DESIGN, DURABILITY, AND THE POLITICS OF SUSTAINABILITY (WHAT DO THE THREE LITTLE PIGS TEACH US?)

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ABSTRACT

In the story of the three little pigs, the big bad wolf blew down the houses built of straw and wood. The third house, built of brick, survived. All three houses were constructed of "sustainable" materials, but only the brick house had qualities enabling it to serve its intended purpose (i.e., keeping the wolf out). Based on this scientific folk wisdom, this paper attempts to increase awareness of the need for durable design and construction to protect natural resources AFTER installation.

Sustainability embraces conservation of energy and the use of renewable, recycled, non-toxic, and abundant materials. However, many discussions of sustainability do not sufficiently emphasize the importance of durable construction in conserving resources. We advocate protecting resources for the future. Sustainability must balance the needs listed above, with sustainable useful life as a major goal of building design. Building a "sustainable" structure is pointless if the structure will not endure.

Effective remediation of a failed masonry wall system often involves partial or entire demolition of the wall system to install new components and replace damaged components. Repairs disrupt occupants and waste natural resources. The associated monetary cost of repairs can be many times greater than providing durable components and quality workmanship initially. Sustainable masonry walls must be designed so that the anticipated lifespan of components, including the flashing and weatherproofing that protect the entire system from moisture and subsequent damage, meets or exceeds the expected service life of the building. Sustainable design must incorporate flashings and waterproofing elements of high quality, since these components are hidden and inaccessible for repairs. Furthermore, the flashing and waterproofing system quality, function and durability must not be sacrificed for aesthetics or initial cost. Reducing the need to rebuild the wall system through appropriate design and workmanship is the cornerstone for sustainability and resource conservation.

Keywords: sustainability, masonry wall durability, water leakage, weather resistance, cavity drainage wall

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INTRODUCTION

Sustainable design emphasizes the use of energy-efficient buildings and systems and the use of renewable recycled, and non-toxic resources to help conserve resources, reduce energy consumption and reduce environmental impact. Discussions of sustainable design, however, tend to overlook the importance of durable construction and the impact of non-durable construction, both in terms of costs to building owners and impact on natural resources and the environment. In the famous parable, two of the three little pigs constructed their houses in a non-durable manner (albeit with renewable, "green" materials). The houses were unable to provide them with protection from the elements (i.e., the big bad wolf), and the somewhat shaken pigs had to find refuge in the well-designed third house. In the case of non-durable masonry wall systems, the "wolf" (i.e., exposure to the elements, and poor design and/or construction) can cause system failure, including damaged structural wall components, deteriorated masonry, and mold growth within the building, potentially leading to poor indoor air quality. In many cases, costly, intrusive reconstruction of wall components is required to remedy problems that would not exist if the wall had been durably constructed.

The quest to reduce building construction costs (e.g., "value engineering") often comes at the expense of workmanship and material qualities needed to provide durability. The lack of knowledge of the potential consequences of such sacrifices, coupled with the lack of understanding of durable masonry wall design and construction, can introduce damaging and costly defects. Deviations from sound design and construction, even seemingly small ones, can affect the durability of building envelopes, especially in regard to water penetration, wind resistance, durability, and structural stability. Correction of non-durable wall construction places great economic burdens on the building owners, and wastes energy, materials and resources. In this paper, we argue that durability equates conservation of natural resources and reduction of waste materials, and that in building construction "sustainability" should provide durability, to avoid the immense cost and waste associated with "doing it right the second time."

CONCEPT OF SUSTAINABILITY

In one author's (Gumpertz) lifetime, the world's population has risen from about two to six billion people. To help conserve resources and energy in the onslaught of this increased demand, the construction and design industry has embraced "sustainability," a.k.a. "green design." Sustainable design typically includes using energy-efficient building systems, such as HVAC and lighting, that conserve energy and reduce operating costs, increased building insulation to reduce heating and cooling losses, use of "green" (i.e., recycled, abundant, non-toxic, and renewable) materials in construction, and orientation of building on the site to take advantage of passive solar heating and lighting or, conversely, to reduce exposure to the sun and cooling costs.

A designer preaching the benefits of green construction may persuade an owner to spend a substantial amount of money for sustainable building systems and features, with the promise of lowered operating and maintenance costs. In some cases, tax credits, grants or other incentives may guide the owner’s choice to incorporate sustainable elements. Incorporating the sustainable features listed above may even require the owner to choose between spending money on the above-listed sustainable features and wall system components of lesser quality and durability. Failure to design durability into components of the building exterior (or any building system, for that matter) can gravely impact the building owner’s future financial resources, and have the following consequences on our natural resources and the environment:

- Demolition and removal of failed components burdens landfills with valuable resources that are unrecoverable after disposal, including the waste of components that have to be removed (and reinstalled) in the course of replacing the defective materials.

- Consumption of energy and natural resources needed to produce materials for the reconstruction activities. This applies even if, for example, a “renewable” resource, such as brick, is used. Brick must be excavated, burned, transported, and hoisted with non-renewable energy.

The initial cost of constructing the wall system in a durable manner costs little, if any, more money than “doing it wrong.” The long-term benefit of constructing a durable wall system, however, far exceeds the minor, initial cost savings gained by sacrificing quality.

ILLUSTRATIVE EXAMPLES

Below we illustrate some of our experiences with failures within exterior masonry wall systems, resulting from combinations of poor design and construction, and selection of materials unfit for their intended purpose.

A Load-Bearing Masonry Wall System

We investigated leakage problems and deterioration of the exterior brick masonry walls at an apartment complex, constructed about 1950. Each building had load-bearing exterior walls of three wythes of brick. The outer wythe was a red clay brick, continuous vertically from the foundation to the roof line. The two inner wythes were a gray, lime-mortar brick, that supported the perimeter of the concrete floor slabs. Joints between wythes were filled with mortar. Brick headers bonded the wythes together. The owner first recorded leakage into the buildings about ten years prior to our visit. Leakage blistered and peeled paint and plaster on walls and ceilings, and fostered mold growth on damp wall finishes. Water trapped within the walls caused efflorescence, loss of mortar, and corrosion of embedded steel, and spalled the faces off brick. Causes of these problems are summarized below:

- Use of Non-Durable Through-Wall Flashing: Asphalt-impregnated through-wall fabric flashing extended beneath masonry atop the floor slab perimeter and turned up against the inside face of the brick wall. The through-wall flashing had weeps with copper baffles on top of the floor slab about every two feet. The fabric flashing had deteriorated and crumbled; in many locations, only a black residue remained of the flashing (Figure 1). Water bypassed the deteriorated flashing and entered the building at the floor slabs. This type of flashing decays in concealed, moist environments, and is unsuitable for use in exterior wall construction.

Figure 1. Asphalt-impregnated fabric through-wall flashing has decayed; all that remains is black residue in the bed joint.

- <u>Poor Through-Wall Flashing Design and Lack of Drainage Cavity</u>: The through-wall flashing did not extend through the outside surface of the wall, terminating about one inch back from the face of the exterior brick. As was common in 1950-vintage bearing walls, the solid masonry walls lacked a drainage cavity to contain water flow from the outside face of the brick wall to the inside surface of the wall. These defects trapped moisture within the wall system, accelerated the deterioration of the flashing, and contributed to damage and efflorescence staining of the brick beneath.

- <u>Poor Design of Window/Door Lintel Flashing:</u> Unsloped copper flashing covered L-shaped steel window lintels. Flashing terminated at the ends of the window opening without panned-up “end dams” to prevent water from draining off the ends of the flashing and into the wall and to protect the steel lintel beneath from moisture (Figure 2). The flashing’s failure to protect the steel lintel resulted in rusting of the lintel. The rust, which expanded up to about 1/4 inch, cracked the masonry, increasing the rate at which water entered the wall system.

Figure 2. Copper lintel flashing lacks end dams to protect embedded steel, which has rusted and expanded, spalling mortar from the brick joint.

The widespread flashing failure and the general inability of the walls to drain admitted moisture caused rusting of the embedded steel and masonry damage, including cracking, spalling and efflorescence. Poor flashing design and selection, and lack of a drainage cavity caused the failure of this otherwise sound and durable wall system. Preserving these buildings called for recladding the existing exterior walls with an adequately drained wall system, but at the expense of wasting otherwise durable materials.

A Large, Public Building

Our investigation of a large concrete frame building, with brick veneer and concrete masonry backup, started shortly after its construction. The problems of brick construction, roofing design and materials, and venting/air conditioning combined to produce untenable conditions that eventually led to stripping the building to its structural frame. Total repair costs exceeded the total original design and construction budgets. We observed the following defects involving the masonry components of this building:

Construction Defects – Brick Veneer

- Because of out-of-plumb erection of the structural frame, the vertical wall planes deviated from the design substantially, leaving the masonry installer with no control over the width of the cavity between veneer and backup. As a result, anchors were spaced irregularly, with many omitted altogether.

- Control of steel shelf angles at slab levels was non-existent, with overextended anchors, excessive shimming, improperly fastened anchors, inadequately tightened nuts on anchors, and randomly burned holes in angles to fit the anchors. Because of the variable width of the cavity, angles did not adequately support the brick veneer, with some of it supported over less than half the brick width.

- Most angles did not support the brick veneer, but the veneer supported the angles. The "soft joints" designed to be located under the angles were filled with mortar, resulting in a force transfer between veneer panels, with resulting spalling and edge cracking. In many cases, soft joints that were designed to avoid direct force transfer between the bottom of the shelf angle, and the top of the brick veneer, were faked by application of a thin sealant bead in front of a solid mortar joint.

- Many parts of the cavity were clogged with mortar droppings, interfering with the drainage function of the cavity.

Construction Defects – Backup Masonry

- The backup concrete block wall lacked required connection to the underside of the floor slabs and the concrete spandrel beams. Much of the required back-up wall reinforcing was never installed; were it was present, it was not bonded to the masonry because of the lack of cavity grouting. The backup masonry was designed to be connected to the concrete floors, but many anchors were missing. In some cases, the anchors were outside of the masonry, extending into the air of the cavity.

- Many anchors between the backup masonry and the edge of the columns were missing.

Construction Defects – Flashing In many cases, the flashing sagged into the cavity, making it impossible for the flashing to conduct moisture from the cavity to the exterior of the building (Figure 3, right). Polyvinyl chloride (PVC) flashing sheets were poorly installed and even omitted in some locations (Figure 3, left). Transverse flashing joints and flashing corners at windows were often unsealed.

Figure 3. Thru-wall flashing is missing at shaft angles (top left) and roof to rising wall intersections (bottom). Where flashing is present, it is unsupported and unsealed at joints.

Design Defects: Even if the construction of the building had been perfect, the design was unfit for the purpose of a functioning building. The design of the air handling system alone condemned the building to failure; in addition, we found the following serious design errors affecting the masonry and its function to keep water out of the building:

- The flashing was unfit for its intended purpose. PVC sheets are made flexible by addition of plasticizers. Over time, the plasticizers migrated from the plastic sheeting, causing it to shrink and become brittle. In addition, plastic flashing could not bridge cavities or be extended beyond the face of the veneer and terminated to form an exposed, downturned drip edge, necessary to help drain water from the cavity to the exterior.

- At loose window lintels, the design did not provide for “panning” (upturned ends) of the flashing to prevent water from entering the wall and building interior.

- At the intersection of the roof rakes with the brick walls, the brick veneer had surface-mounted, metal expansion joint flashings, sealed along the top edge to the brick face. (Figure 3, bottom). Sealants are hole-fillers, not masonry waterproofers; within a short time, the sealant bond to the flashing and/or the face of the brick veneer failed and allowed water to penetrate into the interior of the building.

- In some locations, the veneer shelf angles were not attached directly to the spandrel beams, but were instead hung from flat strap anchors. Because the straps have insufficient bending resistance to the eccentric load imposed by the brick veneer, the shelf angles rotated. As a result, the veneer brick bulged and allowed water entry into the opened joints. At the ends of the strap-supported angles, the wall rotation produced cracks in the adjoining brick wall, causing more water to enter the wall.

None of the above design and construction defects appear to be major. They are not primarily structural. Yet, by themselves, their effect on the wall’s stability and waterproofing function caused the complete removal and reconstruction of the wall and associated building components.

Brick Veneer/Steel Stud Building

Our investigation of a 10-year old building constructed with exterior walls of brick veneer and steel-stud backup revealed substantial damage to masonry and interior finishes resulting from water infiltration through the masonry and into the building walls. The building had brick masonry veneer walls, with windows set into punched openings. Projected concrete block accent bands ran horizontally beneath windows. We observed the following construction defects involving the masonry components of this building:

- Faulty Installation of Through-Wall Flashings: Through-wall roof counterflashings flashings lacked sealed joints and end dams. Water breached openings in the flashing, entered the ceilings of occupied spaces below and damaged the roofing system. Flashing below roof parapet coping blocks did not extend through the face of the masonry, causing rusting of steel beneath and heaving the coping blocks (Figure 4).

Fig. 4. Flashing beneath these coping blocks terminated behind sealant. The resulting water ingress rusted reinforcing steel beneath the blocks and heaved them upward.

- Failure to Protect Exposed Masonry Surfaces: Block accent bands, which projected beyond windowsills, were partially covered by a sheet metal window sill flashing (Figure 5). The outboard edge of the sill flashing turned down and terminated within a sealant-filled, saw-cut kerf along the top of the block, about one inch behind the face of the block. Over the ten years of the building's existence, water bypassing the sealant and entering the block eroded and spalled the mortar out of the joints between the block and rusted reinforcing steel within the block joints. In some locations the block crept outward and presented a hazard to the public.

Fig. 5. Significant damage has been caused by the termination of sill flashing above the concrete block, and by failure to extend flashing over the face of the block. These defects directed water into the masonry.

- Poor Installation and Design of Window Flashings: Window jamb flashings drained water into the interior wall behind the window instead of into the wall drainage cavity, causing interior finish damage and mold growth. The metal sill flashing terminated behind the sill perimeter joint, trapping water collected on the sill flashing within the wall, saturating and damaging masonry beneath.

SMALL ERRORS – MAJOR CONSEQUENCES

A building's exterior wall system must protect the building occupants, contents and structure from water and other elements, and from unseasonable outside air temperatures. The wall system must also resist structural loads, including wind and seismic loads, and define the appearance and aesthetic character of the building. The exterior wall system must be durable, i.e., it must have the ability to protect itself from weathering and other mechanisms of degradation. Design and construction defects that impair the wall's ability to perform these functions can produce serious effects that escalate into costly repairs or even major demolition and reconstruction that can cost more, by itself, than the initial cost of the building. What has the design profession learned from this type of experience? We present below some "discoveries", based on our observations of small errors resulting in serious damage, that may help conserve resources and reduce negative environmental impact if incorporated into design and construction of masonry wall systems.

Masonry and Wall Waterproofing Design

Exterior wall systems must be designed to capture and drain water from the wall, allow for thermal and other movements within the wall, and for transfer of loads to the structure. The designer must recognize the limitations of different wall system components (such as sealants) which cannot reliably stop water from entering the masonry wall system. Wall weatherproofing component failure can have a "trickle down" effect, causing failure of moisture sensitive components. We list key design considerations below:

- Design for durability: an "expensive" component is usually less costly in the long run, if it does the work reliably, than a "cheap" component. The more inaccessible a component is after construction, the more resistant it must be to the ravages of time, exterior forces, water, and other threats to durability. Replacement of a weathered, but exposed, coating is easy; replacing non-durable through-wall flashing is costly and complicated because of its location. The Brick Industry of America (BIA) Technical Note 7 estimates the lifespan of a durable masonry wall may be 100 years or more. Concealed components such as flashings should have lifespans matching or exceeding the expected lifespan of the wall.

- Through-wall flashing design is critical, since these flashings capture the water that enters the wall cavity and drain the water to the exterior before it can attack moisture-susceptible wall components or enter the building interior. Flashings should have watertight joinery, upturned legs and end dams, slope to drain, sufficient weepage, and should terminate outside the face of the masonry with a downturned drip edge. Failure to design flashing with these elements may accelerate deterioration of the masonry and wall system components, or allow water leakage into the building.

- Durability is not absolute, but a function of use and exposure to weathering. Masonry elements protected from weathering may last for centuries, but may disintegrate within two to three years if exposed to a steady stream of water. Details such as unprotected water tables, unflashed masonry copings, and termination of through-wall flashings behind the face of the masonry (instead of terminating outside the wall with a downturned drip edge) can expose masonry elements to excessive weathering or retain rain and snow that can accelerate masonry deterioration. These non-durable details, which are often used for aesthetic considerations, have no place in masonry construction. As a general principle, all flat and sloped exterior surfaces should be considered to be roofs, and must be designed accordingly. Masonry elements used at non-vertical exposures should be protected by reliable means, such as a metal cap.

- The building should be weathertight before the veneer or sealant is installed. This is a good test for the effectiveness of the masonry wall’s back-up waterproofing system.

- Windows and wall penetrations are particularly vulnerable to water penetration. In many instances, this leakage is caused by use of sealants at window perimeters or penetrations, instead of properly flashing these details. Flashings at these details must be integrated with wall cavity waterproofing to reliably drain water from the cavity.

- Space restrictions may tempt the installer to reduce wall cavity width or to fill it with insulation, thus preventing the drainage of water from the wall, and thereby subjecting the wall to freeze-thaw damage or water penetration into the interior.

- Water trapped or admitted into the wall system due to lack of waterproofing, condensation because of materials with unsuitable vapor resistance, or omission of weepholes, etc. can create an atmosphere favorable to infestation of insects or fungi. Such growths constitute a health risk to inhabitants, and usually cannot be removed without demolition of the involved building components.

- Corrosion-susceptible wall components, such as steel window lintels and shelf angles, must be protected by adequate flashings, and should be hot-dip zinc coated. When moisture exposure creates rust, the associated expansion of the corrosion product can exert very high compressive forces on a masonry wall, causing major damage to the brickwork and its anchorage. Corroded anchors can lead to collapse of brick veneer.

- Failure to provide “soft” joints at shelf angles allows the transfer of vertical forces between masonry veneer sections. In multi-story buildings, this can lead to a transfer of gravity forces from the structural frame of the building to the brick veneer as the frame compresses due to concrete creep and as the brick expands due to gradual moisture takeup and thermal effects. This can cause cracking and spalling of brick veneer; eventually it can cause buckling, loss of anchorage, and collapse of veneer. Soft joints should be provided at these support conditions to accommodate building frame creep, brick expansion, thermal movement, and floor-to-floor deflections.

- Horizontal moisture expansion and thermal movement of brick can cause buckling, or even horizontal, outward migration of brick veneer past building corners. It can also cause cracking of concrete foundations at building corners when the friction between the veneer and the concrete can overcome the tensile strength of the concrete. All clay brick walls need vertical relief joints to accommodate the brick's tendency to expand for a long time after manufacture. Vertical control joints should be provided to accommodate brick expansion and thermal movement of the veneer at building corners and at regular intervals.

Masonry and Wall Construction

To help avoid construction problems, we recommend the following advice: "If everything else fails, read the directions." For success in construction, the best protection against problems is prevention, usually in the form of proper drawings and specifications. Sketchy design documents, which leave it to the installer to "design in the field", can be disastrous. For example, we have seen countless contractors who believe that the brick veneer and joint sealants (not the cavity waterproofing and through-wall flashings) keep all the water out of the building; they install flashings and waterproofing with little regard to their importance. In our experience with defective masonry, we have encountered the following workmanship defects:

- Deviation from a predetermined and vertical plane for a masonry wall. This is usually the result of a poorly erected structural frame. Lack of proper fit (or skill in erection) can cause the frame to be out of plumb. The masonry contractor may increase or decrease the cavity width, to help compensate for the out-of plumb frame to avoid an irregular brick face. If the resulting cavity is too narrow, it may interfere with the prompt drainage of penetrating water because mortar droppings may block and bridge the cavity, transferring water to the building interior. If the resulting cavity is too wide, the bonding of the veneer to the masonry or steel stud backup may become difficult, due to the increased buckling potential of veneer ties. Deviation from the specified cavity width may tempt the contractor to ignore the specified geometry, to use unsuitable or unspecified anchors, anchor into "thin air," or to omit anchors altogether.

- Violation of basic workmanship principles dealing with mortar placement, including failure to fill mortar joints, can result in poor and incomplete bond between brick and mortar. Failure to keep the cavity free of excess mortar can bridge the cavity, allowing water to enter the building interior and impeding drainage.

- In an attempt to place the brick veneer to a proper line, the mason may be tempted to move the veneer too far out from the steel shelf angle, resulting in inadequate veneer support. Bricks should be supported at least two-thirds of their width by supporting shelf angles, to provide adequate support and reduce tendency for veneer bending.

- If joint reinforcing, seismic anchorage, or special ties are required, experience shows that proper placement can be compromised, especially if these components are difficult to install. Improper placement or omission of these components may compromise the strength of the masonry wall.

- The quality of the bricks must be sufficient to satisfy the requirements of the design. Potential defects include softness (insufficient strength), poor freeze-thaw resistance (usually correlated to high water absorption), and high efflorescence potential.

- Poor execution of the through-wall flashing design, including leaky transverse joints, omission of end dams, termination of flashings within the wall instead of extending flashing through the face to form a drip edge, and failure to overlap the upstanding rear flashing leg with the cavity waterproofing, can allow water penetration through the exterior wall system and can accelerate masonry deterioration.

- Failure to keep the soft joints under shelf angles free of mortar, thereby transmitting vertical forces across the joint between panels. Panels above and below these joints should be allowed to move independently.

- With hollow block or steel stud backup, it is easy for the installer to miss secure anchorage points for the veneer ties, causing insufficient lateral support of veneer .

As stated above, the best protection against problems is prevention. Methods of protecting against construction problems, defects, and shoddy workmanship include:

- Have a competent field inspector on-site during construction to “encourage” the contractor to produce a quality installation, and detect problems before they are concealed within the wall.

- Use only qualified tradesmen and mechanics. Take the time to select bidders based on their qualifications and past workmanship, and award contracts on merit, not solely on price. It is unfortunate that many building owners opt for (and many public bid laws require) awarding construction contracts to the “Lowest Bidder,” which often guarantees substandard workmanship.

- Test, test, test. Even simple field quality control measures such as testing flashings for leakage with a hose, before installation of the veneer, can isolate problems before they become concealed within the wall system.

CONCLUSION

Durability is a key factor in resource conservation and reduction of waste and pollution.

The concept of durability, and building things to last, has been around for time immemorial, far longer than the relatively new concept of sustainable design. As two out of three little pigs can attest, the use of “sustainable” wall materials unsuited for their intended function or in conjunction with a poor design does not guarantee a sustainable finished product. Wasted material, be it renewable, recyclable, or from abundant resources, is still wasted material.

Just as sustainable design considers energy, life-cycle and operating costs it, too, must consider costs, both economic and in terms of environmental impact, associated with providing (or failing to provide) durable construction. Key decision-making criteria used in green construction, such as operating costs and energy consumption, are not easily quantified when developing post-construction costs for durable versus non-durable wall system construction. Presenting an “operating budget” for durable construction in the conventional sense, therefore, is probably not practical. In some cases, shoddily constructed buildings may perform without problems for a long time (it is usually difficult to guarantee that a building will fail). The owner should be made aware of the potential consequences of “cheap” construction, just as the owner is made aware of the benefits of other sustainable building features.

Sustainability is not only a function of use of rare or irreplaceable resources versus using renewable resources, but of making every building component work effectively – the first time. Few building materials are renewable. Many are salvageable. Most are irreplaceable. Ensuring that installed materials will enjoy a long service life and will not have to be wasted to fix careless defects that could have been easily avoided will eliminate the waste of materials, energy and money, and will conserve resources and reduce the waste burden for future generations.

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