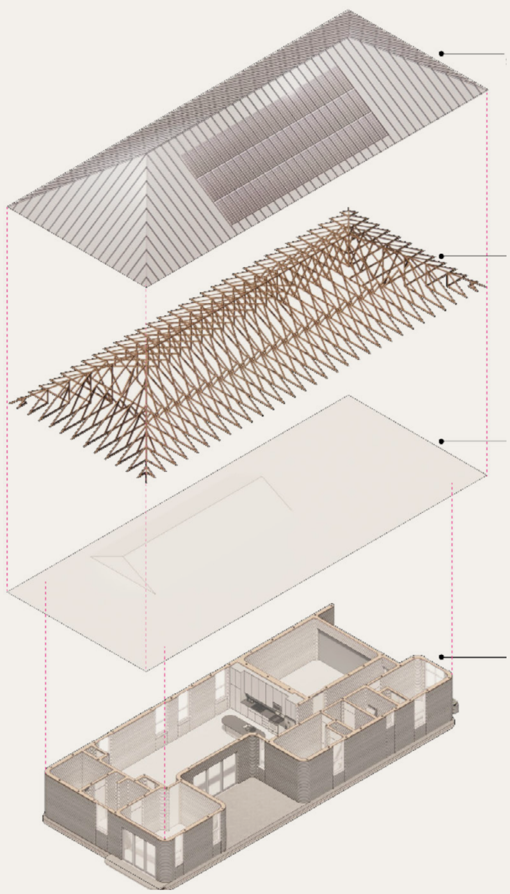
ARCHITECTURE & BUILDING PERFORMANCE TEAM

ARCHITECT'S HANDBOOK

VERSION 2.2



ICON

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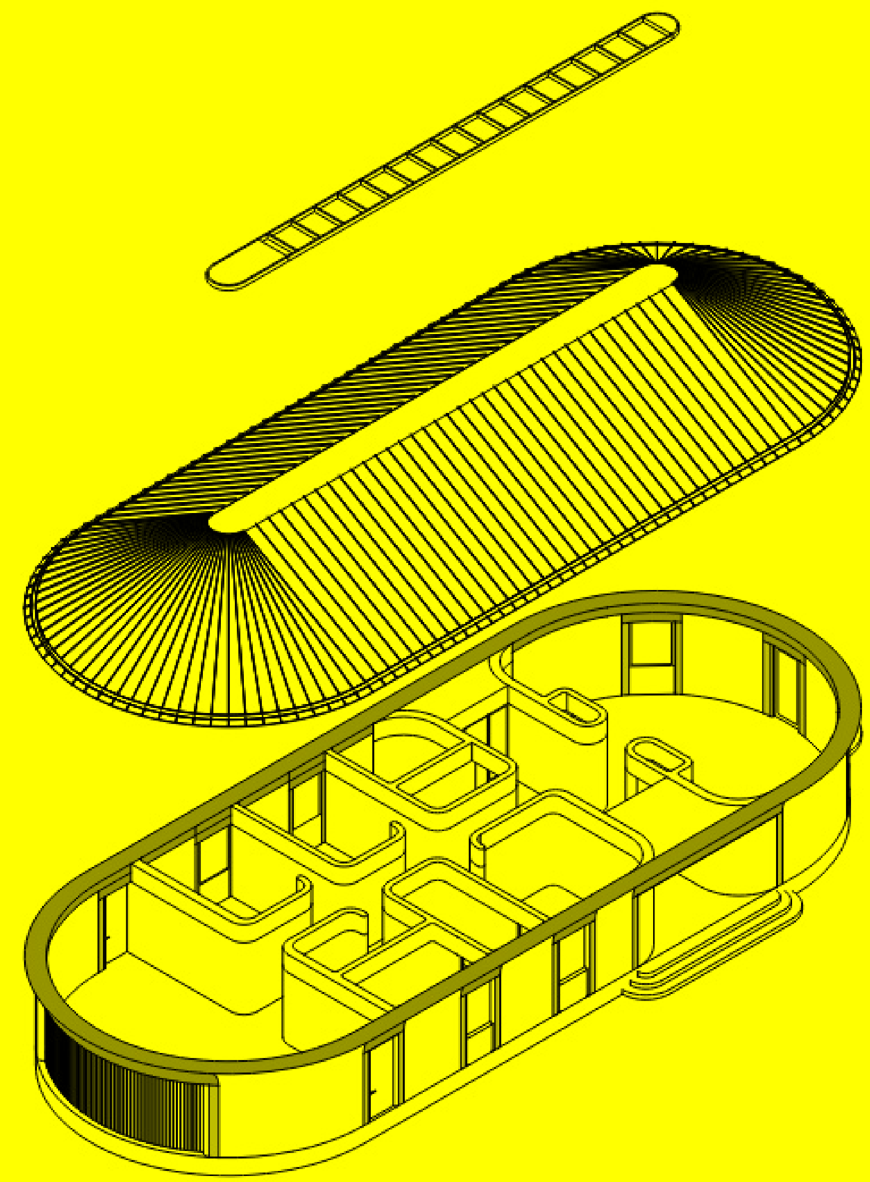
The Architect's Handbook

The Architect’s Handbook is a resource developed by the Architecture & Building Performance team at ICON to communicate guidelines and specifications relative to ICON's wall systems, standards for construction, hardware constraints, and design-to-print workflow.

The Handbook presents design opportunities, guidelines, constraints, as well as documentation relevant to architectural design and structural engineering for ICON wall systems. The Handbook also communicates project workflow, architectural detailing for the wall system and relevant interfaces, as well as best practices in construction based on our experience designing and delivering 3D-printed structures.

> **The Handbook will continue to evolve and expand as our repertoire of built work grows, and will incorporate lessons learned from prototyping and the development of new and innovative features for residential construction.**



About ICON

ICON develops advanced construction technologies that advance humanity. Using proprietary 3D printing robotics, software, advanced materials, and architecture, ICON is shifting the paradigm of building on Earth and beyond.

The housing of the future must be different from the housing we have known. ICON exists as a response to the global housing crisis. Construction-scale 3D printing not only delivers higher-quality homes faster and more affordable, but fleets of printers can change the way that entire communities are built for the better. There is a profound need to swiftly increase supply without compromising quality, beauty, or sustainability and that is exactly the strength of ICON's technology.

ICON's Vulcan construction system extrudes a proprietary mixture called Lavacrete layer by layer to deliver and replace the full wall system of a home. The printer is controlled by a tablet and the homes are printed on site by operators. This eliminates multiple manual trades and material supply chains, combining them into one process.

ICON's proven 3D printing technology provides safer, more resilient homes that are designed to withstand fire, flood, wind, and other natural disasters better than conventionally built homes. ICON has built homes for the homeless, delivered the first 3D-printed homes sold in the U.S., constructed a Martian habitat for NASA, printed barracks for those serving their country with the Department of Defense, and a 100 home community with Lennar in Georgetown, TX.

Working With The HOME Team

The Architecture & Building Performance department is referred to in shorthand as the HOME team. The HOME team holds responsibility for diverse facets of project delivery, encompassing:

Architecture

Building Science and Performance

Design Technology

Structural Engineering

Regulatory Affairs

Furthermore, the home team plays a crucial role in facilitating:

Project design, development, documentation and coordination

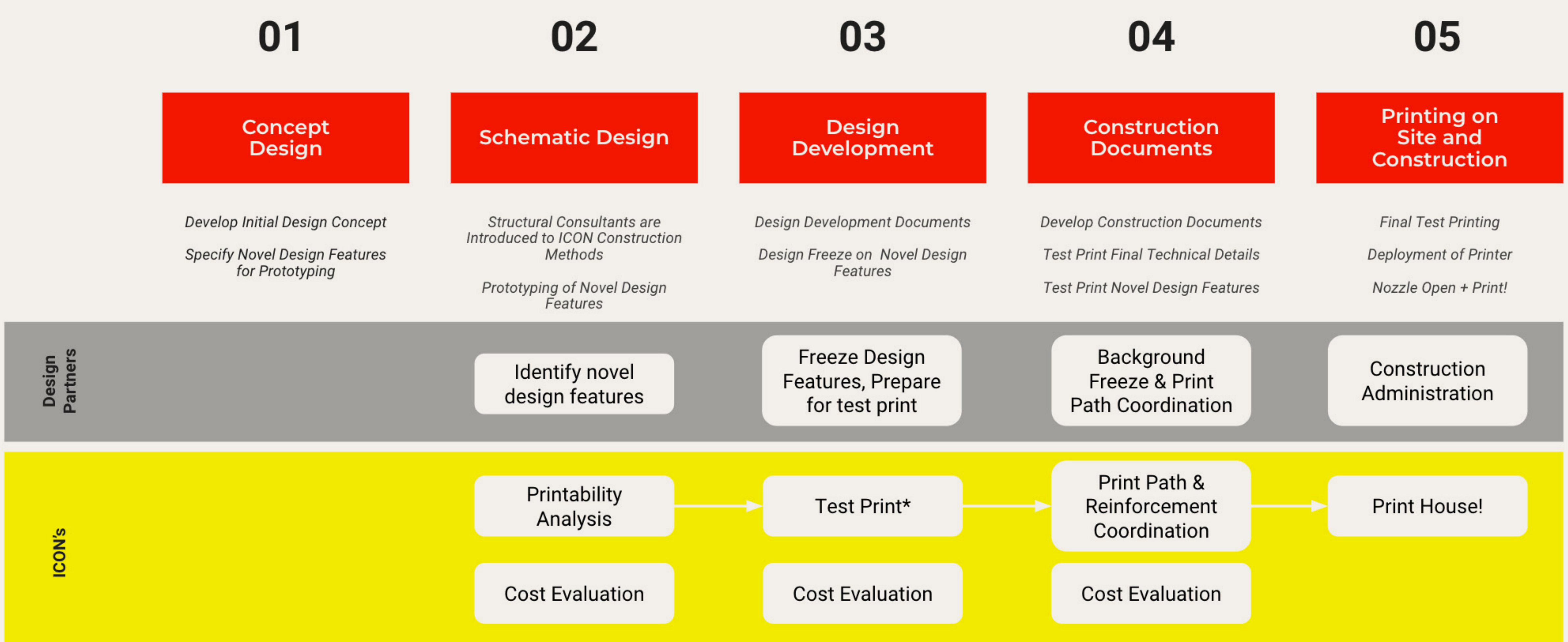
Printed Wall Detailing

Print Path Coordination

TYPICAL DESIGN-BUILD WORKFLOW

Design to Construction Workflow

We support our design partners in multiple phases of project delivery by ensuring that designs are printable, ensuring they align with project budgets, and coordinating the design's print path prior to construction.



TYPICAL DESIGN-BUILD WORKFLOW

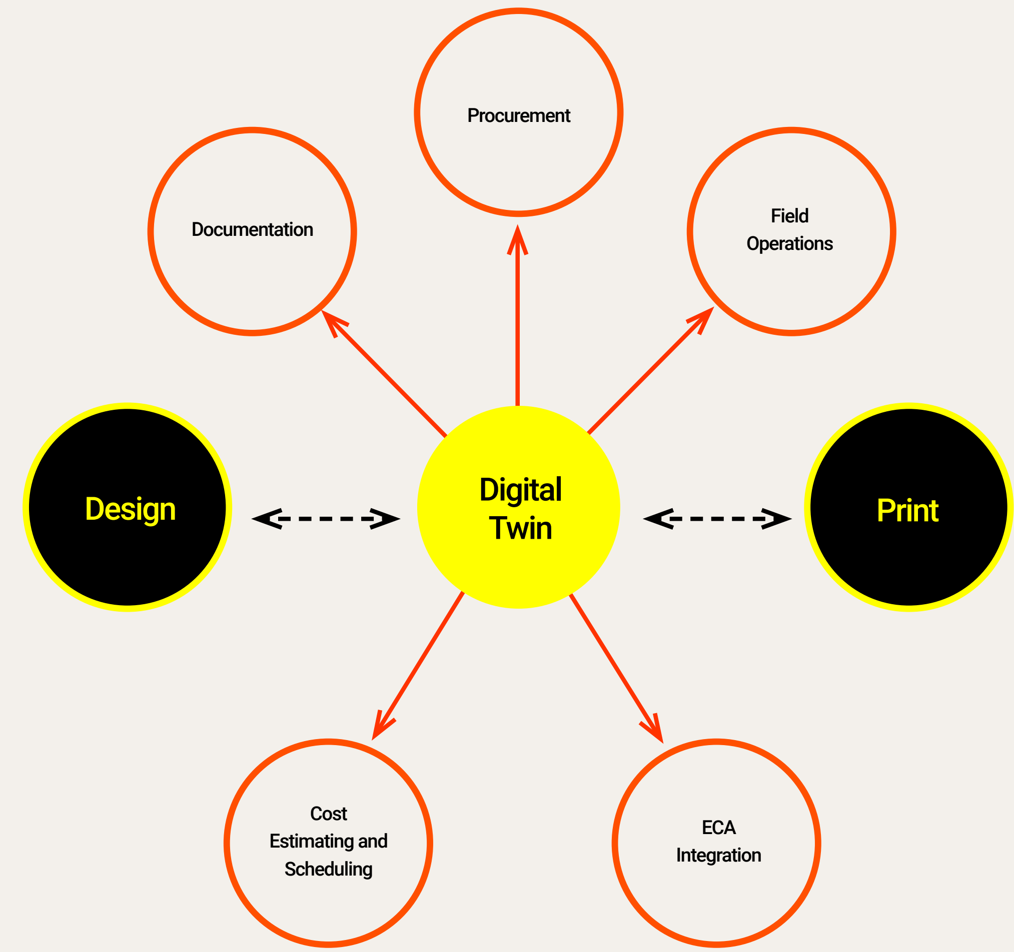
Designing with ICON Using BIM

The advent of fully digitalized 3D printing in construction has revolutionized the way we approach Building Information Modeling (BIM) in architecture and construction. This method, akin to the manufacturing industry, minimizes human intervention, necessitating a more comprehensive digital twin with increased data and detail. This ensures a seamless transition from design to print.

At ICON, BIM integration commences at as early as the concept stage. ICON boasts a fully BIM-oriented workflow from design to construction, starting with the alignment of all stakeholders through the ICON BIM Execution Plan, which delineates the guiding principles of BIM practice protocols.

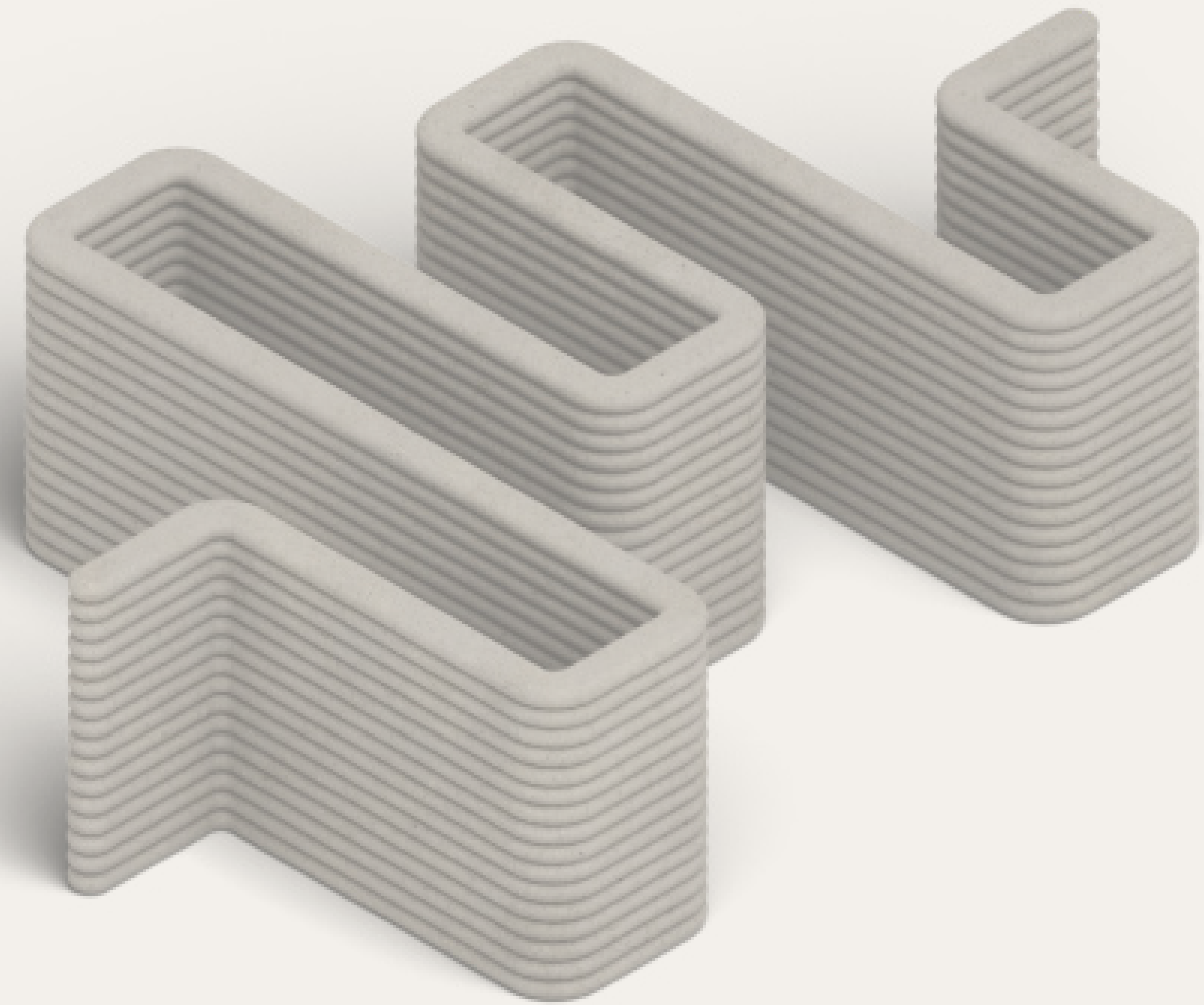
The current BIM software ecosystem at ICON primarily focuses on the workflow from design to print, translating design intentions into printable languages. This involves taking design models from architects and engineers and undergoing a series of steps: print path coordination (translation of design model to printable language, like G-code), reinforcement coordination (aligning pre-engineered printed wall system reinforcements with project variables and requirements), and quality assurance protocols, which utilize automation and documentation to ensure the execution of design intentions and requirements.

The data extracted from digital twins is optimized for various ancillary purposes, including cost estimation, procurement, project management, field digitalization, energy analysis, and quality assurance. These applications evolve continuously as ICON's proprietary software ecosystem and workflows mature.



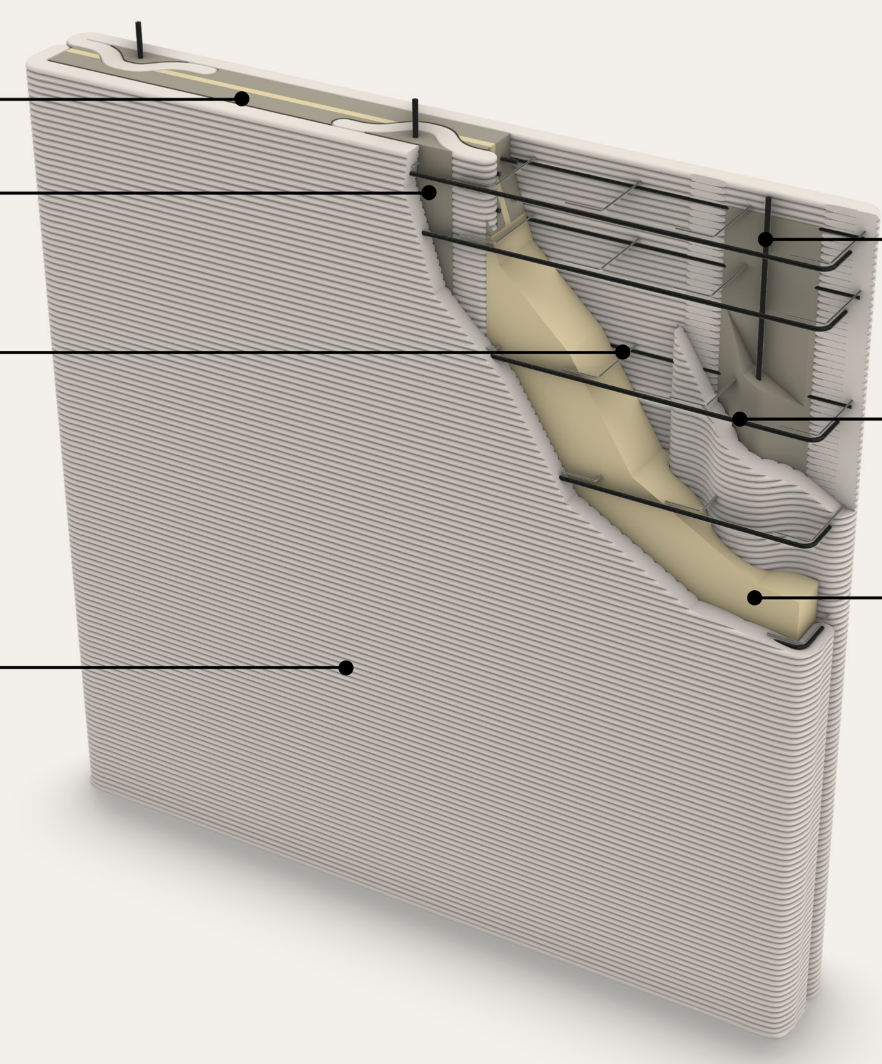
It's important to note that the design-to-print workflow tackles an information processing challenge through two simultaneous approaches. One is facilitated by software enhancements within ICON's proprietary software, while the other is managed through protocols, standardization, coordination, and quality control and assurance by the architecture and building performance team.

ICON Wall Systems & Building Performance



TYPICAL WALL ASSEMBLIES & SPECIFICATION

Typical Load-Bearing Walls



① **Inner Shell Structural Wall.**
The interior wall is made from a combination of 1 or 2 printed beads and core sections. This section of the wall provides the resistance capacity for axial, bending, and shear.

② **Outer Shell.**
The exterior bead consists of 1 or 2 printed beads and protects the structural wall section from impacts and transfers the out-of-plane loads to the structural wall via the ties. Some wall types may have cores on the outer shell of the wall.

③ **Cores.**
Fully grouted cores are spaced through the structural wall section have vertical reinforcement running through the wall and into the foundation. Cores are located on the inner or outer shell or both. Grout is consolidated around the reinforcement within the cores.

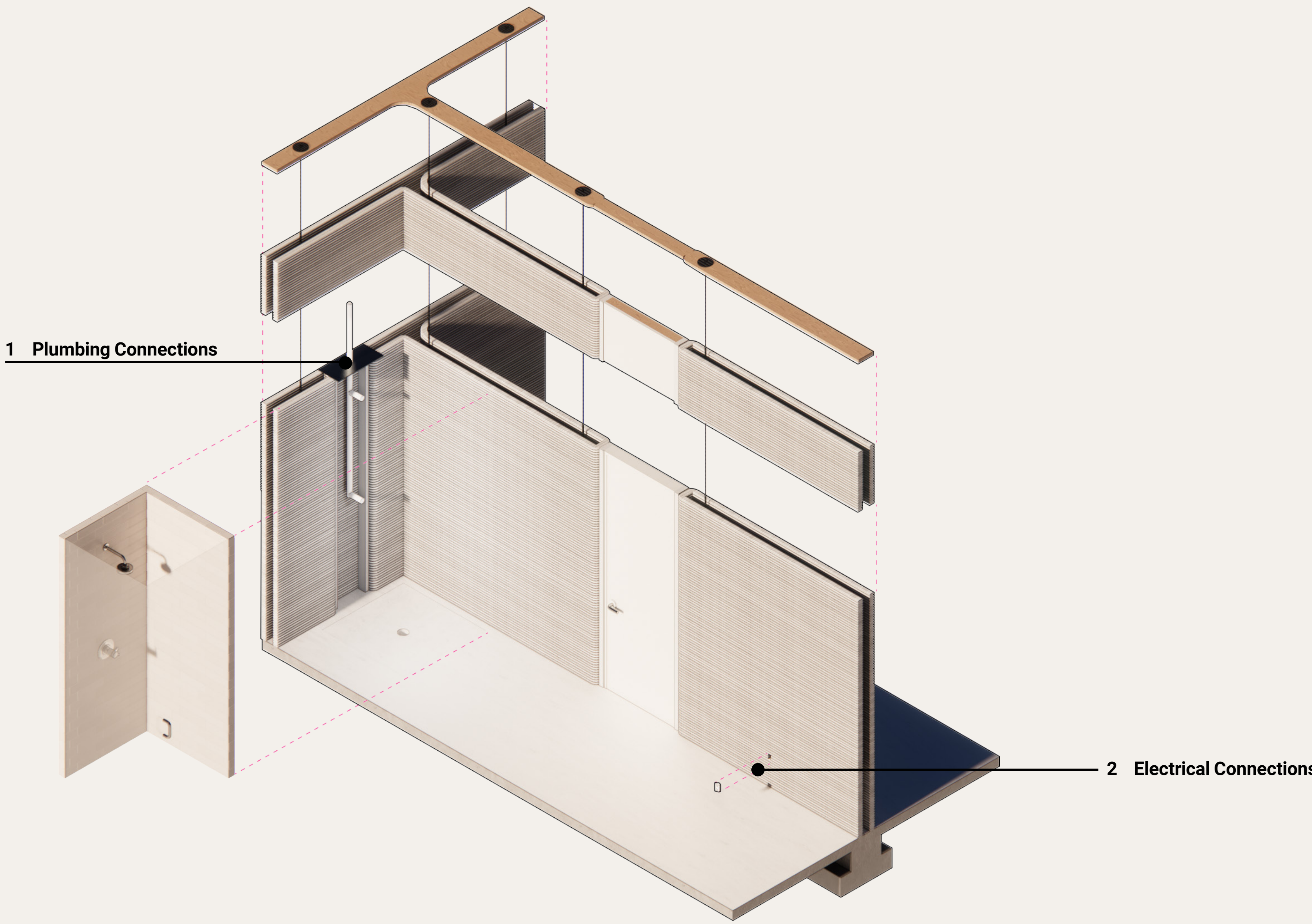
④ **Horizontal Reinforcement.**
Horizontal reinforcement located within the print provides capacity to span between cores and provides shrinkage cracking mitigation.

⑤ **Wall Ties.**
Wall ties, or cross ties, are placed at intervals along the wall to tie the two shells together and transfer loads between the shells.

⑥ **Insulation.**
The open cell spray foam insulation within the wall cavity does is not taken into consideration in the structural design of the wall system and only provides the thermal performance of the wall.

TYPICAL WALL ASSEMBLIES & SPECIFICATION

Typical Interior Wall and MEP Integrations

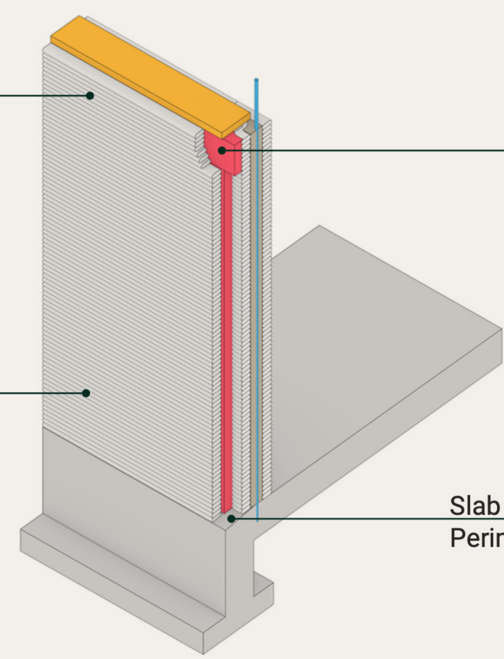


① **Accessible Plumbing Connections**
Plumbing fittings are exposed behind removable finishes – they are not buried within printed walls.

② **Electrical concealed within the Wall**
Electrical is fed from above through the wall cavity to the receptacle.

WEATHERIZATION AND THERMAL PERFORMANCE

Weatherization Overview



Term	Property
Class II Vapor Retarder	> 0.1 perm and ≤ 1.0 perm
Class III Vapor Retarder	> 1.0 perm and ≤ 10.0 perm

AIR BARRIER ASSESSMENT

The solid ICON wall assembly can be assumed to have very low leakage and no more than 0.04 cfm/ft2 at 75 Pa.

Similar to most wall systems, the greatest source of leakage will be at joints between dissimilar materials such as wood or metal. Care should be taken to detail sealing these joints to reduce air leakage.

Homes should perform a blower door test to confirm low leakage and seal any sources of leaks found prior to or as a result of the test.

Background:

IRC 2021 Chapter 11 defines an air barrier as one or more materials joined together in a continuous manner to restrict or prevent the passage of air through the building thermal envelope and its assemblies. Not specific criteria are provided as part of this section of the code.

ASHRAE Std. 90.1-2019 defines an air barrier (assembly) as a material with a maximum air leakage of 0.04 cfm/ft2 at a minimum of 75 Pa (table 5.8.3.1) notes below the table list cast-in-place and precast concrete as meeting this requirement. Note that ASHRAE Std.90.1 is applied to commercial construction through the IECC and IBC.

MOISTURE CONTROL

Lavacrete has a tested water vapor transmission of 1.47 perm and is considered a Class III Vapor Retarder per ASTM E96 Method A

WEATHERIZATION AND THERMAL PERFORMANCE

Water Penetration Management

The ICON wall system utilizes a barrier wall approach to weatherization and bulk water management. ICON has completed several field tests in accordance with ASTM E1105 and a modified ASTM E1105 test for prolonged exposure and no water passed through the wall construction itself from the exterior to the interior.

Careful water management is required around penetrations for window and door openings.

All window and door openings need to be carefully detailed to provide continuous flashing from the exterior bead face to the window jam and allow for drainage at the sill.

As with any wall system, overhangs to prevent the top of the wall from coming in direct contact with rain are recommended.

BEADS COATINGS

Coatings such as block filler and paint are typically required to provide an additional layer of protection against bulk water penetration, conceal flashing and weatherization details. Use of uncoated beads are discussed and addressed on a case by case basis.

Based on field test results during an ASTM E1105 block filler and paint coatings eliminated the capillary action that occurs on uncoated beads.

WEATHERIZATION AND THERMAL PERFORMANCE

Wall Thermal Performance

The ICON wall system falls under the classification of a mass wall under both IECC and ASHRAE Std. 90.1.

A number of factors influence the overall thermal conductivity of the wall, including the depth of the wall cavity, core spacing, window and door detailing and structural configurations.

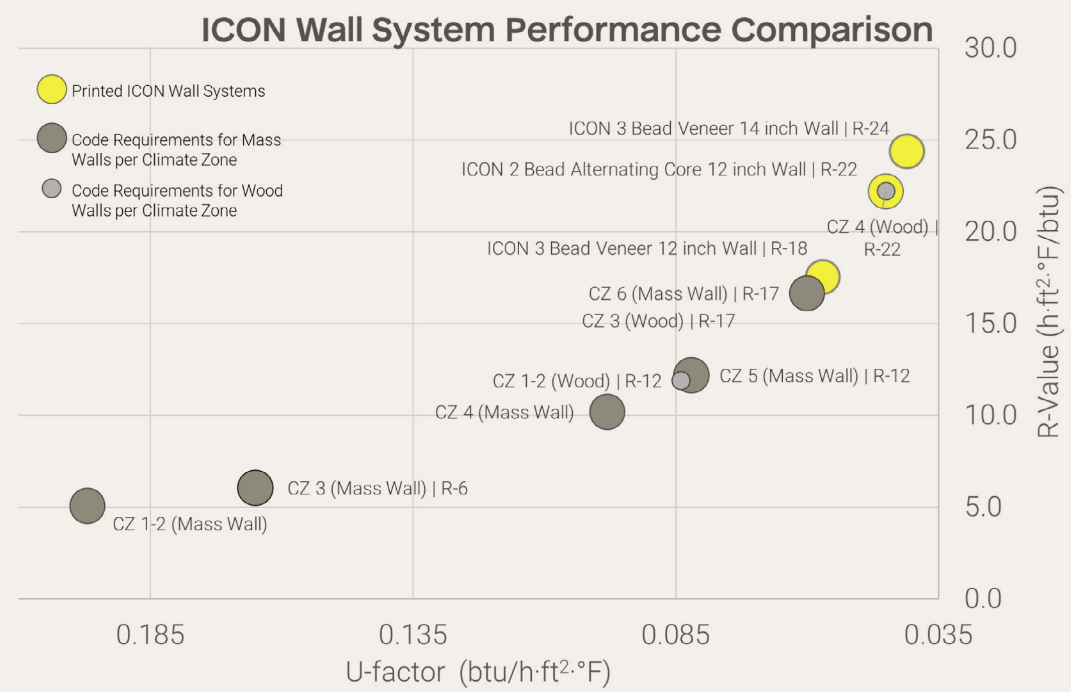
The thermal performance of the ICON wall system is determined using an analytical approach utilizing Heat2. Heat2 is a two-dimensional transient and steady-state heat transfer program that is validated against standard EN ISO 10211 and EN ISO 10077-2 . Similar analysis has also been carried out using Lawrence Berkeley National Laboratory (LBNL) THERM Finite Element Simulator with similar results. Heat2 provides superior analysis capabilities and user interface for more detailed analysis of the wall sections beyond thermal conductivity and is used as the ICON standard for assembly analysis.

Thermal properties of the materials, including ICON's printing material, called Lavacrete, is based upon independent 3rd party studies or information provided by the manufacturer.

Managing Thermal Bridging

Lavacrete has a relatively high thermal conductivity compared to wood. As a result, care must be taken when detailing window and door details to prevent a thermal bridge of Lavacrete between the interior and exterior portions of the wall. Even at localized conditions, inserting 1/2 inch to 1 inch of EPS insulation provides benefit to prevent thermal bridging.

Bond beams without a thermal bread are to be avoided - top plates or bond beams with 1 inch of rigid insulation to provide a thermal break are generally required.



WEATHERIZATION AND THERMAL PERFORMANCE

Coatings and Finishes

Coatings and finishes on the interior and exterior wall surfaces are used to ensure the longevity and durability of the wall system.

Most residential projects apply a block filler with a top coat on the exterior walls improves bulk water management and reduces wicking of water along the beads. The block filler also helps bridge gaps and smooth out the finished surface of the wall.

Any coatings that are applied to the interior or exterior surfaces must be vapor permeable. Non-vapor permeable coatings such as latex are not to be used without ICON approval.

PREFERRED AND RECOMMENDED COATING BLOCK FILLER / PAINT SYSTEM:

APPLICATION	LOCATION	PRODUCT	INSTALLATION DIRECTIONS
Block Filler	Exterior + Interior	Sherwin Williams Loxon Block Surfacer LX01W200	Spray apply with backroll. Apply 1 coat at a rate of 16 mils wet.
Top Coat	Exterior	Sherwin Williams Loxon XP Waterproofing Masonry Coating - LX11W0051	Spray apply with backroll. Apply 1 coat at a rate of 16 mils wet, or 2 coats at a rate of 8 mils wet.
Top Coat	Interior	Sherwin Williams Painters Edge Plus Interior Latex - PE4500051	Spray apply with backroll as needed. Apply 2 coat at a rate of 4 mils wet per coat.

REGULATORY CERTIFICATIONS & COMPLIANCES

3-Bead Veneer Wall

Refer to ICC-ES ESR, following AC 509

For connection design, refer to anchor testing data

Approved for Seismic Design Categories A&B

Approved for Wind Zone 4, Missile Level B Impacts

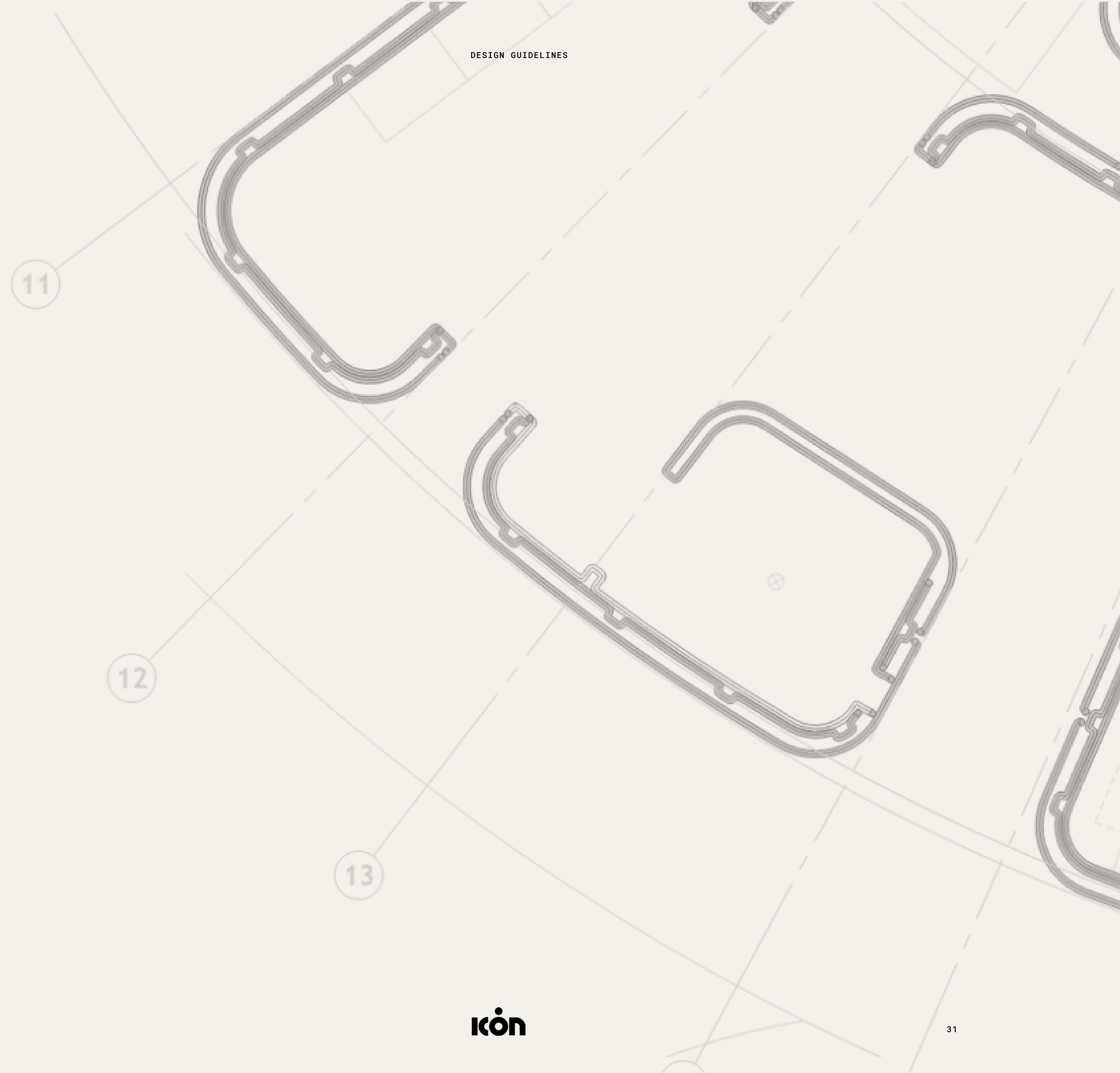
Ability to achieve Texas Windstorm and FORTIFIED Gold Projects

2-Bead Alternating Core Wall

Refer to ICON Design Guidelines, verified by testing

Pending testing for high wind zones
(needed for Texas Windstorm and FORTIFIED)

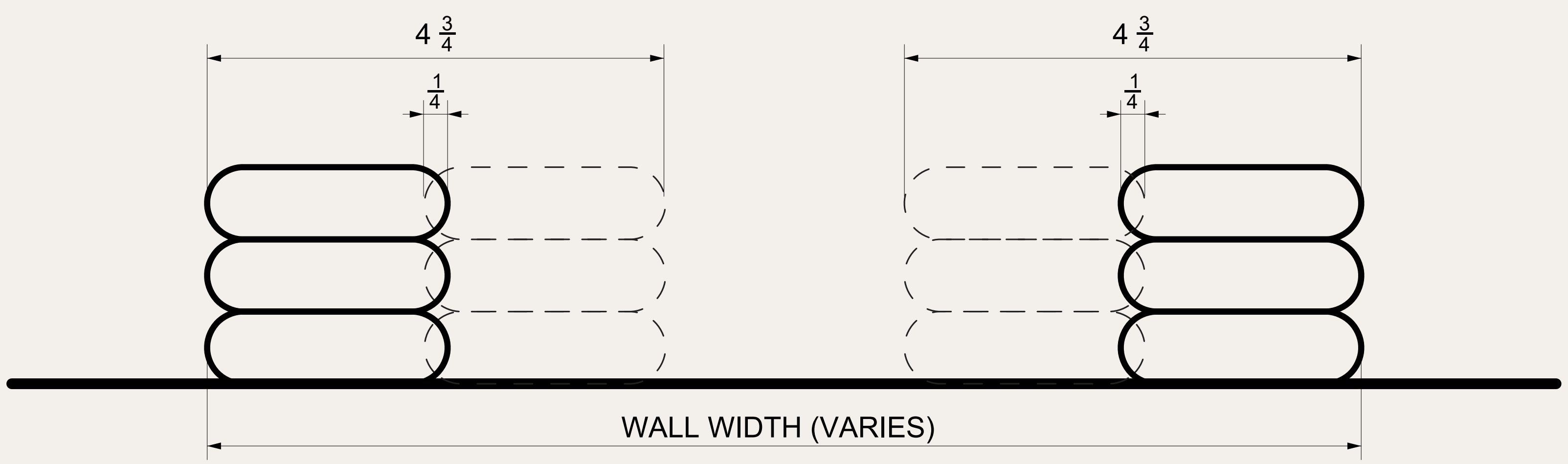
Design Guidelines



GEOMETRICAL CONSTRAINTS

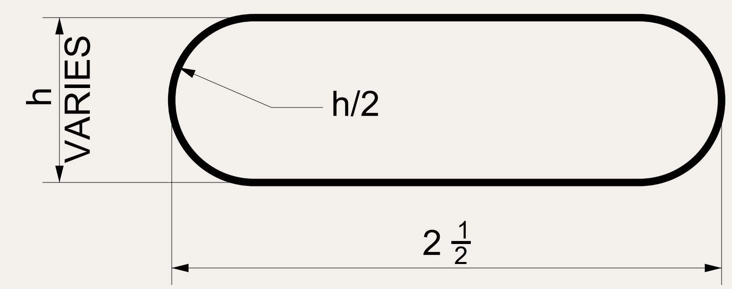
How to Draw Printed Beads

Section Cut of Through Multiple Beads



Single Bead Section Cut

The height of the beads varies depending on the print geometryand design requirements for a project. The typical values for bead height range from 0.55" up to 1.125"



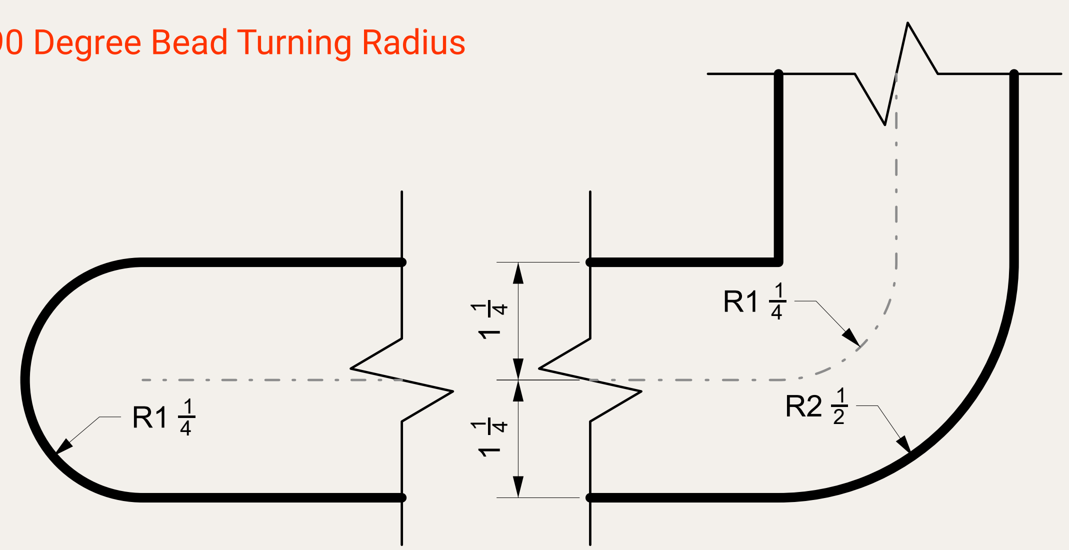
GEOMETRICAL CONSTRAINTS

How to Draw Printed Beads

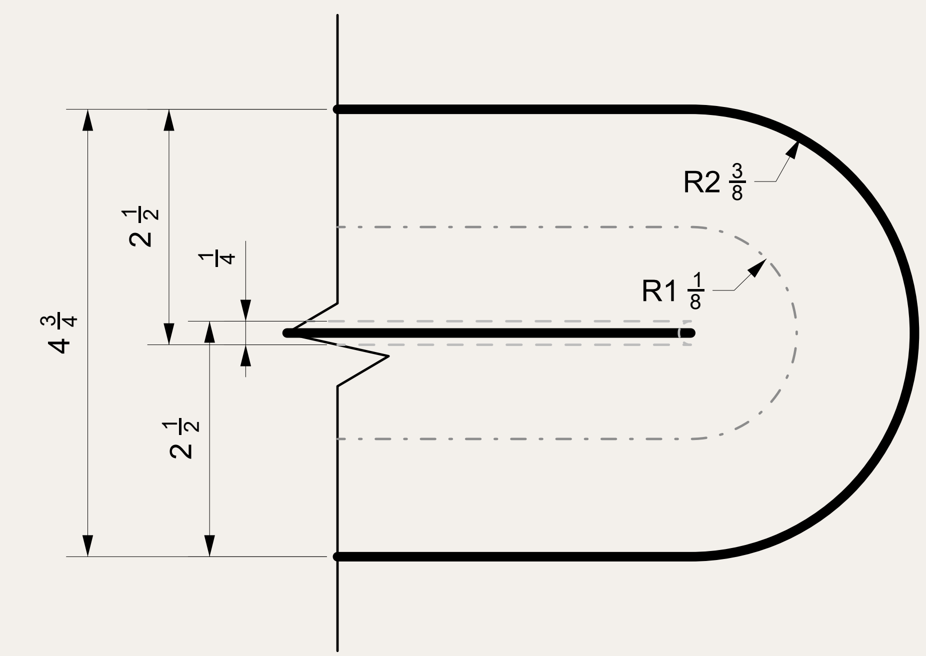
Due to the shape and dimensions of printed beads, sharp corners are possible only on the interior side of a bead.

At the exterior side of a turn, the minimum radius is equivalent to the bead width, in this case 2.5in. The centerline of the bead has a radius that is half the bead width, or 1.25in

90 Degree Bead Turning Radius



180 Degree Bead Turning Radius



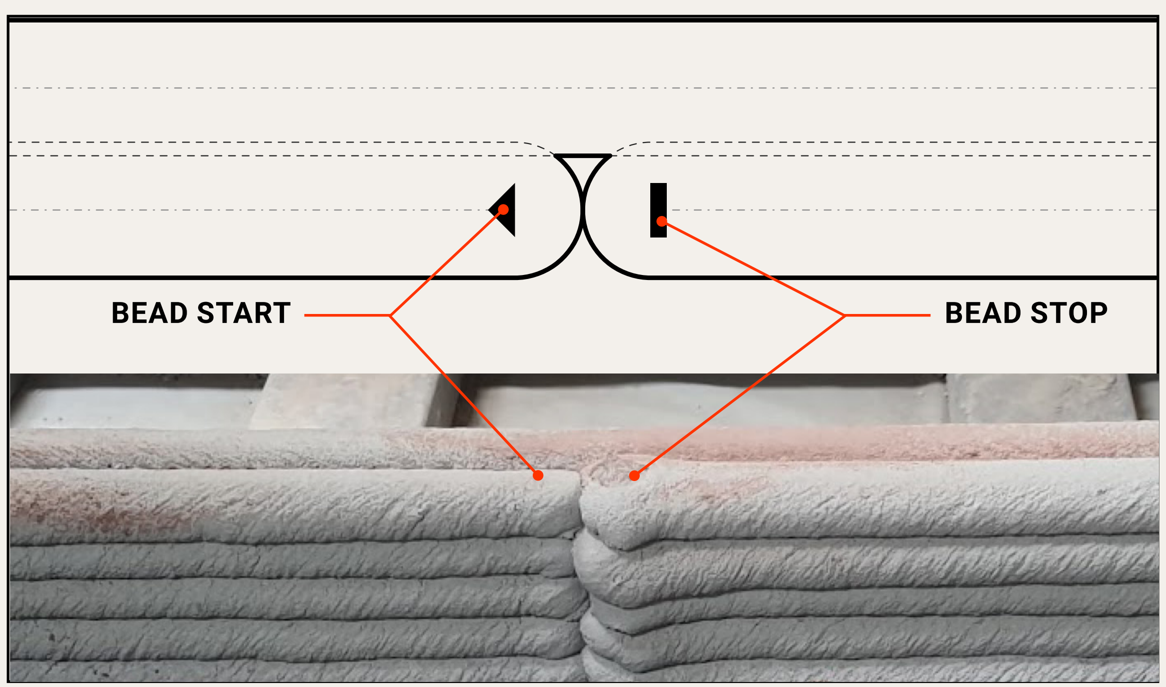
GEOMETRICAL CONSTRAINTS

Start and Stop of Print Path

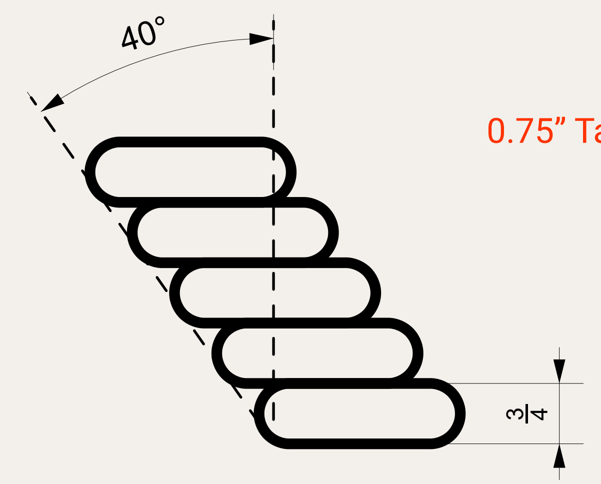
Every print path has a “start” and “end” point with distinct features in the physical print.

• Start points are typically narrower, and less consistent.

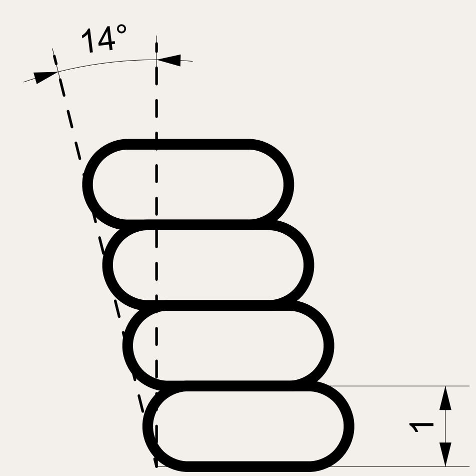
• End points are wider, but more consistent.



Maximum Loft Angles



0.75” Tall Beads



1” Tall Beads

SITE PREPARATION & PLANNING

Vulcan and Magma on Site

Vulcan works in tandem with Magma, ICON's material delivery system.

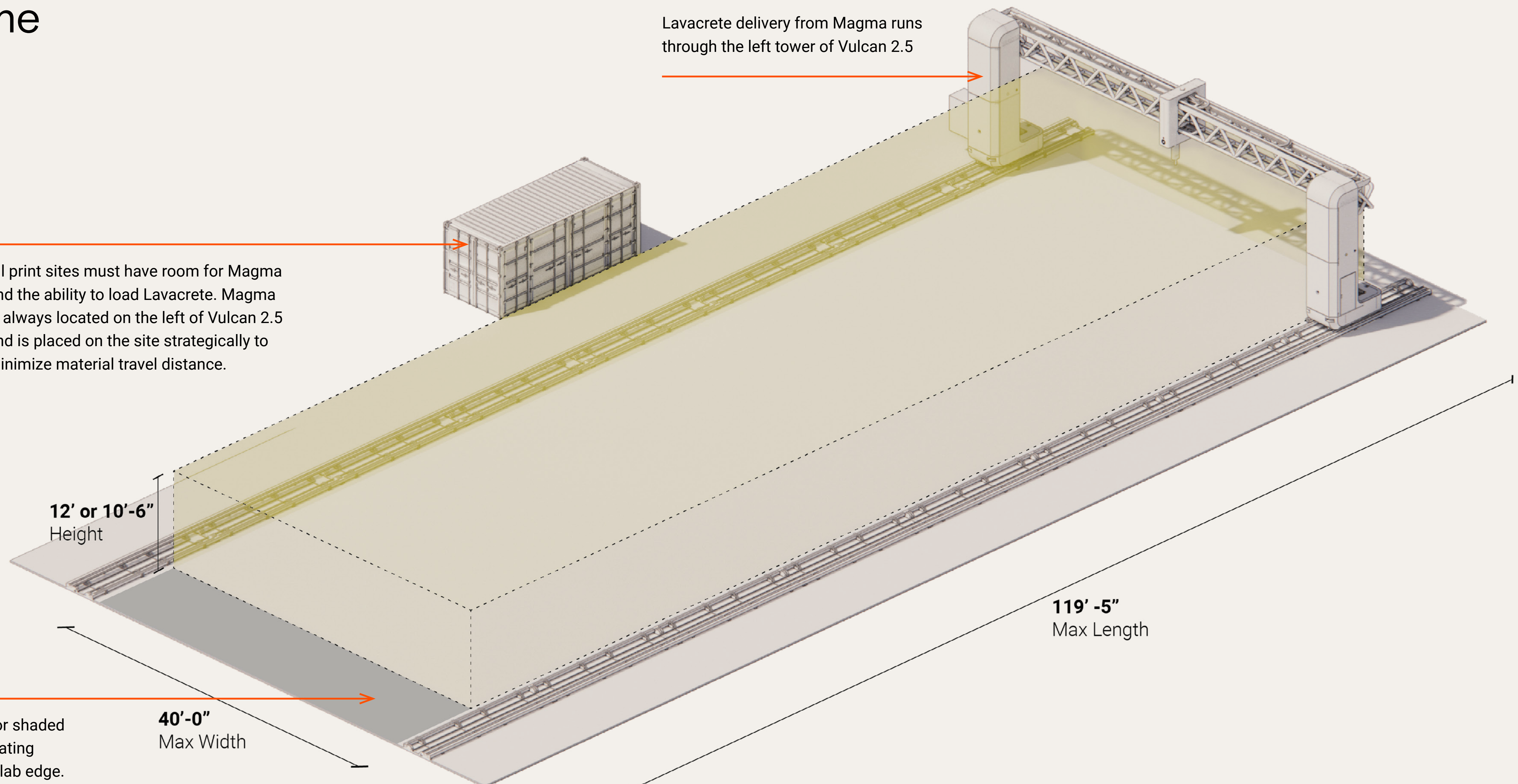
Magma receives dry and wet components of Lavacrete, ICON's proprietary printing material, and extrudes printable material, at a maximum throughput of 2 cubic yards per hour. This roughly translates to 3000 linear feet of beads per hour.

SITE PREPARATION & PLANNING

Vulcan 2.5
Build Volume

Lavacrete delivery from Magma runs through the left tower of Vulcan 2.5

All print sites must have room for Magma and the ability to load Lavacrete. Magma is always located on the left of Vulcan 2.5 and is placed on the site strategically to minimize material travel distance.



Provide space on site for shaded zone. It is used for operating Vulcan and accessing slab edge.

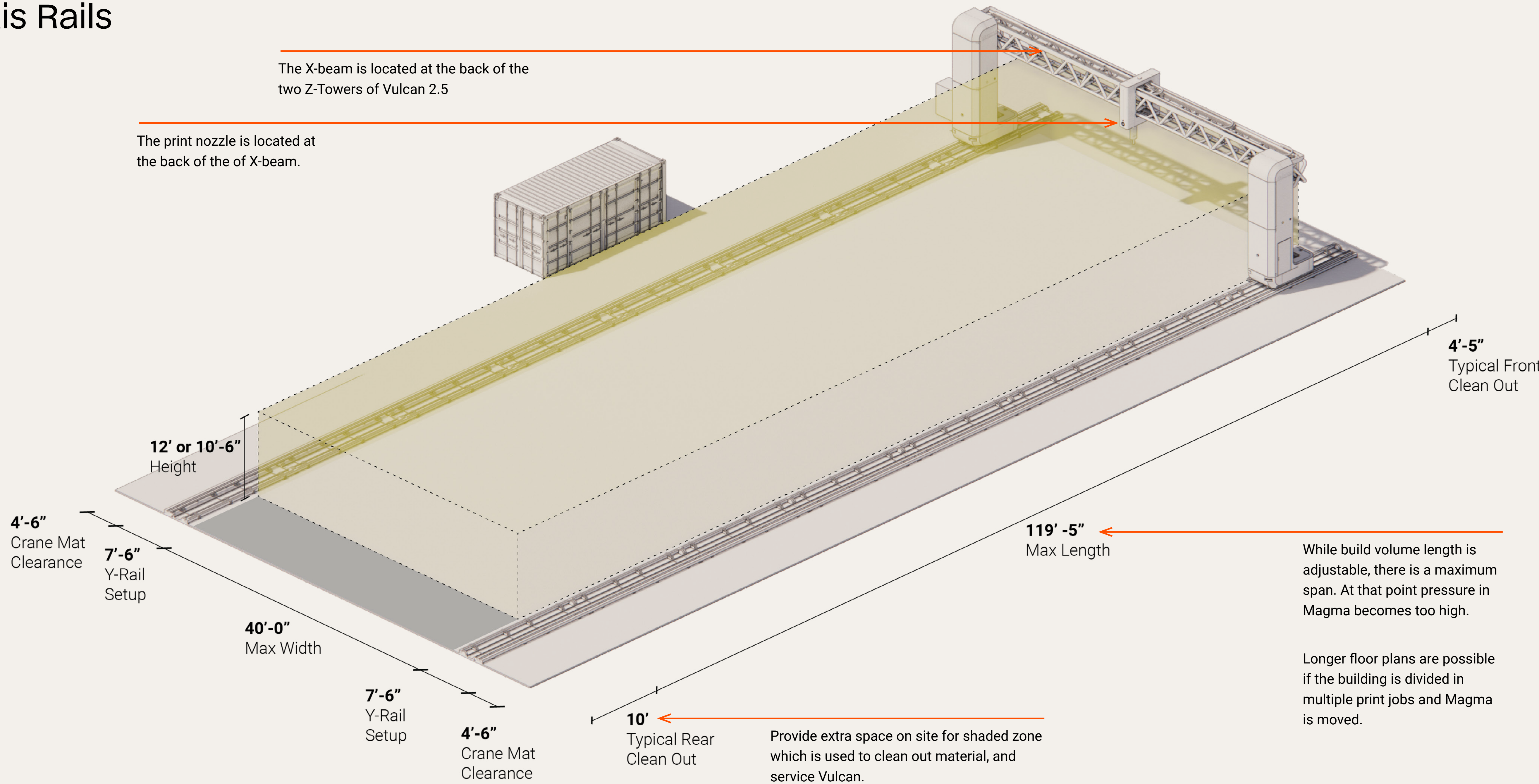
Material staging and job site logistics should be coordinated with ICON early on to ensure optimal site setup, minimize job site material deliveries and ensure continuous printing, all of which contribute to efficient printing.

SITE PREPARATION & PLANNING

Vulcan 2.5
Y-Axis Rails

The X-beam is located at the back of the two Z-Towers of Vulcan 2.5

The print nozzle is located at the back of the of X-beam.



Provide extra space on site for shaded zone which is used to clean out material, and service Vulcan.

While build volume length is adjustable, there is a maximum span. At that point pressure in Magma becomes too high.

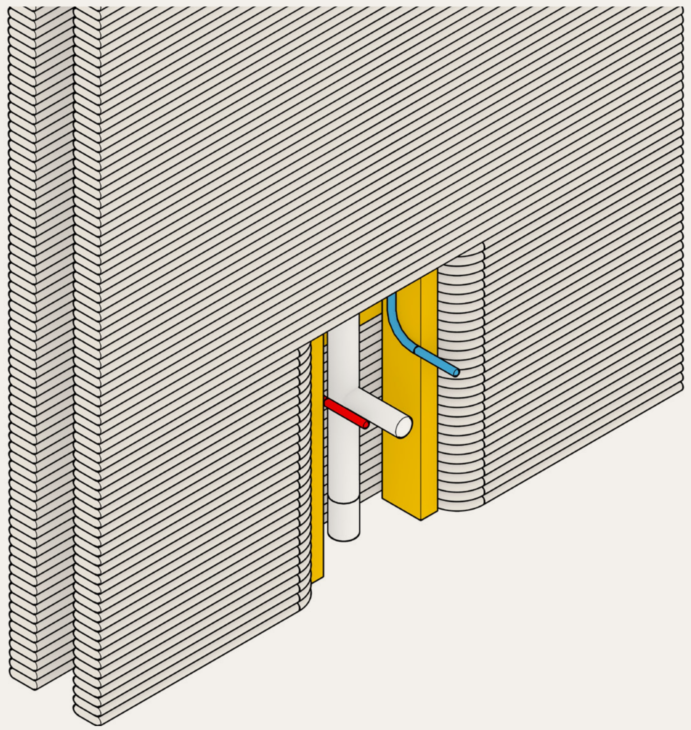
Longer floor plans are possible if the building is divided in multiple print jobs and Magma is moved.

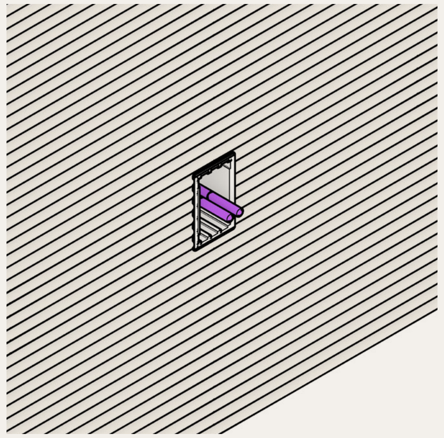
MEP DESIGN INSTALLATION GUIDELINES

Wall Penetrations

Printed Openings

Large rectangular openings created by modifying the print path, typically used for fixture connections



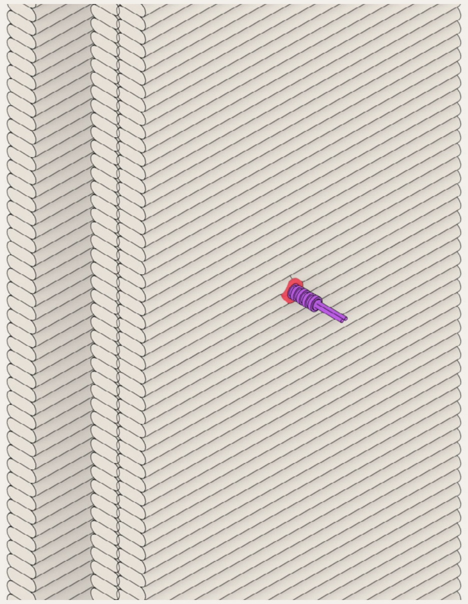


Wet Cut Openings

Small rectangular openings created by cutting the beads during the print, typically used for electrical boxes

Core Drilled & Saw Cut Openings

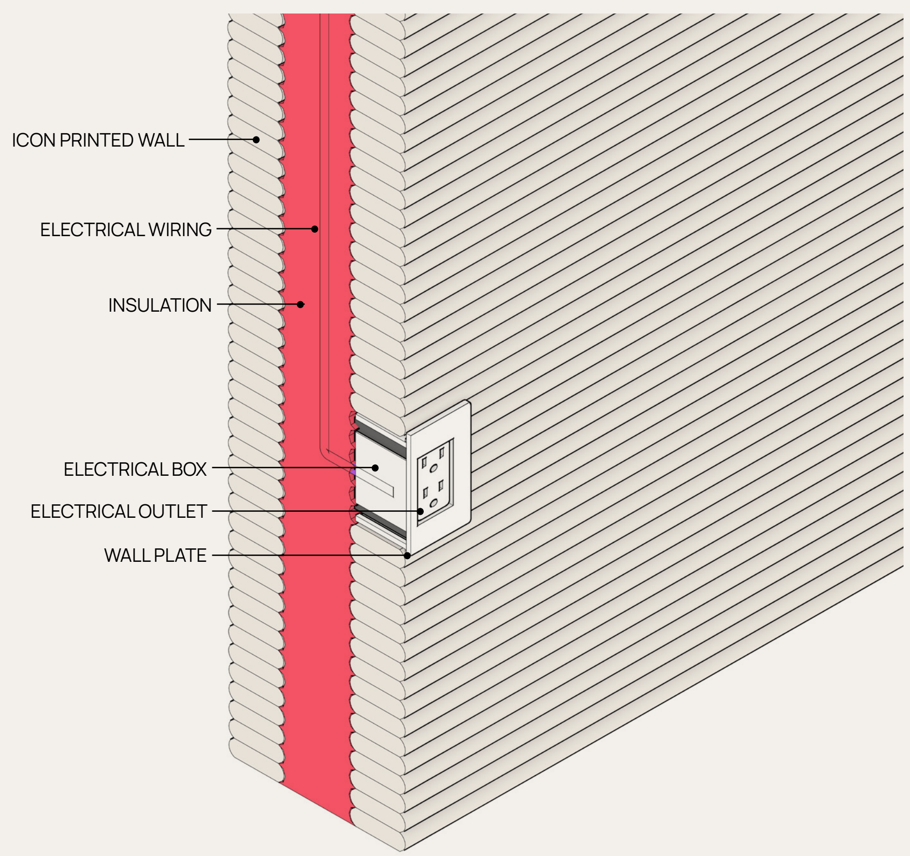
Circular or rectangular openings created by cutting the beads after the print is dry, typically used for low voltage fixtures & toilet water supply lines



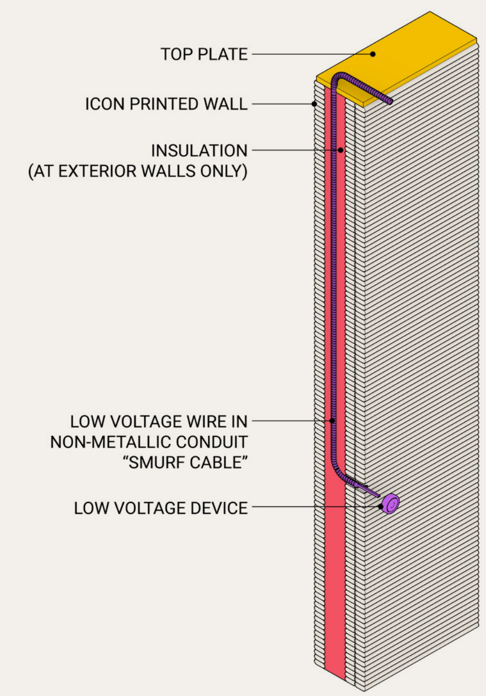
MEP DESIGN INSTALLATION GUIDELINES

Electrical and Low Voltage Installation Overview

Typical Receptacle & Wall Switch



Low Voltage Devices



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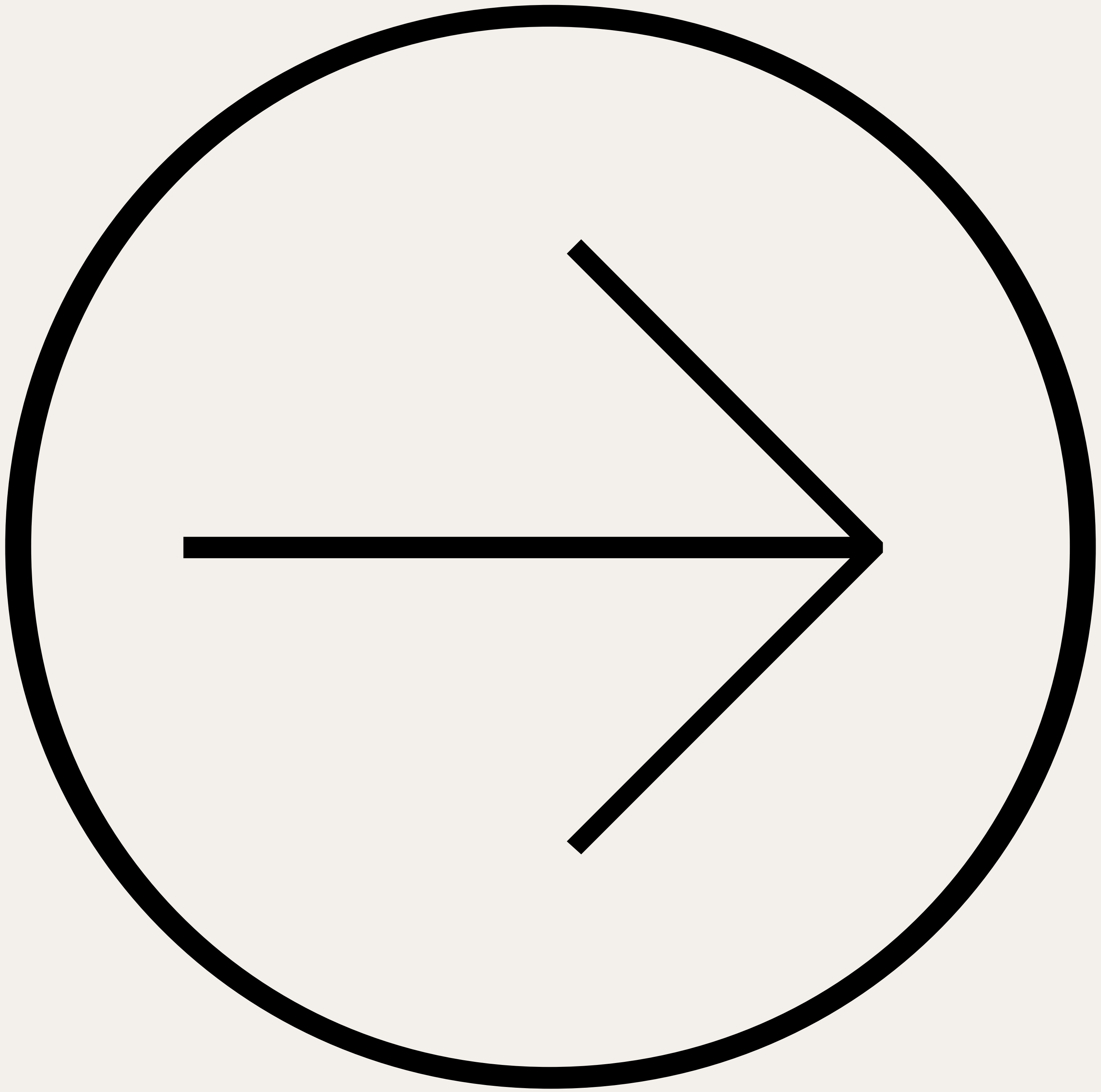
Project Profiles



AUSTIN, TEXAS

House Zero

House Zero is a 2,000+ sq-ft, 3 bedroom/2.5 bath home with a 350 sq-ft, 1 bedroom/ 1 bath accessory dwelling unit, featuring ICON's resilient 3D-printed wall system, which replaces a building system traditionally made up of multiple steps saving time, waste and cost.

Since its unveiling, House Zero has won multiple awards in the architecture and design communities, including being named one of TIME's Best Inventions of 2022, Builder Magazine's Project of the Year for the 2022 Builder's Choice Design Awards, an Innovation By Design award from Fast Company, a Texas Society of Architects TxA Design Award and two (2) Architizer A+ Awards.

Architect of Record: Lake Flato Architects
Engineer of Record: GNA
Date Completed: February, 2022

AUSTIN, TEXAS

East 17th Street

This multi-home mainstream housing development in East Austin leveraged ICON's proprietary 3D printing technology to construct more resilient homes to meet the current demand in one of the hottest real estate markets in the U.S.

This collection of four unique homes, ranging in size from 900 sqft. to 2,000 sqft., offer 2 and 4 bedroom configurations that are designed to be stronger and longer-lasting than traditionally built homes.

Architect of Record: Logan Architecture
Engineer of Record: Fort Structures
Date Completed:

BARRACKS

Camp Swift

In 2021, the Texas Military Department (TMD) partnered with ICON to design and 3D print an innovative, energy-efficient training barracks at the Camp Swift Training Center in Bastrop, Texas.

At the time, it was the largest 3D-printed structure in North America. Additional barracks by ICON for the United States Army have since claimed that title.

Architect of Record: Logan Architecture
Engineer of Record: Fort Structures
Date Completed:

GEORGETOWN, TX

Genesis Collection at Wolf Ranch

Built by Lennar, one of the nation's leading homebuilders and ICON, and codesigned by BIG-Bjarke Ingels Group, the innovative community features eight floorplans, 24 elevations and each home equipped with rooftop solar panels.

Nestled in the Texas Hill Country the Wolf Ranch community of high-performance homes are inherently strong, resilient and more energy-efficient.

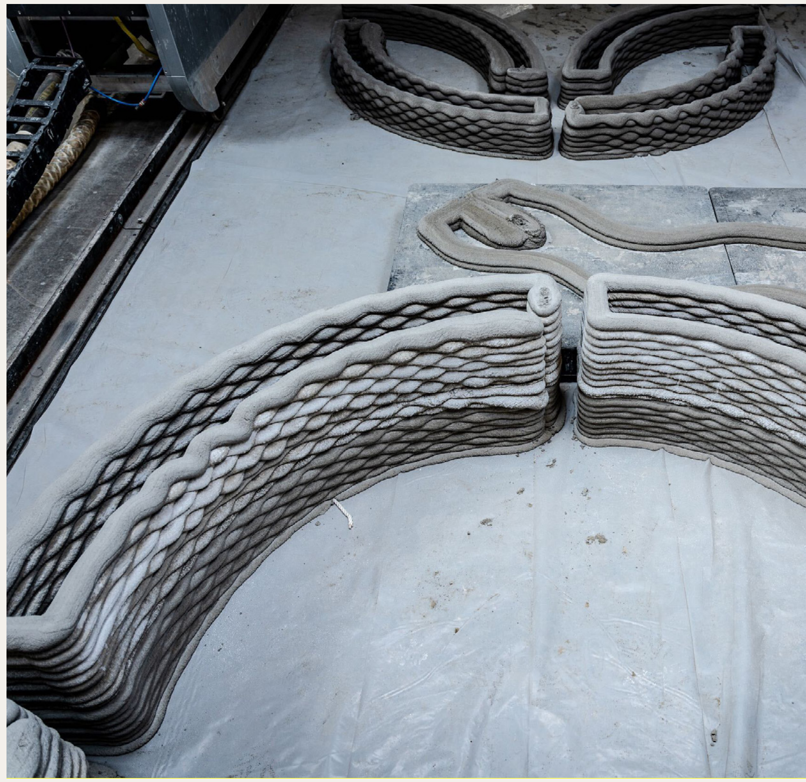
Design Architect: Bjarke Ingels Group
Architect of Record: Midtown Architects
Engineer of Record: Fort Structures
Date Completed:

GEORGETOWN, TX

Advanced Geometries

The flexibility of 3D printing allows for the creation of unprecedented geometry with little impact on time needed for production. The AWG Program aims to leverage that potential and investigate novel wall geometries such as wall texture, pattern and perforations.

Several projects at ICON already have feature walls incorporating trigonometric patterns, and Home Team is currently conducting a series of internal test prints to further expand our Advanced Wall Geometry design catalog.



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