Developments in the use of high-resolution point cloud data to inform heritage restoration

T. Lamberts & J. Alexander
Holmes Consulting LP, Christchurch.

ABSTRACT

While considered an emerging technology at the time of the Canterbury Earthquakes, extensive use of laser scanning derived point cloud data over the last 10 years has resulted in refined processes with new and existing applications to harness the power of this high-resolution data.

All heritage restoration projects come with the guarantee of unexpected coordination challenges related to the existing building fabric. The use of point cloud data enables an increased understanding of the existing building condition, which aids in the planning, design and construction phases of the project. Whether it be coordinating spatial requirements for specialised rooms between out-of-plumb walls or using laser scans to provide a true and accurate record of damaged elements, point cloud data and heritage restoration now go hand in hand.

The high-resolution data that is captured provides the ability to fully document all building elements with increased accuracy without the risks and challenges associated in gaining access to areas for a site measure – particularly areas at height. In badly damaged buildings, laser scanning is used to measure aspects such as the offset of damaged stonework from a distance without needing to expose people to the hazards present. The use of the high-resolution imagery in damage reports and documentation enables better informed decisions for practical stabilisation solutions to be made and clearer communication to contractors.

In this paper we will explore examples of how point clouds have been utilised effectively, to accurately coordinate the design with the condition of existing structure.

1 INTRODUCTION

Following the Canterbury Earthquakes and with many heritage restoration projects to action, design teams across the region were struck with the immediate challenge of finding the best way to gather information on the existing buildings. It was quickly recognised that using laser scanning / reality capture technologies was a time and cost-efficient way to site measure existing geometry to inform the engineering analysis and documentation processes (Figure 1), and to understand the extent of sustained damage.

Over the past 10 years, reality capture hardware and the resulting data outputs have been steadily improving. Advancements in laser scanning hardware have allowed for much faster data capture at ever increasing scanning resolutions, resulting in more accurate data sets being provided by local surveyors to design teams. In conjunction with this, the technical abilities and creative thinking for how engineers and designers use and manipulate the data has greatly improved. Elevating the use of point cloud data from supplementary site measure information to a vital part of our daily coordination on a heritage restoration project.

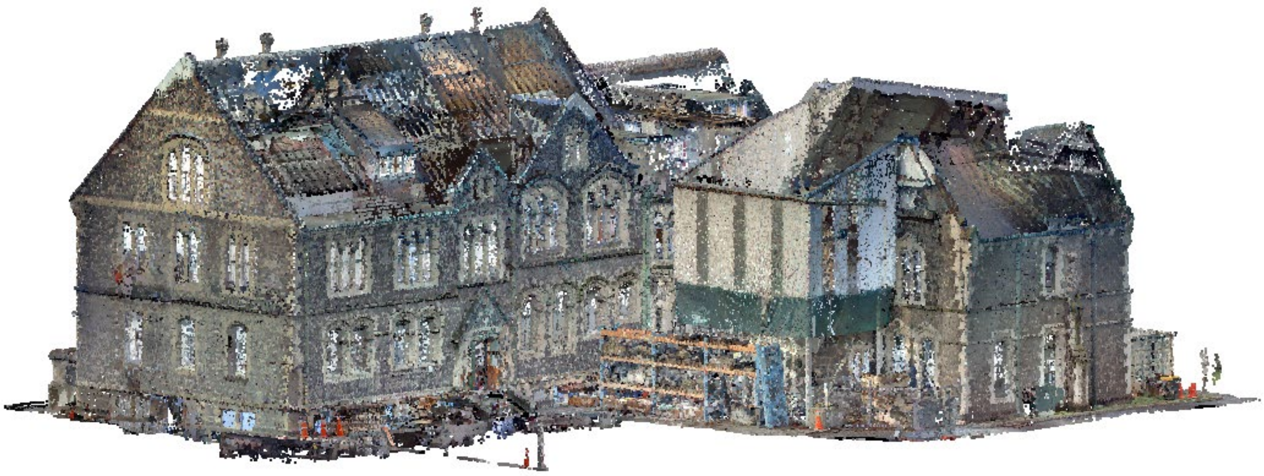

Figure 1: The Arts Centre Christchurch F Block point cloud used for informing geometry for engineering analysis and documentation purposes.

2 DEVELOPMENTS OF POINT CLOUD DATA

With advancements in scanning technology, point cloud graphics moved from greyscale to full colour, dramatically improving our ability to interpret the data. Figures 2 and 3 show a comparison of clouds from 2013 and 2018, imported into Revit – a BIM authoring application that has the ability to import and interrogate point cloud data. This increase in definition has not only increased our ability to measure and locate elements, it has enhanced our ability to view the condition of scanned elements to a similar level as a photograph would. The shape and material can now be quickly and clearly identified in an office environment, reducing the reliance on site investigation to verify the point cloud data with associated time and cost savings.

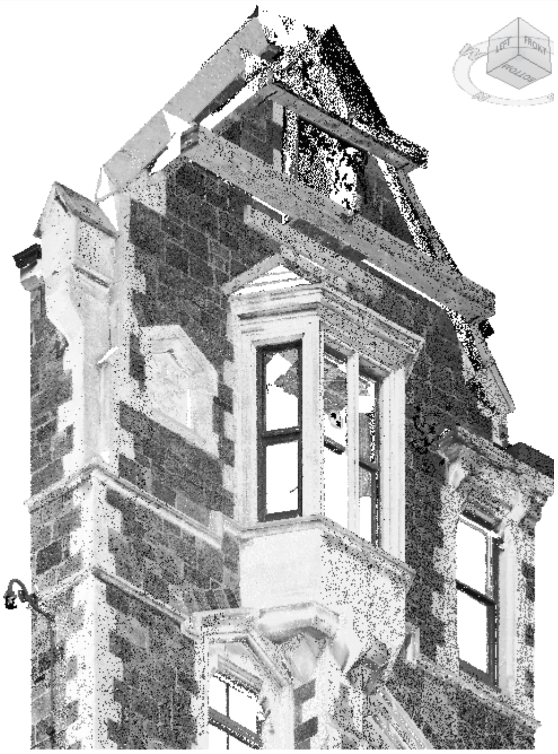

Figure 2: point cloud data from 2013.

Figure 3: point cloud data from 2018.

Experience gained from over 10 years of heritage restoration projects highlights that the existing structure seen with the naked eye can be deceivingly inaccurate. Something that appears to line up or be plumb may not be so. This could be due to historically accepted construction tolerances, building settlement over time, or an event such as the Canterbury Earthquakes in 2010/2011.

Structural engineers working on heritage restoration projects, are not only required to coordinate with other consultants and compliance requirements but, also need to consider the existing building in its true condition. An effective way to do this is to use high-resolution point cloud data sets as a “source of truth”, with point cloud data improving to the point where users not only have an understanding of size and location of an element, but also a clear and accurate understanding of the shape of an out-of-plumb masonry wall, deflection in a suspended timber floor, or an offset of stone due to earthquake damage. There is now the capability for a greater than ever understanding of the existing building’s design constraints allowing for better informed decisions during the design and investigation phases of a heritage restoration project.

3 PRODUCING AND COORDINATING DESIGN DOCUMENTATION

3.1 Producing planar design documentation

When producing documentation for existing buildings engineers are faced with challenges of how to represent existing structure efficiently and accurately. Using Revit as a primary documentation tool existing and new structure can be recreated in a 3D environment. Although engineers are seeing the use of 3D models on site increase with each project, during construction 2D drawings and documentation are still the primary communication tool between engineers and contractors.

Although in theory it is possible, it is not reasonably practical to represent the true nature of existing heritage structure in a 3D model and 2D drawings, due to time and cost constraints. Therefore, when modelling and drawing existing structures from point cloud data sets, documentation should be produced from planar elements with a line of best fit approach, as shown in Figure 4. Using point cloud data allows the user to view the data capture in a true planar view, whereas scaling off a photo would have projection issues, increasing the accuracy of measurements significantly.

This has been found to be an effective and efficient approach during the design phase, allowing for clear communication of design intent. These lines of best fit are considered carefully, based around an understanding of what the true coordination constraints are. For example, the line of best fit could be the middle of an out of plumb element or on an edge.

By overlaying the point cloud and drawings digitally the distance between best fit and true location is measurable and can be incorporated into the design tolerance during detailing. During construction the contractor will need to allow for any differences between scanned data and planar drawings.

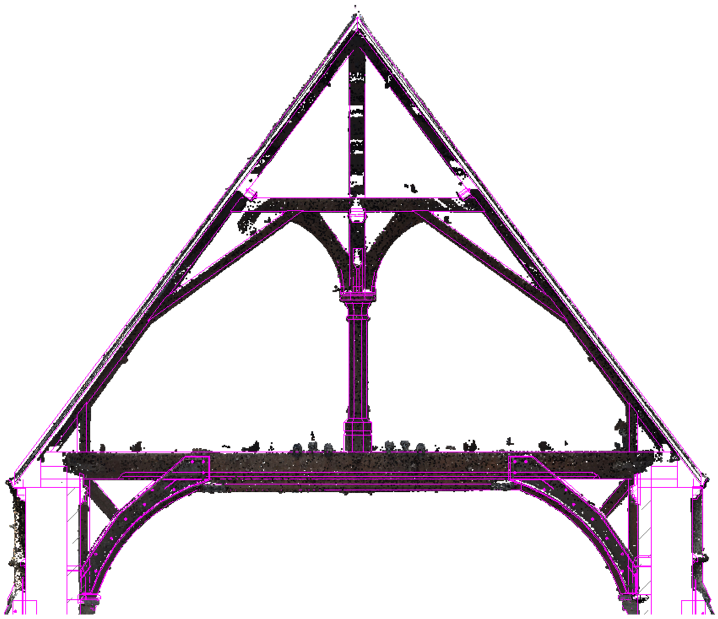

Figure 4: Line of best fit modelling over point clouds, where magenta lines indicate model edges.

3.2 Reviewing point cloud data for compliance constraints of non-planar construction

In a heritage restoration project, if a wall is not plumb or not parallel with the opposite wall, causing a room to be trapezoidal, this information might need to be reviewed for compliance constraints. For example, a boutique cinema in a heritage building will need to have rows of seating of a specified dimension, and an access walkway of a specified dimension (Figure 5).

Using high quality point cloud data as an accurate representation of the existing condition of the walls engineers can identify and coordinate with the narrowest point in the room and set our design constraints accordingly. The drawings may still represent an orthogonal existing structure, but the tolerance can be accounted for through either min. or max. dimensions, or with specific notes on the design constraints, communicating coordination decisions to the contractor.

Where previously this type of coordination could have been missed until during construction, engineers are now able to identify and resolve spatial issues before they leave the design phase.

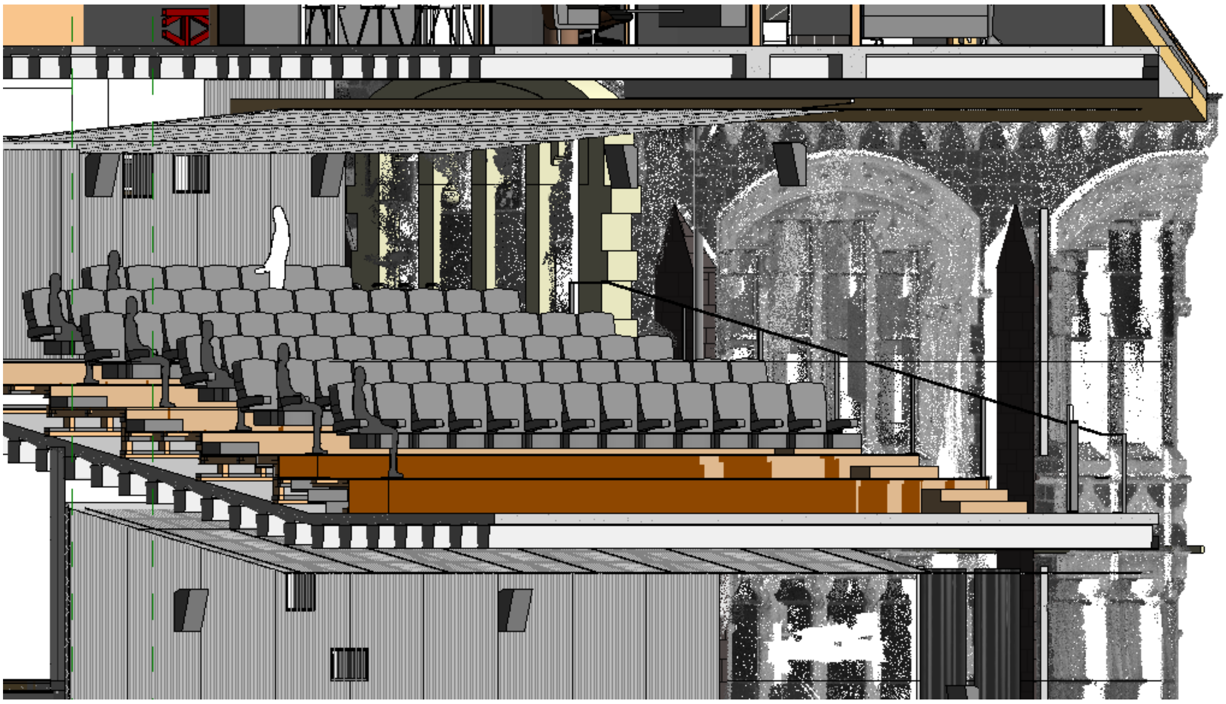

Figure 5: Coordinating with compliance constraints using point clouds in Revit.

3.3 Coordinating tight spaces with non-planar construction

The space between the ceiling and a floor above on any building is prime real estate for supporting structure. In a heritage restoration project, a timber joist floor or ceiling likely has a sag mid-span, this quickly reduces the useable space available as shown in Figure 6.

Using point cloud data, engineers can accurately measure the deflection and allow for design tolerance in our detailing. Perhaps, resulting in a variable depth of timber packing between our steel strengthening beam and the existing timber floor joists that can be cut to suit the existing building conditions on site.

The planar modelled elements are coordinated with the tight spatial requirements presented on site during the design phase using point clouds as an accurate "source of truth".

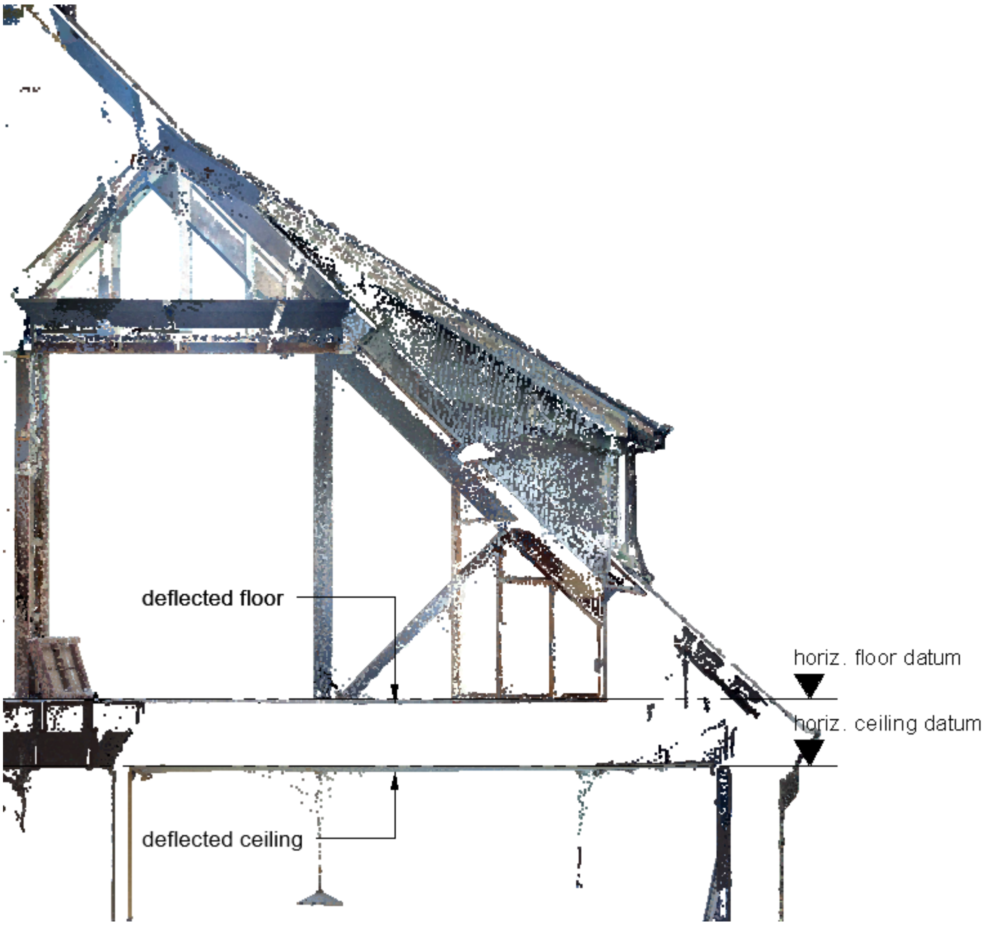

Figure 6: Point cloud indicating floor and ceiling deflections.

4 USING POINT CLOUD DATA TO INFORM DAMAGE ASSESSMENTS

Since the time of the Canterbury Earthquakes in 2010/2011 engineers have seen vast improvements to the quality and accuracy of point cloud scanning. The data that is now received provides enough detail that it can be used as a reliable data source for assessing structural damage to unreinforced masonry structures.

Often observed damage is not easily or safely accessible for an engineer to observe in detail. During crack mapping exercises an engineer might be forced to estimate crack widths or stone offsets due to areas being out of reach. Using high resolution point cloud data to supplement visual inspections, it is possible to accurately locate and measure structural damage in unreinforced masonry.

For example, looking up at a 20m high gable wall on site, it can be difficult to see if the wall is out of plumb or has local stone offsets. Using Revit, engineers can create a series of "slices" through a point cloud graphic and apply a datum line that can measure against. Engineers can then assess the condition of a section of existing building against what is considered to be its intended form. With "slices" at regular intervals its possible to gain a good understanding of the true nature of the wall and make appropriate design and safety decisions accordingly.

In some unreinforced masonry walls and columns earthquake damage has resulted in significant offsets of stone. Figures 7 and 8 show how point cloud data has been used to provide an accurate record of earthquake damage, used in damage reports and health and safety plans.

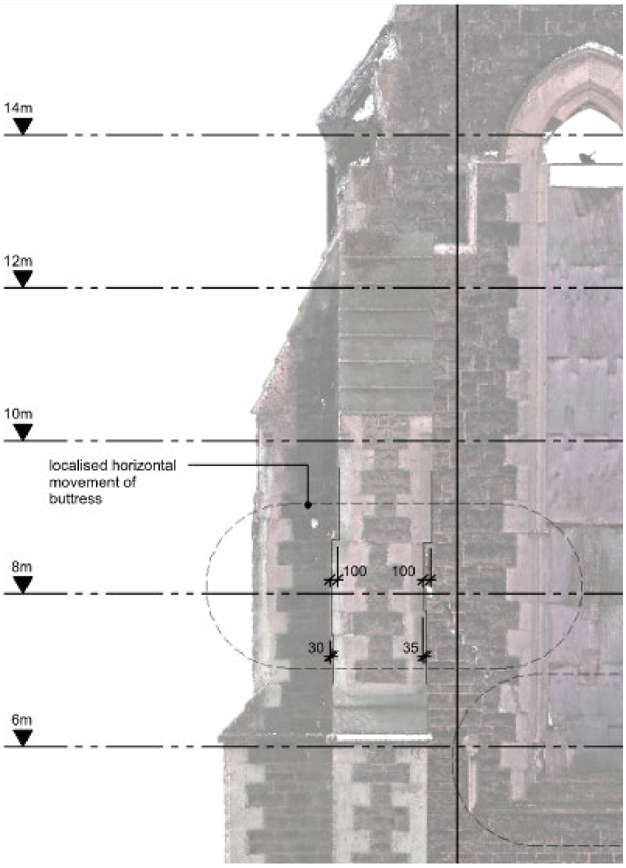

Figure 7: Point cloud data used to inform damage assessment. The image shows horizontal movement damage being accurately measured in an elevation view.

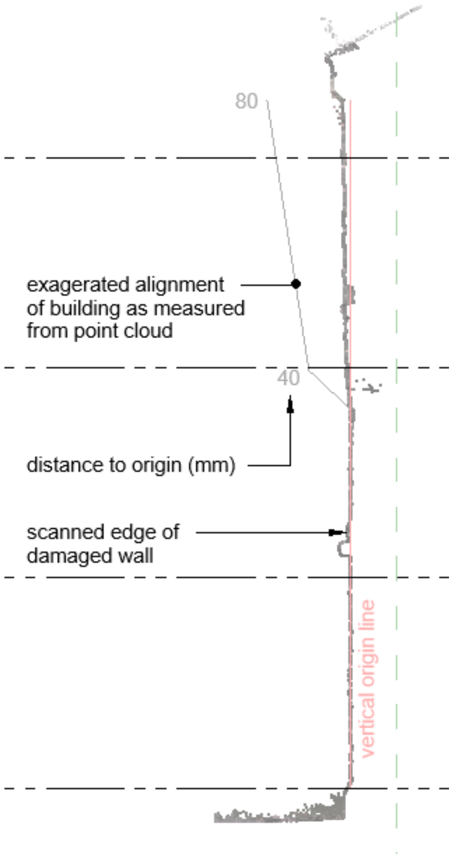

Figure 8: Point cloud data used to inform damage assessment. The image shows a "slice" cut through a point cloud to assess vertical alignment.

5 USING POINT CLOUD DATA TO LOCATE KEY CONSTRUCTION POINTS

Point cloud data has also been used to clearly convey detailed placement of strengthening elements to a contractor. Figure 9 shows a drawing prepared for the contractor identifying the locations where dowels are to be drilled through the stonework to tie the inner and outer skins of the rubble-filled unreinforced masonry wall together.

These dowel locators were selected by reviewing point cloud scans of the inner and outer skins so that dowel locations could be selected to engage large stones on the outside face and be within mortar joints on the inner face as shown in Figure 10.

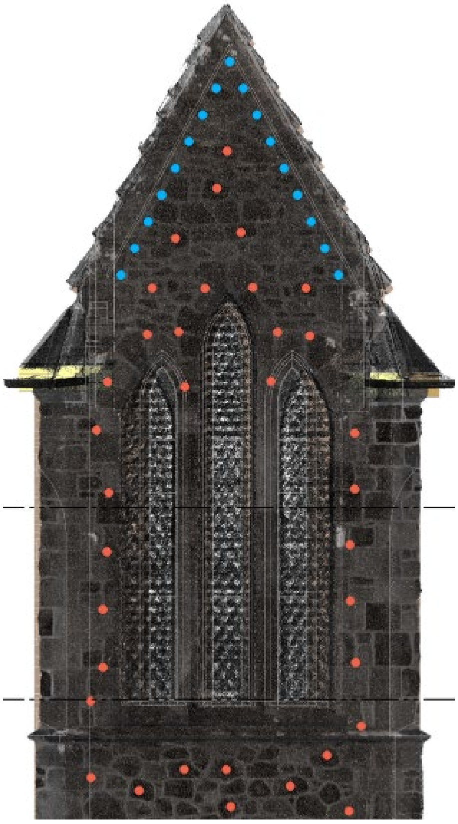

Figure 9: Specification of pinning locations to engage stones on both skins.

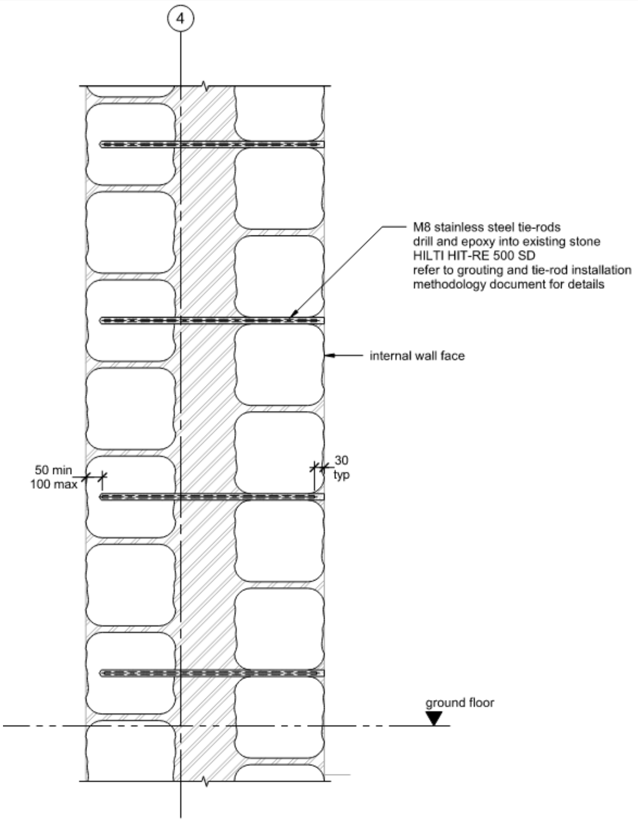

Figure 10: Detail of dowels through skins to engage large stones on outer skin and mortar joints on inner skin

6 CONCLUSION

The Canterbury Earthquakes prompted the use of point clouds to aid us, as design teams, in understanding the geometry of existing buildings and damage sustained by them. Over the past 10 years engineers have continually challenged how to maximise the use of increasingly accurate point cloud data to make informed decisions throughout investigation, design, and construction phases. A technology that was reasonably new to our industry has now grown to be a part of our day-to-day work on a heritage restoration project.

Holding a source of truth to the nature of the existing building, whether it be out of plumb or earthquake damaged, high resolution point cloud data sets have become such an integral part of a heritage restoration project that they are now as big of a stakeholder in design coordination decisions as other consultants.

When producing 2D drawings and 3D models from point cloud data it is best to take a line-of-best-fit approach to clearly communicate the design intent. The planar drawings are coordinated with the point cloud to inform design tolerances to be considered on site.