Much Ado about Sandstone: Technical Guidelines for Selecting New Sandstone for Localized Use in Preservation Projects to Balance Long-Term Durability and Compatibility with the Existing Stone

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ABSTRACT

North America and the British Isles both have a rich architectural heritage of buildings with sandstone facades. Lewis Mumford famously termed 1865-95 "The Brown Decades," but the widespread use of sandstone extended well beyond these decades, and well beyond "brownstone" (brown sandstone), to encompass a broader range of sandstones spanning several centuries.

Preservation professionals often face two profound dilemmas:

1) Many historic sandstone quarries are now closed, thus obtaining stones from the original quarry for use in preservation is often not possible.

2) Some sandstones were notoriously non-durable in the climate in which the building was constructed, and have been failing badly for decades. How do we avoid repeating this durability problem, while respecting the original historic fabric, and while not creating new problems by introducing localized "harder" sandstone in contact with a "softer," less durable weathered original stone?

Both dilemmas evoke the same difficult question: "Where the original stone has proven non-durable, and is failing badly, how should localized replacement stone be selected to balance compatibility and historic appropriateness with improved durability?"

The authors present a broadly applicable guideline of principles and approaches for preservation professionals to consider in selecting suitably durable sandstone for localized use in preservation projects where the original stone is no longer available, and the original stone is deteriorating.

KEYWORDS

Sandstone, brownstone, selection, specification

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THE RISE AND FALL OF SANDSTONE FACADE CONSTRUCTION IN THE 19TH AND 20TH CENTURIES

North America and the British Isles both have a rich architectural heritage of sandstone buildings. Lewis Mumford famously termed 1865-95 “The Brown Decades” [1], but the widespread use of sandstone extended well beyond these decades, and well beyond “brownstone” (brown sandstone), to encompass a broader range of sandstone colors and types spanning three centuries in North America, and many more centuries in the British Isles. In addition to these locations, where the authors’ experience lies, sandstone is used worldwide, in a broad range of climates, from the grandest to humblest buildings, from Harlem to Edinburgh to Angkor Wat, rendering the applicability of the guidelines presented herein much broader.

A peak in construction with stone masonry in both North America and the British Isles occurred in the late 19th century, coinciding with the advent of the railroad and the industrial era. However, moving into the 20th century, with the onset of the World Wars and the Great Depression, came the decline of constructing building walls with natural stone, as lower-cost materials, such as brick, terra cotta, and cast stone, gradually reduced the use of natural stone, including sandstone. Post-war rebuilding programs, especially in Europe, trended toward lower-cost building materials, and when they did use stone, it tended to be thinner, further reducing the demand for the volume of stone quarried. Throughout this time, many quarries in both North America and Europe closed [2].

In recent decades, a small number of closed quarries have occasionally re-opened, often primarily for preservation, such as Cullalo Quarry in Scotland, which reopened in 2004 [3], and the Portland Brownstone quarry near Portland, Connecticut, US, which reopened in 1994, and closed again in 2012 [4]. However, despite these laudable efforts, the fact remains that only a fraction of the quarries that were used to construct the sandstone buildings in the later 19th and early 20th centuries remain open today; thus, procuring stone from the original quarry for preservation work often is not possible. For example, fewer than ten stone quarries remain open in Scotland today, while in 1860 over 1,200 were open [3]. In the United States, over 500 quarries existed in 1880 [5], with merely 17 open in 2025 [6]. Parallel histories exist elsewhere, of high numbers of sandstone and other stone quarries operating in the 19th century, but only a fraction of those quarries open today.

THE DILEMMA OF SELECTING SANDSTONE FOR PRESERVATION

Sandstone, like all building materials, deteriorates. In comparison to other common building stones, such as granite, limestone, and travertine, many sandstones are relatively less durable and more prone to significant deterioration. Thus, new sandstone is often needed for localized repair and preservation work on heritage buildings. Ideally, the new sandstone used for localized repairs should be aesthetically matching and technically “compatible” (similar in its key technical properties) with the original stone. However, when the original stone has performed poorly and is highly deteriorated, choosing a new stone is not always as simple as going back to the original quarry, or finding the closest match to the technical properties of the original stone, for the reasons outlined below.

1) Many of the historic sandstone quarries are now closed, thus obtaining stones from the original quarry for use in facade preservation is often not possible

2) Some specific sandstones were notoriously non-durable in the climate in which the building was constructed, and have been in poor condition for many decades, sometimes creating public safety falling hazards from severe stone deterioration. How do we avoid repeating/recreating this durability problem and safety hazard for future generations, while at the same time respecting the character and authenticity of the original fabric, without creating entirely new problems by introducing localized areas of new stone that is

more durable, but “harder” and incompatible with the surviving original “softer,” weaker, less durable sandstone?

Both these dilemmas lead to the same difficult question: "How should new stone be selected for use in preservation to best balance long-term durability with compatibility of the new stone with the older, and often “softer,” less durable, weathered original stone? In some cases, the answer to this question is simple, while more often it is complex, as further discussed below.

The Simple Cases

Selecting a suitable new stone for preservation work is generally simple in cases where BOTH of the following are true:

- time and the elements have shown the existing original stone to be generally durable in the climate in which the building was constructed (e.g., if most of the stone on the building is generally in good condition), AND,
- the original stone used to construct the building is still available (either the original quarry is still open, or stone from the original quarry is available from a stockpile or from salvaged sources).

In the simple case where both these statements are true, using stone from the original quarry for the preservation is technically, aesthetically, and historically appropriate.

The Complex Cases

However, in cases where one or both of the statements above are false, selecting a suitable stone for preservation work is far more complex. If the original stone is not available, what technical properties should we seek in a new stone for use in preservation? If the original stone used to construct the building is available, but the stone on the building has deteriorated badly and proven not suitably durable in the climate, then despite the historic authenticity of such an approach, will reusing the stone from the original source only perpetuate the durability and safety problems for future generations? However, if we use a “harder,” more durable stone for localized preservation (e.g., partial stone replacements, “dutchman” repairs, etc.), will we simply exacerbate the deterioration of the older, “softer,” weaker, adjacent original stone, by putting it in direct contact with a “harder”, stronger new stone?

FURTHER CONSIDERATIONS FOR THE COMPLEX CASES

Exposure

As water is the foremost agent of deterioration of sandstone, the different exposures to water of different existing stones on different areas of the same building significantly affect their rate of deterioration and, hence, their durability. Figure 1 illustrates some common severities of exposure on an example building.

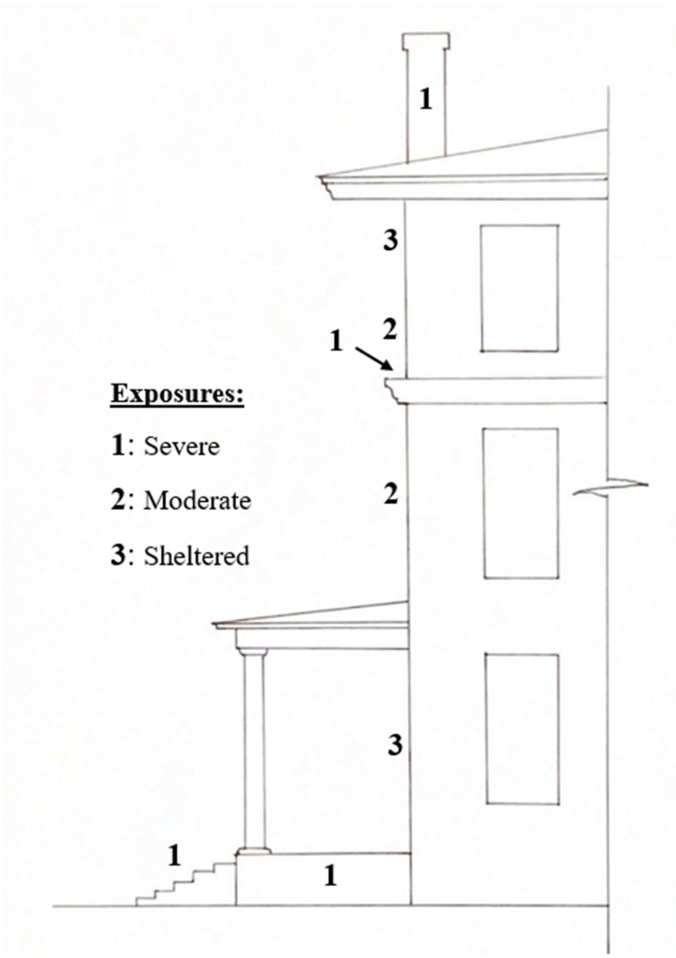

Figure 1: Building Diagram Showing Some Common Relative Exposures

We define these three exposures as follows:

Moderate Exposure: Areas of the building or structure with the typical exposure of vertical wall surfaces that are neither sheltered by overhangs, nor are they exposed to a more severe exposure as described below.

Sheltered Exposure: Areas of the building or structure that are more sheltered from precipitation and moisture than the typical exposure of vertical wall surfaces, such as areas sheltered by an overhanging roof, cornice, or porch, that are not in contact with grade.

Severe Exposure: Areas of the building or structure that create a more severe environment or microclimate for stone durability than the typical unsheltered vertical wall surface. These tend to fall into three general categories, as follows.

- Elements at grade, such as exposed foundations and water tables, are often subjected to rising damp, rain splash-up, and accumulated snow, slush, and deicing salts in cold climates.
- Sky-facing surfaces, such as stone surfaces that are uncapped and exposed to the sky at ledges, band courses, projecting window hoods and sill, and unsheltered steps, are subjected to increased horizontal surface area for rain and snow to accumulate on and be absorbed into the stone.

- Rooftop elements, such as parapets, chimneys, towers, pinnacles, and steeples are subjected to precipitation on all sides, and often receive less heat from the interior than the typical vertical wall surfaces of occupied floors of the building.

The overall severity of the climate with respect to stone deterioration is a significant factor in creating a diagram such as Figure 1 for any building under consideration. For example, if a diagram such as Figure 1 were created for a sandstone building in Washington D.C., we would expect the rating of each element to be more severe for an identical sandstone building in Quebec City, and we also expect the rating for each element to be less severe for an identical sandstone building in Santa Fe, New Mexico. However, we provide this schematic diagram to indicate the relative severity of some common architectural elements on the same building, in the same climate. While the diagram in Figure 1 illustrates architectural elements on one elevation, it is important to note that even an identical architectural element on the same building in the same location may have a more severe or a less severe exposure depending upon the orientation of the elevation. For example, on buildings in the northeastern United States, we have found that identical architectural elements in identical locations on the facade are often more deteriorated on the north elevation than on the south elevation, for two reasons: the north elevation receives significantly more wind-driven rain than the south, and the north receives little if any solar drying. Thus, in the northeastern US, the north elevation typically gets wetter and stays wetter longer than the south elevation. As another example, we've found that for buildings directly on the seacoast, the elevation facing the ocean deteriorates more quickly than the other three elevations (as a result of salt spray, storm direction, wind fetch, etc.), regardless of cardinal orientation. Although water is the foremost agent of the deterioration of stone, other factors also contribute to deterioration rates and severity of exposure. In cold northern climates, where freeze/thaw cycling is significant, and where deicing salts are often used in winter, we often find that sandstone near main doors and at entrance steps and stoops, the stone is much more severely deteriorated than similar areas elsewhere on the building as a result of heavy use of deicing salts each winter. As most heritage stone buildings have had little or no insulation for most of their history, heating the building has tended to mitigate freeze/thaw damage, both by warming the exterior walls, and also by increasing the drying potential of those walls to the interior. Thus, we often see that architectural elements that receive little or no interior heat, such as buttresses that project significantly beyond the main plane of the facade, unheated towers and spires, and unused cold chimneys, etc., are often more severely deteriorated than similar elements that receive more interior heat.

Condition of Existing Stone

Given the significant variation in the severity of different climates to stone deterioration, the significant variation of exposures and microclimates on an individual building, and the significant variation in the general durability and material properties of various sandstones, and sometimes even the difference in durability of different veins and beds of stone within the same general quarry, the condition of the existing, original stone on a heritage building provides incredibly valuable highly specific data of how all those highly variable factors have played out, over many decades, sometimes over more than a century, and the level of deterioration (or lack thereof) that has resulted on each specific elevation and architectural element of the building. For these reasons, the condition of the existing stone contributes significantly to our recommendations for the selection of new stone, as further described in the recommendations section below. The condition of the existing stone on a building often varies considerably in the different exposures illustrated in Figure 1. For example, we often see roughly century-old buildings where the original sandstone in sheltered and moderate exposures is in relatively good condition, but the stone in one or more of the severe exposures (e.g., sky-facing surfaces, water table, stoop) is in poor condition. In these circumstances, where stone from the original source is available, to simply replace the badly failed stone with stone from the same source and not change anything else would simply recreate and repeat the same problem for future generations. Two possible options to mitigate the problem are to use a more durable stone in these areas, or, in some cases, to mitigate the microclimate itself. The two general approaches are not mutually exclusive; they may be used together. As the topic of this paper is sandstone selection, we focus herein on the former. Regarding the latter, examples of some strategies that preservation professionals can consider to mitigate the microclimate in certain cases are:

- Mitigating deterioration at sky-facing surfaces such as the tops of ledges and window hoods by capping those sky-facing surfaces with a relatively watertight material, such as metal flashing, slate or clay tile roofing, glazed terra cotta coping caps, etc. Such treatment of sky-facing surfaces were part of the original design of some, but certainly not all heritage buildings.
- Mitigating deterioration at grade from rising damp by installing a horizontal damp proof course in the base of the masonry wall, and improving site drainage to slope away from the base of the building on all sides.
- Mitigating deterioration from deicing salts by switching to coarse traction sand (rather than deicing salts) for all but the most extreme events, and then using more gentle chemical deicers rather than traditional deicing salts in extreme events.

In other cases, practical, relatively inconspicuous means to mitigate a severe microclimate may not exist. For example:

- When a seacoast building has a severe exposure on its seaward elevation.
- When a building in New England has a severe exposure on its north elevation from prevailing wind-driven rain and lack of solar drying.

Time is also a factor in the condition and demonstrated durability of in-situ stone. If two different types of stone on two different buildings in the same city with the same exposure are in very similar condition, but one building is 100 years old, while the other is 500 years old, obviously the stone on the older building has proven more durable over time. Thus, new stone from the same quarry as the 500 year old building has greater prospects for future durability than new stone from the same quarry as the 100 year old building.

Mortar

Regardless of the stone chosen, the mortar chosen must always be appropriate for use with the stone, as well as for the climate/ exposure, as recommended in Preservation Brief #2 [7]. In any stone or brick masonry building, the mortar should always be the weak link (meaning if something fails in the masonry, it should be the mortar rather than the stone or brick), thus the mortar should always be of significantly lower strength than the unit masonry (e.g., the stone or brick). While this is true in any project, it is particularly critical in buildings constructed with a relatively low-durability stone.

RECOMMENDATIONS

The Simple Cases

For the simple cases as previously described (where time and the elements have shown the existing stone to be durable on the building, and the stone is available from the original source), we recommend using stone from the original source when stones are needed for repair or preservation.

The Complex Cases

Tables 1 and 2 and our related text below summarize the suggestions we recommend preservation professionals consider when selecting new sandstone in the Complex Cases as defined herein. We acknowledge that each individual building presents a unique set of existing conditions and circumstances, so we do not intend these as hard and fast inflexible rules, but rather as additional information for a preservation professional to review and consider in their decision making process for these complex cases.

Table 1: Relative Durability Levels of Sandstone

Relative Durability	**Absorption, max. (%)** per ASTM C97 [8]	**Density, min. (g/cm^3 (pcf))** per ASTM C97 [8]	**Compressive Strength, min. (MPa (psi))** per ASTM C170 [9]	**Standard Classification for quartz-based stone,** per ASTM C616 [10]
Most Durable	1%	2.56 (160)	138 (20,000)	Type III - Quartzite
	2%	2.48 (155)	90 (13,000)	Type II – Quartzitic Sandstone
	3%	2.40 (150)	69 (10,000)	
	4%	2.32 (145)	59 (8,500)	Type I - Sandstone
	5%	2.24 (140)	48 (7,000)	
	6%	2.16 (135)	40 (5,750)	
	7%	2.08 (130)	33 (4,750)	
	8%	2.00 (125)	28 (4,000)	
Least Durable	9% or more	1.99 (120) or less	24 (3,500) or less	None

Note: The gray rows above come directly from ASTM C616, where they define the minimum standards of Type I, II, and II quartz-based stones. The other rows were created by the authors to introduce additional intermediate steps between these defined standards where many sandstones on heritage buildings test; for these lines we approximated common relative density and compressive strength values from curves we plotted of various sandstone test results.

We define the symbols and terminology used in Table 2 as follows:

>> Use a stone that is significantly more durable - if the existing stone absorption is greater than 4%, use a stone with 4% absorption or less, and if the existing stone absorption is 4% or less, use a stone one row above in Table 1

> Use a more durable stone – at least one row above in Table 1

≥ Use a stone that is equal to or slightly more durable than the existing – the same row or one row equal or above in Table 1

= Use a stone that is as close as possible to the existing – within one row above or below in Table 1

R Priority for replacing all stones in an entire element with new more durable stones

Element: An entire architectural element or feature composed of many stones, such as a water table, chimney, ledge, or stairs.

Exposure: The highly localized exposure and microclimate that different stones on the building are subjected to, including exposure to rain, snow, rising damp, deicing salts in northern climates, etc. Severe, Moderate and Sheltered exposures are as previously defined in this paper.

Good Condition: Overall the area of stone has little noticeable deterioration, and any deterioration is very limited, localized, and minor, and does not compromise the overall strength or integrity of the stone, such as surficial surface erosion, shallow scaling, or hairline cracks.

Fair Condition: Overall the area of stone has a fair amount of noticeable deterioration, which may include deeper loss of surface from erosion or scaling, and wider cracks, but does not compromise the overall strength or integrity of the stone element.

Poor Condition: Overall the area of stone has widespread and more severe deterioration that may include severe loss of surface depth, stone cross section, strength and hardness, and may include stones with severe cracks and stones that have become friable.

Whole Stone Replacement: Removal and replacement of an entire individual existing stone on a building.

Partial Stone Replacement: Removal and replacement of only a portion of an individual existing stone on a building, often colloquially referred to as a "dutchman" repair in the US or an "indent" in the UK.

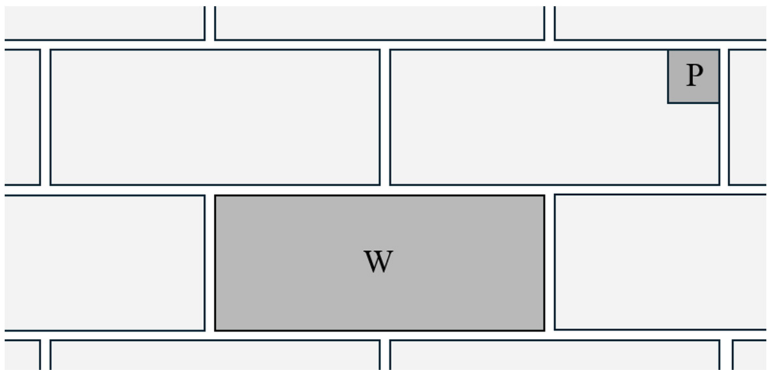

Figure 2: Diagram of Whole Stone Replacement (W) versus Partial Stone Replacement (P)

Table 2: Suggestions for Selection of Sandstone for Whole Stone Replacement*

Exposure	**Condition of existing stone on building****		
	Poor	**Fair**	**Good**
Severe (e.g., elements at grade, sky-facing elements such as ledges and unsheltered stairs, and rooftop elements such as pinnacles, chimneys, etc.)	>>, R	>	≥
Moderate (e.g., planar vertical wall surfaces, the field of the wall)	>	≥	=
Sheltered (e.g., sheltered beneath overhanging elements such as cornices, porches, porticoes, etc.)	≥	=	=

Notes:

*Table 2 is for Whole Stone Replacement only. For Partial Stone Replacement, we recommend = in all cases (matching the existing stone properties as closely as possible) for compatibility reasons that are further discussed in the text that follows.

** Examples of Poor, Fair, and Good condition of existing stone on building are shown below.

Figure 3: Examples of Sandstone in Poor Condition

Figure 4: Examples of Sandstone in Fair Condition

Figure 5: Examples of Sandstone in Good Condition

Potential Design Strategies for Implementation during Preservation

In simple cases where stone from the original quarry is being used for all restoration work, the key technical properties of the new stone and the existing stone will be nearly identical, resulting in no concern with technical incompatibility between the new and existing stone.

In complex cases, especially those where a significantly stronger, more durable new stone will be used in the restoration work (e.g., as denoted by symbol >> in Table 2), concerns arise with technical incompatibility of the new stone with the existing one. The specific concerns are that the increased strength, hardness, and durability of the new stone, in direct contact with the older, softer, weaker original stone could cause edge spalling of the older original stone, particularly if the two stones also have different coefficients of thermal expansion/contraction. A related second concern is that the lower absorption of the new stone will force water that naturally migrates out of the wall (e.g., as the wall dries out after a rain event) to follow the path of least resistance, migrating around a partial replacement new stone in a larger old stone, concentrating increased water content at the interface between the old stone and new stone, and further exacerbating accelerated deterioration of the older, weaker, more absorptive stone, along the line of its interface with the new, stronger, harder, less absorptive stone.

For these reasons, one overriding principle that we utilize and recommend others utilize in such cases (new stone is significantly stronger, more durable, and less absorptive than the existing stone), is the following:

- Design the restoration work such that the new stone is never used in direct contact with the existing stone.
  - Rather, design the restoration such that there is always a mortar joint between the new and existing stones, with a mortar joint that is softer, weaker, and more absorptive than the existing stone.

- Thus, the mortar joint becomes the intentional weak link between the two stones, so that any distress or deterioration from an incompatibility of strength, hardness, absorption, or thermal expansion/contraction will occur in the weak link mortar joint rather than in either of the two stones.

The fundamental outcomes of employing this principle are to:

- When using stronger new stone, only use it for whole stone replacements (which always have a mortar joint on all sides to separate the stone from direct intimate contact with any other stone).
- Never use stronger new stone for partial stone replacements (e.g., "Dutchman repairs" or "indents"), which are by definition in direct intimate contact with the existing "parent" stone.
- Use only original stone for partial stone replacements, which are by definition in direct intimate contact with the existing stone, so that the properties of the two original stones in direct contact are essentially identical, both aesthetically and technically (Figure 6, the letter P indicates the partial stone replacements using original stone).

Figure 6: Example of Partial Stone Replacements Using Salvaged Original Stone

The design question then becomes, if stone from the original quarry is not available, where will the original stone for use in partial repairs come from? The design strategy we have employed in these situations, and that we suggest other professionals consider, is to "harvest" original stones from the building for use in partial stone replacements. Three potential opportunities for harvesting are:

- Unfinished attic or cellar spaces: Occasionally, buildings have unfinished attic or cellar spaces with rough-cut original sandstone exposed at the interior face of the wall. In such cases, original stones can be harvested (removed), replaced with new sandstone, and the original stone can then be cut and used for multiple partial stone replacements on the facade.

- Deteriorated facade stones: Where a significant portion of a facade stone is deteriorated beyond repair, but other portions of the same stone remain sound and intact, the entire stone can be removed and replaced with a new stone. Then, the deteriorated and unsound portions of the removed original stone can be cut off and discarded, and the remaining sound portions of the original stone can be cut and used for multiple partial stone replacements on the facade.

- Entire architectural elements: As indicated in Table 2, in some cases an entire architectural element with a severe exposure (e.g., a water table at grade, a projecting ledge, an unused chimney) is in poor condition with widespread deterioration, whereas in other areas of the facade the stone is in relatively good condition, and requires only localized repairs. In these situations, time and exposure to the elements have demonstrated that the original stone was adequately durable for the majority of the facade, but not for the severe exposure area and element. In this situation, ALL stones at the deteriorated severe exposure area (e.g., the water table at grade in Figure 6) can be removed and replaced with new (significantly more durable) stones that are suitable for the severe exposure, where the original stones were not. Then, the deteriorated and unsound portions of the removed original stones can be cut off and discarded, and the remaining sound portions of the original stone can be cut and used for multiple partial stone replacements elsewhere on the facade, where time and the elements have shown the original stone to be suitably durable. In terms of preservation/conservation philosophy, some arguments against this approach are that it is not taking a minimalist, "less is more" approach to conservation and is removing and relocating some portions of intact sound stone. One preservation philosophy counterpoint against this argument is that time and the elements have clearly demonstrated that the original stone cannot last in this severe exposure, and if left in place it is just a matter of time before the remaining original stone is lost to deterioration. Thus, by removing it now, and using it for localized repairs in areas of the facade with gentler exposures, one can save original historic fabric that would otherwise be lost, and thereby preserve more original historic fabric over the long term.

Figure 7: Replacing and Harvesting Stone at an Entire Architectural Element

ACKNOWLEDGEMENTS

We acknowledge the remarkably useful table "Suggested Mortar Types for Different Exposures" in *Preservation Brief 2* [7] as inspiring our general form for Table 2 in this paper, and we thank its authors and contributors. We thank the many building owners who entrusted us to work on their sandstone buildings, for that was where our thinking on this topic both began and evolved. We thank our colleagues at Simpson Gumpertz & Heger Inc. and Ramboll UK for their encouragement in writing this paper.

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