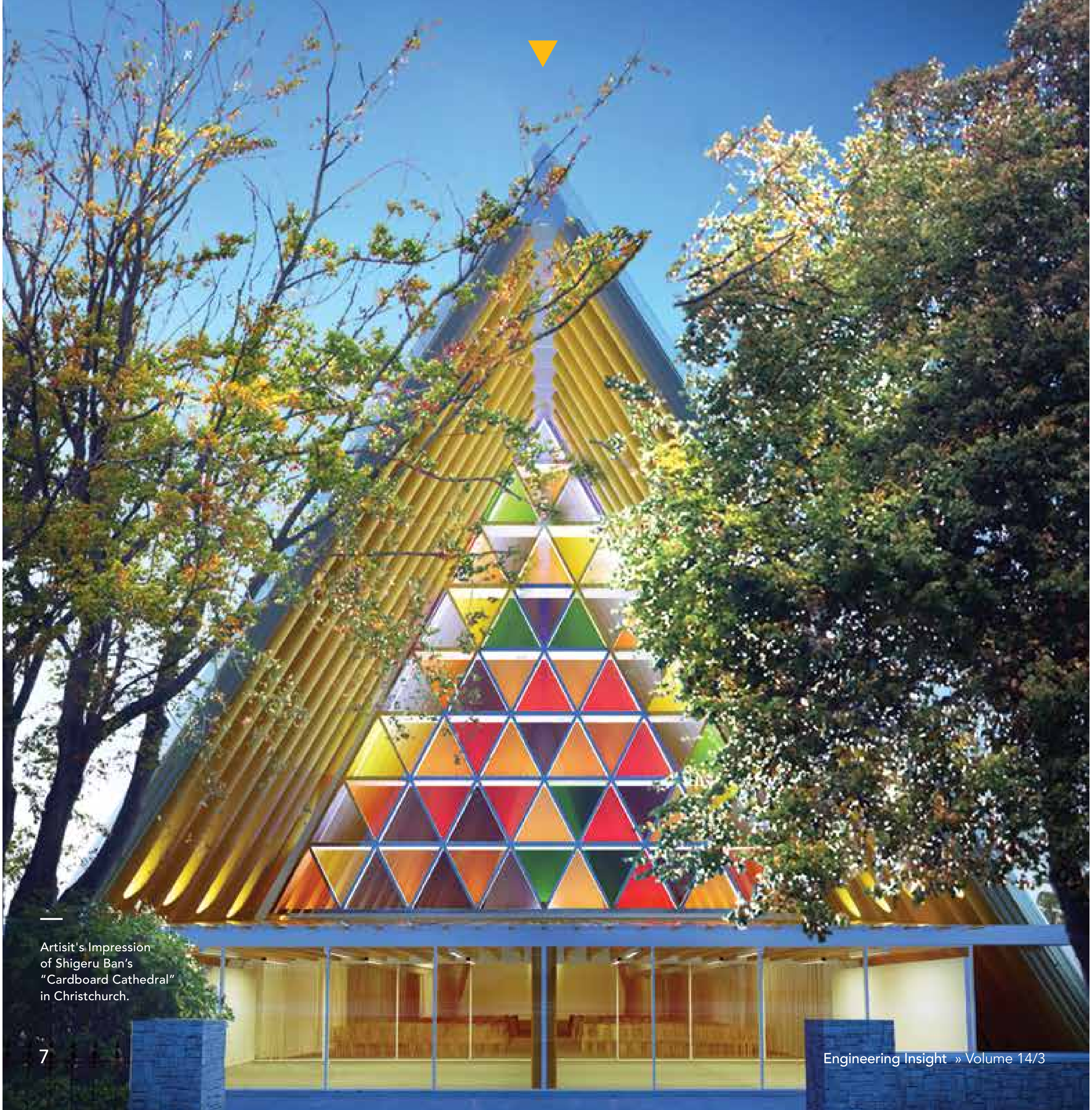
Extraordinary Structure

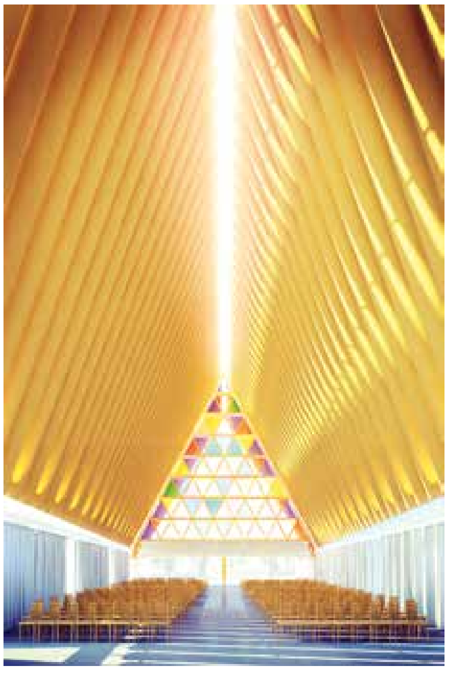
Writer Matt Philp

Christchurch's Transitional Cathedral is set to become an icon of the city's post-earthquake rebuild – a symbol of hope for the city and region.



Artisit's Impression of Shigeru Ban's "Cardboard Cathedral" in Christchurch.

Right: Artist's impression of the finished Christchurch's Transitional Cathedral.



If you looked at it purely on paper – no pun intended – Christchurch's so-called "Cardboard Cathedral" stands out for its novelty value and economy. A six-storey, 36-metre-long place of worship built out of cardboard ticks those boxes. But once it is completed, this extraordinary structure in Latimer Square is going to be something else entirely – a uniquely beautiful building.

Picture a towering A-framed nave formed from more than 90 mammoth cardboard tubes, all of them 600 millimetres in diameter and the largest 20 metres in length. Above the entrance is a vast window comprised of interlocking triangles of coloured glass. The entire edifice is encased in opaque polycarbonate so light pours into the nave between the steeply pitched tubes. Seen at night, the building appears to glow.

The brainchild of Japanese architect Shigeru Ban, the building was conceived in response to the damage wrought on ChristChurch Cathedral by the 2011 February quake. Initially intended to have a lifespan of 10 years, it has since been reconceived as a permanent structure, with a design life of 50 years. It is a "transitional" cathedral now only in the sense that it serves as the seat of the Bishop until something else is built at Cathedral Square. Given the architect's fame for using cardboard tubing, the choice of material for Christchurch was never in doubt, The Reverend Craig Dixon, who is the Marketing and Development Manager for the Transitional Cathedral, says. "But we didn't really have any idea of the scale until recently when the tubes went up at Latimer Square – particularly that six-storey back wall. It is very impressive."

Why the change of tack, from temporary to permanent structure? Several reasons, according to the Rev Dixon. New earthquake strengthening regulations meant whatever was built needed to be designed to last. Furthermore, the new Cathedral is intended to serve not only the ChristChurch congregation but also that of St John's parish, whose church at Latimer Square was destroyed by the February 2011 quake. When the former congregation returns to Cathedral Square, the cardboard structure will be handed over to St John's.

Reinventing the building as a permanent structure has necessitated many changes to the original design.

"As you go from a temporary to permanent structure there are changed requirements in terms of the Building Code," Project Manager, Johnny McFarlane, says. "There are qualitative changes like structural design events, warranty requirements, use of temporary materials for a permanent structure and a whole range of design elements that change. And there have been quantitative changes, particularly to the foundation, structure and change in operational needs for the proposed uses.

"The original design had larger cardboard cores and timber trusses – however the cores couldn't be manufactured locally. The new design required smaller diameter cores, and while they aren't structural they are very beautiful and unique elements that create the whole look and feel of the nave."

In essence, the new Cathedral is a portal design held together by steel and timber laminated veneer lumber (LVL) rafters. At the base are several steel shipping containers – which are so familiar to the people of Christchurch. The cardboard cores are supported internally by LVL rafters, which connect the containers' structural steel to the main ridge beam and provide the basic structure. "The load is transferred through

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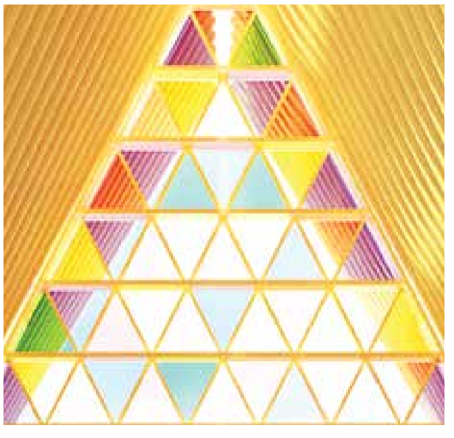

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structural steel to the foundation rather than through the containers themselves."

The foundation is a kind of reinforced concrete raft, 900-millimetres thick and designed to be self-supporting over a five-square-metre area in the event of liquefaction. In common with all new buildings, the Transitional Cathedral is being built to 100 per cent of the Building Code.

At first glance, you couldn't get two more radically different buildings than Christchurch's much loved neo-Gothic stone cathedral and its A-frame cardboard replacement. Yet the new building's footprint is based on the original ratio, right down to the floor plan and nave height.

It's that deceptively simple shape that makes this building such an engineering challenge, according to Mr McFarlane.

"Shigeru's wish to respect the ChristChurch Cathedral dimensions resulted in a trapezoidal floor plan, and a ridge beam which rises five metres over the length of the building from the entry to the altar. This creates a flared shape to the building. At the altar, the rafters are at about 70 degrees but they change by about half a degree each rafter all the way down to about 50 degrees at the front of the Cathedral.

"Every connection point on that ridge is slightly different and each pair of bracing elements, steel connections, rafters and purlins connects at different angles – 3D modelling was used to confirm the building dimensions and every one of those connection points. When putting on the roof you also have to match that twist and flare. So while it is a simple form in terms of layout, it's taken a remarkable amount of complex design management to deliver that simplicity and meet the architectural vision."

Key to that vision, of course, is the cardboard. Mr McFarlane remarks that the use of the material in Christchurch is not only a New Zealand first but that "Shigeru has previously used cardboard cores in vertical scenarios and lattice structures – however, nothing angled on a scale like this."

Where do you start with a new material?

"This material required a 'first principles' approach to material selection. For GIB Board you can get a warranty. For the polycarbonate roof on this building we could get a warranty. But cardboard cores are not products designed as building materials. So we led the client through a risk-based approach. We identified the potential risks in manufacturing cardboard cores and worked out how to mitigate them. Fire was one risk, but there was also moisture ingress, meeting the required architectural finish and maintenance requirements to consider."

The cores, manufactured locally using high density paper for added strength, have a polyethylene internal liner and are wound spirally so the paper overlaps to shed water. As added insurance, the cardboard was given three coats of polyurethane, with painting done by some 70 volunteers ranging from the Student Volunteer Army to aged retirees.

"It was a risk based-slash-best practice-slash-alternative solutions approach we took, to get some confidence in the ability to manufacture and install the material in the short term. Shigeru is the expert, and we relied heavily on his advice in terms of the long term performance of the material. His view is that the cores will perform really well and will harden over time."

For Mr McFarlane, it's been an enormously challenging and rewarding project to lead.

"It's required a very agile approach … in terms of design scope, a flexible procurement model, programme sequence, costings, operational requirements. We've had to manage a significant amount of change to the scope of the building to provide value management solutions for the client. We've had the issue of using new materials like cardboard, and newish ones like the steel containers. The polycarbonate roofing was tested for weathertightness at wind speeds of up to 300 kilometres per hour."

Novelty extended to almost every aspect of this project. "One of the project objectives was to involve the community in the rebuild, which again is an unusual one." In addition, most of the experts involved worked *pro bono* during the concept phase, and contractors and suppliers also came to the party. Naylor Love Construction, for example, took on the job for zero per cent profit.

Everyone seems to have recognized this project's significance as a milestone in Christchurch's recovery. As Mr McFarlane notes, it feels good to be part of creating a landmark at a time when most of the activity around town is pulling things down. Throw in the fact that it is a ground-breaking design by a visionary architect for a brave client and you understand his sense of excitement.

"We all agree, this really is a once-in-a-lifetime project. Despite all the complexity, innovative materials, and unusual challenges, we are extremely pleased with our ability to provide an outcome and project leadership. Projects are a blend of fantastic people, best practice processes and positive behaviours and I'm particularly proud of the solution-focused project team we formed for the build. We've all had to use a bit of muscle to get it to where it is today."

You don't need to look any further for solution-focused examples than the Cathedral's fire engineering, which was provided by Holmes Fire. Darin Millar, a Christchurch-based senior fire engineer, led the project for Holmes. It was he who encouraged the firm to get involved in the Cathedral, after hearing early whispers about it on the engineering grapevine.

"We chased this project because it looked so iconic and unique," he says.

Early involvement meant that fire-proofing considerations were integral rather than after-thoughts on this project. Moreover, the Cathedral project has borne out Mr Millar's sense that fire engineering is increasingly regarded as a legitimate and important voice in the process of creating new buildings from their inception. "We're now getting involved with architects even before structural engineers are called in. Fire engineering is seen as a profession that can influence design in a positive manner at a very early stage."

The flipside of being there so early on this particular project, however, was that much of what the fire engineers had to consider was still in the realm of the unknown. Not only were they dealing with a structure built of a novel material – cardboard on an outsized scale – but even the structure's location was undecided.

The eventual site, on the fringe of Latimer Square, turned out to be a good distance from any neighbours. For a long period, however, Mr Millar and his colleagues had to factor in the possibility that the Cathedral would be close to other buildings, which included calculating the possibility of fire spreading. "We identified the risks and discussed how to mitigate them, potentially by placing the building in a certain orientation. Thankfully it became an academic exercise."

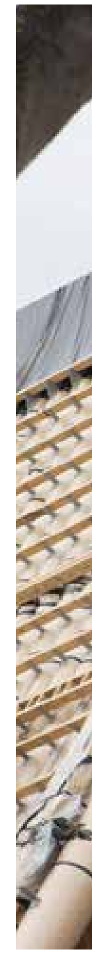
Another unknown was the cutting edge design's performance when exposed to heat. The obvious question: those cardboard tubes will burst into flame, won't they?

This was critical and had to be cleared up early, even before the cardboard tube supplier had finalised the product. Taking one of the supplier's generic products and using the University of Canterbury's

Top: A view of the rear wall showing the steep pitch of the cardboard rafters. Photo Dean Carruthers.

Middle: Detail of the cardboard rafters prior to lifting in place on site. Each of the cardboard cores is manufactured off site, purlin cleats attached, and wrapped in plastic sheeting to reduce water and handling damage.

Bottom: Naylor Love Construction fixing the base connection of the cardboard rafter to the container steel. Every connection is at a different angle and each rafter has been 3D modelled throughout the building to allow set out of the flare. The container fit-out and structural steel is also visible.



"You don't need to look any further for solution-focused examples than the Cathedral's fire engineering."

laboratory facilities, the tubes' ignition resistance threshold was tested.

"We wanted to get a general idea. Does this thing burst into flames or char like a dense piece of timber? How does it perform? Does it start delaminating? Does the flame propagate quickly up the length of the tube? We found that it performed very well. It didn't propagate flames in a rapid process but behaved much more like a hard piece of wood – it charred a small amount, but the paper didn't peel away. In fact, it was potentially better than some forms of timber. So now we had some information to dispel any misconceptions we might have had about how these tubes would perform in a fire."

The next step involved fire testing the tubes with three mooted surface finishings – polyurethane, an intumescent coating, and an unfinished, or raw finish – against a set of performance criteria. The engineers also wanted to be confident that, even when coated, the tubes couldn't contribute to a fire to the extent that worshippers in the Cathedral couldn't escape. Specifically, they invoked something known as radiant flux.

"Radiant flux is a measure of energy received by radiation over a given area. In this test you apply heat from a radiating heated panel and you can modify the amount of flux you're imposing on the material to check performance. We tried to determine how long it would take before the item either spontaneously ignites, or ignites given an added ignition source. We weren't necessarily interested in what flux was required to ignite the product as required by a standard test method; rather, our criteria was to get people out of the building, which would take in the order of five minutes."

All three forms of the cardboard tubes comfortably passed muster, but because of the need to consider durability, as well as cost and aesthetics, polyurethane was eventually chosen for the finishing.

Mr Millar says the second factor, aesthetics, was a significant issue in all the fire engineering decisions made about the Cathedral.

"In fact, I've never been involved in a project in which something with so small a footprint had such a strong aesthetic driver. This is going to be an absolutely stunning building and we wanted to keep the design looking as good as we possibly could. We put a lot of effort into coming up with unobtrusive solutions and hiding the details."

Smoke detection, for example. The standard issue solution just wouldn't work given a design that put such a premium on clean lines – and there were other complications. The nave's extremely high ceilings ruled out installing ceiling detectors because it would be impossible to maintain them, and of course, this is a church, a place of candles and incense that could generate nuisance alarms. The fire engineers even investigated how many candles were likely to be burned in a range of ceremonies and events to arrive at an operational plan for the building.

Far Left:Installation of the cardboard core columns. Photo Dean Carruthers.

Left: Installation of the cardboard core rafters at the northern brace bay, including the connection to the steel ridge beam. The ridge framing to support the polycarbonate can also be seen above the ridge beam draped in polythene to reduce water ingress. Photo Dean Carruthers.

Top Right: Strong project leadership and faith in delivery team – Johnny McFarlane, Project Manager from Beca. Photo Dean Carruthers.

Bottom Right: Brace bay elements, including the vertical timber compression chords, horizontal structural support beam at third points, and diagonal Macalloy bars. Photo Dean Carruthers.

"To ensure adequate protection for the building we went for an aspirating detection system. Effectively, it is a network of pipes with holes that are constantly sniffing the air the whole time. The spacing between the cardboard tubes was an advantage here: smoke would migrate behind the tubes, allowing us to install unobtrusive detection system there."

The drive to keep fire-related fixtures as unobtrusive as possible extended to the choice and placement of sprinklers, which were deployed only in the low-ceiling areas outside of the main foyer and in back-of-house spaces. In the end, the sprinkler question became an opportunity for the fire engineers to influence the building's final design. Original plans had included a very deep and solid structure at the entrance, which would have necessitated many more sprinklers. A choice was made to go for something flatter, with cleaner lines, instead. "It was great to be able to advise early in the piece on the impacts of the likely system, rather than have to address it further down the line," Mr Millar says.

All of which suggests that the Cathedral's unique design did nothing but pose challenges. In fact, the building also had some unique benefits from a fire engineering perspective. Spacing between the cardboard tubes, for example, works to limit fire spread. The high ceilings, meanwhile, limit heat build-up and radiative feedback, creating more time to evacuate. The building's simple layout and many egress points aid the evacuation process.

For the fire engineers, seeing the completed structure, signed off, safe and yet still a beautiful clean-lined space, will be a moment of satisfaction. "We just wanted to be part of this," Mr Millar says. "Guys from across the various offices got involved because they could see this was a unique building, one that would be appreciated not only locally but internationally."