

FIBONACCI SEQUENCE

First 3D Printed Home in Canada

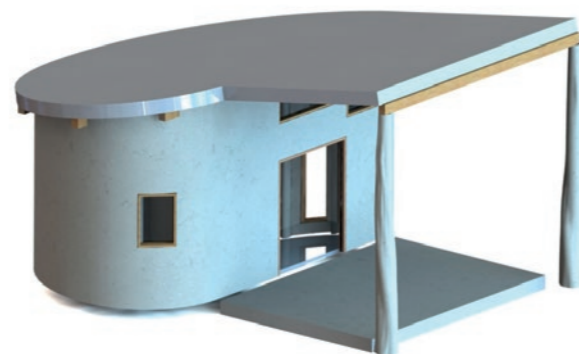
Twente Additive Manufacturing was founded in November of 2018 by Tim Brodesser, Jonathan Ladouceur, Adam Rumjahn, Jim Ziemiński and Ian Comishin. All of the founders are operationally involved on a daily basis. They set out to build a company from scratch with a few goals in mind. As strong believers in digital manufacturing they felt they could influence the architectural world by bringing more automation to the build site and the factories of construction element suppliers. Freeform design is loose term used by architects to describe elements that are comprised using arcs, curves and otherwise non-rectilinear shapes and surfaces. The conventional building processes used today often make freeform design cost-prohibitive to most housing projects. Buildings that have compound curves in their walls and landscape elements can be much more easily created with robust concrete 3D printing equipment. Until now, most cities and towns have been covered in generic rectangular buildings which Twente hopes to change to include more creative and expressive living spaces.



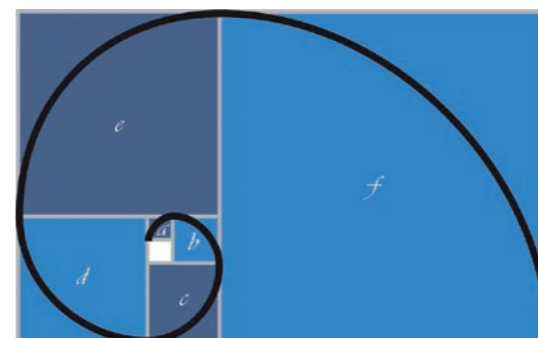
Photo: Ian Comishin

Jon Caften, Lac Siesta, Canada

More importantly though, they have the goal to influence the human consumption behaviours around home ownership in the current era; a time of an enormous amount of wastefulness. By using advanced concrete structures that consider home ergonomics and material optimization, they hope to eliminate the need for so much disposability. For example, a good house design will reduce the waste associated with cheap furniture and weaker building structures that need to be destroyed due to wearing and rotting.



Using a patio as the reference point and a ratio formula used as far back as 300BC, Twente designed a very challenging to build mini-home. Rendering: Tim Brodesser



Along each edge the square root follows $a+b=c$, $b+c=d$, $c+d=e$, $d+e=f$

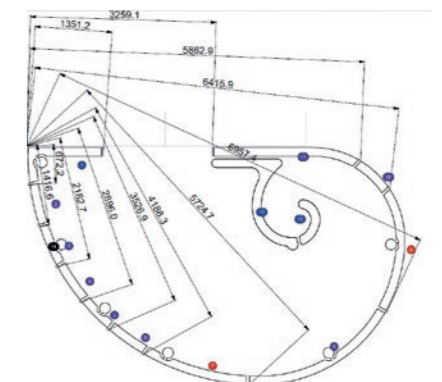




Photo: Jonathan Ladouceur

■ Ian and Jim discuss the positioning of the house to the patio slab.

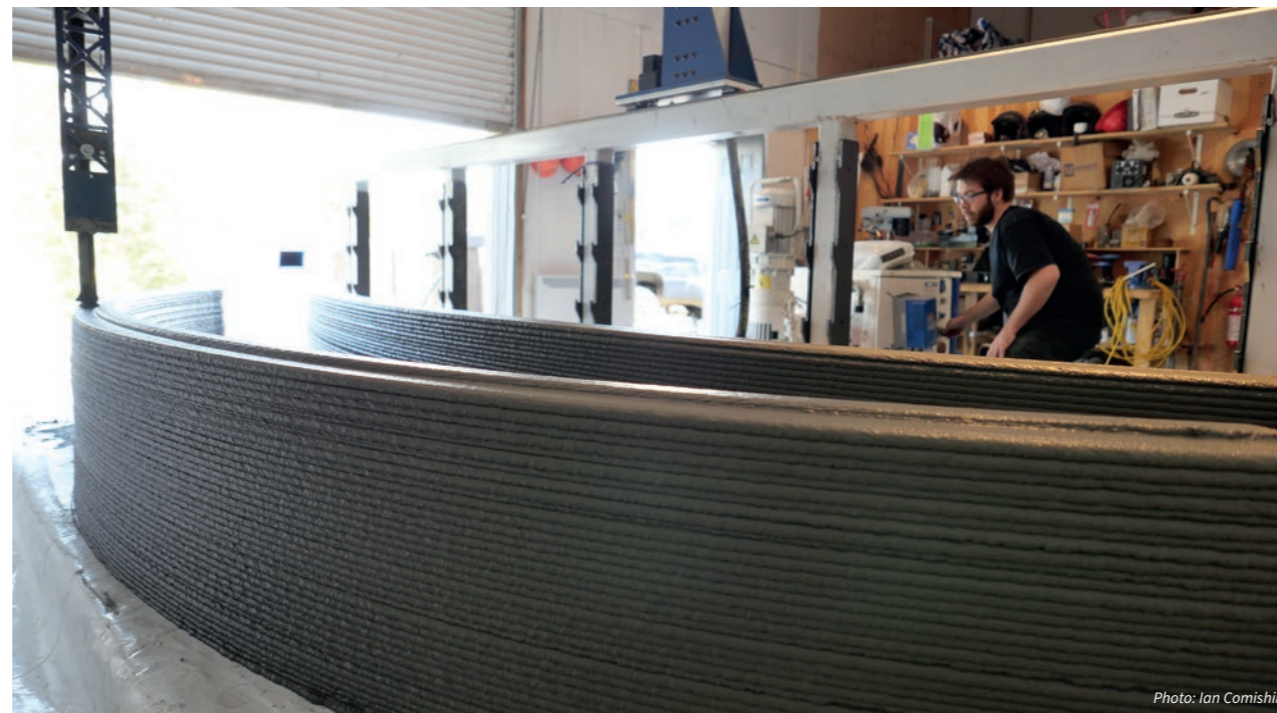


Photo: Ian Comishin

■ Jonathan inspects print quality of the footing moulds being produced on the Kebbekinator gantry printer.



Photo: Jonathan Ladouceur

■ With the footing moulds in place, Jim ties in the rebar after under-slab insulation was applied.

It is probably understandable that this seems a bit weird of vision for a company that has its core competences in industrial automation to be focused on design and infrastructure. In fact, it is not even really the goal of Twente to even be designing and creating all these futuristic homes and objects, but rather to develop and improve the 3D printing equipment and methods that will facilitate the truly imaginative architects to be able to have their dreams realized. Currently many companies in concrete industry are stuck in the past with respect to the processes that are used for creating buildings. Twente sees how the major cement brands and construction firms can adopt this technology to move their companies into the next era.

Until now Twente is a self-financed organization, so they had to set out with ambitious but still somewhat humble objectives. They chose to open 2 research and development facilities apart from their head office in Enschede Netherlands. The first printer was installed in Isny, Germany, which is basically the midpoint between Munich and Zurich. This printer is based on a 6-axis Kuka robot and an m-tec mortar pumping system. Very shortly afterwards they built a gantry printer in Montreal, Canada, based on conventional cartesian G-code movements. Their crown jewel however is the R&D machine they affectionately call the Doucinator named after their head of engineering Jonathan Ladouceur and the Bauminator system designed by Baunit from Austria. This machine uses the Baunit nozzle technology when Twente needs to print in 2K materials and self-developed nozzles for when they need to print with lower cost mortars. It also uses m-tec and Mai pumps depending on the type of mortar being used.

This machine is so big that it required its own specific building. In November of 2019 Twente completed the erection of their R&D facility in Nelson, Canada, which they built themselves using a conventional timber-frame structure. That will certainly be the last building they have ever built as a solely timber-framed assembly.

As soon as the snow melted, they undertook their first printed home which is the feature of this article. Rather than designing a home that would be simple to print, they chose to make life difficult on themselves to best trial and error what they know their customers will painfully endure as they adopt 3D printing into their own construction toolboxes. It was important to showcase the capabilities of 3D printing so they opted to use the famous mathematical formula known as the Fibonacci sequence. The structure coils away from a center point inevitably finishing as an asymmetric building with virtually no rectilinear walls. (Each 90° corner is the sum radius of the two previous 90° corner segments: $a+a=b$, $a+b=c$, $b+c=d$, ...)

To make matters even more difficult for themselves, they did not get to choose their dimensions from scratch but rather opted to use a derelict slab of concrete that was hastily poured in a random location. On the day they built the floor for the R&D facility, the cement truck they hired contained a surplus of material so they very hurriedly assembled an 'almost' rectangular mould; it was filled and troweled pretty much as an afterthought. This slab now serves as the patio entrance way for the Fibonacci house; it is fair to say that there are not many entire houses in this world that were designed specifically to fit an already existing patio slab. Twente seems to enjoy creating their own hardships.

The Fibonacci house is a modest structure with big ambition. It only uses a 29m² footprint however with elements up to 4m tall at the front of the home it easily capacitates two mezzanines that will serve as sleeping areas. The main motivation to build this home was born in the middle of the Covid-19 pandemic.

Twente was in the process of building a luxury home to showcase the potential of concrete 3D printing when the pandemic exploded and they switched directions. Their new project would be to showcase a living space that could be easily deployed at a low cost for the various governmental housing projects.

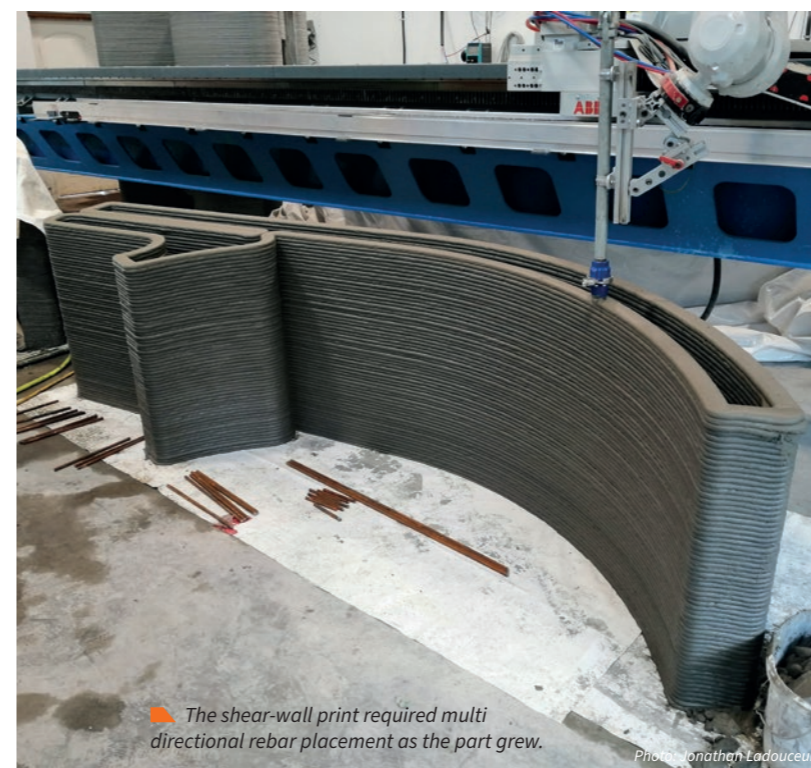


Photo: Jonathan Ladouceur

■ The shear-wall print required multi directional rebar placement as the part grew.



Photo: Jonathan Ladouceur

■ Unique to this project, walls built with angles were achieved through varying the concrete deposition height and line speed of the printer.



Photo: Jonathan Ladouceur

Parts were moved from the R&D facility to the site by means of crane truck which was used for final placement of the parts.

sing agencies currently rattled by the lack of isolation space for the low-income communities around the world. Twente gave themselves a materials budget of 10,000€ which meant they would have to scour recycling stations for second hand windows, doors and other ancillary components. These second hand items would create another set of design parameters that the team would have to adjust to. (All in, they have still kept it to under 12,000€). This pricing of course takes nothing into consideration for the labour that was performed 100% by the Twente team, including all plumbing, electrical, landscaping etc.)

For print materials they chose to work mostly with Connecticut-based Laticrete, who shipped out 1.2 tonne super-sacks of their M68 printing mortar to Twente's Nelson R&D facility. The decorative columns supporting the patio cover are printed using Baunit's 230 printcrete. The roof structure is a wooden beam and rafter design cut by CNC at Spearhead Timberworks, one of the world's most renowned digital manufacturers of timber-frame homes. The engineering drawings were assembled by Effistruc who helped Twente to navigate the local building code for the region where the Fibonacci house was built. In order to receive their building



Photo: Jonathan Ladouceur

As the walls started to come together the Twente team found that positioning became quite difficult without access to laser scanning equipment.



Photo: Tim Brodesser

Aerial view of the Fibonacci house in its final assembly before the roof structure and patio columns installed.



Photo: Tim Brodesser

Painstaking boulder placement continues the Fibonacci geometry in the landscaping.



permit, Twente had to incorporate infill areas that will serve as columns and a shear-wall that has conventionally poured concrete and rebar. The compressive strength of the walls themselves were not taking into consideration to complete the structural calculations as currently they are no accepted standards on the books as to how printed mortar performs. This is however the first 3D printed home in Canada and it is a fully permitted structure.

The footing forms are also the slab form as they chose to use a monolith pour. The footing shapes are single bead moulds that were printed on their gantry printer while the rest of the elements came off of their 9-axis robotic printer. The walls, columns and footing moulds were not printed in-situ, but rather as prefab elements that needed to be craned onto a flat-deck and then positioned to their final location. The majority of the printing was done in only a few days however they took pause to allow the parts to full cure before putting them on a crane truck and moving them to the site.

The walls were created using a strategy that included an inner wall and an exterior wall joined by small sections of rebar. The ends of the walls were also printed but then cut away once the parts were at the installation position. This is essential in Canada where there is a massive temperature fluctuation that makes insulating much more difficult if the solid concrete joiners would be left in place to act as a thermal bridge between the indoors and the outdoors. The walls are then filled with expansion foam.

They decided to keep the max height of their prints to 2.1m for ease of manipulation with the crane equipment available to them. For some parts it made the most sense to print 3 or 4 of them together and then cut them apart to maximize the build volume in the printer as many nested parts take up much less space than if they were printed to their actual footprint position. This is one of the advantages of pre-fab printing. Additionally, the larger the volume of material needed, the faster the vertical build rate they can use.



A very unique process was used by Twente that they are not certain has been achieved by anyone else before now in order to create angular walls. They varied the print nozzle angle and line speed to be able to make the bead dimensions change in the Z (vertical) but not in the XY (horizontal). By doing so, they could make parts that were taller on one end than the other side and parts that had lower sections in the middle. This has been already achieved of course by companies such as Incremental3d from Austria using a 2-component mixer at the nozzle level, but this may be the first time that it has been performed industry wide using a single component dry-mix. Twente claims they had several collapsing parts while trying to get this right.

In retrospect, the Twente team has certainly learned a lot by intentionally making things so difficult for themselves. Registration is very difficult without rectilinear elements and placing two tonne parts to a resolution of $\pm 3\text{mm}$ requires a steady hand on the crane controls. To add to their anxiety, they

even chose to print some elements of the Fibonacci house as a live demonstration during the recent Digital Concrete 2020 conference held by TU/Eindhoven and Rilem. Anxious not just because it was live, but because they had to wake up at 3:00 in the morning to do their demonstrations considering the 9-hour time zone difference.

The biggest takeaway for them from the Fibonacci experience is their newfound knowledge of how to design a house specifically for being printed in concrete. They will be able to advise architects and construction firms on the pitfalls such a project can entail and of course, their new knowledge will give them the insights they wanted to further develop and advance their already incredibly sophisticated 3D printing equipment.



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