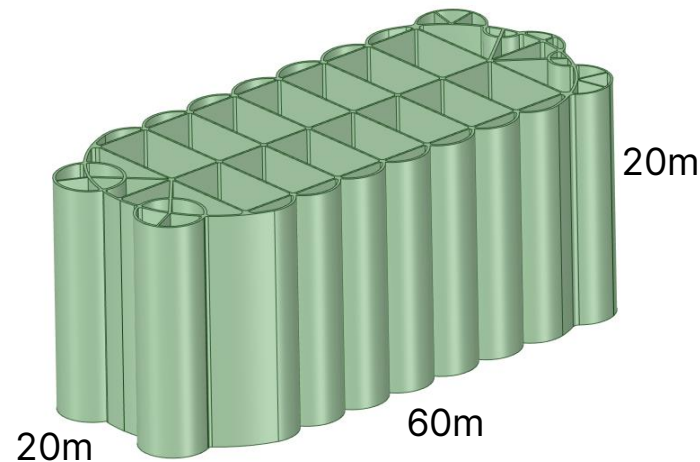
CAISSONS (SÆNKEKASSER)

Traditional form work design (Acciona)

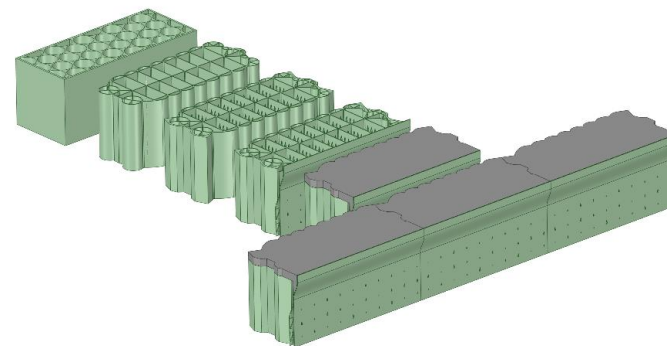


7.700 m³

3D printed caisson (COBOD)



3.600 m³ – 53% reduction



Description

Caissons (under water foundations), also called box caissons, are typically made with straight exterior sides and square boxes inside.

The caissons are mainly exposed to forces from the water from the outside.

The straight walls does not provide optimal support from the geometry leading to the need for thick walls and many support walls when using formwork.

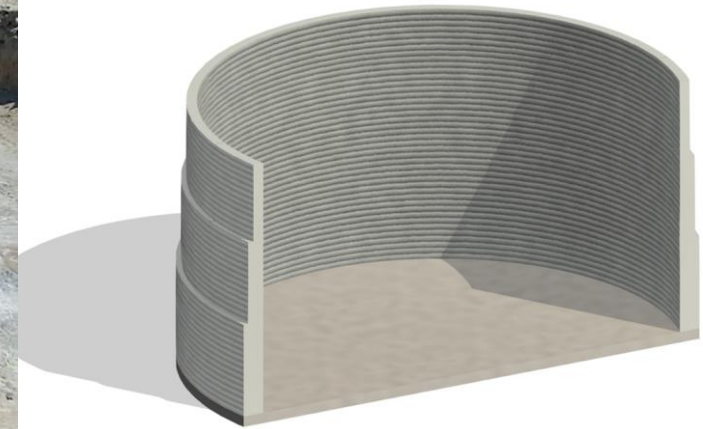
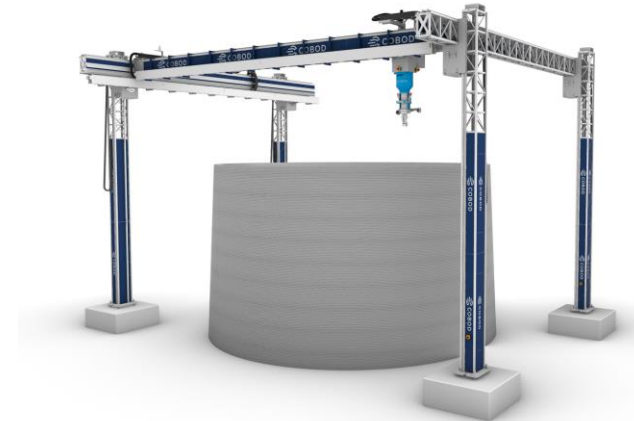
By printing the walls round on the exterior side and thereby provide maximum structural support from the geometry, the thickness of the walls and the need for support walls can be dramatically reduced, leading to a 53% savings in amount of concrete and reinforcement used.

By 3D printing the caissons it is also possible to cerate holes, carves out and other features to improve marine life. 12

▶ WATER, BIOGAS AND OTHER LIQUID STORAGE TANKS

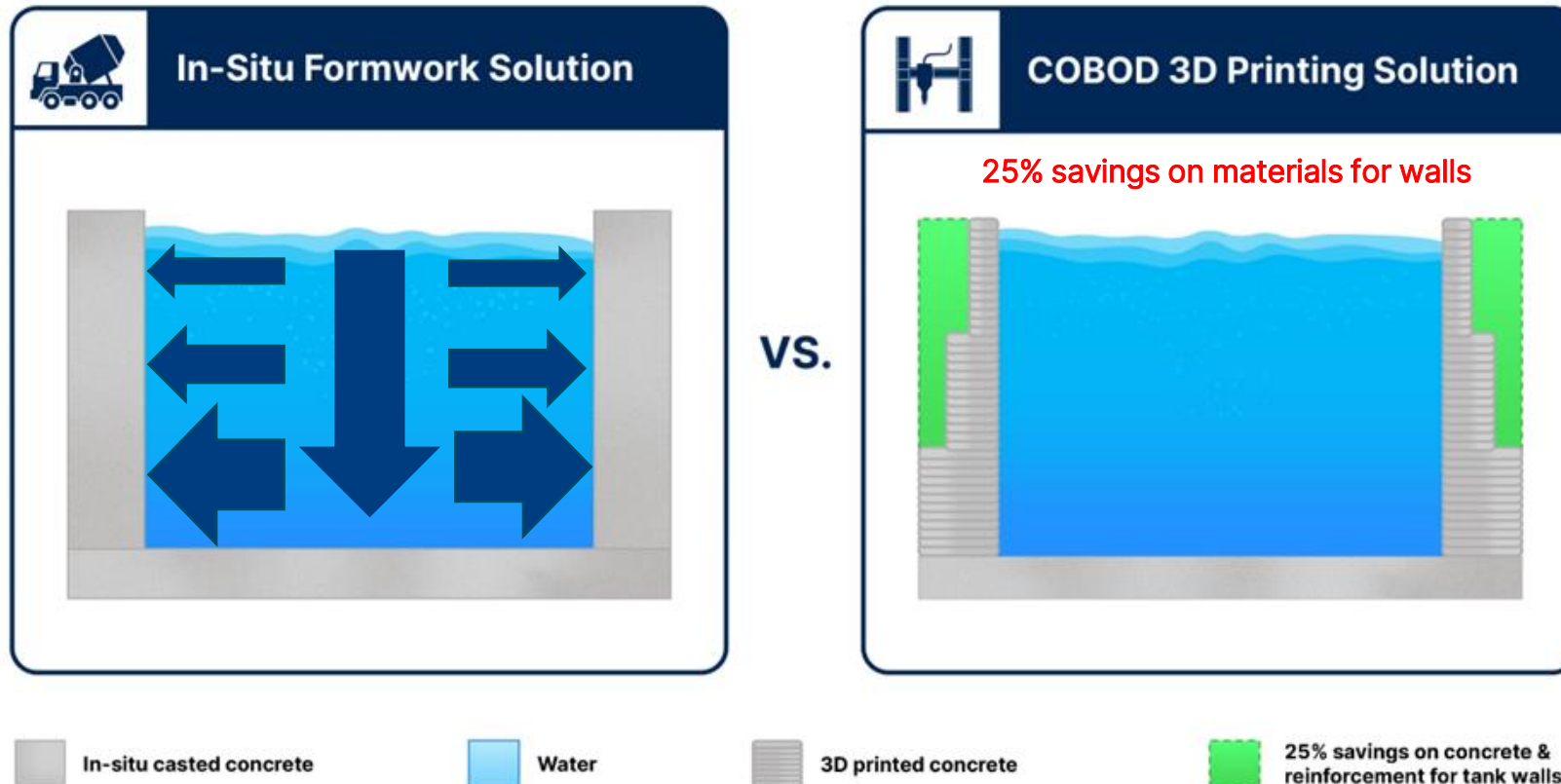


2 chicken drinking water tanks, 4,5m tall and 7m diameter. Kuwait.



WHY 3D PRINTING WATER, BIOGAS AND OTHER LIQUID STORAGE TANKS

3D Printing **Enables 25% Savings** on **Concrete & Reinforcement** Used for the Tank Walls in **Water Tanks**



Logic

As the pressure from the water is decreasing with height, it makes no sense to make the walls with the same thickness all the way up.

With in-situ formwork it is not possible to variate the wall thickness, but with 3D construction printing technology it is.

The tanks were reinforced by 3D printing concrete, which contained macro fibers.

Concluding remarks:

The inherent limitations of the concrete construction methods of the past have meant that for decades materials and co2 inefficient constructions have been made.

With the new 3D construction printing ability, there are so many new possibilities for optimizing the geometry to enable that the geometry provides maximum support to the structural integrity, thereby limiting the need for using excessive materials and constructing much more sustainable !

Sustainable construction for the future through 3D construction printing!

