NARRO

Working with Low Carbon Brick Alternatives for repairs to Imperial Sized Bricks in Historic Buildings

With Glasgow School of Art, Kenoteq and Heriot Watt University

Summary

Narro Associates are the appointed Structural Engineers on Stabilisation works at the Mackintosh School of Art Building following the 2018 fire. On behalf of the Glasgow School of Art (GSA), Narro have been investigating the potential challenges associated with sourcing new compatible materials for repair and rebuilding of brick mass masonry walls. As part of the optioneering exercise, a collaboration has been developed with the researchers at Heriot-Watt University, to explore the potential for adapting a new low carbon brick to make it compatible with historic brick masonry.

The GSA are considering several potential responses to these challenges and are balancing many factors to find the best solution for the Mackintosh Building. A low carbon brick is only one possibility, but the GSAs support of the collaboration has been integral to the development of the concept for potential future use in other projects.

The Challenge

The rebuilding and repair of Historic Buildings requires a supply of new materials that are compatible with the existing historic structure. Visual compatibility can be a choice of aesthetics, but materials properties and strength compatibility are essential for functionality and durability. Sourcing suitable materials can become challenging when the original manufacturers are no-longer in business, or the manufacturing techniques are no-longer widely practiced or environmentally viable. Historic, imperial sized, fired Clay Bricks provide an example of this.

The Mackintosh building of the Glasgow School of Art suffered a significant fire in June 2018 and will require a large volume of newly sourced structural material to replace the fire damaged areas of structure. This will include stone, steel, timber, and bricks.

The Mackintosh Building was built in 2 phases at the end of the 19th and start of the 20th century and is of significant historic and cultural value and very close to the hearts of the city and its residents. The 2018 fire destroyed most of the internal structure. Consequently, a key conservation goal and engineering challenge has been to retain and stabilise as much as possible of the remaining original building fabric. Where this isn't possible, any potential salvage material has been kept, including a stockpile of bricks.

To achieve the structural requirements of rebuilding and the architectural requirements allow conservation and make the building fit for future use, new materials will need to match or complement the retained sections of the building and the salvaged materials.

Solid clay bricks were used in many areas of the original construction. Bricks were used for load bearing and non-load bearing partition walls as well as the main spine walls of the building. Bricks were used to form mass masonry panels, arches of a variety of spans and columns supporting pad-stones and beams. They were used architecturally as exposed brickwork, painted, and rendered. The original bricks were locally made at various historic brickworks which all closed in the 20th century. These bricks have imperial dimensions and strengths, porosity/pore characteristics, material compositions and colours that do not match the standard engineering bricks of today.

Initial estimates anticipate that around 500,000 brick units will be required to reinstate the Mackintosh Building for which there are several options. Each option provides advantages and poses challenges. The main engineering considerations are:

1) Dimensional Compatibility - the imperial bricks used in the construction are 234mm x 112 mm x 90mm (for reference modern bricks are generally 215 x 110 x 73). To carry out infill repairs and successfully rebuild partial courses, we will need to be able to piece in new bricks that fit with these dimensions.

2) Structural properties – combining bricks of different strengths in repairs can risk creating 'hard spots' in the building. This leads to a risk of distortion of the load paths through the compressive brick structure and unexpected load concentrations in some areas.

3) Material properties – combining bricks of differing water absorption and vapour permeability for repairs can create unwanted barriers to moisture movement and localised damp pockets and erosion risks particularly in external mass masonry walls subject to wetting and drying.

4) In addition to the engineering properties, there is the challenge to make the reinstatement of the Mackintosh building as environmentally friendly as possible. To achieve this, every avenue will need to be explored to improve the environmental credentials of the rebuild.

New imperial bricks are still made by a few manufacturers in England, often by hand or with historic infrastructure that has been maintained since the 19th century. These bricks would likely be good match to the original condition of the bricks used in the construction of the building although not necessarily the condition of the bricks after 130 years, 2 major fires and exposure to the elements. Careful consideration also needs to be given to supply chain to make sure that enough bricks can be provided. The environmental credentials could also be challenging. New imperial bricks are often fired using traditional coal fired methods which do not perform well in carbon calculations and supplier locations mean that transport implications need to be considered.

Reclaimed imperial bricks can be sourced via salvage from other buildings of the same age. These will likely provide a good match for the dimensions and materials properties of the original bricks in their current condition. The challenges here lie with supply and consistency of quality/properties as it is difficult to determine in advance a new supply of salvaged bricks might become available, and each new supply will need to be vetted for material properties. The carbon cost associated with transport may also become a consideration if bricks cannot be found locally.

New modern sized fired clay bricks would provide the most straightforward supply chain but pose challenges in terms of their different dimensions, structural and material properties and environmental credentials.

New low carbon brick alternatives that could be made to imperial dimensions were identified as a possible route to meeting some of the challenges above and have been explored through a collaboration between Narro, The Glasgow School of Art, and Heriot Watt University.

The Collaboration

The K-BRIQ® is a resource-efficient F2 A2 facing brick made from inert recycled input materials. K-BRIQ® was developed at Heriot Watt University and the spin out company Kenoteq. They are structural grade bricks formed from certified inert non-organic construction waste product, K-BRIQ®s have significantly less embodied carbon than fired bricks due to the re-use of recycled materials and no high temperature fossil-fuel based firing in the production process. Due to the lower energy requirements required for K-BRIQ® production, the manufacturing equipment is more efficient than a conventional brickworks which allows possibilities for moving it to take advantage of material supply locations and to reduce transport requirements.

The formulation is such that it would be possible to used crushed debris from the clearance of the building, or any down takings required for stabilisation as the feedstock for new bricks providing a very clear illustration of the potential for circular economies.

New moulds can be developed to provide units to match desired dimensions – including those of the imperial bricks.

Conversations on the potential for using K-BRIQ® at the Mackintosh building commenced in 2020 and in 2022 the Glasgow School of Art, via Narro Associates, commissioned Kenoteq and Heriot Watt University to carry out materials examination and comparison of samples of brickwork salvaged from site and the proposed K-BRIQ® formulation using sample crushed debris feedstock from the building clearance.

This investigation showed that the K-BRIQ® could provide an improved property match with the historic bricks from the Mackintosh building in terms of water vapour permeability and water vapour resistance factor. They would also provide a compressive strength more comparable to the historic bricks than a modern engineering brick is (2x rather than 10 x). (See table provided as Image 1).

The initial water absorption (and hence an estimate of capillary action) is much lower in the bespoke masonry K-Units than in the salvaged bricks. In this parameter, the K-BRIQ® is comparable with a modern engineering brick. This highlights an area of future research required before these bespoke K-Units, or any other alternative source of brick, can be adopted in an external mass masonry wall where wetting and drying and interaction with external renders are important. Heriot-Watt university and Kenoteq's R&D team continue to refine and improve all technical parameters of the K-BRIQ and their other products to fully understand how innovative products made from recycled construction materials compare with traditional and modern building materials through novel research techniques such as development of pore scale imaging techniques.

The investigation showed that there was significant variability of the material properties of the salvaged bricks, even though all samples had been taken from the Mackintosh Building itself and therefore had experienced similar conditions throughout their service life including the fire itself and the salvage process. This further highlighted the challenge of compatibility listed above.

Brick Manufacturer	Average Dimensions (mm)	Average Unit Density (g/cm3)	Average dry U.C.S. (N/mm2)	Average wet U.C.S. (N/mm2)	Initial rate of water absorption (kg/(m2·min))	24h cold water absorption (%)	water vapour permeability (kg/m·s·Pa)	water vapour resistance factor
Kelvinside	233.7x111.6x91.2	1.85	8.5	7.63	22.3	9.7	$5.37x10^{-11}$	3.76
Bishopbriggs	234.3x112.3x89.6	1.65	7.5	9.03	23.59	8.6	$2.23x10^{-11}$	9.06
Garscube	232.6x111.9x88.0	1.8	9.6	10.55	18.35	14.9	4.0510^{-11}	4.98
K-briq	215x102.5x65	1.71	27.7	20.56	0.61	0.9	3.72810^{-11}	5.43

Image 1: Table Summary of individual unit test experimental values of GSoA and K-BRIQ® (note here a standard dimension K-BRIQ® was used as an imperial mould was not yet available.)

Image 2: Prototype frogged bricks developed using feedstock from existing damaged GSoA bricks

Image 3: Example of salvaged brick units From the Mackintosh Building

Practical Application and Future Work

The materials analysis and comparison with the K-BRIQ® trial allowed for the development of a suitable material specification which was included in the technical specifications for the next stabilisation repairs phase on the Mackintosh Building.

Given that this is a new specialised context for the use of the K-BRIQ® in a historic building, the suggestion of a trial area has been made. One current challenge is the initial costs involved with this trial. When produced at scale, as they would be for a full reinstatement project, the cost of an imperial sized K-BRIQ® would be slightly less than a new imperial sized fired clay brick and comparable to a cleaned salvaged imperial fired clay brick from another source.

To produce K-BRIQ®s at scale a new production mould is required. These moulds are built to withstand high pressures and continuous usage. The commissioning of a mould would be a vital part of any trial and when set against the cost of a small number of K-BRIQ® units, a mould is a relatively expensive part of the assessment when compared to the other materials alternatives.

Narro are continuing to work with Kenoteq and Heriot Watt to explore how this sustainable technology can play a role in built heritage conservation in Scotland and across the UK.

References - Images taken from Heriot-Watt/Kenoteq report – Development of Glasgow School Of Art Historic Bricks Replacement Unit

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