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TIMBER-MASONRY INTERACTION MECHANICS: OLD BUILDINGS, NEW APPROACHES

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ABSTRACT: Working on hybrid timber/masonry buildings a number of recurring problems related to the load response of timber diaphragms and flexural members on the masonry gravity load resisting walls have been identified. Structural distress is particularly pronounced on early modern architectural masonry assemblies such as rain walls, for example, from the late 1800s where the form, materials and construction techniques appear to be incompatible.

In this discussion three timber/masonry buildings are examined, looking at how unintended long-term loads have imposed stresses on the connected masonry structural elements, of which climate plays a prominent role. Considering these buildings and their structural problems we review the distinct analytical, stabilization and repair approaches warranted by each of these unique buildings, from the simple and inexpensive to the highly computational. We also consider the role of structural health monitoring and modelling in diagnosis and remediation of structural pathologies and the challenges posed by timber.

This also delves into practical considerations from a structural engineering practitioner's perspective, especially one working in remote locations. Among these are permitting, training of tradespeople and the availability of materials. These and others play major roles in shaping our solutions to timber engineering problems.

KEYWORDS: timber, masonry, existing structures, climate

1 – INTRODUCTION

More than 70% of the world's existing buildings are masonry [1] of which unreinforced masonry (URM) buildings constitute the majority in jurisdictions throughout the world [2], as indicated in Table 1, below:

Table 1: Percentage of URM buildings in total inventory

Country	***Year***	***URM as % of Inventory****
Australia	2000	52.9
Indonesia	2001	60.0
Iran	2005	56.7
Italy	2006	62.2
Mexico	2000	75.7
Pakistan	1998	93.0
Peru	2007	73.2

**The above is partially reproduced from [8], p.8*

These are primarily low- to mid-rise buildings and best suited to areas of low-seismicity. URM buildings use no reinforcement beyond what is needed—and often not even that—for crack control and tying wythes, or vertical sections of wall, together. URM buildings rely on the strength of the masonry alone to resist global loads [3]. Almost universally these URM buildings have wood structural systems ranging from window lintels to shear walls and floor plus roof diaphragms. Wood not only lends flexural capacity to URM structures, but it also favours economy of construction. The images of Figure 1, of a 700-year-old mosque in Bukhara, Uzbekistan, demonstrate the long history of sophisticated architectural and structural design of timber-masonry buildings.

The cost effective and reliable preservation of old buildings is a pressing issue. Motivation to protect and preserve these buildings stems from the value of their architecture and craftsmanship plus their importance as part of our built heritage. Additionally, these buildings hold value as living structures for residential, commercial, liturgical and innumerable other purposes. Masonry buildings are proven to last hundreds and even thousands of years; consider, for example, the 2000-year-old Pantheon in Rome. Experience tells us that countless hybrid-timber masonry buildings in the current global

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Figure 1. Exterior and interior photos of a 700-year-old mosque in Bukhara, Uzbekistan. The building has URM exterior walls and timber post and beam floor and roof systems. The image at right shows a camel felt pad for seismic isolation at an interior column base.

building stock will be with us for hundreds of years to come. Maintaining these buildings is a matter of environmental stewardship and financial prudence. In our age of acute sensitivity to the impact of construction on the environment it is worth remembering the adage that the most efficient building is the one you already have. Rehabilitating old buildings can also play a role for jurisdictions facing residential housing shortages.

Current design codes and standards are generally silent on the analysis and assessment of old buildings, providing little guidance to practitioners. In the absence of minimum intervention conservation approaches, old buildings are lost in favour of new building solutions better codified for regulatory compliance, but more economically and environmentally costly. In large measure, this is attributable to professional practitioners on whose expertise and authority design and construction is undertaken having little training in old buildings and URM in particular. Old buildings can be considerably more difficult to work with than new ones; practices and materials used in new buildings are often incompatible in application to old buildings.

Carrying out structural assessments in URM buildings seems at times like forensic investigation as one traces oblique load paths and tries to divine the original design intent without original documentation. Engineers versed in conventional modern materials are often confounded as to what mechanical properties to attribute to URM assemblies. Whether steel is manufactured in Brazil, China or United States, for example, we accurately know and rely upon the published mechanical properties. URM mechanical properties, on the other hand, are functions of multiple factors including: how the masonry (e.g., brick) was made; the quality of workmanship; temperature and humidity during installation; and so on. Journal papers offer empirical methods and reference values for estimating URM physical properties [4][5], but for builders and practitioners these are not widely disseminated. The normal recourse is to follow codes and practices as applied to new buildings.

Hybrid timber-masonry buildings are part of our built environment for the long-term; they are exceptionally durable and their continued use makes social, environmental and economic sense. Promulgating knowledge and expertise in working with these buildings as well promoting the incorporation of modern techniques and materials, such as mass timber, in their renovation is not only pragmatic, but advances the use of timber in our future built environment.

Here we examine the analysis, assessment and conservation approaches followed in the renovation of three hybrid timber-unreinforced masonry buildings constructed during the 1800s in Newfoundland, Canada. Although each has different architectural and structural forms, common timber-masonry structural problems are found. The discussion to follow looks at how each building demonstrates a different aspect of timber-masonry interaction: moisture control; roof thrust; and form plus material compatibility. The analysis and repair approaches in each differ not only according to the structural pathologies but also according to the exigencies of available budgets and schedules, constraints with which practitioners are well familiar.

2 – BACKGROUND

The buildings at hand are functioning structures for residential, civic and spiritual purposes: one is being renovated as a single-family living space; one is a church; and the other was built as a Freemasons's temple, but in recent decades has been used as a theatre and public rental space for weddings and receptions. Each is recognized locally and nationally for its social and historic importance. Current work on the buildings is not to simply maintain the structures and their functions, but also to revitalize them for new and expanded use. Multiple past interventions attest to their long-term value.

While account must be made for the influence of changing environment loads, inappropriate and incompatible past interventions have exacerbated structural problems. Throughout North America misguided repairs, even while following the prescription of the building codes, are a common and vexing occurrence. Well intentioned interventions to improve structural and thermal performance, for example, frequently create unanticipated collateral problems.

Motivation for undertaking the projects discussed in this paper was in all cases driven by evident symptoms of structural distress. Externally apparent signs include fracturing of masonry in the vicinity of where timber and masonry systems meet and wood decay at timber-masonry interfaces. Attendant signs of movement and distress in timber members are invariably found upon closer inspection. Gravity-induced lateral loads in roof structures are a consistent and primary source of structural problems affecting timber-masonry hybrid systems. Secondary problems related to moisture and creep are also common.

Compatibility of structural form, material and construction techniques is a central tenet in the conception of an efficient, well-functioning building. It is arguable that perfect form-material-technique compatibility does not exist; architectural ornamentation and practical constraints of budgets, available skills and code requirements heavily influence the final constructed building. In each of these buildings we see the effects of incompatibility, some of which require relatively minor repairs, while others have created considerable structural challenges.

3 – PROJECT DESCRIPTION

3.1 THE CARRIAGE HOUSE

This building was originally constructed in the 1850s as a horse stable and carriage house. It has a floor area of ~270 m^2 spread over three storeys. It's one of the last remaining carriage houses from the 1800s in eastern Canada. Presently it is being converted for residential use. Since it was constructed moisture from groundwater contact with the foundation has been a continual problem. Misguided past repairs might have provided short-term relief, but degradation of the masonry and adjoining timber members have been the long-term effects.

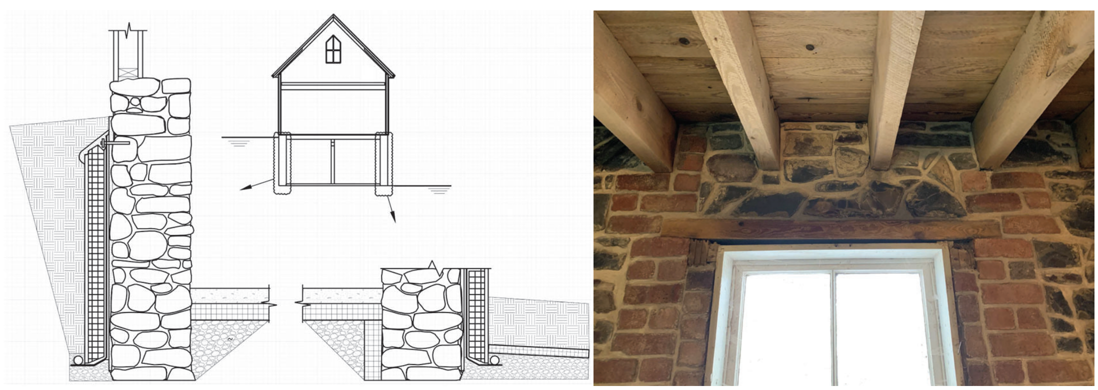

Figure 2. At left, cross section of stone rubble wall supporting wood superstructure framing. At right, timber floor joists and window lintel set into pockets in the stone masonry wall. Brick has been used to build a rectangular window opening.

The carriage house has a rubble masonry foundation wall supporting the main floor flooring system and a balloon-framed two storey superstructure with a 12:12 pitch roof framed with tied rafters. Rafter ties also act as floor joists. Being supported by the masonry wall, as shown in Figure 2, the timber's structural integrity is directly linked to that of the masonry. At the outset of the project the foundation wall showed signs of water ingress throughout its sub-grade portions.

Until the 20th century it was common for flooring systems supported by masonry walls to have beams and joists set into pockets in masonry walls. Beside carrying the floor's gravity loads, the floor diaphragm also provides lateral support against out-of-plane loads acting on the foundation wall. Where masonry walls are saturated, serious internal damp and rot problems can

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develop, ultimately leading to loss of capacity and movement of the timber system.

Coating masonry walls in clay or lime daub, a practice that is thousands of years old, provides a protective finish that can be painted or rendered to appear more refined, mimicking cut rectangular stone, for example. Modern (i.e., early 20th century) Portland-based cementitious coatings trap moisture within walls, whereas clay and lime daubs are porous and allow evaporation from walls. Where timber members are present, impervious coatings promote moisture transfer into the timber members embedded in masonry. The effects of past masonry repairs were manifest in the timber structure of the carriage house by rot in the pocketed tails of the timber joists.

Soft and vapour permeable lime mortars were typically used until the early 20th century. They promote evaporation of moisture through walls and, under normal conditions, their softness allows minor moisture and thermal related movements to be absorbed. That is, they breathe and redistribute stress. Conversely, hard mortar traps moisture and local pockets of stiff material concentrate stress. Transferred into adjacent stone this stress can cause fracturing, as shown in Figure 3. The comparatively fast cure times of Portland-based mortars

Figure 3. Stone masonry fracturing where hard, cementitious mortar has been used for earlier repairs.

were an obvious incentive for masons; lime mortars can take months or years to cure.

In another past repair, an interior timber wall was constructed in front of the foundation to pick up the joists with rotted tails. This alleviated axial load on the wall with consequent failure of the masonry. Masonry walls are tremendously strong under compressive axial load, but relatively weak under lateral load. From another view, masonry is most vulnerable to lateral loads when axial loads are removed, as in the moment-axial load relationship in concrete column interaction diagrams. Retrofit framing parallel to masonry walls is a common strategy to enhance wall strength and stiffness. But, it must be done cautiously, understanding how changing the load path can adversely affect masonry wall and worsen the condition the framing is meant to mitigate.

Timber and masonry systems in a hybrid building are inextricably linked; what affects one, affects the other. In developing the repair strategy, we have to be conscious of the compatibility of engineered solutions while following acceptable preservation practices [6][7]. Our solutions also must also comply with regulatory codes. To these ends we had to resort to some old and some new tools.

To insulate and protect the exterior sub-grade foundation wall against the surface and groundwater, we designed a system to waterproof from the outside while allowing moisture transfer from the interior. This system comprises: high density polyethylene (HDPE) drain board; closed cell insulation; bentonite clay liner blanket; and low-strength, vapour permeable Portland-lime-sand mortar coating applied over the stone masonry, as shown in Figure 2. On the interior, existing mortar was raked, joints were repointed and embedded stainless helical ties were used to stitch cracks and weak areas. Knife plates with self-drilling, barrel headed screws were used at the bases of existing timber columns supporting floor beams. Long, fully threaded screws were used for shear reinforcement of damaged joist and beam tails as well at wooden column capitals to increase stiffness by effectively reducing the beam spans. By these means we were able to meet the current strength and serviceability code requirements while keeping all original structural systems and architectural elements in place.

On the theme of embracing old techniques as part of our built future, architectural needs caused us to look to the past for structural solutions. Plans calling for additional headroom in the attic space while preserving an existing transom window in the floor below left 125 mm (5 in) depth available for the flooring system. For this we turned to an antiquated, but simple and elegant solution that has found renewed appeal with the advent of engineered mass timber, a mill floor, more commonly known as a nail-laminated (NLT) floor [8]. With a span of around 2.4 m between glulam beams, 38x89 (2x4) Spruce-Pine-Fir plies easily met code prescribed strength and serviceability requirements. While cross-laminated timber (CLT) panels would have performed suitably, working in an existing building with limited crane access prohibited its use. Delivery logistics to a remote location was also an impediment. The idea of using NLT was initially resisted by the builders; the notion of floor system 89 mm deep floor ran counter to their experience and instincts. More importantly, the local building inspectors also needed to be satisfied. Being prepared, having at hand case studies from other jurisdictions and code compliance calculations as in [8] proved invaluable not just for passing inspections but also for education of builders and inspectors alike.

Execution of the work with locally milled lumber, simple hand tools and lots of nails resulted in timely and economical construction. Applying old principles and new materials, the building has been structurally renewed while staying true to its original character.

3.2 THE VICTORIAN GOTHIC CHURCH

This Presbyterian church is cited as one of Canada's finest expressions of Victorian Gothic Revival architecture. It also has the tallest church tower in Atlantic Canada. Its liturgical function is much diminished, but it has found renewed purpose in community use. Virtually all the buildings structural problems start at the 15:12 slope, 12 m span timber roof where a thrusting load path acts on exterior masonry walls. Original architectural choices and questionable repair interventions have played roles in the structural distress exhibited. In the most recent structural interventions, limited funds dictated the use of targeted, cost-effective solutions to stabilize the building by re-coupling the timber and masonry elements.

As evidenced by their longevity, Gothic masonry buildings are engineering feats, though formal analysis played little role in their design. The architects, or more accurately the architect-engineers, and masons used intuitive knowledge and experience to create structural forms for which strength and stability derive from their geometric proportions [9]. These proportions have been notably shaped by the need to resolve thrust loads from timber roofs. Simple frame models and hand calculations verify observed deformations caused by roof splaying, as shown in Figure 4. Through a combination of external loads, creep and ductile connections vaulted timber roofs are susceptible to spreading distortion that imposes lateral load on exterior walls, even with thrust-resisting ties in place.

The wall section here is composed of a non-load bearing exterior masonry veneer backed by two inner structural wythes stiffened by wood strongbacks, as seen in Figure 5. The wood strongbacks enhance the wall's out-of-plane flexural properties. The hard, smooth surface of the veneer is aesthetically pleasing and provides protection against rain and snow. Veneers are typically of higher quality brick than the interior wythes. Here the veneer is made from Scottish Accrington brick brought to Newfoundland on a 3400 km voyage as ships' ballast. The veneer is laid in a running bind pattern, where the successive rows of brick are staggered, typically, by a third or half a brick length. The veneer and inner wythes are bonded by lime mortar. In assessing masonry walls, running bond laid exterior walls hints that the outer layer of brick might be ornamental rather than load bearing. Structural wythes often have bricks periodically laid out-of-plane so that adjoining wythes lock together and act compositely.

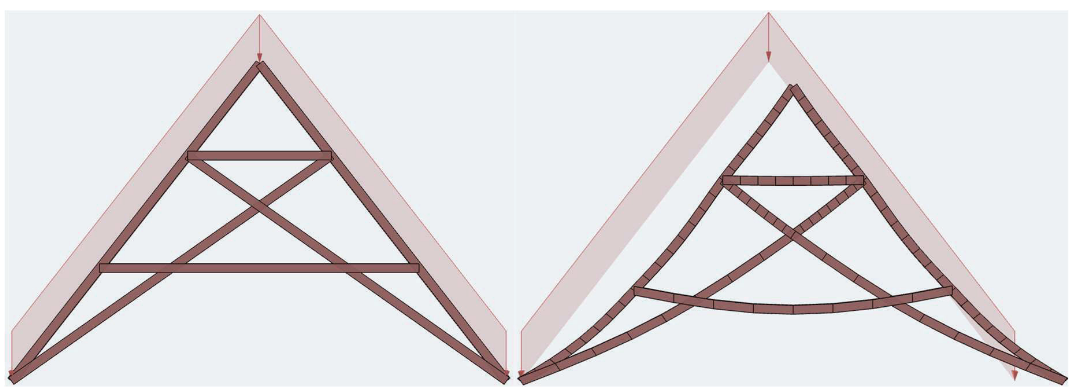

Figure 4. The demonstrates the splaying behaviour of the scissor trusses at the church. A simple frame stiffness model was developed using SkyCiv software taking as input characteristic self-weight and snow loads. The deflection scale is exaggerated for illustration.

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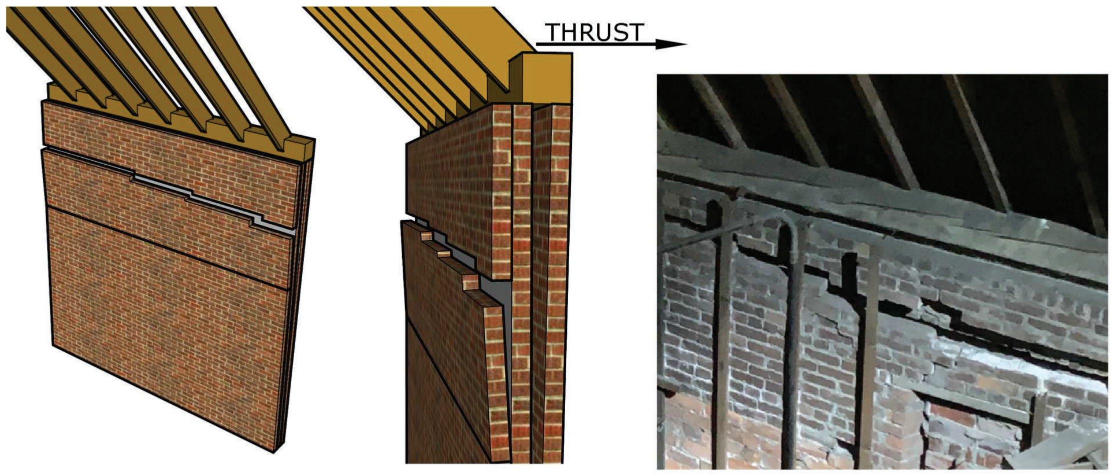

Figure 5. The left and centre images are graphical illustrations of the effects of thrust from timber rafters on the multi-wythe brick exterior walls. These rafters are above the chancel where there are no trusses. Thrust has caused fracturing of the interior structural wythes and complete separation of the exterior veneer wythe. The photo at right shows the cracked wall with timber strongbacks attached for flexural reinforcement.

The gable roof structure of the church is a combination of heavy timber scissor trusses over the nave and untied rafters over the chancel. Scissor trusses have been widely used in Gothic churches as the sloping bottom chords accommodate vaulting ceilings extended above the height of the side walls.

The tendency of scissor trusses to spread is a well-known trade-off in return for gaining extra ceiling height [10]. Traditionally in Gothic cathedrals, for example, thick exterior walls and buttresses have been used to contain the thrust. Wall thickness, by virtue of mass and inertia, is critical in resisting out-of-plane loads. The walls here are of a relatively thin, modern style with thrust-resisting pilasters aligned with the trusses. These features have proven to be of limited effectiveness in resisting lateral thrust.

The history and mechanics of scissor trusses are well described elsewhere [11], so in this just a few salient features are discussed. It is common to build scissor trusses using continuous cross members, as is the case here. A simple bolt at the crux, or crossing point, connects the lapped cross members and renders them susceptible to cross grain tension. Vertical ties from the ridge to the crux are normal features of scissors trusses that are essential for developing truss behaviour, that is, a structural assembly primarily subject to axial loads rather than bending. The absence of vertical ties, as is the case here, increases bending stresses in the top chords and cross members. Inherent in the design, the trusses at St Andrew's were preconditioned for long-term stress and deformation.

Over the vault of the chancel of the church, there are no trusses. In this area the ceiling is higher than over the trussed roof of the nave. The design principle that structure follows social spaces [12] was adhered to in this location where the liturgical need for vault height prevailed over adequate framing. Although the nearby transept walls help brace against the roof thrust, this is the area of the most severe damage. Inner wythes of the brick wall have fractured and separated from the exterior wythe, as shown in Figure 5. Roof thrust has sheared the masonry wall just below timber top plate. Consequently, the exterior wythe, originally built as an ornamental veneer, has become inadvertently load bearing. The visibly bent wood strongbacks that connect the sheared wall segments have proven their function.

Structural interventions were carried out around 25 years ago to address the splaying of the roof. These include the installation of steel side plates to stiffen the truss connections, the addition of collar ties and tensioning cables at the lower horizontal ties. Even though these interventions were relatively recent, no records exist to give guidance as to their rationale. Site observations and basic truss analysis indicates that these efforts were of dubious value. A simpler and more economical installation of vertical tension ties connecting the peak to crux would have been more efficacious, which calculations can attest. Vertical ties have for centuries been well-tested, regular features in scissor trusses.

Past repairs to the exterior walls involved the installation of cavity walls, decoupling the veneer from interior wythes, backed by impermeable rubber membranes. Two potential problems arise from this: reconstruction of the stressed veneer does not augment or restore the strength of the wall, rather it temporarily dresses the signs of stress; and impermeable membranes can trap moisture in the wall, as previously discussed. Despite considerable funds and effort spent during that intervention, no work was carried out to abate the roof thrust above the vault of the chancel where there are no trusses and masonry damage is greatest.

incipient structural problems weakening timber systems that are already overtaxed by loads.

3.3 THE FREEMASON TEMPLE

The cornerstone of the temple was laid in 1894 with completion by 1896. Built by the Freemasons, it now serves for community functions and major renovations are in progress. It is noted in the Canada Historic Places listing for the Classical Revival style decorative features of its façade. In plan the building is 21 m by 21 m, with two above ground storeys and a basement, for a total floor area of ~1300 m^2. The ground to top of roof height of the building is about 17 m.

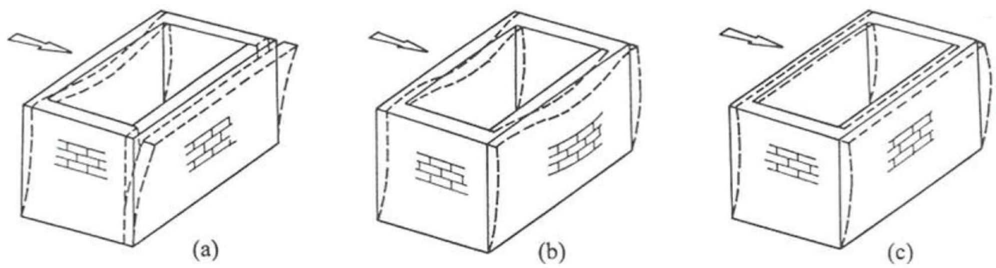

Figure 6. The middle image (b)is representative of the flexural shape of the flexible roof diaphragm. Images (a) and (c) represent no diaphragm and a rigid diaphragm, respectively. The figure above is copied from New Zealand seismic assessment guidelines [16].

As is usual with church repairs in Canada, available funds are limited. So, we had to focus on where the needs are immediate and repairs would be most effective. Effort was therefore directed towards stabilization of the exterior walls through recoupling the inner and outer wythes. To this end we used 500 mm long helical anchor ties manufactured by Simpson Strong Tie and high-strength threaded steel anchors from Python in New Zealand. Research following the 2011 Canterbury earthquake led to the development of the Python anchors and their use in Canada is somewhat novel. Ease of installation made these fasteners good choices for installation by local contractors and being visually inconspicuous made them well suited for a heritage building. To improve flexural performance, on the interior side new 38x89 (2x4) strongbacks oriented about their stiff axes were added to the coupled masonry walls.

It is acknowledged that this effort addresses a small portion of the building's needs. It represents the best that can be done with the resources at hand. The goal is to stabilize the building while further planning and financing are underway. Many other problems in the building are not strictly structural, but rather related to serviceability and the building envelope. Leaks, for one, are pervasive serviceability problems in this and other old buildings; left unchecked leaks are often

In this section we look at issues related to material and form compatibility plus diaphragm behaviour. The 450 mm thick exterior walls are of similar construction to the church. The temple also has a veneer of Scottish Accrington brick. Architecturally the building is of late 19th century modern form, square in plan, ringed with cast stone friezes between storeys. As with the church, the wall thickness is less than would be found using traditional proportions. Severe fracturing at the top of the east side masonry walls is directly related to thrust from the timber Mansard roof framing driven by wind and gravity loads from snow plus self-weight. Poor rafter connections from the original construction offer little resistance. We also see evidence of torsional shears at the corners, presumably driven by unbalanced wind loads acting perpendicular to long, unstiffened walls.

Considering the state of the art of building in that era it is assumed that the designers and builders followed accepted standards. There was no building code in Newfoundland nor Canada around the turn of the 20th century, but there was one in New York City (NYC) that can be used for reference. Referring to the NYC building code of 1899 [13], the building's wall thicknesses are in keeping with those prescribed in Part VI, Sec 31 of the code. As for wind loads, the New

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York code explicitly states that they can be ignored for buildings under 100 ft (30.5 m) in height (Part XXIV, Sec. 140). In 1899, long-term performance data for tall brick buildings was scarce. Reflecting why codes must evolve, there is anecdotal evidence of increasing variability and environmental loads in Eastern Canada, though the long-term data record is likewise incomplete [14]. Future editions of the National Building Code of Canada (NBCC) are expected to revise environmental loads.

The flexibility of the wooden roof diaphragm, as shown in Figure 6, is compounded by lightly nailed connections at the rafter tops that are easily rotated under load. At the top of the building's eastern exterior wall, splaying wooden rafters, rotating about their ridge connections, have pushed the masonry wall outwards as evidenced by substantial deformation and fracturing of the inner structural wythes. The principal loading comes from drifting snow, driven by the prevailing westerly winds, piling along the eastern roof edge, as shown in Figure 7. Taking the roof self-weight and 3 kPa NBCC specified snow load for the location and using reference values in Borri [4] to find wall cross section resistance, hand calculations give a rough estimate of service load (i.e., actual, unfactored) demand to capacity of 468 kN/302 kN, or 1.55. The veneer wythe, on the compression side, has pronounced deformation, but remains intact.

Friction plus debris in cracks and fissures makes deformed masonry nearly impossible to restore to its original geometry. In dealing with masonry deformation two options are available: to stabilize masonry in its deformed state; or rebuild. For interim stabilization the roof diaphragm was tied to the splaying rafter tails using off the shelf shear wall hold-downs, as shown in Figure 7. While renovation planning is underway this low-cost measure arrests further movement and if desired can serve for long-term stabilization. In the two years the tie assemblies have been in place, no further deformation has been observed. Early out-of-plane movement data collected as part of a structural health monitoring program (SHM) being carried out by Carleton University in Ottawa is in line with site observations.

The SHM and accompanying digital-twin model development is being carried out under the auspices of a National Science and Engineering Research Council of Canada (NSERC) grant [15]. An objective of this work is to develop an accurate methodology for analysing hybrid timber-masonry buildings to identify and quantify the governing failure modes and thus efficaciously target interventions. This involves a combination of SHM, in-situ observations and computational modelling. Facing widely unknown variables and properties, engineers typically resort to highly conservative, crude models of masonry behaviour. Demolition is frequently carried out where repairs are viable and more appropriate. Although the NSERC research is still in progress, so far it is yielding practical results for our understanding of where to target

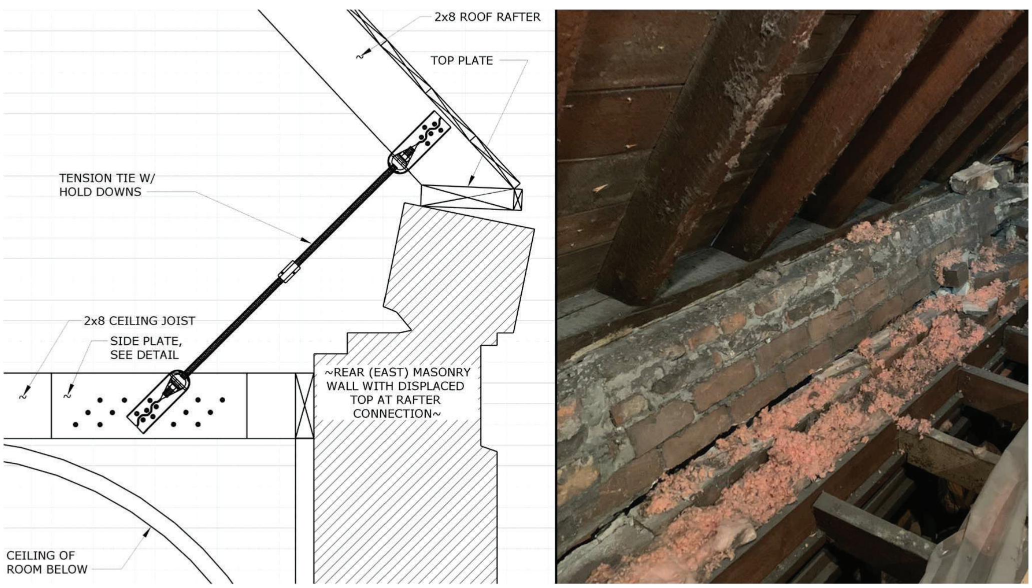

Figure 7. The above shows fracturing at the top of the east wall as a result of lateral thrust from rafters driven by self-weight, snow and creep. To restrain against further movement tension tie assemblies made from threaded steel rod and shear wall hold downs were used. On the compression side of the wall, on the exterior side opposite, the wall gently flares out with no fracturing present.

interventions. Earlier modelling with Carleton University as part of a shear capacity assessment of the building gave results that correctly identified the eastern top of wall as an area of concern, as shown in Figure 8, inspiring confidence in our ongoing efforts.

are vulnerable to damage from freezing and thermal movement with attendant crumbling of mortar and spalling of brick faces. Spalling exposes to moisture the soft, porous brick interiors, accelerating deterioration. Timber window lintels and posts set into the interior brick wythes are then subject to rot. As lintels rot, the

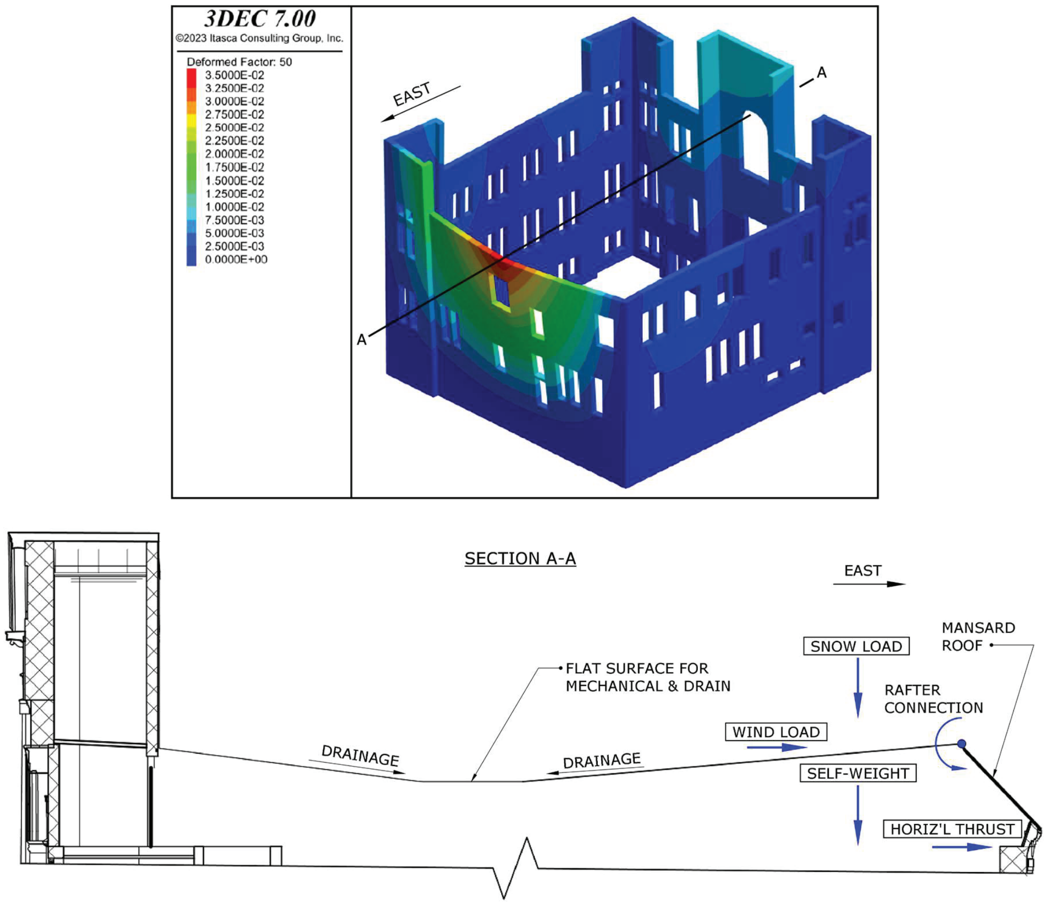

Figure 7. The top image shows predicted displacement fields on the east wall due to wind loading. In general, the modelled pattern agrees with site observations. The bottom image shows a cross section through the roof, denoted A-A in the top image, and the forces acting on the east wall..

Looking at incompatible materials, sometime in the early 2000s efforts were made to improve the building's thermal performance through better insulation. Insulation in the original building was provided solely by the wall materials. For heating, a coal-fired furnace using ambient air for combustion drew cold, dry winter air through relatively porous clay brick and lime mortar walls. This constantly kept the masonry walls and adjoining timber aerated and dry. Renovations that included a new oil-fired furnace drawing air from a point source on the exterior wall plus lining the interior wall surfaces with extruded polystyrene (XPS) sheet insulation significantly changed exterior-interior air exchange and moisture balance. Besides acting as insulation, XPS acts as vapour barrier. Veneer brick and mortar wetted by rain and snow now stay wet and

bricks above lose support from the timber lintel. By what mechanism the brick wall panel above is then carried is an interesting question; there might be beam or arching action in the brick panel, or reserve capacity in the lintel acting as a simply supported beam or fixed end cantilever. In any case, the lintel capacity is reduced and exact load path becomes obscure.

XPS and similar vapour impermeable closed cell insulation are widely installed in old masonry, often as directed by architects and engineers. Although well-intentioned, it almost invariably results in eventual damage to masonry and embedded wood members. This type of collateral damage is foreseeable if one is attuned to the mechanics of old timber-masonry buildings.

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4 – CONCLUSIONS AND RECOMMENDATIONS

When planning repairs to a historic building it is important to understand and assess the direct and collateral effects of proposed interventions. Where the prescriptive remedies in current codes and standards provide scant guidance in working with old buildings, practitioners have a duty to fill the void. Beyond analysis and design, this extends to the duty to educate owners, workers and inspectors in a manner intelligible to non-technical practitioners. Applying simple principals and solutions are frequently effective whereas some instances warrant an investment in modelling and deeper study.

Statutory requirements increasingly necessitate that we address the effects of construction on climate change and, conversely, the effects of changing climate on existing structures. Climate change policy and advances in building science mean thermal performance requirements are continually evolving in codes, typically becoming more stringent. So, we must increasingly find the balance between building science and regulations. New codes, new materials and best practices with old buildings are frequently odds. How this is reconciled in our restoration and rejuvenation of old timber-masonry buildings will motivate the development of intelligent, practical solutions for decades to come.

Sharing the hard-won knowledge and experience gained in working with old buildings promotes confidence in engineers and architects in their analysis. In turn, furthering expertise in the field prevents unnecessary and costly repairs or the implementation of irreversible, possibly misguided, structural solutions. Beyond the general dissemination of knowledge, the goal is to compose the lessons learned from these and other projects into practical, robust and systematic procedures for practitioners dealing with old timber hybrid buildings.

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