THE CHOICE IS YOURS: CONSIDERATIONS & METHODS FOR THE EVALUATION & SELECTION OF SUBSTITUTE MATERIALS FOR HISTORIC PRESERVATION

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To my family,

for their constant love and support—

and for always telling me that

"engineers can do anything"

…even Historic Preservation.

Thank you.

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CHAPTER 1: INTRODUCTION

For the past several decades, the field of preservation of historic buildings in Europe, the United Kingdom, and the United States of America has placed significant emphasis on material authenticity. The repair of deteriorated features is recommended over replacement whenever possible, and in cases where severe deterioration warrants replacement, in-kind replacement is preferred. However, in light of practical performance and cost requirements, as well as the decreasing availability of historic natural materials or craft techniques, preservation practitioners may have to turn to substitute materials to replace historic elements with increasing frequency.

The use of substitute materials in building construction is not new. Less expensive and more readily available materials have been used to imitate other architectural materials for centuries. For example, stone has been replicated using sand-painted wood, scored stucco, terra cotta, cast stone, cast iron, and various other substitutes. Today, substitute materials are sometimes used by preservation practitioners to replace severely deteriorated historic features. Substitutes may be selected because the original material or craft technique is no longer available, or because the substitute material offers equal or superior performance and durability at a lower cost. Whatever the reason, the reality is that substitute materials have become a common solution in contemporary preservation practice.

In the 1980s and early 1990s, the field of preservation addressed the proliferation of substitute materials on historic projects. Several publications, including a National Park Service (NPS) Preservation Brief, were released, offering guidance to preservation practitioners considering substitutes.[1] Since the early 1990s, there has been little published writing on the subject. Today, new issues warrant another look at the implications that substitutes can have for preservation.

The growing sustainability movement has placed renewed emphasis on environmental awareness. In coming decades, with the changing availability of energy and resources, material availability, cost, and environmental impact will play an increasingly important role in decisions pertaining to historic buildings and their preservation. In-kind replacements of certain historic materials such as natural stone or wood may not always be available, or the economic or environmental cost of obtaining them may be prohibitive. The current interest in sustainability has led to the introduction of a wide variety of new "green" or environmentally friendly materials. While these materials are generally found in new construction, it is likely that they will also be considered for use in existing and historic buildings in future years; therefore it is important that preservation practitioners have the knowledge and tools for successful evaluation and selection of substitute materials for historic buildings.

In addition, the preservation of mid-to-late 20th century architecture and materials, especially mass-produced and manufactured materials, will require new philosophical approaches to substitute materials in historic preservation. Over the past decade, several authors have written about the "growing argument for a preservation philosophy that

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[1] Sharon C. Park, *Preservation Brief 16: The Use of Substitute Materials on Historic Building Exteriors* (Washington, D.C.: National Park Service, Technical Preservation Services, 1988).

privileges conceptual aesthetics and the architect's intent over the constructed realities."[2] Substitute materials may be desirable for projects where the goal is to recreate the original design intent, especially if the original material performed inadequately. Many mid-20th century manufactured materials and components, such as J.J. Earley's architectural precast concrete panels and early curtain wall construction, were incorporated into buildings at a nascent stage of development, before durability and quality control issues were resolved; this may complicate their retention or replacement today.[3] Preservation practitioners should consider evolving preservation philosophy alongside technical and economic considerations when evaluating and selecting substitute materials.

In light of the above, this thesis seeks to answer the following questions:

- Is adequate guidance available to preservation practitioners for the evaluation and selection of substitute materials?
- What considerations are necessary when evaluating and selecting substitute materials?
- Is a new method necessary to better equip preservation practitioners to make decisions about substitute materials within the framework of preservation philosophy, material properties and performance, economics, and sustainability?

This thesis is not a survey of all available substitute materials and their properties, but instead focuses on the process and methods for evaluation and selection of materials. The result is an inventory of necessary considerations for evaluation, as well as suggestions for a method that can be used by preservation practitioners to select (or reject) substitute

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2 Frank Matero and Robert Fitzgerald, "The Fallacies of Intent: 'Finishing' Frank Lloyd Wright's Guggenheim Museum," *APT Bulletin* 38, no. 1 (2007): 3-12. This article cites many of the key works on the preservation of modern architecture.

3 Ellen Buckley, "The Interplay of Technology and Durability: The Evolution of 20th Century High-Rises and Implications for Preservation Philosophy" (M.S. Thesis, University of Pennsylvania, 2008), and Jenna Cellini, "The Development of Precast Exposed Aggregate Concrete Cladding: The Legacy of John J. Earley and the Implications for Preservation Philosophy" (M.S. Thesis, University of Pennsylvania, 2008).

materials within the contemporary context of preservation philosophy, material properties and performance, economics, and sustainability.

DEFINITIONS: IN-KIND VS. SUBSTITUTE

Throughout this thesis, the difference between replacement *in-kind* and replacement with a *substitute material* is a key concept. Replacement *in-kind* usually refers to replacement with the same material. The term *substitute material* usually refers to the use of a different material, or any replacement that is not *in-kind*. However, there is some ambiguity surrounding the term *in-kind*. The United States Occupational Safety and Health Administration (OSHA) defines replacement in-kind as "a replacement which satisfies the design specification."[4] *The Secretary of the Interior's Standards for the Treatment of Historic Properties* also uses the term, but without a formal definition.[5] Under the heading, "Limited Replacement In Kind," the *Standards* state, "The replacement material needs to match the old both physically and visually, i.e., wood with wood, etc.," and "The new work should match the old in material, design, color, and texture."[6]

Ambiguity stems from the degree of match that is implied by the term *in-kind*. Some preservation practitioners would argue that replacing "wood with wood" does not necessarily constitute replacement in-kind. The properties and performance characteristics such as strength and rot-resistance vary between different species of wood, but they can also

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4 Occupational Safety and Health Administration, "Final Rule on Process Safety Management of Highly Hazardous Chemicals; Explosives and Blasting Agents," 29 CFR Part 1910, Department of Labor, 24 Feb 1992, http://www.osha.gov/pls/oshaweb/owadisp.show_document?p_table=FEDERAL_REGISTER&p_id=13207.

5 Kay D. Weeks and Anne E. Grimmer, *The Secretary of the Interior's Standards for the Treatment of Historic Properties with Guidelines for Preserving, Rehabilitating, Restoring & Reconstructing Historic Buildings* (Washington, DC: US Department of the Interior, 1995).

6 Ibid., 20, 25.

vary significantly between new- and old-growth wood of the same species. The degree of match implied by the term *in-kind* can also be unclear when considering natural stone replacement. The properties and performance characteristics such as color, composition, porosity, permeability, and resistance to weathering vary between different geological types of stone, but they can also vary significantly within the same type of stone.[7] Stone from different quarries, or even different locations within the same quarry, may perform quite differently.

Similar concerns may arise when considering the replacement of man-made materials. Modern machine-made reproductions of historically handmade materials such as bricks, terra cotta, or cast stone, will have significantly different properties than the original materials. The differences can include, for example, straighter, truer surfaces, free of the irregularities that characterize handmade materials, more uniform colors, or even differences in density and durability.[8] Even when steps are taken to replicate historic materials with traditional methods of fabrication, there will always be subtle differences.

When considering any replacement material, whether in-kind or substitute, it is necessary to ask questions regarding properties and performance characteristics. Simply specifying replacement in-kind will not automatically ensure a compatible match. The distinction between replacement in-kind and replacement with a substitute material is not a hard line, but instead, it is more of a gradient based on the degree of match between material properties and performance characteristics. Though the focus of this thesis is primarily on

[7] These considerations for in-kind replacement are also discussed by Theodore Prudon in his article: "Substitute Materials Find a Place in Preservation," *Commercial Renovation* 11 (June 1989): 36-41.
[8] Prudon, 38, and de Teel Patterson Tiller, *Preservation Brief 7: The Preservation of Historic Glazed Architectural Terra Cotta* (Washington, D.C.: National Park Service, Technical Preservation Services, 1979).

substitute materials, the considerations and methods presented are equally applicable for all types of historic material replacements ranging from in-kind to substitute.

METHODOLOGY

First, a historic and contextual literature review was undertaken to provide justification and background for this thesis (Chapter 2). Following this initial review, additional literature was consulted to determine the methods and considerations that preservation practitioners use to evaluate and select substitute materials today. Sources consulted include scholarly journals, conference proceedings, and other published literature from the field of preservation, as well as current publications such as newspapers and online magazines covering preservation topics.[9] Because the published literature on the subject is quite sparse, a survey was created and distributed to preservation practitioners to gain insight into the methods and considerations that are commonly used to evaluate and select substitute materials (Chapter 3).[10]

Considerations and criteria mentioned in the literature and preservation practitioner survey were then compiled and discussed with respect to preservation philosophy, material properties and performance, economics, and sustainability. Where applicable, additional considerations were added from materials selection guides and publications from the related fields of objects conservation, architecture, and engineering to create a comprehensive inventory of considerations (Chapter 4).

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[9] Please note that unpublished project reports or other project literature that may cover substitute materials was not consulted for this thesis. All conclusions drawn regarding the contemporary use of substitute materials were therefore drawn only from published or online sources, personal interviews, and the preservation practitioner survey.
[10] The methodology followed for the practitioner survey is included in Chapter 3.

Finally, the methods used by preservation practitioners, as reported in the published literature and the practitioner survey, were analyzed, and methods of structured decision-making from other fields were reviewed for potential application or adaptation for the evaluation and selection of substitute materials. A new method that utilizes the inventory of considerations was then formulated, drawing from the concepts of established structured decision-making methods and the needs of preservation practitioners who may consider the use of substitute materials (Chapter 5).

CHAPTER 2: LITERATURE REVIEW

INTRODUCTION

The following literature review provides the context and framework of research for this thesis. It is organized by topic, including the History of Substitute Materials, Preservation Philosophy, Economics, and Sustainability. This review begins with a brief history of the use of and attitudes towards substitute materials, as they are not a recent trend, and they have certainly elicited substantive opinions throughout the history of their use. A discussion of pertinent preservation philosophies follows, providing insight into the general attitudes towards the use of substitute materials on historic projects today. Finally, sections on the economic costs of materials for historic structures and the interface between the current sustainability movement and preservation are included, as these topics provide a contemporary basis for the consideration of substitute materials.

A HISTORY OF SUBSTITUTE MATERIALS

Substitute materials have a long history of use in architectural applications. Pamela H. Simpson's book, *Cheap, Quick, & Easy: Imitative Architectural Materials, 1870-1930*, covers a wide range of materials, with a focus on the aesthetic debates and social implications of the use of imitative materials in the late 19th and early 20th centuries.[11] While various types of substitute materials date to antiquity, many modern versions appeared in the 18th century with the Industrial Revolution. Simpson includes detailed chapters on exterior features such as concrete block and ornamental sheet metal, as well as interior features such as metal and embossed walls and ceilings and linoleum floors. She also includes a chapter that briefly

[11] Pamela H. Simpson, *Cheap, Quick, & Easy: Imitative Architectural Materials, 1870-1930* (Knoxville: The University of Tennessee Press, 1999).

discusses other materials and techniques such as composition ornament or "compo," imitation plasters, artificial marbles and other stone, terra cotta, and marbling and graining. Evident by her choice of materials, Simpson's focus is ornamental. While many substitute structural materials such as reinforced concrete, iron, and steel were viewed more favorably throughout history as technological advances, imitative ornamental materials often faced harsh criticism.

Simpson documents several well known critics of substitute materials that emerged in the 19th and 20th centuries, beginning with Augustus Welby North Pugin (1812-52). The famous Gothic revival architect is known for the "moral fervor of his call for honesty of materials and for a return to craftsmanship."[12] Art critic John Ruskin (1819-1900) promoted similar "moral honesty in architecture," claiming that imitative materials were wrong because the "intent was to deceive."[13] In addition to the moral implications that Pugin and Ruskin espoused, they shared a common anti-machine stance. These arguments were also supported by artist and designer William Morris (1834-1896), who criticized "machine-made, cheap ornament that imitated handmade materials" and campaigned for the continuation of the handmade craft process.[14]

These English critics spoke at a time that is sometimes called the "Second Industrial Revolution…a time of innovation, rapid development, and broad acceptance for the new ornamental materials [by ordinary people]."[15] However, the discussion of imitative materials also took place in the United States where "Americans seemed more accepting of machine

12 Ibid., 138.
13 Ibid., 139.
14 Ibid., 143.
15 Ibid., 5.

production than Europeans were… [and] were more willing to experiment with new materials."[16] Gustav Stickley (1858-1942) of the American Arts and Crafts Movement maintained that while technology was not inherently bad, it should be used to "create a style of simplicity and honesty."[17] Frank Lloyd Wright also accepted the machine as a "tool for creating art," proposing that machines should be used in ways that best express material qualities.[18]

The vast majority of the critics of imitative materials were designers and architects who were opposed to the "substitute gimcrackery" that was accepted by ordinary people who had traditionally been unable to afford ornamental materials for their homes.[19] Much of the defense of these new materials was made by manufacturers and advertising, which was given merit by the widespread popularity of the products. The major arguments for these materials were their cheapness, durability, and cleanliness. The new materials were cheaper than the materials they imitated, and were typically available in a wide variety of grades. Simpson also notes that the materials were as "durable as what they imitated, [and] they were even more durable than what they replaced."[20] For the most part, these materials were not used as substitutes for the expensive high quality materials that they imitated, but instead, they offered ordinary people the opportunity to upgrade from lower quality materials. Finally, hygiene and sanitation were prevalent concerns around the turn of the 20th century, and many of these new materials advertised that they were safer and cleaner than traditional

16 Ibid., 148.
17 Ibid., 149.
18 Ibid., 149.
19 Ibid., 136.
20 Ibid., 152.

materials.[21]

The National Park Service *Preservation Brief 16: The Use of Substitute Materials on Historic Building Exteriors* includes a brief section on the historical use of substitute materials.[22] It refers to techniques such as sand-painted wood or stucco scored to imitate stone, as well as several materials that are now considered "traditional." These include molded or cast masonry substitutes such as cast stone or concrete, metal products as substitutes for wood, stone or tile, and terra cotta as a substitute for carved stone. The brief notes that these historic substitute materials were "selected on the basis of the availability of materials and local craftsmanship, as well as durability and cost. The criteria for selection today are not much different."[23]

The brief also references new synthetic materials such as fiberglass, acrylic polymers, and epoxy resins, but expresses concerns that these materials have not "established solid performance records."[24] The now "traditional" materials mentioned above were also once in this category of new technology, which begs the question, is time and proven performance the only way that new materials can be accepted for use in preservation?

The materials discussed above range from purely ornamental elements to part of the building envelope or structural components. When it comes to the history of structural systems and materials, at the time of their inception, new structural materials were not regarded as "substitutes," but rather as new technologies. New structural materials were also different in that they did not seek to imitate their replacements aesthetically, as did the

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21 Ibid., 152-155.
22 Park, *Preservation Brief 16*.
23 Ibid.
24 Ibid.

ornamental materials discussed by Simpson. Among the many authors who have written about historic architectural technologies, Donald Friedman discusses the evolution of the structural system in his book *Historical Building Construction: Design, Materials, and Technology*.[25] The change to modern construction took place after the Industrial Revolution, gaining momentum in the mid-19th century.[26] While the transition from wood and masonry construction to iron, steel, and concrete did not render wood or stone obsolete, it revolutionized the methods of structural design and analysis. Friedman says:

> The most obvious consequence of the economics of construction is the replacement of labor-intensive techniques with technology-intensive materials. When no alternatives to hand construction existed, the amount of labor required to build a thick brick wall was not an issue. Once iron columns could be used in the place of that wall, building designers began to examine the trade-off of the more expensive materials of more modern technology against the more expensive labor of traditional methods. Typically, technology won.[27]

This trade-off between labor and materials is still an inherent part of decisions regarding substitute materials today.

PRESERVATION PHILOSOPHY

After considering the social, philosophical, and aesthetic responses to the historic use of substitute materials, it is pertinent to explore preservation principles and attitudes towards the use of substitute materials on historic projects today.

Frank Matero summarizes the beginning of preservation theory as it relates to modern conservation theory in his article "Loss, Compensation and Authenticity in

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[25] Donald Friedman, *Historical Building Construction: Design, Materials, and Technology* (New York: W.W. Norton & Company, 1995).
[26] Ibid., 10.
[27] Ibid., 11.

Architectural Conservation."[28] He begins with the 19th century juxtaposition between John Ruskin and Eugene-Emmanuel Viollet-le-Duc (1814-1879). As noted above, Ruskin promoted "truth in the form and fabric of the building," and "rejected imitation as not being equal to the original," as did Viollet-le-Duc.[29] Ruskin argued for preservation instead of restoration, promoting the value of the weathering and imperfections that come with age. Viollet-le-Duc, on the other hand, argued for restoration, which he defined as "to re-establish it in a finished state, which may in fact never have existed at any given time."[30]

In the early 20th century, Alois Riegl (1858-1905), the Austrian art historian, reflected on the Ruskinian preference for age value, saying that the contemporary viewer disliked "signs of decay in new works…as much as signs of new production in old works."[31] This statement, though made at the turn of the century, provides insight to one of the preservation dilemmas faced today. How should works of Modernism and the recent past be preserved? Several recent Historic Preservation Masters Theses have explored this question, but its relevance to the consideration of substitute materials in particular has not yet been investigated.[32]

Italian theorist Cesare Brandi wrote his "Theory of Restoration" in 1963, emphasizing the "whole of the work as that comprised of its physical form and fabric, its

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28 Frank Matero, "Loss, Compensation and Authenticity in Architectural Conservation," *Journal of Architectural Conservation* 12, no .1 (March 2006): 71-90.
29 Ibid., 78, 80.
30 Eugene-Emmanuel Viollet-le-Duc, "Restoration" in *The Foundations of Architecture: Selections from the Dictionnaire Raisonne*, trans. Whitehead, K.D. (New York: George Braziller, 1990), 195.
31 Alois Riegl, "The Modern Cult of Monuments: Its Essence and Its Development (1903)," in *Historical and Philosophical Issues in the Conservation of Cultural Heritage,* eds. N. Stanley Price, M.K. Talley Jr., and A.M. Vaccaro (Los Angeles: The Getty Conservation Institute, 1996), 69-83.
32 Buckley, "The Interplay of Technology and Durability," and Cellini, "The Development of Precast Exposed Aggregate Concrete Cladding."

history, and its context."[33] Though Brandi states that "materials should never take precedence over the image,"[34] Matero summarizes his theory of restoration as follows:

> Cesare Brandi placed material authenticity at the at the forefront of conservation's priorities, whereby the first aim of conservation was to conserve the original material of the work, its material authenticity, and the second aim was to re-establish its potential unity so far as this was possible without committing a fake and without canceling significant traces of its history.[35]

Matero also notes that like Brandi, the recent trends in preservation seem to place significant emphasis on the authenticity of materials. The concept of "authenticity" has a range of possible meanings, but Matero describes "authentic objects, buildings, and sites [as] those original to their creators or possessors, they are unique to their time and place."[36] The use of substitute materials presents a challenge to this concept of material authenticity.

In 1965, two years after the publication of Brandi's "Theory of Restoration," the *ICOMOS Venice Charter* was adopted as a set of international principles. The charter states that restoration is "based on respect for original material and authentic documents."[37] However, the charter also accepts that:

> Where traditional techniques prove inadequate, the consolidation of a monument can be achieved by the use of any modern technique for conservation and construction, the efficacy of which has been shown by scientific data and proved by experience.[38]

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33 Matero, "Loss, Compensation and Authenticity," 72.
34 Cesare Brandi, "Theory of Restoration (1963)," in *Historical and Philosophical Issues in the Conservation of Cultural Heritage,* eds. N. Stanley Price, M.K. Talley Jr., and A.M. Vaccaro (Los Angeles: The Getty Conservation Institute, 1996), 233.
35 Matero, "Loss, Compensation and Authenticity," 85.
36 Ibid., 83.
37 ICOMOS, *International Charter for the Conservation and Restoration of Monuments and Sites (The Venice Charter)* (Venice: ICOMOS, 1965), Article 9.
38 Ibid,. Article 10.

This acceptance of modern technology in certain circumstances has helped to legitimize the use of substitute materials for historic projects, but in-kind replacement has still been preferred over the past several decades.

Since their initial publication in 1976, *The Secretary of the Interior's Standards for the Treatment of Historic Properties* have provided guidance for the application of preservation principles to historic preservation, rehabilitation, restoration, reconstruction projects.[39] The Standards for Rehabilitation, which accept a higher level of alteration, state that:

> Deteriorated historic features will be repaired rather than replaced. Where the severity of deterioration requires replacement of a distinctive feature, the new feature shall match the old in design, color, texture, and, where possible, materials. Replacement of missing features will be substantiated by documentary and physical evidence.[40]

These guidelines are regulatory for projects receiving federal grant funding, but they can be applied to any historic building. The recommendation that historic fabric be retained and repaired if possible reflects the contemporary preservation emphasis on the authenticity of materials. The next best alternative, according to the standards, is replacement in-kind, followed by replacement with a substitute material only if no other acceptable alternative can be found.

The National Park Service Preservation Briefs are another resource, in addition to the *Secretary of the Interior's Standards,* that provide practical guidance for historic projects. *Preservation Brief 16: The Use of Substitute Materials on Historic Building Exteriors*, a copy of which is included in Appendix A, says:

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39 Weeks and Grimmer, *The Secretary of the Interior's Standards for the Treatment of Historic Properties.*
40 Ibid., *Standards for Rehabilitation*, no. 6.

> When deteriorated, damaged, or lost features of a historic building need repair or replacement, it is almost always best to use historic materials. In limited circumstances substitute materials that imitate historic materials may be used if the appearance and properties of the historic materials can be matched closely and no damage to the remaining historic fabric will result.[41]

This Preservation Brief begins, as mentioned previously, with a very brief history of the use of substitute materials, as well as a set of general circumstances under which the use of substitute materials may be appropriate today. These circumstances include:

1. the unavailability of historic materials;
2. the unavailability of historic craft techniques and lack of skilled artisans;
3. inherent flaws in the original materials; and
4. code-related changes[42]

The brief also recognizes that cost may or may not be a factor, but that "depending on the area of the country, the amount of the material needed, and the projected life of less durable substitute materials, it may be cheaper in the long run to use the original material."[43] The generalization of substitute materials as inherently "less durable," and the statement that they should only be considered as a last resort, convey the typical contemporary preservation attitude that substitute materials are inferior and should not be used. While this Preservation Brief does provide guidance on the use of various materials such as cast aluminum, cast stone, glass fiber reinforced concretes, precast concrete, fiber reinforced polymers, and epoxies, it may be the perception of inferiority that has prevented much other substantive writing on the use of these materials from the preservation community.

Among these few preservation resources on substitute materials is Thomas Fisher's

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41 Park, *Preservation Brief 16*.
42 Ibid.
43 Ibid.

1985 article in *Progressive Architecture*, "The Sincerest Form of Flattery."[44] This article, in addition to citing reasons and criteria for the selection of substitute materials (which will be discussed in greater depth later in this thesis) asks the question, "[Given that] substitute materials have lowered the cost of preservation…At what point is the integrity of historic buildings lost?"[45] He bridges the gap between the historic use of new technologies as substitute materials and their use in preservation:

> While many building products have emerged throughout history as substitutes for something else, most have only had to function like the products they replace. Initially, concrete construction only had to function like stone; steel, like cast iron; and brick, like adobe. The substitute materials required in preservation have an added twist: they must look like the original. It's a twist made harder by the modern stigma against imitation.[46]

This "stigma" is certainly still apparent over twenty years after the publication of this article. However, there are emerging trends that may justify a closer look at substitute materials.

ECONOMICS

While *Preservation Brief 16* says that cost "may or may not be a determining factor in considering the use of substitute materials," the reality is that it most often is a factor, and it can even be the deciding factor.[47] Fisher's 1985 article was written in response to the lowered cost of preservation as a result of new technologies in the field of substitute materials. He quotes Theodore Prudon, who says, "Life-cycle costs often show that original materials are as cost effective as their substitutes."[48] While this may certainly be the case for

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[44] Thomas Fisher, "The Sincerest Form of Flattery," *Progressive Architecture* 11, no. 85 (Nov. 1985): 118-123.
[45] Ibid., 118.
[46] Ibid., 119.
[47] Park, *Preservation Brief 16*.
[48] Fisher, "The Sincerest Form of Flattery," 119.

many projects, the opposite may just as easily be true. The important message is that the initial cost of a material is not the only element that affects its economic value. Costs over the entire life-cycle of the material should be analyzed.

Life-cycle costing (LCC), or whole life appraisal (WLA), has been developed for use in the construction industry under the general topic of building economics. There are many resources available, including ASTM E917-05 "Standard Practice for Measuring Life-Cycle Costs of Buildings and Building Systems," which states:

> The LCC method is particularly suitable for determining whether the higher initial cost of a building or building system is economically justified by reductions in future costs (for example, operating, maintenance, repair, or replacement costs) when compared with an alternative that has a lower initial cost but higher future costs.[49]

While this method is typically applied to a whole building or building system, the concept is applicable for substitute materials. However, one of the major obstacles is that the service life of many new replacement materials is unknown. The concept of service life analysis of buildings is a relatively new field, especially when applied to historic structures.

Ellen Buckley's 2007 Masters Thesis for the University of Pennsylvania's Graduate Program in Historic Preservation explores the concept of service life analysis applied to 20th century high-rise buildings.[50] Others, such as the British Building Research Establishment, have applied these same methods to both traditional materials, such as wooden windows, and what could be considered substitute materials, such as fiber-based cement slate

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[49] ASTM Standard E917, 2005, "Standard Practice for Measuring Life-Cycle Costs of Buildings and Building Systems," ASTM International, West Conshohocken, PA, www.astm.org.
[50] Buckley, "The Interplay of Technology and Durability."

roofing.[51] The BRE Report indicates the pitfall mentioned above—that the knowledge base regarding long-term performance for new materials is significantly under-developed, specifically under the "effect of numerous deteriorating agents acting together" as well as with regards to materials' "typical achieved design and installation quality."[52] The discussion of the "unknowns" associated with substitute materials will be continued later in this thesis.

SUSTAINABILITY

In 1978, the National Park Service published its third Preservation Brief, *Conserving Energy in Historic Buildings*.[53] The brief asserts the fact that historic buildings have certain features that are inherently energy efficient, such as operable windows and high thermal mass. The focus of the brief is on conserving energy by reducing the energy usage necessary for building operations. Some of the recommendations include passive measures to ensure optimal efficiency of systems, and retrofitting techniques such as minimizing air infiltration, installing storm windows, and adding insulation in various locations.[54]

Today, the focus on tying the principles of sustainability to historic buildings places less emphasis on improving the efficiency of operations, and more emphasis on the fact that historic buildings are inherently "green" based on the concept of embodied energy. In 2005, the Association for Preservation Technology dedicated an entire volume of its *APT Bulletin* to the relationship between sustainability and preservation. Mike Jackson's article, "Embodied Energy and Historic Preservation: A Needed Reassessment," defines embodied

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51 Kathryn Bourke and Hywel Davies, *Building Research Establishment Laboratory Report, Factors affecting service life predictions of buildings: a discussion paper* (BRE Press, 1997).
52 Ibid., 5, 24.
53 Baird M. Smith, *Preservation Brief 3: Conserving Energy in Historic Buildings* (Washington DC: National Park Service, Technical Preservation Services, 1978).
54 Ibid.

energy as "the sum of all the energy required to extract, process, deliver, and install the materials needed to construct a building."[55] He cites the 1967 report *Energy Use for Building Construction*, which provides estimated values of embodied energy for many building materials and assemblies, as the basis for embodied energy research in the United States.[56] He also mentions the concept of life-cycle analysis, which in this case focuses on environmental impact rather than cost, that combines embodied energy and operating costs. In his conclusion, Jackson calls for more comprehensive inclusion of embodied energy in green-building rating systems such as the U.S. Green Building Council's Leadership in Energy and Environmental Design (LEED) System to adequately represent historic structures.[57]

In this same issue of the *APT Bulletin*, Helena Meryman addresses "Structural Materials in Historic Restoration: Environmental Issues and Greener Strategies."[58] She points out the current environmental concerns regarding structural materials, and makes recommendations for historic preservation projects specifically. Though preservation and sustainability both support the retention of historic materials, structural reinforcement, repair, or replacement is one area in which both groups can agree that change is sometimes necessary, due to either code requirements or general safety concerns. For example, though wood itself is a renewable resource, contemporary foresting practices are not always sustainable, and modern lumber, in general, is of a lesser quality than it was historically.[59] Her recommendations include the retention of structurally sound historic wood, using

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[55] Mike Jackson, "Embodied Energy and Historic Preservation: A Needed Reassessment," *APT Bulletin* 36, no. 4 (Jan. 2005): 47-52.
[56] Ibid., 47.
[57] Ibid., 51.
[58] Helena Meryman, "Structural Materials in Historic Restoration: Environmental Issues and Greener Strategies," *APT Bulletin* 36, no. 4 (Jan. 2005): 31-38.
[59] Ibid., 33. See the article for explanation of reasons behind these assertions.

salvaged wood, or using durable species and construction details. She also recommends using engineered wood products as a potential substitute material.[60] The recommendations for steel include:

> For unexposed elements, using the most corrosion-resistant material is of paramount importance. In such cases, using a material with a higher embodied-energy content is justifiable. For example, stainless steel, while more energy intensive to produce than mild steel, pays for itself environmentally by being maintenance free, and from a preservation standpoint, by preventing corrosion-related façade damage over the long term.[61]

While it is not explicitly expressed whether or not these structural substitutes are considered acceptable from a preservation standpoint simply because they may not be visible, this article does reveal that making the case for a substitute material may be easier with the aid of sustainable principles.

As sustainability is currently a popular topic within the preservation community, there are many other recent publications that discuss how sustainable principles can and should be applied to historic projects. One of the results of this newfound coverage is, in fact, the resurfacing of questions regarding substitute materials. While the bulk of writing on the topic in the 1980s may have been an indirect result of the 1970s Energy Crisis, today's interest is likely a result of similar energy concerns and the movement towards sustainability. The National Alliance of Preservation Commissions has discussed substitute materials within the context of sustainability at their last two bi-annual Forums.[62] The question of how to address requests from residents for approval to use environmentally-friendly substitute

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[60] Ibid., 34.
[61] Ibid., 35.
[62] National Alliance of Preservation Commissions Forum 2006 Working Round-table Report, http://www.uga.edu/napc/programs/napc/forum.htm. The 2008 report has not yet been published.

materials is covered under the heading "New Materials Mayhem: Determining Sustainability."[63] It is difficult to evaluate the wide variety of new materials that are available today. The Commission realizes that neither insurance companies nor homeowners will always be able to afford the cost of renovations with historic materials, but that the commissions cannot "educate applicants on the use of new materials until [they] understand their cost, performance and usage."[64] This thesis seeks to address precisely this concern—what methods and considerations should preservation professionals use to evaluate substitute materials?

CONCLUSION

While this literature review certainly does not cover the full range of sources that have been consulted for this thesis, it seeks to present the context and framework of literature that will guide the research, analysis, and conclusions about substitute materials within the following chapters.

63 Ibid.
64 Ibid.

CHAPTER 3: CONTEMPORARY USE OF SUBSTITUTE MATERIALS

INTRODUCTION

As material science and building technology continue to advance at a rapid pace, an ever-expanding variety of substitute materials are becoming available for use on historic buildings. In the introduction to his book *Transmaterial: A Catalog of Materials that Redefine our Physical Environment*, Blaine Brownell says:

> …it has become a widely held belief that more new products have been developed in the last twenty years than in the prior history of materials science…one could make a case that there is a veritable material revolution underway, and this revolution is affecting all industries. No traditional product or building system is safe from scrutiny, as all materials are being closely studied for enhancement or replacement.[65]

While this book does not focus on materials that are used specifically for historic projects, the message is clear. As Chief Architect for the Illinois Historic Preservation Agency, Mike Jackson acknowledges, even when dealing with historic buildings, it seems that "cheaper, faster and lighter always wins."[66]

However, the evaluation and selection of substitute materials for historic building projects requires attention to more than just function and cost. As noted by Thomas Fisher, substitute materials for preservation have the added requirement of looking like the materials they replace.[67] The range of considerations, including aesthetics, functionality, economics and more, will be discussed in detail in the following chapter.

This chapter will describe the currently available literature and publications that offer

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[65] Blaine Brownell, ed., *Transmaterial: A Catalog of Materials that Redefine our Physical Environment* (New York: Princeton Architectural Press, 2006), 6.
[66] Mike Jackson, personal interview, February 26, 2009.
[67] Fisher, "The Sincerest Form of Flattery," 118.

guidance for the use of substitute materials, as well as recent trends in the use of these materials. Sources consulted include scholarly journals, conference proceedings, and other published literature from the field of preservation, as well as current publications such as newspapers and online magazines covering preservation topics.[68] Because published preservation literature and other resources covering actual uses of substitutes are often anecdotal and far from comprehensive, an electronic survey of preservation practitioners was also conducted to develop an overall understanding of current practice.

LITERATURE & PUBLICATIONS FOR GUIDANCE

As mentioned in the previous literature review chapter, for the past several decades, the preservation community has largely focused on material authenticity. While the retention of historic fabric is always recommended if an element is intact and functioning, sometimes replacement is necessitated by severe deterioration. When this is the case, the widely held belief is that in-kind replacement is the best alternative. However, substitute materials have been recognized as acceptable under certain circumstances, and when certain criteria are met. The following are the major published resources providing guidance for the use of substitute materials.

Regulatory Publications & Guidelines

The Secretary of the Interior's Standards for the Treatment of Historic Properties, sets the stage for the necessary criteria for substitute materials, stating that any replacements, whether in-kind or substitute, should match the original in "design, color, [and] texture."[69] The

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[68] Unpublished project reports or other project literature that may cover substitute materials was not consulted for this thesis, as they are not widely available to other preservation practitioners.
[69] Weeks and Grimmer, *Standards for Rehabilitation*, no. 6.

guidelines that accompany the standards are similarly brief, explaining, "If using the same kind of material is not technically or economically feasible, then a compatible substitute material may be considered."[70] They allude to the aspects of material compatibility by also stating that, "Using a substitute material that does not convey the visual appearance of the surviving parts of the…feature or that is physically or chemically incompatible" is not recommended.[71]

In December 2007, the Technical Preservation Services (TPS) of the National Park Service published new guidance on the use of substitute materials for historic preservation tax incentive projects.[72] The following is a summary of the general steps in the evaluation process as suggested by this TPS guidance:

- First, the need for replacing historic material is assessed.
- Second, the amount and location of replacement materials is evaluated in relation to the building's historic character.
- Third, the appropriateness of a particular substitute material is considered in regard to its appearance and other factors, such as the location of the application, and the known physical compatibility of the substitute materials relative to the historic material.[73]

This guidance also notes that most replacements, even those made in-kind, will include some measure of change, so it is important to determine the degree of match that is necessary, both for aesthetics and performance.

Parks Canada provides guidance for the treatment of heritage properties in the

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70 Ibid., *Guidelines for Rehabilitating Historic Buildings*.
71 Ibid.
72 "Evaluating Substitute Materials in Historic Buildings," Historic Preservation Tax Incentives Program, National Park Service, Technical Preservation Services, Dec. 2007. http://www.nps.gov/history/hps/tps/tax/download/substitute_materials.pdf.
73 Ibid.

Standards and Guidelines for the Conservation of Historic Places in Canada.[74] Though the standards themselves specify in-kind replacement for non-repairable deteriorated features, the guidelines are prefaced with a brief section devoted to substitute materials. The section defines substitute materials as "those products used to imitate historic materials," and reinforces that substitute materials should only be used as a last resort after all options for repair and replacement in-kind have been examined.[75] The guidelines acknowledge the lack of long-term performance data for many substitute materials, and offer the following direction for practitioners considering substitutes:

> Because there are so many unknowns regarding the long-term performance of substitute materials, their use should not be considered without a thorough investigation into the proposed materials, the manufacturer, the installer, the availability of specifications and the use of that material in a similar situation in a similar environment. The importance of matching the appearance and physical properties of historic materials and, thus, of finding a successful long-term solution cannot be overstated.[76]

As recognized by Parks Canada, the investigation of material manufacturers, installers, and specifications is equally important to matching aesthetic qualities when using substitute materials.

The national standards and guidelines above are regulatory for properties that are nationally listed or eligible to be listed (on either on the U.S. National Register of Historic Places or the Canadian Register of Historic Places) and are seeking government financial incentives for preservation. However, at a state and local level, additional regulations enforced by a State Historic Preservation Office (SHPO) or a local Historic Commission can

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[74] *Standards and Guidelines for the Conservation of Historic Places in Canada* (Parks Canada, 2003).
[75] Ibid.
[76] Ibid.

further limit or allow the use of substitute materials.

As mentioned in the previous literature review chapter, the National Alliance of Preservation Commissions has discussed the topic of substitute materials at its last two bi-annual Forums. Though the report for the 2008 Forum is not yet available, a roundtable discussion pertaining to substitutes was held, titled "Developing a Materials Evaluation Methodology," with the following description:

> Commissions are regularly besieged by requests for substitute materials and find themselves groping in the dark to determine suitability. This roundtable will develop an evaluation methodology commissions can use to make consistent and defensible decisions.[77]

Another group, the Maryland Association of Historic District Commissions, ran a workshop in 2008 titled "Substitute Materials and Replacements: Why We Say No, When to Say Yes" that explains their recommendations for which types of replacements are acceptable and which are not.[78] They specifically address potential substitute materials for siding, porches and details, landscape features, windows, and roofs.

Though this thesis focuses on the evaluation and selection of substitute materials by preservation practitioners such as architects, engineers, conservators, and historic preservation consultants, the approval by local architectural review boards or historic commissions can be a deciding factor in whether substitute materials are selected or rejected.

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[77] The National Alliance of Preservation Commissions, *Forum 2008 Preliminary Program*, http://www.uga.edu/napc/programs/napc/pdfs/forum2008/Prelim%20Program%20Forum08FINALweb.pdf. According to the NAPC staff, the roundtable reports from the 2008 Forum should be available by May 2009.

[78] Maryland Association of Historic District Commissions. *Substitute Materials and Replacements: Why We Say No, When to Say Yes*. Sept.-Oct. 2008. Presentation Summaries. 2008 Workshop Series.

Technical Guidance

In 1981, David W. Look of the National Park Service presented a paper at the annual Association for Preservation Technology (APT) meeting titled "Criteria for the Selection of Substitute Materials."[79] This paper appears to have been the first technical discussion of the criteria for selection of substitute materials, inspiring additional dialogue and writing on the subject over the next decade. In 1985, Thomas Fisher published an article in *Progressive Architecture* titled "The Sincerest Form of Flattery," in which he cites some of the technical issues raised by Look.[80] In addition to Look's criteria, Fisher includes interviews with preservation practitioners such as Hymen Myers of the Vitetta Group and Theodore Prudon, formerly of the Ehrenkrantz Group. Fisher discusses some of the technical issues pertaining to replacements for terra cotta, wood, roofing, and cast iron, while also raising the following philosophical questions: "At what point does a building lose its integrity? When does it become more substitute than real? Will we, with all the best intentions, someday have only polymers to preserve?"[81] Finally, he acknowledges in the "Further Reading" section that at the time this article was published, "no one source on this subject exist[ed]."[82]

In 1988, the National Park Service published *Preservation Brief 16: The Use of Substitute Materials on Historic Building Exteriors*, by Sharon C. Park, a copy of which is included in Appendix A. This brief sought to provide a more complete overview of the issues surrounding the use of substitute materials. It was later adapted for an article published in

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[79] David. W. Look, email message to author, January 6, 2009. Unfortunately a copy of this unpublished paper could not be obtained.
[80] Fisher, "The Sincerest Form of Flattery," 119.
[81] Ibid., 123.
[82] Ibid.

1992 in *Technology & Conservation*.[83] The criteria discussed in these sources will be covered in depth in the following chapter.

Soon after the publication of the Preservation Brief, Theodore Prudon published an article titled "Substitute Materials Find a Place in Preservation" in *Commercial Renovation*.[84] This article presents similar criteria to guide the use of substitute materials, which again, will be discussed in detail in the following chapter. While Prudon notes that his discussion focuses on the replacement of masonry materials, the criteria is essentially applicable to all types of materials, with the exception of wood, which he says is best replaced in-kind. He includes sections covering cast stone, glass fiber reinforced concrete (GFRC), fiber reinforced plastic (FRP), glass reinforced gypsum, polymer castings, insulation foams, and sheet metal.

MATERIAL-SPECIFIC GUIDANCE & CASE STUDIES

Since the publication of the sources above in the late-1980s and early 1990s, there have been few comprehensive publications on the topic of substitute materials and considerations for their selection. Instead, the majority of publications that offer guidance discuss specific materials or specific projects. The following summary of sources is not meant to be a comprehensive discussion of all available types of substitute materials, or even all those that have been the subject of written review. Rather, it is a collection of key resources in which the materials are discussed in the context of their use as substitutes. More information is available on specific materials that are used as substitutes for historic

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83 Sharon C. Park, "The Use of Substitute Materials in Building Preservation Projects: Planning & Specifying for Proper Performance & Appearance," *Technology & Conservation* (Winter 1992-1993): 24-33.

84 Prudon, "Substitute Materials Find A Place In Preservation," 36-41.

originals, but it is not the focus of this thesis to present a catalogue of materials.

The NPS Preservation Briefs are a good source of general guidance for various types of substitute materials. In addition to *Preservation Brief 16*, there are several material-specific briefs that touch on substitutes, including:[85]

- **Brief 4:** Roofing for Historic Buildings
- **Brief 7:** The Preservation of Historic Glazed Architectural Terra-Cotta
- **Brief 8:** Aluminum and Vinyl Siding on Historic Buildings: The Appropriateness of Substitute Materials for Resurfacing Historic Wood Frame Buildings
- **Brief 12:** The Preservation of Historic Pigmented Structural Glass (Vitrolite and Carrara Glass)
- **Brief 27:** The Maintenance and Repair of Architectural Cast Iron
- **Brief 29:** The Repair, Replacement, and Maintenance of Historic Slate Roofs
- **Brief 30:** The Preservation and Repair of Historic Clay Tile Roofs
- **Brief 42:** The Maintenance, Repair and Replacement of Historic Cast Stone

For the most part, these briefs recommend that in-kind replacement is the preferred option (if repair is not possible). However, some of them also present information on various available substitute materials, along with a professional opinion on the appropriateness and limitations of their use. Still, these briefs are by no means a complete guide to evaluating, selecting, and using substitute materials for specific projects.

Siding, Roofing & Windows

It appears that the use of substitute materials for siding, roofing and windows has elicited a good deal of attention and writing from preservation professionals over the past couple decades. Because the decision to replace these elements often lies in the hands of the owner (who is usually untrained in preservation philosophy and practice), professionals have

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[85] Various authors. Links to the electronic versions of the briefs can be found at http://www.nps.gov/history/hps/tps/briefs/presbhom.htm.

attempted to provide written guidance to deter owners from using materials that might negatively alter the historic character and integrity of their properties.

John H. Cluver of Voith & Mactavish Architects in Philadelphia expresses his concerns regarding the use of substitute materials for siding and roofing in his article "No Substitute: Inexpensive and maintenance free or short sighted and maintenance proof: How do substitute materials stack up in the long run?"[86] He says, "The real problems are aggressive marketing, a lack of knowledge about historic materials and a focus on short-term costs to the detriment of the long term."[87] He presents "five fables" that he believes contribute to the overuse of inappropriate substitutes:

- **Fable #1:** Replacement is cheaper than repair.
- **Fable #2:** The best price is the best deal.
- **Fable #3:** New looks better than old.
- **Fable #4:** Replacement is more energy efficient than repair.
- **Fable #5:** No maintenance is the ultimate goal.[88]

Cluver attempts to dispel these fables with three basic arguments:

- **Aesthetic cost:** "new materials will not look as good as the old."
- **Environmental cost:** "restoration is an environmentally sustainable practice, as it not only saves landfill space, but also saves the energy related to the replacement material."
- **Economic cost:** "the material that offers the cheapest initial cost frequently ends up costing as much as, if not more than, the seemingly more expensive option."[89]

These arguments parallel the general considerations for the evaluation of substitute materials

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[86] John H. Cluver, "No Substitute: Inexpensive and maintenance free or short sighted and maintenance proof: How do substitute materials stack up in the long run?" *Clem Labine's Period Homes* (Nov. 2005): 12-16.
[87] Ibid., 12.
[88] Ibid., 12.
[89] Ibid., 12-13.

that have already been presented in this thesis, including preservation philosophy, sustainability, and life-cycle economics. Cluver examines typical substitute materials for siding and roofing within the context of his three arguments. Using quantitative life-cycle analysis for both economic and environmental costs, he shows that the restoration of the existing materials is often a better solution than replacement with a substitute. However, it should be noted that some of the quantitative comparisons are based on repair of the original versus replacement with a substitute, rather than the comparison of wholesale replacement in-kind versus replacement with a substitute. The reality is that each situation is different, but the application of this type of analysis can shed new light on the evaluation.

Wood

One of the materials that has spurred quite a bit of discussion regarding its replacement is wood. It is often one of the major components of siding, roofing and windows, but it is used in other exterior applications as well, including, for example, porch decks and railings, trim and ornamentation.

Preservation Brief 16 and Theodore Prudon's 1989 article both maintain that wood elements should be replaced in-kind, since wood is a readily available material. This illustrates the ambiguity that can accompany the term "in-kind." Today it is impossible to obtain old-growth wood of certain species that were used historically. Are the less-durable present-day sources of the same species still considered "in-kind" material?

In 1986, Mary B. Dierickx argued that "wood makes the best substitute material for wood" in her article "Substitute Materials for Wooden Buildings: The System or the

Artifact?"[90] She notes that wood has many properties that are difficult to recreate with a substitute material including texture and grain, weathering characteristics, appearance when painted, methods of joining, flexibility and expansion, and even noises and smells. She recommends the use of wood as a replacement material (even wood of a different species or laminated wood members) since it has similar properties and allows "wooden systems to retain their integrity as systems."[91] She also notes that the use of wood supports the continuation of traditional carpentry craft. Modern methods, including reinforcement with steel and the use of epoxies and resins, while perhaps retaining the "artifacts—beams, trusses, porch posts," change the way the materials and system behave.[92] This approach, system versus artifact, is an interesting question of preservation philosophy that is applicable for many types of materials and systems.

Judith Capen, preservation architect and author of several of the Capitol Hill Preservation Guidelines, raises some other philosophical and practical questions regarding the use of wood substitutes in her column for the *Hill Rag*.[93] A reader posed the question of what types of substitute materials might be appropriate for use on a home in a historic district. Capen answers, "I think good substitute materials are not only acceptable, but may be the only reasonable choice for some exterior wood elements on old buildings."[94] She notes that Victorian-era structures often utilized materials in imitation of others, especially for trim, and she would rather see a substitute material with a good aesthetic match than a deteriorating poor quality modern wood replacement. Even the traditionally durable species

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90 Mary B. Dierickx, "Substitute Materials for Wooden Buildings: The System or the Artifact?" *APT Bulletin* 18, no. 3 (1986): 4-5.
91 Ibid., 4.
92 Ibid., 5.
93 Judith Capen, "Using Substitute Materials in a Historic District," *Hill Rag* (Feb. 2008): 134-135.
94 Ibid., 134.

of wood that are now sustainably farmed do not possess the same rot and insect resistance because of the high percentage of sapwood.

For trim materials, Capen asks, "If the original intention was cream cheese, no joints, no expression of the material, what does it mater what the material is underneath the coat of paint?"[95] Today, composite trim materials such as AZEK or Trex, some made from recycled wood and plastic, are available that can serve this purpose with a supposedly much longer service life. Mike Jackson, Chief Architect for the Illinois Historic Preservation Agency, also acknowledges the incredibly poor performance of new wood, saying that he has seen some exterior replacement elements rot out in as little as four years. His agency approves the use of substitute materials to help prevent this problem.[96]

Stone

Another material that can lead to some ambiguity in the term "replacement in-kind" is stone. It is evident that stones from different geographic regions, quarries, and even locations within a single quarry can have very different appearances and material properties, and so, for instance, replacing brownstone with brownstone is not a guarantee that it will be an acceptable match. Additionally, many historic quarries are now closed, limiting the options for replacement with natural stone.

In addition to the Preservation Briefs, the NPS Technical Preservation Services provides other advice materials, including a series of Technical Notes and various online educational resources. One of their Tech Notes, titled "Substitute Materials: Replacing

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[95] Ibid., 134.
[96] Mike Jackson, personal interview, February 26, 2009.

Deteriorated Serpentine Stone with Pre-Cast Concrete," describes a project at Six Logan Circle in Washington, D.C. in which the severely deteriorated serpentine façade was replaced with pigmented pre-cast concrete.[97] Because the green serpentine stone is naturally soft and prone to deterioration, it is no longer quarried for exterior building use. No other natural stone exhibits the same distinctive green coloring, so the decision was made to use a pigmented pre-cast concrete substitute. Upon completion, the project was "considered a success by all the participants."[98] However, the Tech Note does not include any long-term evaluation of the substitute material.

Another type of stone that has garnered significant attention in the past several years is brownstone. In 2003, the NPS published the *Rehab Yes & No Learning Program* on their website to help clarify the *Secretary of the Interior's Standards for Rehabilitation* through a series of case studies. The first "Rehab Yes" says, "If exterior materials can't be repaired, DO find suitable replacement materials!"[99] In this case study, an 1870 Italianate rowhouse with a severely deteriorated brownstone façade was refaced with a portland cement stucco that was tooled to match the original. This solution met the *Secretary of the Interior's Standards*, specifically Standard Six which pertains to replacements. While this "Rehab Yes" is only a brief synopsis of the project, it is clear that the NPS encourages the appropriate use of contemporary substitute materials.

A *New York Times* article titled "Brownstone (The Real Thing) Comes Back" explores

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97 Robert M. Powers, "Masonry Tech Note Number 1: Substitute Materials: Replacing Deteriorated Serpentine Stone with Pre-Cast Concrete" (Washington, D.C.: National Park Service, Technical Preservation Services, 1988).
98 Ibid.
99 "Rehab Yes No. 1," *The Rehab Yes & No Learning Program*, National Park Service, Technical Preservation Services, 2003, http://www.nps.gov/history/HPS/rehabyes-no/rehabyes1.htm.

an alternative to cementitious coverings.[100] The reopening of the Portland Brownstone quarries has spurred discussion on whether brownstone should be reused as a building material because of its inherent performance problems. Stone from the reopened quarry has been used at Cooper Union in New York, as well as several other rehabilitation projects. However, at the Cathedral of the Immaculate Conception in Albany, where Portland brownstone was the original material, preservation architect John Mesick chose to use an international source for more durable replacement stone. Proponents of replacement in-kind say that many failures can be attributed to the use of poor quality brownstone and installation defects. Rather than covering deteriorating brownstone with a cementitious stucco, they say that replacement in-kind will produce acceptable long-term results with proper quality control.

However, in-kind replacement of natural stone with inherent performance problems sometimes fails. At Alvar Aalto's Finlandia Hall (constructed between 1967 and 1971) in Helsinki, the thin marble veneer panels warped and cracked due to thermal hysteresis in the harsh winter climate.[101] Because the building was under government protection, in-kind replacement was selected and implemented between 1997 and 1999. By 2001, the panels were already warped and had lost between 20 and 30 percent of their overall strength. The author of *Failed Stone*, architect and engineer Patrick Loughran, says, "The story of the [in-kind] cladding at Finlandia Hall demonstrates the irrational loyalty a community can have for great works of architecture."[102]

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100 Tracie Rozhon, "Brownstone (The Real Thing) Comes Back," *New York Times*, July 4, 2000.
101 Patrick Loughran, *Failed Stone: Problems and Solutions with Concrete and Masonry* (Boston: Birkhauser, 2007), 18-19.
102 Ibid., 19.

Fiber-Reinforced Plastics and Cements

Fiber reinforced polymers (FRP), such as fiberglass, and glass fiber reinforced concretes (GFRC) are a very popular choice as substitutes for stone, wood, metal, or terra cotta. In a 2002 *New York Times* article titled "The Bionic Brownstone," Charles F. Wittman, the owner of Architectural Fiberglass Corporation of Copiague of Long Island, says that his company has installed "well over nine miles of fiberglass material" in New York City."[103] The New York City Landmarks Preservation Commission allows the use of these types of materials on a case by case basis. Other commissions, such as the Philadelphia Historic Commission, are much more cautious in approving these newer technologies and techniques.[104]

At its Milwaukee headquarters, the Northwestern Mutual Life Insurance Company has chosen to replace the granite cornice and terra cotta ornament with GFRC.[105] GFRC is about 50 percent lighter, and is projected to last longer than the granite, which was already replaced in 1982. Supporters say that this option is less invasive to the building than the structural upgrades necessary for replacing the granite in-kind would be. Skeptics note that "the technology is still evolving," and it is unclear how the GFRC will perform in the harsh Milwaukee climate over the long-term.[106]

Long-term performance is one of the most difficult measures to pin down when evaluating and selecting substitute materials. One of the only studies that looks at long-term performance of actual applications of any type of substitute material is John A. Fidler's 1982

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103 Jim O'Grady, "The Bionic Brownstone," *New York Times*, August 18, 2002.
104 Ibid.
105 Whitney Gould, "Substitute Materials are Iffy for Insurer's Iconic Building," *Milwaukee Journal Sentinel*, JS Online, March 11, 2007. http://www.jsonline.com/story/index.aspx?id=575909.
106 Ibid.

article "Glass-Reinforced Plastic Facsimiles in Building Restoration."[107] In 1987 he added information on GFRC in "Glassfibre-Reinforced Plastic and Cement Facsimiles in Building Restoration."[108] These articles examine the problems with visual appearance and durability that had emerged over 20 years of use of these products in Great Britain. In 2002, Fidler published an update to this study titled, "Plastic Dreams: Weathering of Glass-Reinforced Plastic Facsimiles," which reports on over 35 years of field observations under the direction of English Heritage.[109] Fidler acknowledges the difficulties in performing objective long-term evaluations, including for example, that owners and occupants change over the years and color information is not always clear on old photographs. However, he confirms his previous conclusion that FRP and GFRC are "unsuitable for the replication of historic materials and component systems in building restoration for technical, aesthetic, and economic reasons."[110]

Other than the material presented above, there are only a handful of published case studies dealing with substitute materials. A 1982 issue of the *APT Bulletin* dedicated to the reproduction of decorative elements includes several articles on projects ranging from the replication of stone with painted wood to the replacement of glass with acrylic panels.[111] However, other than John Fidler's articles on FRP and GFRC, not one of these published articles or case studies includes a long-term evaluation of the success of the project.

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107 John A. Fidler, "Glass-Reinforced Plastic Facsimiles in Building Restoration," *APT Bulletin* 14.3 (1982): 21-25.
108 John A. Fidler, "Glassfibre-Reinforced Plastic and Cement Facsimiles in Building Restoration," *Association for Studies in the Conservation of Historic Buildings Transactions* 12 (1987): 17-25.
109 John A. Fidler, "Plastic Dreams: Weathering of Glass-Reinforced Plastic Facsimiles," *APT Bulletin* 33, no. 2/3 (2002): 5-12.
110 Ibid., 11.
111 *APT Bulletin* 14, no. 3, Reproduction of Decorative Elements (1982).

PRESERVATION PRACTITIONER SURVEY

The literature review in the previous section reveals that very few contemporary preservation practitioners are publishing reports on their evaluation, selection, and use of substitute materials today. To supplement the relatively sparse literature on the topic, a survey was distributed to preservation practitioners to gain insight into the considerations and methods that are commonly used.

Methodology

The survey was designed to be completed by preservation practitioners who have had the opportunity to use or recommend substitute materials. It was created using an online survey program, and a link to the survey was distributed via email to approximately 1,200 members of the Association for Preservation Technology (APT). The distribution was limited to APT members who have identified their location as "United States." After the initial distribution, certain recipients forwarded the email and survey link to the Architectural Specialty Group of the American Institute of Conservators (which has over 200 members, many of whom are also APT members[112]) and the preservation listserv at the University of Texas at Austin (which has 108 subscribers[113]). Because the link was not limited to specific respondents and the survey was anonymous unless the respondents chose to leave their contact information, it is possible that the link was forwarded to other individuals as well.

The fourteen question survey, containing ten topic-based questions and four personal information questions, was designed to take approximately ten to fifteen minutes

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112 *Architecture Specialty Group*, The American Institute for Conservation of Historic & Artistic Works, http://aic.stanford.edu/sg/aboutASG.html.
113 *UT Lists*. Information Technology Services, University of Texas at Austin. https:// utlists.utexas.edu/sympa/info/preservation.

(though after collecting responses it was clear that approximately twenty minutes or more were necessary to provide full, well-thought-out responses). The topic-based questions were a combination of multiple choice, forced ranking, and open-ended response questions. The personal information questions sought to provide an overview of each respondent's background in the field.

Results

The survey was open for four weeks and 250 individuals responded. The majority of responses (approximately 200) were posted within two days of the email distribution. This section will discuss the results that can be quantified, as well as key responses to the open-ended questions. To view the complete survey and results, please refer to Appendix B.

As the survey was intended for APT members, the respondents were asked to characterize their background according to the APT list of 29 areas of expertise (respondents were allowed to mark multiple areas). The most commonly selected areas of expertise were as follows:

- Architect (50.6%)
- Historic Preservation Consultant (40.6%)
- Conservator (20.1%)

Other notable areas of expertise that demonstrate direct involvement with historic preservation projects include:

- Project Manager (19.3%)
- Contractor (13.3%)
- Engineer (12.0%)
- Crafts/Trades (9.6%)

The ten topic-based questions and results are included below. Please note that all percentages are based on the total number of respondents for each particular question. Most respondents answered all of the questions, but it is noted below when the response count for a question is lower than the total number of surveys completed.

- Assuming you are dealing with a historic building, would you consider using a substitute material for the replacement of historic elements that cannot be repaired? *(250 responses)*

Nearly all respondents (96.8%) replied that "yes," they would consider using a substitute material. Of those that replied "no" (3.2%), all went on to mark conditions under which they would use a substitute material in the following question. It is therefore possible that these negative responses were made in error.

- Under what conditions would you use a substitute material? *(250 responses)*

The intent of this question was to determine for what reasons and under what conditions preservation practitioners use substitute materials. Ten potential conditions were listed, along with an "other" category. Approximately one quarter of respondents marked all of the listed conditions. Additionally, the percentages correlated closely with the order of listing (i.e. more respondents selected conditions at the top of the list). This may be due to the fact that the list was presented in a semi-ordered format, but it may also have led to artificially high rankings of the conditions at the beginning of the list. The following graph shows the conditions and response percentages in the order they were listed:

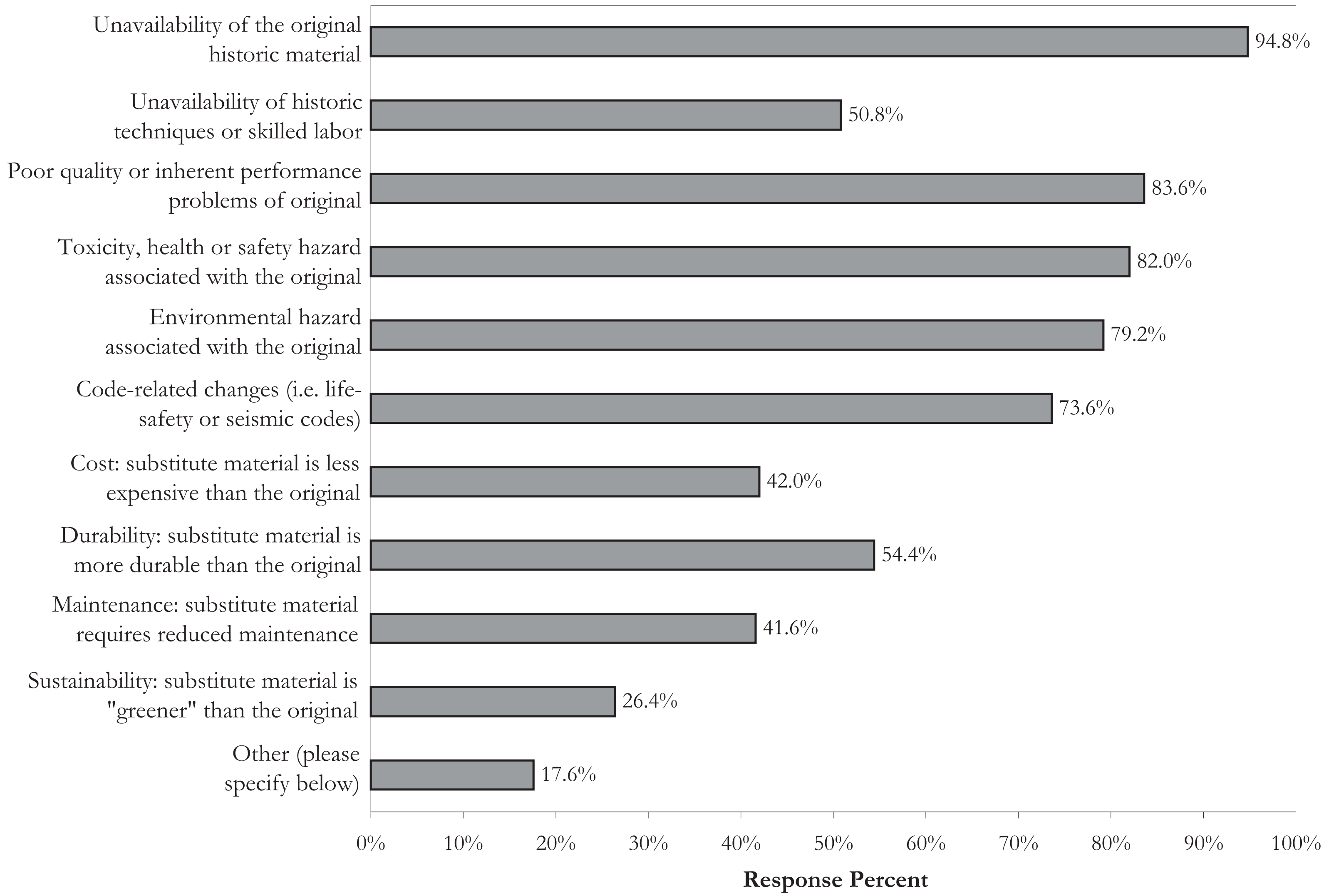

Figure 1. Conditions under which respondents to the Preservation Practitioner Survey use substitute materials

It is interesting to note two departures of the ranking from the listing order. Only about half (50.8%) of respondents indicated that they would use substitutes due to a lack of historic techniques or skilled labor, and some respondents noted that these challenges can usually be circumvented through specialized training. Also, only 42.0 percent of respondents indicated that they would use a substitute because it is less expensive than the original material. However, other respondents observed the opposite, noting, for example, that "unfortunately, cost usually becomes the deciding factor." This difference in opinion may result from the variety of projects and clients with whom the responding practitioners work, as well as the idealistic notion that cost should not be the deciding factor when it comes to preserving priceless cultural heritage. Still, it is clear that cost almost always plays some role in the decision to use a substitute material.

Respondents also listed some interesting additional conditions in the "other" category, including:

- Short-term or temporary stabilization or protection pending future work
- Shorter lead-times to obtain substitute materials
- Clear distinction between new work and original
- Client's insistence

Many of the respondents noted that the listed conditions should always be considered in combination and on a "project-by-project" basis, and that many of them may warrant the consideration of a substitute material, but should not necessarily dictate the use of that material.

- Which classes of substitute materials would you use? *(247 responses)*

The majority of respondents checked all three of the listed classes, but there is a clear majority that prefer "traditional materials" (93.9%) over "synthetic materials" (67.6%) and "green materials" (61.5%). Of those that listed "other" (15.8%), the majority of the materials specified would fit into one of the three listed classes. Some respondents used the "other" response box to again emphasize that each project is a unique case, or to present their qualms about using one or more of the classes of materials listed. Several individuals noted that the durability of synthetics and "green" materials is often difficult to track.

- If you have worked on historic projects involving substitutes, do you use a similar set of criteria for every project, or is each case unique? *(243 responses)*

The majority of respondents indicated that they use a unique set of criteria for each project (76.1%). 13.2 percent use the same set of criteria for every project, and 10.7 percent indicated that they have not applied specific criteria. As mentioned previously, many respondents emphasized in their comments the fact that each project has a unique set of circumstances and requires a unique set of criteria.

- Of the following criteria, please rank those you consider essential. *(243 responses)*

For this question, nine specific criteria and "other" were listed, and the ranking was forced, meaning that no two criteria could be ranked at the same level of importance. The intent of the forced ranking was to encourage respondents to consider and weigh each of the criteria. Again, several respondents commented that each project is unique and that the importance of certain criteria will change with the circumstances. Several others simply checked the criteria in order from top to bottom, potentially skewing the results and giving the criteria that were listed first an artificially high importance ranking. The following figure shows the average ranking results, shown in the same order they were listed on the survey.

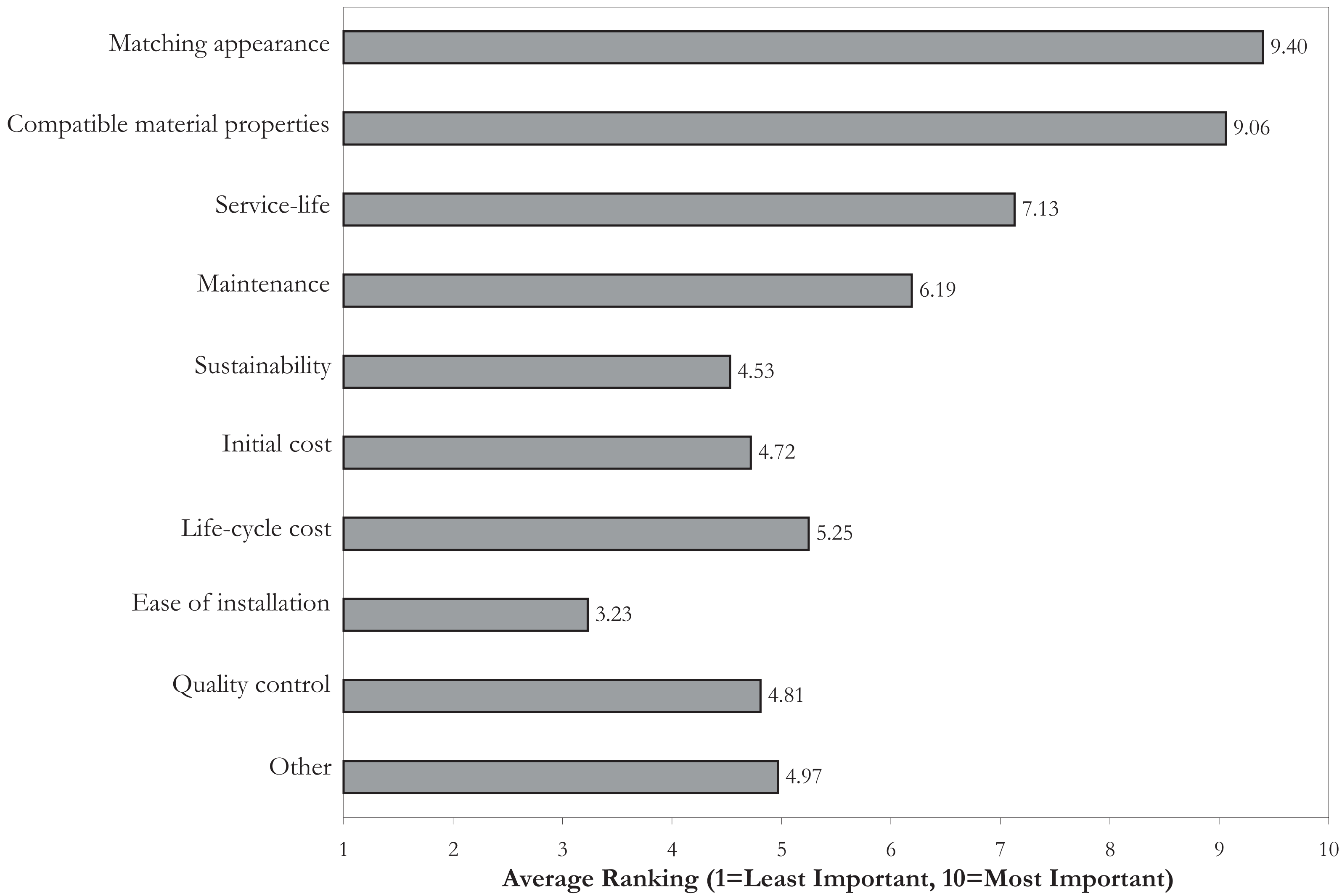

Figure 2. Essential criteria for the selection of substitute materials as reported in the Preservation Practitioner Survey

Despite the potential skew due to the listing order, the results still offer some insight, especially when respondents included "other" criteria that were not originally listed. Matching appearance and compatible material properties were selected as the most important criteria, and ease of installation and sustainability were selected as the least important. Some "other" useful criteria that respondents provided include:

- Historic significance of the building and/or original material
- Original design intent or function
- Location or visibility on the building
- Reversibility (i.e. non-invasive and non-damaging)
- Proven performance record of the substitute material
- Availability or lead-time associated with the substitute material

The listed criteria, respondent-provided criteria, and additional criteria that may be valuable will be discussed in detail in the following chapter.

- Do you utilize a specific method to evaluate substitute materials based on the criteria above? If so, what kind? *(243 responses)*

Over two-thirds of respondents (67.9%) indicated that they do not use a specific method to evaluate substitute materials and that instead, they "consider the criteria informally." For those that do use a specific method, the results were as follows:

- Decision Matrix (11.9%)
- Checklist (6.6%)
- Decision Tree (2.1%)
- Other (11.5%)

Respondents that selected "other" were asked to specify their method in an open-ended response box. Several noted that they rely on discussions and consultations with the owner, other practitioners, manufacturers' representatives, and installers to make informed decisions. Others utilize laboratory material testing methods, value analysis, or cost-benefit analysis (these methods will be discussed in detail in Chapter 5). Also, some respondents expressed doubts about the efficacy of a specific methodology, again citing that each project is unique.

- If you use substitute materials for historic projects, do you complete follow-up evaluations of in-situ performance? *(241 responses)*

The majority of respondents (74.7%) reported that they complete a "casual evaluation" of in-situ performance. Only 14.5 percent complete a formal evaluation, and 10.8 percent do not complete any follow-up evaluation. The range of comments accompanying this question indicate that varying perceptions of when follow-up evaluations should be completed (i.e. soon after completion of the project or several years or decades after completion) may have affected responses. Those that indicated that they do not complete follow-ups cited a lack of available budget or no longer being under contract for the project. Some noted that follow-up evaluations are only required when there has been a reported failure.

- Have you used substitute materials successfully? *(241 responses)*

Nearly all respondents answered "yes" to this question (90.9%), indicating that they have used substitute materials successfully (this corresponds to 87.6% of total survey respondents). The question was intentionally left open-ended to allow users to interpret and explain their answers. One respondent raised the question of how to define successfully, which is related to the preservation philosophy and goals for intervention that should guide the selection of substitutes. Others noted that materials they have used have been successful “so far,” or that not enough time has passed to make a conclusive judgment.

Respondents were also asked to specify which materials they have used. Analysis of the open-ended responses revealed successful use of the types of materials included in the figure on the following page. Please note that because answers ranged from specific proprietary materials to much more general material types, the numbers in this list are approximate, and materials that were mentioned fewer than five times were not included. The responses from the following question regarding material failures are also included in this figure for comparison.

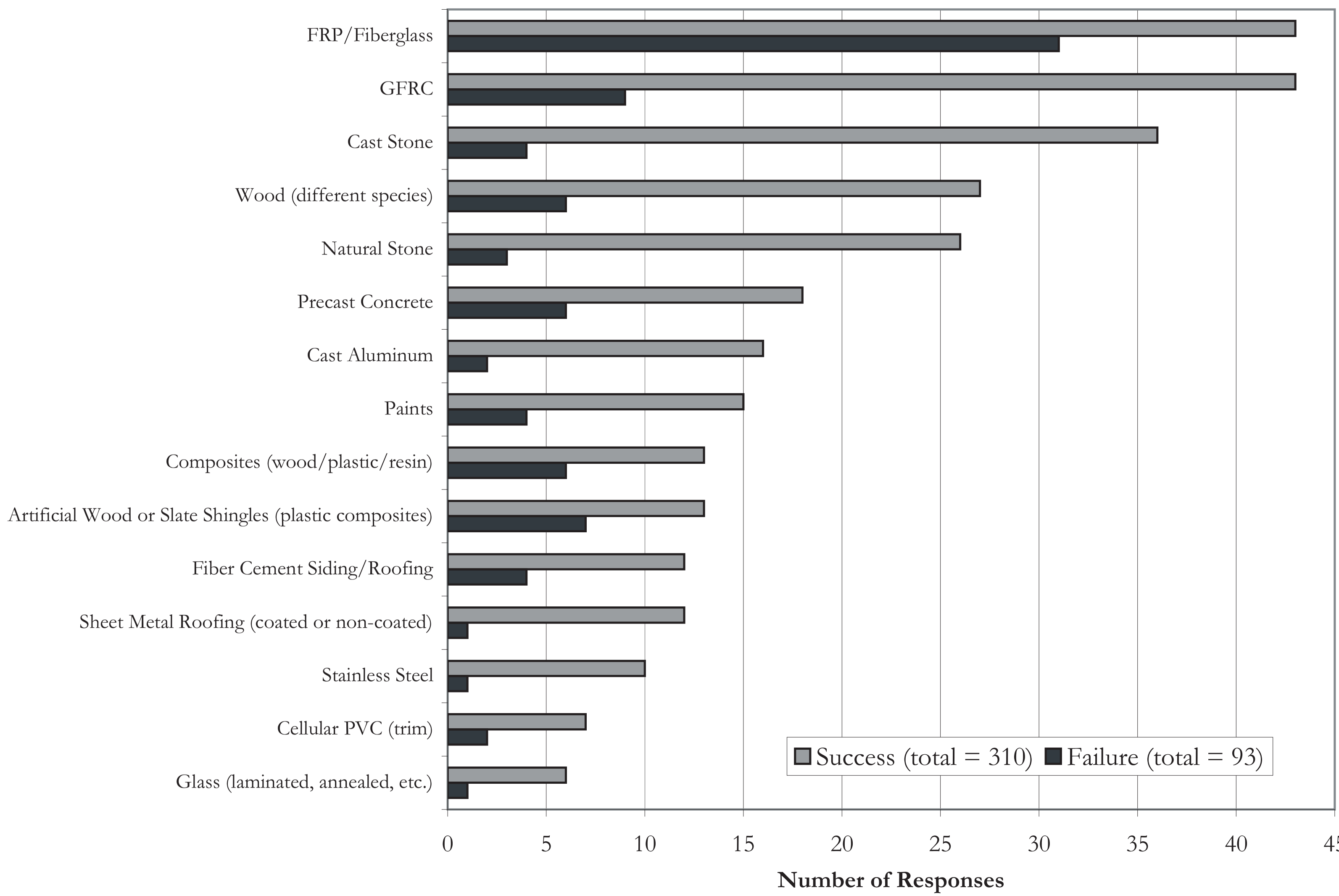

Figure 3. Substitute material successes and failures as reported in the Preservation Practitioner Survey

- Are you aware of any failures of substitute materials? *(236 responses)*

The majority of respondents of this question (61.9%) replied that, "yes," they are aware of material failures. This corresponds to 58.4 percent of total survey respondents (compared to the 87.6% of survey respondents that have used substitute materials successfully). Respondents were also asked to indicate which materials had failed and what went wrong. The material failure information is included on the previous chart, allowing for comparison with reported successes.

Though far fewer material-specific failures were reported than successes (310 successes, 93 failures), this is not necessarily indicative of the overall performance of substitute materials. 146 respondents indicated that they were aware of failures, but less than 93 actually specified materials. This could be due to hesitance to disclose specific information, or because respondents were "aware of" failures on projects that were not their own and did not know specific details. The relatively large number of respondents that indicated awareness of failures of fiber reinforced polymers (FRP), fiberglass, and glass fiber reinforced concrete (GFRC), for example, could be due to the publication of John Fidler's reviews of these materials in the *APT Bulletin*, a publication that is distributed to all APT members.

Respondents also cited similar reasons for failures of substitute materials including:

- Poor quality control in fabrication and application
- Acceptance of manufacturer's claims without testing
- Client's insistence
- Lack of long-term in-situ performance data

Finally, respondents were asked if they thought a "more comprehensive selection method or list of criteria would have helped prevent the failure." Only approximately fifteen individuals addressed this last question, and the results were split evenly between those who believe that a list of criteria or method would be helpful and those that did not. In some cases, those that said "no" to this final part of the question indicated their reasoning. The most commonly cited reason is that without long-term performance data, an evaluation and selection method would have limited utility. Others' answers were project-specific (i.e. budget or clients dictated the use of a certain substitute so a better selection method would not have been utilized). The utility of a list of criteria and selection method will be discussed in further detail in the following two chapters.

- Any additional comments or questions? *(72 responses)*

Just over a quarter of respondents offered additional thoughts on substitute materials and selection criteria and methods, which have proven very insightful. Many similar comments were offered in the previous open-ended questions, but this final question served as a catch-all for any additional related comments. The following are some of the issues or themes that were raised by several respondents.

Every project is unique! As mentioned again and again throughout the survey responses, practitioners understand that each project will have different priorities, criteria, and solutions. Some are skeptical that a comprehensive list of criteria or an evaluation method would be applicable to every project, which underscores the need for flexibility.

Long-term performance data is needed. Many respondents indicated that the biggest challenge in the evaluation and selection of substitute materials is the lack of long-term performance data for substitute materials installed in similar situations and environments. Some expressed the desire for a database or similar resource for material performance information. Others recommended that professional preservation and conservation organizations, as well as regulatory agencies and granting bodies, require long-term follow-up evaluations of projects to "inform potential users of actual performance of substitutes."

Preservation philosophy should guide material selection. Many respondents, especially those who work for the NPS or other agencies or commissions, noted that the selection of substitutes should be highly dependent on the historic significance of the building and original material or element and the corresponding preservation philosophy.

Educating the client can be a challenge. Sometimes one of the greatest challenges on a project can be educating the client about the use of historic materials or appropriate substitute materials. Manufacturers are very good at marketing new products, so practitioners may face an uphill battle when trying to recommend more traditional approaches. Some respondents noted that a comprehensive list of criteria or an evaluation method could help to inform clients about possible solutions.

CONCLUSION

Contemporary preservation literature lacks comprehensive guidance on the evaluation and selection of substitute materials, as well as long-term evaluations of the performance of available substitute materials.[114] While practitioners rarely publish detailed reports on the use of substitutes on their projects, it is evident from the survey that practitioners are using a wide variety of substitute materials. Though most preservation

[114] With the exception of John Fidler's previously-cited examination of FRP and GFRC.

practitioners consider using substitute materials from time to time, less than one third use a formal method of evaluating and selecting (or rejecting) these materials, and approximately ten percent do not even consider specific criteria when making decisions.

The respondents to the practitioner survey clearly realize that each project is unique and will require a tailored solution, and some even expressed reservations that an established set of criteria or structured evaluation method would lead to omissions or poor decisions. Still, many others expressed an interest in the development of a comprehensive set of criteria or a method that could guide the decision-making process. The following chapters will explore in detail necessary considerations for the evaluation of substitute materials on historic projects, and decision-making methods that may aid in this evaluation and selection.

CHAPTER 4: CONSIDERATIONS FOR THE EVALUATION & SELECTION OF SUBSTITUTE MATERIALS

INTRODUCTION

The previous chapter discussed the use of substitute materials in contemporary preservation practice. While the practitioner survey showed that the majority of preservation practitioners will consider using substitute materials on historic projects, the published literature offering guidance on the evaluation and selection of these materials is relatively general in scope. There is also a lack of published long-term performance data on most types of substitute materials, which can be challenging when selecting these materials for historic projects.

This chapter is a synthesis of the applicable considerations for the evaluation and selection of substitute materials, drawing from the published literature and practitioner survey discussed in the previous chapter. Other sources of potentially applicable considerations were also consulted, including materials selection guides as well as other publications from the fields of objects conservation, architecture, and engineering. The list is meant to be as comprehensive as possible. However, because each project will have a unique set of circumstances and priorities, not all of the considerations will apply to every case. It is the responsibility of the preservation practitioner, together with the client, to determine which are applicable.

The following discussion has been organized into three general categories:

- Preservation Philosophy
- Material Properties and Performance
- Cost (both economic and environmental)

These categories echo the main reasons why practitioners turn to substitute materials for the replacement of historic elements, as well as the basic areas that should be considered before a substitute material is selected. A graphic representation of the complete inventory of considerations is included at the end of this chapter.

PRESERVATION PHILOSOPHY

Preservation philosophy and attitudes towards substitute materials for use on historic projects has changed over time. While there is still a strong emphasis on material authenticity today, it is also understood that different approaches may be appropriate for different historic resources. *The Secretary of the Interior's Standards* provide guidance for a variety of projects ranging from preservation, rehabilitation, restoration, and reconstruction of historic properties. In the introduction, they state:

> The Standards are neither technical nor prescriptive, but are intended to promote responsible preservation practices that help protect our Nation's irreplaceable cultural resources. For example, they cannot, in and of themselves, be used to make essential decisions about which features of the historic building should be saved and which can be changed. But once a treatment is selected, the Standards provide philosophical consistency to the work.[115]

"Philosophical consistency" is key when considering the use of substitute materials. *The Standards* and other NPS publications emphasize this as part of the decision-making process, but many of the more technical publications are silent when it comes to preservation philosophy. As preservation engineer Robert Silman notes, "we can do practically anything nowadays in constructing and preserving the built environment…the proper question to ask now [is], 'Ought we do such-and-such a thing?' The inquiry [has] shifted from the technical

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115 Weeks and Grimmer, *The Secretary of the Interior's Standards for the Treatment of Historic Properties.*

to the philosophical and the moral."[116]

While preservation philosophy does not translate particularly well into "criteria" that can be checked off a checklist, there are certainly philosophical questions that should be addressed at the outset of any project. To determine if *any* substitute material is appropriate, the following philosophical issues should be considered.

Significance of the Building

The *Secretary of the Interior's Standards* list a property's "relative importance in history" as the first issue to consider when determining a treatment philosophy.[117] Designation as a National Historic Landmark or listing on the National Register of Historic Places can be a guide to the level of importance of a specific property, and usually a statement of significance written by a historian or a preservation practitioner will accompany these listings. It is not the purpose or scope of this thesis to describe the many values that make a property historically significant.[118] However, different types of significance may warrant different preservation philosophies. For example, a property listed because it was designed by a famous master architect and is an excellent example of a certain architectural style may require more emphasis on material authenticity than a property that was listed because it was the site of an important historical event.

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116 Robert Silman, "Is Preservation Technology Neutral?" *APT Bulletin* 38, no. 4 (2007): 3.
117 Weeks and Grimmer, *The Secretary of the Interior's Standards for the Treatment of Historic Properties.*
118 Barbara Appelbaum, *Conservation Treatment Methodology* (Oxford: Butterworth-Heinemann, 2007). Appelbaum discusses the various values that may be relevant to a conservation treatment methodology for objects. Many of these values may also be relevant when considering the use of substitute materials on historic buildings.

Significance of the Element or Material

When considering the replacement of a specific element or material, it is equally important to consider its contribution to the significance of the building as a whole. Is the material something that is no longer readily available? Does it exhibit a high level of historic craftsmanship that cannot be replicated today? Was it an innovative or new technology at the time of installation? Is it a part of a larger system whose integrity would be compromised by its replacement? Is the material a key part of the original design intent?

This last question regarding design intent is especially applicable when dealing with the preservation of modern architecture. Over the past decade, several authors have written about the philosophical issues surrounding the preservation of modern architecture.[119] According to Frank Matero and Robert Fitzgerald, there is "growing argument for a preservation philosophy that privileges conceptual aesthetics and the architect's intent over the constructed realities."[120] At Frank Lloyd Wright's Solomon R. Guggenheim Museum, the architect's original intent for "a continuous mass and free-flowing surface," had been challenged by thermal cracking. Matero notes that "the dilemma of how to interpret the exterior of the Guggenheim Museum centers around the decision to reinstate with new materials either what Wright intended or what was actually delivered."[121] Substitute materials may be desirable for projects where the goal is to recreate the original design intent, especially if the original material performed inadequately.

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119 Matero and Fitzgerald, "The Fallacies of Intent," 3-12. This article cites many of the key works on the preservation of modern architecture.
120 Ibid., 3.
121 Ibid., 10.

Physical Condition of the Original Element

The *Standards* also note that the degree of material integrity of a resource should help to guide the selection of a treatment philosophy.[122] The prevailing preservation attitude is that materials that can be repaired should be retained, and only severe deterioration, damage, or loss warrants replacement. However, if an original material has performed poorly, a substitute material may be appropriate. Characterization of the properties and performance of the original material, as well as a thorough diagnosis of the causes of failure, are necessary to inform the selection and design of any replacement material. The importance of an accurate diagnosis will be discussed in further detail under "Material Properties & Performance."

Amount and Location of Proposed Substitute Materials

The recently published guidance from the NPS Historic Preservation Tax Incentives Program divides the evaluation of substitute materials into three issues.[123] The first is the need for substitute materials, which is usually based on the unavailability of historic materials or craft techniques, or poor performance of the original material. The second is the amount and location of substitute materials. This guidance warns against the excessive use of substitutes that can threaten the integrity of the building as a whole, and notes that the location of the proposed substitute is critical to its acceptance.

Substitutes are usually more acceptable for less-visible features, "for example, a replacement cornice using a substitute material proposed for a two-story building would

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122 Weeks and Grimmer, *The Secretary of the Interior's Standards for the Treatment of Historic Properties.*
123 "Evaluating Substitute Materials in Historic Buildings." Historic Preservation Tax Incentives Program.

have to match more closely the historic element than one intended for a ten-story building."[124] Additionally, because materials on less-visible elevations tend to contribute less to the building's overall character and significance, substitute materials may be acceptable in these locations. This raises the question: are substitute materials acceptable if they will be hidden from view (e.g. structural substitutions)? While they may be acceptable in certain cases, the answer should still be dependent on the significance of the specific project and material as discussed above.

As noted by some of the practitioner survey respondents, location can also be a practical issue when installing certain types of substitute materials, such as fiberglass casts, that may be prone to damage by impact or excessive loading. Finally, substitutes should never be installed in locations where they might obscure the root problem or ongoing deterioration.

Proposed Use

The proposed use of a particular historic building will also be a factor in its preservation philosophy. An adaptive reuse that is different than the original use may result in changes that are needed to make the building functional, and substitute materials may be required as part of this improved functionality. Substitute materials might be required to resolve hazardous materials, life-safety, or seismic code conformance issues.

Establishing the Goal of Intervention

The considerations listed above should all contribute to a project-specific preservation philosophy and an overall goal for intervention. As Barbara Appelbaum notes

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124 Ibid.

in her book, *Conservation Treatment Methodology*, establishing a realistic goal for treatment is critical to the evaluation of potential solutions.[125] While her methodology focuses primarily on objects conservation, a realistic goal for intervention is important for the replacement of building materials as well.

A primary goal of any intervention with a replacement material should be to prevent the recurrence of the original material loss or failure, which is informed by a thorough diagnosis of the causes of the original material failure. Additionally, a realistic goal for intervention should include expectations for the projected lifespan, aesthetics, and performance of the substitute material. Is the material is intended to be sacrificial? Is the intent to create a clear distinction between new and old material? While these considerations will be discussed in further detail in the following sections, it is important to note that performance expectations will vary from project to project. In some cases, the use of a substitute material that will require replacement every ten years is acceptable, while other projects require materials with a service life of up to a century. Whatever the expectations, they should be based on a sound project-specific preservation philosophy.

MATERIAL PROPERTIES & PERFORMANCE

One of the major considerations in any building material selection, whether for new construction or replacement, is material performance. While substitute materials used on historic projects tend to require greater emphasis on material compatibility, both aesthetically and functionally, the general performance requirements are similar to those for new construction. Preservation practitioners can utilize some of the many published resources

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[125] Appelbaum, *Conservation Treatment Methodology*.

on the evaluation and selection of new building materials to ensure a comprehensive consideration of all applicable performance characteristics.

In 1964, the International Council for Building Research, Studies, and Documentation (CIB) published *A Master List of Properties for Building Materials and Products,* which included a comprehensive list of material properties, as well as other considerations such as design and detailing, work and maintenance instructions, and economics, that affect material performance.[126] In 1979, engineer Harold J. Rosen and architect Philip M. Bennett distilled this list to the following major performance requirements in their book, *Construction Materials Evaluation and Selection*:

1. Structural serviceability
2. Fire safety
3. Habitability
4. Durability
5. Practicability
6. Compatibility
7. Maintainability
8. Code acceptability
9. Economics[127]

These categories will be included in the discussion of material performance below. Each of these categories also includes more specific criteria to be used within a system of evaluation and selection.

Other sources such as volume 20 of the *ASM Handbook*, *Materials Selection and Design*, (published by ASM International, formerly the American Society for Metals) provide a more

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[126] Harold J. Rosen and Philip M. Bennett, *Construction Materials Evaluation and Selection: A Systematic Approach* (New York: John Wiley & Sons, 1979), 7.
[127] Ibid., 16-17.

technical view of the material selection process.[128] While this volume is primarily intended for materials and design engineers, with an emphasis on product design and manufacturing, many of the property lists and decision-making methods can be also be useful to preservation practitioners.

Finally, engineering publications can also offer guidance on considerations specific to repair or rehabilitation. When dealing with existing buildings, compatibility between the new and existing materials is a primary concern. A recent article titled "Compatibility and Concrete Repair" in *The Construction Specifier* explores the critical differences between repair and new construction.[129] While this article focuses on concrete repair, the various types of compatibility, including dimensional, chemical, permeability, electrochemical, and aesthetic compatibility, are also applicable to many substitute materials.

The following discussion of material properties and performance supplements the technical guidance provided in the published preservation literature with information from the sources above. Because factors affecting material performance are often interdependent, there is some overlap between the considerations listed in the following categories:

- Material Properties
- Design & Detailing
- Fabrication & Installation
- Functionality
- Durability

Also, please note that the following considerations do not include quantitative limits

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128 *ASM Handbook*, vol. 20, *Materials Selection and Design* (Materials Park, OH: ASM International, 1997).

129 Alexander M. Vaysburd, Benoit Bissonnette, and Christopher C. Brown, "Compatibility and Concrete Repair," *The Construction Specifier* (Jan 2009): 44-52.

or acceptable values, as this level of guidance is specific to each material combination and situation, and is outside the scope of this thesis.

Material Properties

The examination of material properties is critical to the performance and compatibility of substitute materials. The original material should be characterized with respect to the following properties, which have been divided into two categories: Aesthetic Properties and Physical, Mechanical, Thermal, and Chemical Properties. A thorough diagnosis of the causes of failure of the original material should reveal which of these properties need improvement in a substitute material to prevent the repetition of the original failure. The material properties of any potential substitute materials should also be examined to ensure compatibility with the surrounding building materials and assemblies. Please note that the surrounding materials may be the same as the original material that is being replaced, or they may be completely different.

Aesthetic Properties. Replicating the visual appearance of the original element is often considered the single most important criterion for the use of substitute materials. The *Secretary of the Interior's Standards* lists matching design, color, and texture as the first requirements for replacement materials. The importance of compatible aesthetics is also reinforced by many other guiding publications, as well as the preservation practitioner survey, where "matching appearance" received the highest overall importance ranking out of the listed criteria.[130] The following material properties contribute to the overall aesthetic compatibility of a substitute material:

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130 Weeks and Grimmer, *The Secretary of the Interior's Standards for the Treatment of Historic Properties.*

- **Color.** Color can be one of the greatest challenges when attempting to match a substitute material to an original. It is important to match the substitute to the original after it has been cleaned, and to determine if the substitute material can replicate the subtle variations in color that are exhibited by many historic materials. Also, will the substitute material still match the original when wet?

- **Texture.** Can the substitute material replicate the texture of the original?

- **Finish.** Is the finish intrinsic to the substitute material? Can it take paint or other coatings? Will it weather differently than the original material?

- **Reflectivity.** Color, texture, and finish contribute to the way in which a material reflects light. Sometimes subtle differences can reveal a substitute material.

- **Size & Shape.** The size and shape in which substitute material units are fabricated are also important, as larger units or different patterns can expose a substitute material. Unit size and shape can also affect performance and will be discussed again under "Design & Detailing."

- **Detailing.** Like unit size and shape, detailing that does not match the original can cause visual incompatibility. This can include, for example, the spacing or location of joints or the sharpness of corners and edges. Design is also important when considering if a substitute can replicate unique units, such as individual ashlar blocks, or if the substitute units will be fabricated in a way that limits variety and causes noticeable uniformity or repetition.

- **Patina, Corrosion & Ultraviolet Degradation.** Whether a material develops a desirable patina or undesirable corrosion or discoloration, it is necessary to consider how the appearance of a substitute will age in comparison to the original.[131]

- **Static Charge & Response to Pollutants.** Varying static charges of substitute materials can cause them to attract soiling differently than the original materials.[132]

Physical, Mechanical, Thermal & Chemical Properties. These material properties have a significant combined impact on the compatibility, functionality, and durability of substitute materials. Again, these properties should be understood for *both* the substitute material and the original material. If certain properties of the original have

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131 While patina and UV degradation are technically chemical properties, they are listed under aesthetic properties because it is critical to consider how and why a material's appearance will change over time.

132 Fisher, "The Sincerest Form of Flattery."

contributed to the deterioration or failure, these may be improved upon with a substitute material. To ensure compatibility, these properties should also be considered with respect to the surrounding or adjacent materials.

- **Weight.** The weight or density of a substitute material can have significant implications for how it must be anchored or supported. Many substitute materials are much lighter than the original materials they replace, which may provide a structural advantage.

- **Strength**. A material's response to tensile, compressive, and shear forces should be considered. Quantitative values for yield strength or ultimate strength may be obtained. With the exception of cases when substitute materials are used for structural applications, substitutes should generally have equal or lesser strength than the original material so that they will be "sacrificial."

- **Flexibility.** In addition to ultimate strength, the manner in which a material responds to tensile, compressive, and shear forces is important to consider. Is the material brittle or flexible? How will it respond to potential impact? Will the material become brittle over time?

- **Hardness.** Will the surface scratch easily?

- **Creep.** Will the material deform slowly under loading or over time?

- **Curing or Drying Shrinkage.** This property is especially critical for cementitious materials. Will the material shrink after it is fabricated? If it is cast, should molds be made larger than the intended finished size?

- **Porosity & Permeability.** These properties are absolutely critical to the compatibility and durability of substitute materials. How does water enter and move through a material? How does moisture leave the material? Will the substitute material trap moisture within the system and cause deterioration of other materials?

- **Hygroscopic Expansion.** Will the material expand when it gets wet? How much?

- **Vapor Permeability.** Is the material vapor permeable? Will it trap moisture within the system?

- **Static Charge.** As mentioned above, the static charges of some substitute materials may cause them to differentially attract pollutants, altering their appearance.

- **Thermal Expansion.** Is the rate and amount of thermal expansion of the material comparable to the surrounding material? How will the dimensions of the substitute material unit affect expansion? Will the substitute and its surroundings move together or are design provisions necessary to accommodate thermal expansion?

- **Other Thermal Properties.** Thermal absorptivity, emissivity, and conductivity (how a material absorbs, emits, and conducts heat) are important when considering how substitute materials perform under very high or very low temperatures. Can the material withstand temperature extremes?

- **Fire Resistance.** This property is important for any building material. Is the material flammable? What happens when it burns?

- **Corrosion Resistance.** As mentioned under Aesthetic Properties, sometimes corrosion products are desirable and are considered "patina." Other times corrosion is visually undesirable and can cause serious performance problems. Is the substitute material susceptible to corrosion that will alter its appearance or affect its performance?

- **Galvanic Corrosion.** When certain materials are placed in contact, especially metals, galvanic corrosion can occur. Will the substitute material be placed in contact with other materials that could create galvanic interaction?

- **Ultraviolet Degradation.** Ultraviolet degradation can cause the appearance of a substitute material to change. However, if severe, UV degradation can also cause performance problems. Is the substitute material susceptible to UV degradation? If it is susceptible, are there effective measures that can be taken to protect the material?

- **Inertness.** Will the substitute material cause a chemical reaction with any adjacent materials? Does the substitute material contain any soluble salts? Is it alkaline or acidic?

- **Rot & Fungal Resistance.** Is the material susceptible to bacterial or fungal attack?

- **Toxicity.** Is the material toxic or does it release any toxic materials during fabrication?

Design & Detailing

In addition to aesthetics, the design and detailing of substitute materials affects functionality, compatibility, and durability. While design is constrained by the necessity to provide an adequate visual match, joints and water-shedding details such as drip edges should not be neglected. Ideally, over a material's history of use, a knowledge base regarding appropriate and effective design and detailing has been developed. The extent of this knowledge base should certainly be considered when attempting to write specifications or draw details for a substitute material assembly.

The design of a substitute material assembly is also critical to its compatibility with adjacent fabric. It is virtually impossible to find a substitute material with material properties that are identical to the original. As mentioned above, it is best to minimize these differences in properties, but sometimes tolerances in design can help to avoid potential problem areas. For example, expansion joints can accommodate differences in thermal expansion. Additionally, well-designed methods of attachment and joining can help to ensure that the substitute material does not damage historic fabric, and can be removed if desired. Sometimes a substitute material may be a reversible solution when in-kind replacement is not (e.g. in-kind replacement requires additional structural reinforcement that would be very invasive but a lighter substitute material can be installed with minimal impact).

Finally, the relative integration with or isolation from the original fabric is a key consideration in the use of any substitute material. For example, masonry patching materials require integration with the original fabric, and any incompatibilities between the materials can be visually apparent or cause performance problems. However, the replacement of complete stone units, particularly if an entire area or façade is replaced, can soften the requirement for compatibility because there is less direct contact between new and old. Sometimes the potential visual "patchwork" effect of replacing only some of an original material, even if the remaining material is in acceptable condition, can be a greater detriment to the significance of a building than complete replacement. If a particular historic material is replaced in total, there is no opportunity for direct visual comparison between new and old, and subtle differences will be less noticeable. Clearly this type of decision should be based on the preservation philosophy for the project and the emphasis on material authenticity.

Fabrication & Installation

Even when the knowledge base for the design and detailing of a particular substitute material assembly is well developed, the fabrication and installation of that material can cause potential problems. Many of the respondents to the practitioner survey indicated that they were aware of material failures due to poor fabrication or installation. Parks Canada notes that a thorough evaluation of the manufacturer and installer is as important as the evaluation of the substitute material itself.[133] This evaluation should also extend to the supplier of any natural substitute material.

When considering a fabricator (or supplier) and installer, the following questions should be asked. Is there an acceptable level of quality control during fabrication or extraction? Does the fabricator have experience with custom orders for historic projects? Are the workers that will be installing the material trained to work on historic projects and do they have experience with this particular material? Sometimes companies will send a trained worker to complete mock-ups or oversee other workers, but to ensure high quality work, it is important to check the qualifications of everyone working on the project.

Other considerations related to fabrication (or extraction) have been mentioned in

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133 *Standards and Guidelines for the Conservation of Historic Places in Canada.*

many of the previous sections, but in summary, the following types of questions should be asked. How is the material fabricated? Can it be cast? What type of molds are required? Will a finish be factory-applied? Can the material be fabricated on-site? Does the method of fabrication allow for the exact replication of original details (e.g. sharpness of corners, variegated surfaces, etc.)?

Rosen and Bennett use the term "practicability" to describe the following types of considerations during transportation and installation.[134] Are there complicated handling requirements during transportation and installation? Is specialized equipment required? Will the material be susceptible to abrasion or breakage? Are there provisions for corrective measures to meet field tolerances? How are the connections made on-site?

Functionality

Like most building materials, substitute materials on building exteriors are usually required to perform some type of function. The following performance requirement categories listed by Rosen and Bennett can be considered functional requirements and are listed together in this section: structural serviceability, fire safety, habitability, maintainability, and code acceptability.[135]

Structural Serviceability. The ability of a material to resist loading, both dead loads such as other building components and live loads such as wind or earthquake loads, is a necessary consideration for substitute materials. Usually these considerations are enforced by code.

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[134] Rosen and Bennett, *Construction Materials Evaluation and Selection,* 21.
[135] Ibid., 16-17.

Fire Safety. As mentioned above, the fire resistance of substitute materials, as well as properties such as "flame propagation, burn through, smoke, [and] toxic gases" should be considered where they may affect life safety. Often these considerations are also enforced by code.

Habitability. Rosen's and Bennett's definition of habitability includes "livability relative to thermal efficiency, acoustic properties, water permeability, optical properties, hygiene, comfort, light and ventilation, etc."[136] For substitute materials on building exteriors, the most critical of these functional properties is the ability to effectively shed water and serve as an enclosure against the elements.

Maintainability. The recently released guidance from the NPS Historic Preservation Tax Incentives Program warns against materials that are marketed as "maintenance-free," noting that because these materials are difficult or impossible to maintain, replacement may be the "only response to deterioration."[137] When determining if a material *can* be maintained, both regular cleaning and periodic repair should be considered. The relative frequency and type of maintenance required by a substitute material with respect to the surrounding fabric is also important. Can building staff perform routine maintenance and repairs or is specialized training necessary? A high degree of difficulty (or cost) of maintenance may mean that it will not be performed and the material and building may suffer as a result.

Code Acceptability. Code acceptability can sometimes be the reason for using a

[136] Ibid., 17.

[137] "Evaluating Substitute Materials in Historic Buildings." Historic Preservation Tax Incentives Program.

substitute material over in-kind replacement. Applicable codes, as noted above, include seismic and structural codes and other life-safety codes.

Durability

The Weathering and Performance of Building Materials includes several definitions of durability, including one from the British Standards Institution Code of Practice that defines durability as, "The quality of maintaining a satisfactory appearance and satisfactory performance of required functions."[138] The authors also state, "Performance data based on real buildings in real situations are essential if a full understanding of the behaviour of external materials and design elements is to be achieved."

While long-term performance data for substitute materials in similar applications is the best way to judge durability, this type of information may not always be available, either because the substitute material has not been in use long enough to accumulate such data, or because practitioners do not complete or share the results of follow-up evaluations for substitute material installations. In the absence of long-term performance data, it is up to the preservation practitioner to estimate the durability or weathering properties of a substitute material. Are there applicable performance standards for the particular type of material? Are there applicable testing methods that could approximate the effects of long-term exposure? Can the weathering properties be predicted based on the material structure and properties? Many preservation practitioners have studied the effects of weathering on various historic materials and can link certain material properties to weathering vulnerability. This type of comparison may be helpful for newer materials that have not yet established a

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[138] John W. Simpson and Peter J. Horrobin, *The Weathering and Performance of Building Materials* (New York: Wiley-Interscience, 1970), 10.

proven track record.

COST: ECONOMIC & ENVIRONMENTAL

The discussions of economic and environmental costs (or more broadly, environmental sustainability) are presented together below, as there are many similarities between the two. For building materials, the factors that influence cost, both economic and environmental, span the entire life-cycle of the material, from extraction or fabrication, transportation, installation, maintenance, and eventually, disposal. While this section includes a discussion of these cost-influencing factors, a more detailed discussion of the various methods of analysis that can be used to evaluate material costs can be found in the following chapter.

Economics

Most of the published preservation literature on the topic of substitute materials concedes that economic cost is often a factor in the decision to use a substitute material. While ideally the best intervention could be chosen regardless of cost, in reality, cost is nearly always a factor, and often, it can be the *deciding* factor. As noted in the previous chapter, 42 percent of the respondents to the preservation practitioner survey marked "cost: substitute material is less expensive than the original," as a condition under which they would use a substitute material. This choice made no distinction between initial cost and life-cycle cost. However, a following question on the criteria for the evaluation of substitute materials did find a slightly higher importance ranking given to "life-cycle cost" (5.25) than "initial cost" (4.72). As one survey respondent noted, life-cycle cost actually depends on many other factors including initial cost, service life, and maintenance. Because so many of these criteria are interrelated, it can be challenging to consider them in isolation.

Initial Cost. Initial cost for new building construction usually includes "land, labor, equipment (capital), and materials."[139] When considering the initial cost of a replacement material only, land costs will be eliminated. The initial cost to use a certain material usually includes the following:

- **Raw Material Cost.** All components of the product.
- **Fabrication or Manufacturing Cost.** Labor and equipment.
- **Transportation Costs.** To fabrication location and to project site.
- **Installation Costs.** Labor and equipment.
- **Lead-Time.** "Time is money."

Many of these may be combined into the list price for the material. However, it is good practice to consider all potential sources of additional cost for various alternatives, especially when the material will be customized for a specific project.

Life-Cycle Cost. Determining the life-cycle cost of using a certain substitute material is considerably more complex than initial cost. Life-cycle cost includes the initial capital cost plus any operation and maintenance or repair costs that the material incurs throughout its service life.

As long-term in-situ performance data is sometimes unavailable for many substitute materials, it can be difficult to accurately estimate service life and determine the type and amount of maintenance that may be required. Still, preservation practitioners rarely use substitute materials without an expectation for service life and some understanding of the maintenance that will be required, which should allow for an estimated value of life-cycle

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[139] Robert Johnson, *The Economics of Building: A Practical Guide for the Design Professional* (New York: John Wiley & Sons, Inc., 1990), 84.

cost. The various methods that can be used to make this estimate will be discussed in the following chapter.

Environmental Sustainability

Sustainable development has been defined as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs."[140] Though the broad term "sustainability" includes environmental, economic, social, and cultural sustainability, the green building movement places the primary focus on environmental sustainability.[141] Since economics and preservation philosophy (in which social and cultural sustainability play a role) have already been discussed, this section will focus primarily on environmental sustainability.

Some preservation practitioners feel that sustainability is only marginally important when considering substitute materials. Very little published preservation literature addresses sustainability with respect to substitute materials, and only about a quarter of respondents to the preservation practitioner survey indicated that they would consider a substitute material because it is "greener" than the original. Others expressed strong concerns about green materials, writing for example, "the drive for sustainability and LEED certification is wreaking havoc on original materials even more so than the deadly times of the 1970s."

Concerns about green building materials are not unfounded. While some standards

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[140] Gro Harlem Brundtland and World Commission on Environment and Development, *Report of the World Commission on Environment and Development : "Our Common Future"* (New York: United Nations, 1987).

[141] Patrice Frey, "Measuring Up: The Performance of Historic Buildings Under the Leed-NC Green Building Rating System." M.S. Thesis, University of Pennsylvania, 2007. Frey challenges the focus on environmental sustainability and recommends a more comprehensive approach including economic, social, and cultural sustainability for the evaluation of historic buildings.

for green building materials do exist, there is no one comprehensive standard that can be applied to all types of materials.[142] Often practitioners are left to rely on manufacturers' data or unsubstantiated claims that their product is green. Because there are many factors that contribute to the environmental impact of a material, it can be challenging for practitioners to evaluate the varying "shades of green" of building materials.[143] The following "general rules of thumb" from *Green Building Materials* can provide some considerations for green materials:

- Maximize durability
- Maximize energy efficiency
- Maximize future recyclability
- Maximize maintainability
- Maximize recycled content
- Maximize use of local or regional materials
- Minimize embodied energy (promote the highest and best use of a material to avoid wasting the embodied energy)
- Minimize use of hazardous natural chemicals
- Minimize use of synthetic chemicals[144]

Notice that many of these considerations overlap with the previously mentioned goals of using substitute materials for preservation. It is by no means the intent of this thesis to promote the replacement of functional historic building materials just because there may be a greener material available today. It is also not the intent to recommend the use of green substitute materials when acceptable in-kind replacement materials are available. However, the goal of preserving cultural heritage and the built environment should go hand-in-hand with environmental preservation, and when choosing between otherwise equal materials, preservation practitioners should feel compelled to use the greener option.

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142 Ross Spiegel and Dru Meadows, *Green Building Materials: A Guide to Product Selection and Specification* (New York: John Wiley & Sons, Inc., 1999), 75.
143 Ibid., 33.
144 Ibid., 78.

CONCLUSION

A comprehensive list of considerations for the evaluation and selection of substitute materials for use on historic projects, shown in the figure on the following page, requires a combination of many different factors.[145] The philosophical considerations that are at the forefront of decision-making for objects conservation must be combined with practical material property and performance considerations integral to the selection of functional and durable building materials. Additionally, both economic and environmental costs can be key factors in the process.

The inventory of considerations formed in this chapter does not lend itself to a simple "yes or no" checklist. Like most preservation decisions, many of the considerations are, in fact, more complex and interdependent issues that require careful examination by a trained preservation practitioner. The following chapter builds upon this discussion to provide a structured method that allows practitioners to utilize the considerations in this chapter for the evaluation and selection of substitute materials.

145 The "Inventory of Considerations" is also included in Appendix C for convenience.

Preservation Philosophy

Significance of Building
Significance of Element or Material
Amount & Location of Substitute
Physical Condition of Original
Proposed Use
Goal of Intervention

Material Properties & Performance

- Material Properties
  - Aesthetic Properties
    - Color
    - Texture
    - Finish
    - Reflectivity
    - Size & Shape
    - Detailing
    - Patina, Corrosion & UV Degradation
    - Static Charge & Response to Pollutants
  - Physical, Mechanical, Thermal & Chemical Properties
    - Weight
    - Strength
    - Flexibility
    - Hardness
    - Creep
    - Curing or Drying Shrinkage
    - Porosity & Permeability
    - Hygroscopic Expansion
    - Vapor Permeability
    - Thermal Expansion
    - Other Thermal Properties
    - Fire Resistance
    - Corrosion Resistance
    - Galvanic Corrosion
    - UV Degradation
    - Inertness
    - Rot & Fungal Resistance
    - Toxicity
- Design & Detailing
  - Knowledge Base
  - Attachment & Joining
  - Invasiveness or Reversibility
  - Relative Integration or Isolation
- Fabrication & Installation
  - Fabricator Experience
  - Material Fabrication Properties
  - Installer Experience
  - Transportation Requirements
- Functionality
  - Structural Serviceability
  - Fire Safety
  - Habitability
  - Maintainability
  - Code Acceptability
- Durability
  - Long-Term Performance Data
  - Weathering Prediction
  - Performance Standards
  - Testing Methods

Costs: Economic & Environmental

- Economics
  - Raw Material Cost
  - Fabrication or Manufacturing Cost
  - Transportation Cost
  - Installation Cost
  - Lead-Time
  - Operation & Maintenance Costs
  - Potential Repair Costs
- Environmental Sustainability
  - Durability
  - Energy Efficiency
  - Future Recyclability
  - Maintainability
  - Recycled Content
  - Embodied Energy
  - Local or Regional Materials
  - Hazardous Natural Chemicals
  - Synthetic Chemicals

Figure 4. Inventory of considerations for evaluation & selection of substitute materials

CHAPTER 5: METHODS FOR THE EVALUATION & SELECTION OF SUBSTITUTE MATERIALS

INTRODUCTION

Two of the main objectives of this thesis are to determine the ways in which contemporary historic preservation practitioners evaluate and select substitute materials, and to determine if a new structured method of evaluation and selection would be beneficial to the field. This chapter includes a brief background on structured decision-making, as well as specific examples of decision-making methods from related fields that may be adaptable for preservation. An analysis of the methods used by contemporary preservation practitioners, as shown in the published preservation literature and in the preservation practitioner survey, follows, demonstrating the need for a new method. The chapter concludes with suggestions for a structured method that preservation practitioners can use to guide their evaluation and selection of substitute materials.

STRUCTURED DECISION-MAKING METHODS

Humans have sought better ways to make decisions for hundreds of years.[146] The study of structured decision-making comes from a variety of disciplines including mathematics, sociology, psychology, economics, and political science.[147] Today, structured decision-making methods are applied with the intent of obtaining better results in fields such as scientific research, medicine, and business management.

As noted in "A Brief History of Decision Making" in the *Harvard Business Review*, in

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146 Leigh Buchanan and Andrew O'Connell. "A Brief History of Decision Making." *Harvard Business Review* (Jan 2006): 32-41.
147 Ibid., 33.

1641, "René Descartes propose[d] that reason is superior to experience as a way of gaining knowledge and establishe[d] the framework for the scientific method."[148] Today, "the most common portrayal of decision-making is one that interprets actions as rational choice."[149] However, research has shown that Descartes' theory of rationalism is limited by "contextual and physiological" restraints such as "complex circumstances, limited time, and inadequate mental computational power."[150] While decision makers should ideally behave in a rational manner, when faced with a complex problem, the tendency is to simplify their perception of the situation through a variety of cognitive simplification processes.[151] Although these processes, often called biases or heuristics, can be useful in certain situations, decision theorists also recognize that "sometimes they lead to severe and systematic errors."[152] In light of these limitations, modern decision theorists have sought to provide methods and tools to help decision makers find acceptable, if not optimal, solutions.

The following approaches to decision-making from related fields have elements that may be applied to preservation practice:[153]

- Engineering Design & Material Selection Strategies
- Multiple Attribute Decision Analysis (MADA)
- Analytical Hierarchy Process (AHP)
- Choosing By Advantages (CBA)
- Economic Decision-Making

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148 Ibid., 36.
149 James G. March and Chip Heath, *A Primer on Decision Making: How Decisions Happen* (New York: Simon & Schuster, 1994): 1.
150 Buchanan and O'Connell, "A Brief History of Decision Making," 33.
151 Charles R. Schwenk, "Cognitive Simplification Processes in Strategic Decision-making," *Strategic Management Journal* 5, no. 2 (1984): 111-128.
152 Daniel Kahneman, Paul Slovic, and Amos Tversky, *Judgment Under Uncertainty: Heuristics and Biases* (Cambridge: Cambridge University Press, 1982): 3.
153 Please note that this list represents only a small fraction of the available structured approaches to decision-making; it is not meant to be comprehensive. For a more complete review of structured decision-making, please consult the resources cited in this chapter.

- Environmental Sustainability Decision-Making
- Conservation Decision-Making

These approaches are discussed in terms of their strengths and weaknesses, and their potential for adaptation for the evaluation and selection of substitute materials.

Engineering Design & Material Selection Strategies

Engineering design involves a broad range of decisions, including the selection of materials (from tens of thousands of available materials) that "best meet the needs of the design, maximizing its performance and minimizing its cost."[154] Engineering decision theorists have identified three main selection strategies to aid designers in making these decisions, including:

- **Free searching, based on quantitative analysis:** This strategy can "reveal solutions that are new and innovative," but requires "precisely detailed inputs."[155] The general process involves specifying the functional requirements, constraints, and objectives, and using a database of material properties and software to screen and rank materials.

- **The questionnaire strategy, based on expertise-capture:** In this strategy, "questionnaires guide the uninformed user through a more or less structured set of decisions, using the built-in expertise to compensate for the lack of it in the user…The simplicity and ease of use are obvious; the obvious difficulties lie in its creation and maintenance."[156]

- **Inductive reasoning and analogy:** This strategy uses similarities from previous experience to inform the current problem. "The new problem is tackled and (with luck) solved by adapting and combining elements of the selected 'cases' to meet the new need."[157]

These strategies may be used in combination to take advantage of the individual strengths

[154] M.F. Ashby et al. "Selection Strategies for Materials and Processes." *Materials & Design* 25 (2004): 51-67.
[155] Ibid., 53.
[156] Ibid., 57-58.
[157] Ibid., 59.

and compensate for individual weaknesses inherent in each method. Because the selection of replacement materials for historic preservation should ideally be based on the combination of a quantitative analysis of material properties and performance, expert opinion, and past experience, these engineering methodologies may be used in preservation.

Theorists have noted limitations with these selection strategies, including for example, the difficulty of selecting materials to be used in combination, optimizing environmental impact for "green" design, and the consideration of aesthetics, which may all play a role in the selection of replacement materials for preservation.[158] Additionally, in comparison to the selection of replacement materials, the selection of materials for engineering design is a relatively under-constrained problem. Engineers may choose from tens of thousands of materials for new designs, while preservation practitioners are limited to a much smaller subset of materials for the replacement of historic elements, which may necessitate a different approach to decision-making. In engineering design the goal is often to "optimize" the solution, which is possible when choosing from thousands of materials; in preservation the goal is often to find an "adequate" solution from the relatively limited range of potential replacement materials.

To differentiate between the process of material selection for new designs and the selection of replacement materials for existing designs, the *ASM Handbook* includes a summary of both processes. The following steps, while written specifically for the selection of replacement materials for product and part design, could be adapted for the selection of substitute materials:

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158 Ibid., 64-65.

1. Characterize the currently used material in terms of performance, manufacturing requirements, and cost.
2. Determine which characteristics must be improved for enhanced product function. Often failure analysis reports play a critical role in this step.
3. Search for alternative materials and/or manufacturing routes.
4. Compile a short list of materials and processing routes, and use these to estimate the costs of manufactured parts.
5. Evaluate the results in step 4, and make a recommendation for a replacement material. Define the critical properties with specifications or testing.[159]

The importance of steps 1 and 2, characterizing the original material and the reason for failure, cannot be over-emphasized when considering replacement materials, either for engineering design or historic preservation projects. Though the diagnostic decision-making process is separate from the material selection process, a misdiagnosis of failure can misdirect the material selection process. For this reason, diagnostic decision-making plays a key role in the successful selection of a replacement material, and should be a key element in any methodology for the selection of materials for historic preservation.

Multiple Attribute Decision Analysis

Multiple Attribute Decision Analysis (MADA), which is sometimes referred to as Multiple Objective Decision Making, is a form of decision-making that involves "choosing among a set of alternatives which are described in terms of their attributes."[160] In the case of evaluating and selecting substitute materials, the alternatives are potential substitute materials (or an in-kind replacement material), and the considerations discussed in the previous chapter would be the attributes.

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[159] George E. Dieter, "Overview of the Materials Selection Process," in *ASM Handbook*, vol. 20, *Materials Selection and Design* (Materials Park, OH: ASM International, 1997), 250.

[160] Kenneth MacCrimmon, "An Overview of Multiple Objective Decision Making," in *Multiple Criteria Decision Making*, eds. James Cochrane and Milan Zeleny (Columbia, South Carolina: University of South Caroline Press, 1973), 18-44. This article also explains the minor differences between multiple attribute decision making and multiple objective decision making.

There are various methods that can be applied for MADA, the most common of which are "weighting methods" and "sequential elimination methods."[161] Generally, weighting methods involve assigning numerical weights to each attribute and numerical scales for attribute values, then totaling the numerical value for each alternative and choosing the alternative with the highest value.[162] Sequential elimination methods "are less demanding of the decision maker."[163] They involve sequentially ordering attributes, followed by "a process for sequentially comparing alternatives on the basis of attribute values so that the alternative can be either eliminated or retained."[164] Usually the evaluation of substitute materials takes place with only a handful of alternatives. However, as shown in the previous chapter, the potential list of attributes for these alternatives is quite large.

The weighted property index method, as described in the *ASM Handbook*, is a MADA method that can be used for the selection of materials.[165] This weighting method uses scaling factors to combine material properties with different units (e.g. strength in megapascals, MPa, and coefficient of thermal expansion in inverse degrees, 1/°C), and it uses weighting factors to combine attributes with different levels of importance. However, the weighting process is subjective, so it must be done carefully to prevent bias.[166]

The *ASM Handbook* also includes an article titled "Decision Matrices in Materials Selection," which describes several different types of matrices. The general format is a table in which the alternatives (potential replacement materials) are listed in columns and the

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161 Ibid., 24.
162 Ibid., 24-25.
163 Ibid., 30.
164 Ibid., 30.
165 Dieter, "Overview of the Materials Selection Process," 251-252.
166 Ibid., 251.

considerations (or objectives) for evaluation are listed in rows.[167] The use of weighting factors is optional. Other resources such as *Construction Materials Evaluation and Selection* also recommend the use of decision matrices to evaluate materials with respect to certain performance characteristics or criteria.[168] As decision matrices are a common method for the evaluation of materials, they may be useful for substitute materials in preservation as well.

Analytical Hierarchy Process

The Whole Building Design Guide (WBDG) recommends the use of ASTM Standard E1765-07 "Standard Practice for Applying Analytical Hierarchy Process (AHP) to Multiattribute Decision Analysis of Investments Related to Buildings and Building Systems," for decisions requiring the consideration of non-monetary benefits, including historic preservation.[169] The Analytical Hierarchy Process "considers non-monetary attributes (qualitative and quantitative) in addition to common economic measures (life-cycle costing or net benefits) when evaluating project alternatives."[170] The strengths of AHP include:

- An efficient attribute weighting process of pairwise comparisons;
- Hierarchical descriptions of attributes, which keep the number of pairwise comparisons manageable;
- Available software to facilitate its use.[171]

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167 David L. Bourell, "Decision Matrices in Materials Selection," in *ASM Handbook*, vol. 20, *Materials Selection and Design* (Materials Park, OH: ASM International, 1997), 291.
168 Rosen and Bennett, *Construction Materials Evaluation and Selection,* 16.
169 Whole Building Design Guide Cost-Effective Committee, "Consider Non-Monetary Benefits such as Aesthetics, Historic Preservation, Security, and Safety," Whole Building Design Guide, February 1, 2007, http://www.wbdg.org/design/consider_benefits.php.
170 ASTM Standard E1765, 2007, "Standard Practice for Applying Analytical Hierarchy Process (AHP) to Multiattribute Decision Analysis of Investments Related to Buildings and Building Systems," ASTM International, West Conshohocken, PA, www.astm.org.
171 Ibid.

ASTM lists some of the uses for AHP as well:

- Use AHP to evaluate a finite and generally small set of discrete and predetermined options or alternatives.
- Use AHP if no single alternative exhibits the most preferred available value of performance for all attributes. This is often the result of an underlying trade-off relationship among attributes.
- Use AHP to evaluate alternatives whose attributes are not all measurable in the same units. Also use AHP when performance relative to some or all of the attributes is impractical, impossible, or too costly to measure.[172]

The standard also notes that AHP can be used specifically for the selection of building materials.

While the AHP ranking of alternatives with respect to a single attribute through matrices of pairwise comparisons is relatively simple, when there are many different attributes (i.e. many relevant considerations that will affect material selection), the process of combining these rankings for all attributes requires the use of support software.[173] Thus, it is unclear if preservation practitioners would consider the use of the AHP method to evaluate substitute materials, unless the decision could be simplified to include only a handful of attributes (i.e. considerations).

Choosing by Advantages

The National Park Service also employs a decision-making system for projects that require the consideration of non-monetary attributes called "Choosing by Advantages" (CBA). The NPS defines CBA as:

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172 Ibid.

173 The AHP/Expert Choice for ASTM Building Evaluation software computes the principle eigenvector of each matrix of pairwise comparisons and the final desirability scores for each alternative. ASTM Standard E1765.

> A system of concepts and methods to structure decision-making. CBA quantifies the relative importance of non-monetary advantages or benefits for a set of alternatives and allows subsequent benefit and cost consideration during decision-making. CBA may be used as an evaluation method during the evaluation phase of the value analysis job plan, in lieu of the more traditional weighted-factor analysis. CBA is the preferred evaluation method where critical non-monetary benefits need to be evaluated.[174]

CBA is a system of decision-making, rather than a specific method or tool. In his book, *The Choosing by Advantages Decisionmaking System*, CBA developer Jim Suhr describes the evolution, advantages, and methods of the system that ultimately lead to better, simpler decision-making.[175] Suhr notes that people often ask why the system does not consider disadvantages; he answers, "sound methods of decisionmaking base decisions on the *differences* among alternatives…I realized that a difference between two alternatives is, simultaneously, an advantage of one and a disadvantage of the other."[176]

As one of the main principles of the system is that "different types of decisions call for different sound methods," the system includes various methods for decisions ranging from simple to complex (including the "two-list" and "tabular" methods, as well as special methods for decisions involving money).[177] Suhr notes that the application of a sound decision-making method is key to the success of any decision, and "unsound decisions are usually methods-caused."[178] The CBA system of decision-making could be well suited to the evaluation and selection of substitute materials because it is simple and quick (in comparison to many of the methods presented above), but still provides a structured, analytical

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174 Director's Order #90: Value Analysis, National Park Service, 2002, http://www.nps.gov/policy/DOrders/DO90.htm.
175 Jim Suhr, *The Choosing by Advantages Decisionmaking System* (Westport, Connecticut: Quorum Books, 1999).
176 Ibid., 9.
177 Ibid., 169.
178 Ibid., 170.

approach.

Economic Decision-Making

Many of the decision-making approaches presented above consider economic value as a factor in the decision process. Engineering design and material selection seek to maximize performance while minimizing costs, and MADA, AHP, and CBA can all include cost as an attribute of various alternatives. Life-cycle costing (LCC) is different from these decision-making methods in that it focuses "exclusively on minimizing cost."

LCC may be defined as "an economic evaluation process that can assist in deciding between alternative building investments by comparing all of the significant, differential costs of ownership over a given period in equivalent dollars."[179] LCC can usually be broken down into initial capital costs and operating and maintenance costs, and is usually applied to whole buildings or building assembly. Traditional models of LCC follow a "present-worth" method that assumes the following costs:

1. Initial capital cost
2. Annual operating cost (energy and maintenance)
3. Periodic replacements
4. Additions and alterations
5. Use costs[180]

Though the concepts of LCC are widely accepted, the process is not used consistently, perhaps due to several potential problems including the unavailability of reliable cost data, the amount of time required for LCC analysis, the uncertainty of predicting future costs and events, and the assumption that "noneconomic performance factors are equal for

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179 Johnson, *The Economics of Building,* 213-214.
180 Ibid, 222-223.

all of the design alternatives."[181] Because "noneconomic performance factors" such as aesthetics and adherence to an appropriate preservation philosophy are central to the success of substitute materials, LCC alone is not appropriate for the evaluation of substitute materials. It is also difficult to determine the in-situ service life of certain substitute materials (in part due to a lack of long-term performance data), which limits its utility for preservation. However, considering economic costs over the lifetime of the material, in addition to initial costs, is a concept that preservation practitioners should employ. LCC can sometimes demonstrate that materials that are more expensive initially are actually more cost-effective in the long run.

Environmental Sustainability Decision-Making

The evaluations of economic and environmental costs often follow parallel tracks. Life-cycle assessment (LCA), sometimes termed life-cycle analysis, is a method by which the environmental impacts of a material can be studied and evaluated.[182] The Society of Environmental Toxicology and Chemistry (SETAC) defines LCA as:

> An objective process to evaluate the environmental burdens associated with a product, process, or activity by identifying and quantifying energy and material usage and environmental releases, to assess the impact of those energy and material uses and releases on the environment, and to evaluate and implement opportunities to effect environmental improvements. The assessment includes the entire life cycle of the product, process or activity, encompassing extracting and processing raw materials; manufacturing, transportation, and distribution; use/re-use/maintenance; recycling and final disposal.[183]

The authors of *Green Building Materials* describe LCA as straightforward in theory, but

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181 Ibid, 214-119.
182 Joel P. Clark, Richard Roth, and Frank R. Field III, "Techno-Economic Issues in Materials Selection," in *ASM Handbook*, vol. 20, *Materials Selection and Design* (Materials Park, OH: ASM International, 1997), 262.
183 SETAC Guidelines for Life-Cycle Assessment: A "Code of Practice," 1993.

complicated and expensive to complete, noting, "The [Environmental Protection Agency] estimates that a complete LCA of a product costs $1,000,000.00."[184] Because LCA is a complex and expensive process, it is not very adaptable for the evaluation of substitute materials.

However, other methods of integrating measures of sustainability into materials selection processes have also been developed. The following quantitative indices for environmental impact can be included as attributes of material alternatives in many of the material selection methods discussed above:[185]

- *Embodied Energy*: "the amount of energy consumed in manufacturing a unit quantity of material."[186]
- *Ecological Rucksack*: the amount of raw material that must be extracted and processed to make a unit quantity of finished material.
- *Ecological Footprint*: "the area of the Earth's surface which is tied up in maintaining the process."[187]

These indices, if available for potential replacement materials, could be an effective way to introduce environmental impact considerations into the selection process for substitute materials in historic preservation. The recent text, *Ecology of Building Materials,* includes environmental profiles for a variety of commonly used building materials.[188] Unfortunately, the list does not include many of the specialized substitute materials that may be used for historic preservation.

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184 Spiegel and Meadows, *Green Building Materials*, 77.
185 J.L. Sturges, "Construction Materials Selection and Sustainability," *Proceedings of the 2nd International Conference on Construction Industry Development*, Singapore, Vol. 1. (1999), 297-304.
186 Ibid.
187 Ibid.
188 Bjorn Berge, *Ecology of Building Materials* (Oxford: Architectural Press, 2000).

Conservation Decision-Making

The application of rational decision-making methods for the preservation of cultural heritage was examined by an interdisciplinary group of experts, including preservation planners and practitioners, conservationists, decision theorists, and others, at the 86th Dahlem Workshop on *Rational Decision-making in the Preservation of Cultural Property* held in 2000.[189] This workshop:

> …focused on identifying the roles of value in the decision-making processes for preservation and conservation of cultural property, elucidating the mechanisms that underlie the setting of goals and priorities, and exploring potential paradigms for rational decision-making in conservation planning for society, cultural institutions, and the conservator or curator.[190]

One of the many questions that the participants of the workshop sought to answer was, "Can we anticipate a general model for decision-making in the preservation of cultural property?"[191] Following a brief history of rational decision-making, modern decision theory, and bounded rationalism, one of the participants whose research focuses on the mathematical modeling of decision-making, suggests that "fast and frugal heuristics" may be more appropriate than rational models for complicated decisions regarding the preservation of cultural property.[192]

In the "Group Report: Paradigms for Rational Decision-making in the Preservation

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189 N.S. Baer and F. Snickars, eds. *Rational Decision-making in the Preservation of Cultural Property*, Report of the 86th Dahlem Workshop, Berlin, March 26-31, 2000 (Berlin: Dahlem University Press, 2001). Cultural heritage refers to moveable property (objects), sites and landscapes, and buildings.
190 Ibid., 3. Note that the major focus of this workshop is decision-making for preservation planning rather than project-specific material interventions.
191 Ibid., 7.
192 L.F. Martignon, "Principles of Adaptive Decision-making." *Rational Decision-making in the Preservation of Cultural Property*, Report of the 86th Dahlem Workshop, Berlin, March 26-31, 2000, eds. N.S. Baer and F. Snickars (Berlin: Dahlem University Press, 2001), 263-275.

of Cultural Property," the participants explore the utility of the "economic paradigm," including methods such as cost-benefit analyses.[193] They note several limitations including "comput[ing] monetary values for the many 'intangibles' associated with cultural property."[194] The report also includes a short summary of three other potentially applicable "paradigms," including rational-decision-making methods that utilize decision trees or expert systems, concepts of marketing science, and risk management strategies.[195] The final conclusion fails to suggest a general model for decision-making, citing the complex and varying nature of the questions surrounding the preservation of cultural property. The authors also note:

> A decision system may not be sufficient: a total management system is also required, which in turn implies strategic thinking of various types. In this respect, management of the preservation of cultural property differs little from other aspects of management in that it seems unlikely that one universally applicable paradigm will ever be developed.[196]

Though a model was not developed, the workshop proceedings demonstrate that the participants believe it is necessary to examine the ways in which decisions regarding the preservation of cultural property are made. Decision-making methods from other fields have limitations, but they may also have elements that are applicable for certain preservation decisions.

Two examples of these decision-making methods are explored by archaeological

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193 G.J. Ashworth et al. "Group Report: Paradigms for Rational Decision-making in the Preservation of Cultural Property." *Rational Decision-making in the Preservation of Cultural Property*, Report of the 86th Dahlem Workshop, Berlin, March 26-31, 2000. eds. N.S. Baer and F. Snickars (Berlin: Dahlem University Press, 2001), 277-293.
194 Ibid., 282.
195 Ibid., 283-288. Expert systems "perform decisions based on information represented adequately in a so-called knowledge base."
196 Ibid., 292.

conservator Chris Caple, in his book, *Conservation Skills: Judgment, Method and Decision Making*.[197] He discusses the application of weighting factors and probabilities through decision trees for the examination of conservation options, as well as the application of risk assessment strategies. While these methods may be appropriate for certain conservation problems, Caple does not attempt to define a universally applicable method.

Barbara Appelbaum addresses the idea that the field of conservation lacks a comprehensive methodology in her book, *Conservation Treatment Methodology*.[198] She presents an eight-step methodology that she suggests is universally applicable for conservation treatments for moveable property or objects:

1. Characterize the object;
2. Reconstruct a history of the object;
3. Determine the *ideal state* for the object;
4. Decide on a *realistic goal* of treatment;
5. Choose the treatment methods and materials;
6. Prepare pre-treatment documentation;
7. Carry out the treatment;
8. Prepare final treatment documentation.[199]

This methodology is primarily designed for objects conservation, and it guides the practitioner from project inception to completion, including the initial collection of data and final implementation. Still, some aspects of this process are applicable to the preservation of the built environment.

The first four steps, on which Appelbaum includes an extensive discussion, are critical to establishing a project-specific preservation philosophy to guide the consideration

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197 Chris Caple, *Conservation Skills: Judgment, Method and Decision Making* (London: Routledge, 2000).
198 Appelbaum, *Conservation Treatment Methodology*.
199 Ibid., xix-xx.

of substitute materials. The fifth step, choosing treatment methods and materials, parallels the primary focus of this thesis. While the discussion of the selection of materials and methods includes specific criteria that should be considered, Appelbaum does not mention explicit decision-making methods for these choices.

CONTEMPORARY METHODS OF SELECTION OF SUBSTITUTE MATERIALS

The contemporary use of substitute materials for historic preservation was discussed at length in Chapter 3. While the published preservation literature provides some guidance and considerations for the evaluation of substitute materials, it is silent on specific methods that can be used to judge alternatives with respect to these considerations. *Preservation Brief 16* lists issues that should be addressed for specific types of substitute materials in the form of questions, similar to an informal checklist, and other literature occasionally mentions profession collaboration or discussion during the decision-making process, but no formal or structured method is presented.[200]

The preservation practitioner survey also revealed a lack of formal methods of evaluation and selection. Over two-thirds of respondents indicated that they do not use a specific method to evaluate substitute materials, but instead "consider the criteria informally." The remaining respondents indicated that they use:

- Decision Matrix (11.9%)
- Checklist (6.6%)
- Decision Tree (2.1%)
- Other (11.5%)

Again, many respondents that selected "other" noted that they rely on discussions and

[200] Park, *Preservation Brief 16*. Also review Chapter 3 for specific resources consulted.

consultations with the owner, other professionals, manufacturers, and installers. Few others mentioned laboratory testing procedures and cost-benefit or value analyses such as LCC. One respondent mentioned the CBA method employed by the NPS. Still, the overwhelming evidence from the survey is that preservation practitioners are not using structured methods for the evaluation and selection of substitute materials.

While several survey respondents expressed interest in the development of a new method that could benefit the practice in their open-ended responses, some respondents also expressed doubts about the efficacy of a comprehensive structured method of evaluation and selection, citing that every project is unique. Others noted that a decision-making method would be limited by the lack of long-term performance data. It is a key outcome of this thesis that more comprehensive long-term material performance data is needed. However, the lack of data affects all decisions regarding material selection equally, regardless of the method employed. When long-term material performance data is not available, the use of a structured decision-making method is even more critical to guide the practitioner through a thorough examination of the potential substitute material.

Appelbaum observed similar sentiments during the development of her conservation treatment methodology, noting that some conservationists felt that "the application of a prescribed methodology might make it harder to 'think outside the box.'"[201] However, Appelbaum argues:

> A single methodology does not mean an imposed uniformity. Asking the same questions for all treatments means finding different answers…Not only does a prescribed conservation treatment methodology *not* impose uniformity, it actually supports different results appropriate to the many variables that treatments must

[201] Appelbaum, *Conservation Treatment Methodology*, xxiv.

> address…Starting at a neutral point and making decisions from scratch each time produces even more diverse approaches than are commonly seen at present.[202]

This argument is equally valid for a method of evaluation and selection of substitute materials. A new approach to evaluating substitute materials, or any replacement, can help to break routine, inflexible thinking patterns, and may offer a fresh look at potentially successful solutions.

A structured system or method may also help to reduce errors that are "methods-caused."[203] Decision theorists have noted that:

> The increased complexities associated with many planning and design problems are too difficult for the average person to comprehend to the degree that reasonable judgments can be made. Because of this complexity, decision makers reduce the problem to manageable proportions by paring away what are thought to be insignificant elements and focusing on the most important aspects of the problem. Heuristic approaches (rules of thumb) usually taken to effect this problem-reduction approach are only adequate after a great deal of experience.[204]

When evaluating substitute materials, this "problem-reduction" can lead to the unintended omission of necessary considerations. As shown in the previous chapter, the range of considerations that may be applicable for specific projects is quite large. A structured method that prompts a thorough consideration of these issues may help to eliminate omissions that could ultimately lead to material failures.

FORMULATION OF A NEW METHOD OF EVALUATION & SELECTION

This section outlines the main objectives of a new method for the evaluation and selection of substitute materials, followed by a suggested structure for this method.

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202 Ibid., xxiv.
203 Suhr, *The Choosing by Advantages Decisionmaking System,* 170.
204 Johnson, *The Economics of Building*, 16.

Method Objectives

The objectives of this method follow from the discussion of structured decision-making methods, as well as the needs of preservation practitioners who may consider the use of substitute materials. The method should:

- *Promote critical thinking*: The method should help reduce bias and encourage the consideration of fresh ideas.
- *Be comprehensive*: The method should help prevent errors of omission by including the consideration of preservation philosophy, material properties and performance, and economic and environmental costs.
- *Be flexible*: The method should be universal in its application for replacement materials. It should allow different levels of evaluation for materials with well-known long-term performance as well as those without.
- *Be usable*: The method should be as quick and easy to use as possible, while still promoting thorough evaluation of alternatives.
- *Emphasize the importance of material diagnostics*: The method should include a diagnosis of the cause of failure in the original material to appropriately inform the selection of a replacement material.
- *Consider input from a variety of sources*: The method should allow and encourage practitioners to consult a variety of sources including published and online resources, product literature, materials standards, other professionals, manufacturers, suppliers, and installers.
- *Add to the preservation knowledge base on substitute materials*: The method should recommend documentation of the evaluation and selection process, as well as follow-up evaluations, that will add to the base of long-term performance data for substitute materials.

Method Structure

The presentation of considerations in the previous chapter suggests the complexity and taxonomy of variables to be addressed by a comprehensive method for the evaluation and selection of substitute materials. However, there are several additional steps that should be part of the process both before and after the actual evaluation and selection, which are included in the method below. It should also be noted at the outset that the application of this method assumes that the original material exhibits severe deterioration, damage, or loss that necessitates replacement. Alternatively, the original material may have been intentionally removed for a reason other than deterioration (e.g. toxicity or health hazard). If repair is possible, the method and considerations may be similar, however, the evaluation of potential repairs is not the focus of this thesis.

The proposed method consists of ten steps. They are:

1. Characterize the original material in terms of material properties and performance.
2. Diagnose the causes of failure within the original material, and determine which characteristics must be improved upon with a replacement material in order to avoid repetition of the first failure.
3. Establish a project-specific preservation philosophy and goal for intervention.
4. Compile a "short list" of potential replacement materials.
5. Evaluate the alternatives with respect to preservation philosophy, material properties and performance, and economic and environmental costs, and recommend an appropriate replacement material.
6. Document the evaluation and selection process.
7. Write specifications for design and installation and oversee project planning.
8. Observe and document the installation process.
9. Complete a long-term follow-up assessment of in-situ performance.
10. Disseminate long-term material performance information for use by other preservation practitioners.

Step 5 is main focus of this thesis, and will include a detailed discussion of methods that may be used for evaluation and selection. The remaining steps, while also integral to the overall process, will be explained in lesser detail. A flowchart illustrating the steps of the method is included on the following page.[205]

[205] This flowchart is also included in Appendix C for convenience.

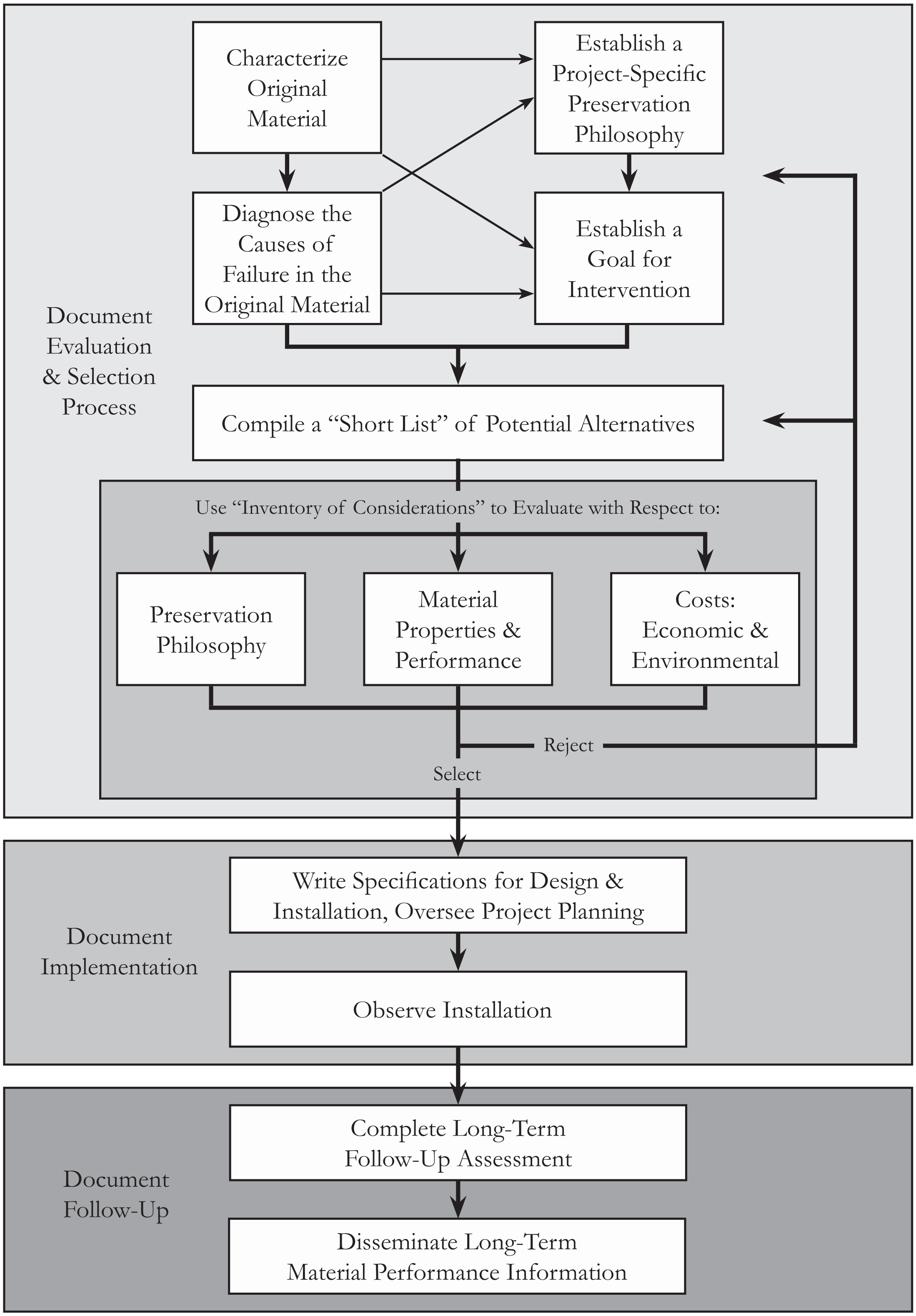

Figure 5. Suggested method for the evaluation & selection of substitute materials

Step 1: Characterize the original material in terms of material properties and performance. After it has been determined that a historic material is deteriorated beyond repair and must be replaced, the first step in the process of selecting an appropriate replacement or substitute material is the characterization of the original material. In other words, what exactly needs replacing? The list of material properties and performance characteristics included in the previous chapter provide a framework for this examination.

Step 2: Diagnose the causes of failure within the original material, and determine which characteristics must be improved upon with a replacement material in order to avoid repetition of the first failure. The published guidance on the use of substitute materials does not emphasize failure diagnostics as part of the replacement material selection process, but it is critical to fully understand the failure of the original to ensure that the new material will not fail for the same reasons. Did the original material fail due to inherent flaws or certain material properties? Did it fail due to poor design or detailing? Did it fail due to improper installation? Whatever the reason, if the original material did not perform adequately, improvements may be made with a substitute material. Determining the cause of failure of the original will reveal material properties or performance characteristics that should be a top priority when evaluating potential replacement materials.

Step 3: Establish a project-specific preservation philosophy and goal for intervention. Much of the challenge when evaluating and selecting a replacement or substitute material is combining the practical economic and technical requirements with a less-tangible preservation philosophy. The considerations included in the preservation philosophy section of the previous chapter will help to guide the establishment of a project-specific preservation philosophy. Together with the characterization of the original material and the determination of the causes of failure, this philosophy should inform a realistic goal for intervention.

Step 4: Compile a "short list" of potential replacement materials. At this point in the process, some of the main requirements for a replacement material will have been considered, including performance requirements based on the original material and the cause of failure, as well as the project-specific preservation philosophy and goal for intervention. From these initial requirements, a short list of potential replacement materials can be compiled. As the name implies, this list should be brief, including materials that appear to meet the initial requirements. While materials with proven performance may be desirable, potentially suitable new materials should not be rejected at this stage. The approximate cost of each alternative should also be considered when compiling the list, as it is rare that a material that costs well over the project budget will be selected.

Step 5: Evaluate the alternatives with respect to preservation philosophy, material properties and performance, and economic and environmental costs, and recommend an appropriate replacement material. In the previous step, a short list of potentially appropriate materials was compiled. The goal of the present step is to evaluate the suitability of these materials for the particular project.

The preservation practitioner survey revealed that the approach taken by many practitioners is to "informally consider the criteria." This approach, which can sometimes be effective, is similar to the heuristic approaches that decision makers often use to simplify complex or uncertain problems. While this type of approach does not allow for the "optimization" of a solution, it can be sufficient to eliminate material alternatives that do not meet a baseline standard. However, the risk of using an informal approach is the potential omission of critical considerations leading to inappropriate selections and possible failure of the substitute material to perform with respect to all the necessary criteria.

Structured decision-making methods discussed earlier in this chapter, such as weighted property methods or decision matrices, can reduce or eliminate the risks of inappropriate material selections. Structured decision-making methods should allow for the formal comparison of multiple alternatives with respect to their full range of attributes. However, as noted by experts who have attempted to create formalized methods for conservation decision-making, it can be difficult to integrate judgments of intangible values of preservation philosophy with judgments of tangible material properties and cost data. In some instances the mathematical calculations or support software utilized by many structured decision-making methods may deter preservation practitioners from using them at all.

Still, providing structure to the method of evaluation and selection of substitute materials is necessary for professional "due diligence," and the long-term benefit, successful material selection, warrants the effort. The comprehensive inventory of considerations presented in the previous chapter, in and of itself, provides an organized and systematic way to approach material characterization and evaluation. While it is not recommended for use as a simple checklist, it may help prevent potential errors due to the omission of critical considerations. This inventory can be adapted into a questionnaire-type material selection method, which would guide a practitioner through each consideration in a sequential manner. For the time being, the organization of the inventory into the categories of preservation philosophy, material properties and performance, and economic and environmental cost should be adequate.

At a minimum, the inventory of considerations should be used to guide the collection of necessary information about each potential replacement material. Potential sources of this information, including material properties, performance, and cost data, may include other preservation practitioners, reports from previous projects, materials testing or standards organizations, material selection guides, manufacturers' product literature, or correspondence with experienced fabricators or installers. When considering claims regarding material performance from manufacturers or fabricators, it is very important to consider the source and validity of the information. Assertions about performance should be supported by experience or testing, or the experience of other practitioners who have used the material. In some cases, independent laboratory or field testing may be appropriate to establish a better understanding of material properties. In other cases, it may not be possible to determine all necessary material properties, particularly those regarding long-term performance and durability. These uncertainties should be noted and taken into account when making a selection.

The method of selection that accompanies the use of the inventory of considerations is relatively simple. If, when examining all of the necessary considerations, a particular material does not meet the goal for intervention or may cause the repetition of the original failure or the introduction of new performance problems, throw it out. If all of the considerations have been thoroughly examined and a material appears adequate, select it. The objective is to guide the practitioner through the process in a structured manner, to reduce the possibility that a critical consideration will be overlooked.

Another objective of this structured method is the flexibility to be used for any type of replacement material. Practitioners using replacement materials with which they are familiar, or with proven performance records, may use the inventory as an added check for compatibility. However, the method is also applicable to newer materials that may not have established long-term performance records. With experiential knowledge of the weathering of different types of building materials, and the detailed characterization of material properties, functionality, durability, and compatibility prompted by the inventory of considerations, preservation practitioners may make educated predictions regarding the long-term performance and durability of newer substitute materials. When consistent with the preservation philosophy and goals for intervention, well-informed performance predictions may be sufficient to support the selection of a particular material.

Step 6: Document the evaluation and selection process. Usually the recommendation to a client regarding an appropriate replacement material will require supporting details, so clear documentation of the evaluation process and the reasons for selection is key. The structured evaluation and selection method that has been followed should help to present a more compelling case for the use of the recommended material. Several respondents to the preservation practitioner survey indicated that a client's preconceived material preferences can sometimes be difficult to overcome, but that a clearly structured and documented method for evaluation and selection may actually help "convince" the client that a different material is more appropriate for the particular project.

In addition, clear documentation of the considerations and reasoning behind the selection of a particular replacement material is important to bridge any potential gap between the evaluation and selection phase and the implementation phase. While a single practitioner would ideally work on the project from inception to completion, it is common for different individuals to handle various phases of work. Clear explanation of *why* a material was selected will lessen the chances that unplanned changes will be made during the implementation process.

Step 7: Write specifications for design and installation and oversee project planning. Design and detailing, fabrication (or extraction for natural materials), and installation can contribute significantly to the success or failure of replacement materials. The critical material properties and performance characteristics outlined in the previous steps, as well as the rationale for selection and any applicable material standards, should be included in the specifications. Fabricators and installers should be selected on the basis of successful experience with the selected material (ideally on similar historic projects), and drawings and specifications regarding design and detailing, fabrication, and installation should be discussed with fabricators and installers to resolve any potential misinterpretation.

Step 8: Observe and document the installation process. Adequate design and specifications do not guarantee that the replacement will be implemented correctly. Sometimes, trained installers may complete mock-ups or supervise other workers, but those completing the work may not be qualified. To ensure that the requirements set forth in the drawings and specifications are met, observation of the installation is highly recommended.

As noted in Step 6, the evaluation and selection process should be well documented to support the final recommendation. Additionally, all subsequent steps up to and including installation should be recorded. This record will inform any long-term follow-up assessments, even if they are completed by a different individual or firm. Documentation of the installation process is also good practice in the event of any premature problems with the replacement.

Step 9: Complete a long-term follow-up assessment of in-situ performance. Finally, the long-term assessment of the in-situ performance of a replacement material is critical to the expansion of the preservation knowledge base on substitute materials. Combined with detailed documentation of the evaluation, selection, and implementation of the material, follow-up assessments can offer helpful insight to other practitioners considering the same or similar materials. At the very minimum, follow-up evaluations should be performed when installation is completed and after the material has been in place for a full year. Ideally, long-term evaluations should also be completed after several years (5-10 years), and even decades (20-30 years).

Respondents to the preservation practitioner survey indicated that follow-up evaluations are often outside the scope of preservation project services. Unless there has been a problem with the replacement, clients rarely consider long-term assessments necessary, and do not budget resources to support them. While there appears to be little incentive to convince private clients that long-term assessments are necessary, institutional or government clients with longer-range planning may consider adding these assessments to a project scope. Alternatively, agencies that provide grants or funding for preservation projects could require long-term assessments as a condition of accepting funding.

Step 10: Disseminate long-term material performance information for use by other preservation practitioners. As mentioned in the previous step, the long-term assessment of material performance will help build the knowledge base on substitute materials. While the preservation practitioner survey revealed that the majority of practitioners have used substitute materials successfully, the review of past and current preservation literature revealed that case studies on the long-term performance of substitute materials are rarely published. The dissemination of performance data through published literature, an online database, or other resources would be especially beneficial for newer or emerging materials. Potential opportunities for this type of support will be discussed in the final chapter.

CONCLUSION

The review of structured decision-making methods, including various material selection strategies, multiple attribute decision analysis, the Choosing by Advantages system, and methods of economic, environmental impact, and conservation decision-making, revealed that elements of these approaches may be adaptable for the evaluation and selection of substitute materials. However, the challenge of combining the intangible values of preservation philosophy with tangible material performance and cost data, as well as the complex and uncertain nature of material replacement decisions, limits the practical utility of a formally-structured, universal, rational decision-making method. Still, the goal of providing structure and an analytical approach to the method of evaluation and selection of substitute materials is possible and necessary. The inventory of considerations, including preservation philosophy, material properties and performance, and economic and environmental costs, provides an organized and systematic approach to the research, evaluation, and selection of substitute materials.

CHAPTER 6: CONCLUSIONS & RECOMMENDATIONS

The use of substitute building materials for necessary replacements on historic preservation projects is not new. For decades, preservation practitioners have turned to substitute materials under various circumstances, including for example, when the original material or craft techniques are no longer available, or when a substitute material offers equal or superior performance and durability at a lower cost. In coming years, the growing emphasis on sustainability and the decreasing availability of many natural historic building materials, as well as the implications of preserving mid-to-late 20th century modern architecture, may lead to more frequent use of a variety of substitute materials for the preservation of historic buildings.

The following are the original research questions that provided direction for this thesis, together with the answers and conclusions that can be drawn from each.

- Is adequate guidance available to preservation practitioners for the evaluation and selection of substitute materials?

In short, no. The review of published preservation literature and other resources revealed that the majority of the written guidance on the use of substitute materials was published in the 1980s and early 1990s. This guidance, including the NPS *Preservation Brief 16: The Use of Substitute Materials on Historic Building Exteriors*, is useful for general reference, but does not address a comprehensive method for evaluation or selection of appropriate substitute materials. Most other preservation publications on the topic are material- and project-specific. While this type of anecdotal information can be helpful to preservation practitioners attempting to evaluate and select a substitute material, descriptions of long-term in-situ material performance would be most valuable. Unfortunately, other than John Fidler's articles on FRP and GFRC, not one of these published articles or case studies includes a long-term assessment of the success of substitute materials used on historic buildings.[206]

It is no secret that substitute materials often fail to perform adequately when used on historic buildings. The preservation practitioner survey, which was completed by 250 individuals, revealed that approximately 60 percent of respondents are aware of substitute material failures. Respondents cited reasons for these failures ranging from the lack of long-term performance data or the acceptance of manufacturers' unfounded claims regarding material performance, to poor quality fabrication or inappropriate installation. With adequate guidance on the considerations and methods for evaluating and selecting substitute materials, many of these failures may have been avoided.

Respondents to the practitioner survey also revealed that one of the greatest challenges regarding the appropriate use of substitute materials can sometimes be educating the client. Novel, less expensive, and "better" alternatives to existing building materials are introduced to the market with increasing frequency, and historic commissions, as well as practitioners working on rehabilitation or preservation projects, repeatedly receive requests from owners and clients to use these new materials, despite their limited performance histories. Recent proceedings, such as the roundtable discussion titled "Developing a Materials Evaluation Methodology" at the National Alliance of Preservation Commissions' 2008 Forum, demonstrate that additional guidance is needed to evaluate the suitability of

206 Fidler, "Plastic Dreams."

these new materials.[207]

- What considerations are necessary when evaluating and selecting substitute materials?

Many respondents to the preservation practitioner survey noted that every preservation project is unique and will have different priorities, criteria, and solutions, which is certainly true. For this reason, some respondents were skeptical that an inventory of considerations would be applicable to every project. However the purpose of creating a comprehensive inventory is not to force a particular set of criteria on every project, but to ensure that all potential sources of error are examined thoroughly before a material is selected. Without a comprehensive inventory for reference, the possibility of omitting a critical consideration is much greater, especially for materials on which there is a limited amount of information or long-term performance data.

The inventory of considerations presented in this thesis draws from published preservation literature, the preservation practitioner survey, materials selection guides, and other publications from the fields of objects conservation, architecture and engineering. It is organized into the categories of preservation philosophy, material properties and performance, and economic and environmental costs. The philosophical considerations intrinsic to preservation decision-making must be combined with practical material property and performance considerations integral to the selection of functional and durable building materials. Additionally, both economic and environmental costs can be key factors in the process of evaluation and selection.

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[207] National Alliance of Preservation Commissions, Forum 2006 Working Round-table Report, http://www.uga.edu/napc/programs/napc/forum.htm.

- Is a new method necessary to better equip preservation practitioners to make decisions about substitute materials within the framework of preservation philosophy, material properties and performance, economics, and sustainability?

A new method of evaluation, which addresses a wide range of considerations in a structured and comprehensive manner, will help preservation practitioners to select substitute materials that are appropriate for use on historic buildings. A survey of structured decision-making approaches used in related fields was undertaken to determine if elements of various methods could be adapted for the evaluation and selection of substitute materials. While aspects of many of these methods, including material selection strategies, multiple attribute decision analysis, the Choosing by Advantages system, and methods of economic, environmental impact, and conservation decision-making, could be applied for preservation, a single universally applicable method was not found. As noted by experts who have attempted to create formalized methods for conservation decision-making, it is extremely difficult to combine the intangible values of preservation philosophy with the tangible material properties and cost data, or in some cases, to even determine or quantify some of these variables individually. Additionally, the mathematical calculations or support software required by many structured rational decision-making methods may deter preservation practitioners from using them at all.

However, goal of providing structure to the process of substitute material selection is not impossible. The inventory of considerations presented in Chapter 4 provides an organized and systematic way to approach material characterization and evaluation, and the ten-step method presented in Chapter 5 provides a sequential process in which the inventory can be utilized. This method has several key objectives including: promoting the critical tie to failure diagnostics, promoting critical thinking and the consideration of fresh ideas, and encouraging follow-up assessments.

While seldom mentioned in the guiding literature, an accurate diagnosis of the causes of failure within the original material is critical to the successful implementation of any substitute material. The material properties, design aspects, or environmental factors that led to the deterioration of the original should inform the material choice and design for any replacement to ensure that the problem is not perpetuated. The evaluation of the potential substitute material on its own merits, as well as its compatibility with the surrounding materials, should then be undertaken to ensure that a new set of problems are not created.

The method is also intended to promote critical thinking and the consideration of fresh ideas, namely, new or innovative solutions. As material technologies continue to evolve, preservation practitioners will face an ever-expanding range of newer, less expensive potential substitute materials, many of which will have limited, or non-existent performance histories. While many preservation practitioners argue that substitute materials should not be used for historic projects until they have established long-term performance records, this precludes the use of many promising new materials.

Many respondents to the preservation practitioner survey indicated that the biggest challenge in the evaluation and selection of substitute materials is the lack of long-term performance data for substitute materials installed in similar situations and environments. The need for long-term performance data on substitute materials or a way to evaluate new materials independently was also confirmed by an email that the author of this thesis received as a response to the practitioner survey. The email came from a preservation practitioner on staff at a local historic commission seeking information regarding the suitability of a relatively new substitute material. He noted that many residents have submitted requests to use this material, but that he has been unable to find any published or online accounts of its use on historic projects:

> …The claims made by the applicants per the information on the [manufacturer's] website is that the material is low maintenance, guaranteed for 50 years, the factory applied paint is warrantied for 15 years, it is insect proof, rot proof, fire proof, etc. Sounds too good to be true, I know.
>
> I have been looking for a report or technical study of this product to counter these claims but to no avail. I have called the [local] SHPO—they know nothing about it—and have [searched for] it on the web. All I find is people asking questions about the product and of course the website, but no definitive study has been conducted. I am also a member of APT but there is nothing in their archives [on the material].
>
> If you have any information or any ideas as to where else I could look, I would sincerely appreciate it. I have trouble believing that no one else has seen this coming. I can see that this product is building momentum as well as appeal with old house owners looking for a guaranteed quick fix for maintenance issues…[208]

As he notes, promotional claims made by manufacturers can make substitute materials sound too good to be true. While it is certainly possible that some new substitutes may be appropriate for historic projects, it is also critical for preservation practitioners to evaluate the suitability of these materials for the specific project at hand in light of manufacturers' claims. With experiential knowledge of the weathering of different types of building materials, and the detailed characterization of material properties, functionality, durability, and compatibility prompted by the inventory of considerations presented in this thesis, preservation practitioners may make educated predictions regarding the long-term performance and durability of newer substitute materials.

Still, a long-term performance record is one of the best indicators that a substitute

[208] Email message to author, March 27, 2009.

material may be appropriate for use on a historic project. Some respondents to the practitioner survey expressed the desire for a database or similar resource for the collection of material performance information. The first step in the creation of this type of resource is the advocacy of long-term assessments of in-situ substitute material performance. The method presented in this thesis recommends these assessments, but as many practitioners have noted, they are rarely included in the contracted scope of work. To counter this trend, professional preservation and conservation organizations, as well as regulatory agencies and granting bodies that support the advancement of the field of preservation, could require long-term follow-up assessments on projects which they work or fund.

The National Center for Preservation Technology and Training (NCPTT), whose mission is to advance "the application of science and technology to historic preservation…through training, education, research, technology transfer and partnerships," could potentially provide the leadership necessary to establish a database of substitute material properties and performance.[209] Andrew Ferrell, the NCPTT Architecture & Engineering Program Chief, noted that the NCPTT is not currently testing new building materials, but that they would certainly be interested in working with substitute materials.[210] While it is unlikely that funding will support a comprehensive testing or data collection project, the NCPTT could potentially serve as a clearinghouse or online database manager for information collected by individual preservation practitioners through long-term performance assessments.

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209 The National Center for Preservation Technology and Training, Home Page, http://www.ncptt.nps.gov/index.php/about-us/.

210 Andrew Ferrell, Architecture & Engineering Program Chief, NCPTT, Personal Interview, March 25, 2009.

The use of substitute materials for the replacement of deteriorated elements can be an appropriate and successful means of preserving the form and function of historic buildings. However, inappropriate substitute materials can also lead to further damage and wasted resources. To aid preservation practitioners in their evaluation and selection of substitute materials, this thesis presents a comprehensive inventory of considerations for an organized and systematic approach to material characterization and evaluation, as well as a ten-step method in which the inventory can be utilized. This guidance, together with long-term performance assessments and the development of a resource for the dissemination of material performance data, should improve the use of substitute materials, and in turn, improve the preservation of historic resources for generations to come.

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APPENDIX A – PRESERVATION BRIEF 16

This appendix includes:

Park, Sharon C. *Preservation Brief 16: The Use of Substitute Materials on Historic Building Exteriors*. Washington, D.C.: National Park Service, Technical Preservation Services, 1988.

The version of this Preservation Brief that follows is the electronic version, available from:

http://www.nps.gov/history/hps/tps/briefs/brief16.htm.

Technical Preservation Services
National Park Service
U.S. Department of the Interior

The Use of Substitute Materials on Historic Building Exteriors

Sharon C. Park, AIA

A NOTE TO OUR USERS: The web versions of the **Preservation Briefs** differ somewhat from the printed versions. Many illustrations are new, captions are simplified, illustrations are typically in color rather than black and white, and some complex charts have been omitted.

The Secretary of the Interior's Standards for Rehabilitation require that "deteriorated architectural features be repaired rather than replaced, wherever possible. In the event that replacement is necessary, the new material should match the material being replaced in composition, design, color, texture, and other visual properties." Substitute materials should be used only on a limited basis and only when they will match the appearance and general properties of the historic material and will not damage the historic resource.

Introduction

When deteriorated, damaged, or lost features of a historic building need repair or replacement, it is almost always best to use historic materials. In limited circumstances substitute materials that imitate historic materials may be used if the appearance and properties of the historic materials can be matched closely and no damage to the remaining historic fabric will result.

Great care must be taken if substitute materials are used on the exteriors of historic buildings. Ultraviolet light, moisture penetration behind joints, and stresses caused by changing temperatures can greatly impair the performance of substitute materials over time. Only after consideration of all options, in consultation with qualified professionals, experienced fabricators and contractors, and development of carefully written specifications should this work be undertaken.


In the reconstruction of the clock tower at Independence Hall, the substitute materials used were cast stone and wood with fiberglass and polyester bronze ornamentation. Photo: NPS files.

The practice of using substitute materials in architecture is not new, yet it continues to pose practical problems and to raise philosophical questions. On the practical level the inappropriate choice or improper installation of substitute materials can cause a radical change in a building's appearance and can cause extensive physical damage over time. On the more philosophical level, the wholesale use of substitute materials can raise questions concerning the integrity of historic buildings largely comprised of new materials. In both cases the integrity of the historic resource can be destroyed.

Some preservationists advocate that substitute materials should be avoided in all but the most limited cases. The fact is, however, that substitute materials are being used more frequently than ever in preservation projects, and in many cases with positive results. They can be cost-effective, can permit the accurate visual duplication of historic materials, and last a reasonable time. Growing evidence indicates that with proper planning, careful specifications and supervision, substitute materials can be used successfully in the process of restoring the visual appearance of historic resources.

This Brief provides general guidance on the use of substitute materials on the exteriors of historic buildings. While substitute materials are frequently used on interiors, these applications are not subject to weathering and moisture penetration, and will not be discussed in this Brief. Given the general nature of this publication, specifications for substitute materials are not provided. The guidance provided should not be used in place of consultations with qualified professionals. This Brief includes a discussion of when to use substitute materials, cautions regarding their expected performance, and descriptions of several substitute materials, their advantages and disadvantages. This review of materials is by no means comprehensive, and attitudes and findings will change as technology develops.

Historical Use of Substitute Materials

The tradition of using cheaper and more common materials in imitation of more expensive and less available materials is a long one. George Washington, for example, used wood painted with sand-impregnated paint at Mount Vernon to imitate cut ashlar stone. This technique along with scoring stucco into block patterns was fairly common in colonial America to imitate stone.

Molded or cast masonry substitutes, such as dry-tamp cast stone and poured concrete, became popular in place of quarried stone during the 19th century. These masonry units were fabricated locally, avoiding expensive quarrying and shipping costs, and were versatile in representing either ornately carved blocks, plain wall stones or rough cut textured surfaces. The end result depended on the type of patterned or textured mold used and was particularly popular in conjunction with mail order houses. Later, panels of cementitious permastone or formstone and less expensive asphalt and sheet metal panels were used to imitate brick or stone.

Metal (cast, stamped, or brake-formed) was used for storefronts, canopies, railings, and other features, such as galvanized metal cornices substituting for wood or stone, stamped metal panels for Spanish clay roofing tiles, and cast-iron column capitals and even entire building fronts in imitation of building stone.

Substitute materials need to be located with care to avoid damage. The fiberglass column base has chipped, whereas the historic cast iron would have remained sound. Photo: NPS files.

Terra-cotta, a molded fired clay product, was itself a substitute material and was very popular in the late 19th and early 20th centuries. It simulated the appearance of intricately carved stonework, which was expensive and time-consuming to produce. Terra cotta could be glazed to imitate a variety of natural stones, from brownstones to limestones, or could be colored for a polychrome effect.

Nineteenth century technology made a variety of materials readily available that not only were able to imitate more expensive materials but were also cheaper to fabricate and easier to use. Throughout the century, imitative materials continued to evolve. For example, ornamental window hoods were originally made of wood or carved stone. In an effort to find a cheaper substitute for carved stone and to speed fabrication time, cast stone, an early form of concrete, or cast-iron hoods often replaced stone. Toward the end of the century, even less expensive sheet metal hoods, imitating stone, also came into widespread use. All of these materials, stone, cast stone, cast iron, and various pressed metals were in production at the same time and were selected on the basis on the basis of the availability of materials and local craftsmanship, as well as durability and cost. The criteria for selection today are not much different.

Many of the materials used historically to imitate other materials are still available. These are often referred to as the traditional materials: wood, cast stone, concrete, terra cotta and cast metals. In the last few decades, however, and partly as a result of the historic preservation movement, new families of synthetic materials, such as fiberglass, acrylic polymers, and epoxy resins, have been developed and are being used as substitute materials in construction. In some respects these newer products (often referred to as high tech materials) show great promise; in others, they are less satisfactory, since they are often difficult to integrate physically with the porous historic materials and may be too new to have established solid performance records.

When to Consider Using Substitute Materials in Preservation Projects

Because the overzealous use of substitute materials can greatly impair the historic character of a historic structure, all preservation options should be explored thoroughly before substitute materials are used. It is important to remember that the purpose of repairing damaged features and of replacing lost and irreparably damaged ones is both to match visually what was there and to cause no further deterioration. For these reasons it is not appropriate to cover up historic materials with synthetic materials that will alter the appearance, proportions and details of a historic building and that will conceal future deterioration.

Some materials have been used successfully for the repair of damaged features such as epoxies for wood infilling, cementitious patching for sandstone repairs, or plastic stone for masonry repairs. Repairs are preferable to replacement whether or not the repairs are in kind or with a synthetic substitute material.

In general, four circumstances warrant the consideration of substitute materials: 1) the unavailability of historic materials; 2) the unavailability of skilled craftsmen; 3) inherent flaws in the original materials; and 4) code-required changes (which in many cases can be extremely destructive of historic resources).

Cost may or may not be a determining factor in considering the use of substitute materials. Depending on the area of the country, the amount of material needed, and the projected life of less durable substitute materials, it may be cheaper in the long run to use the original material, even though it may be harder to find.

The core of a deteriorated wood outrigger was first drilled out. Photos (left and right): Courtesy, Harrison Goodall.

An inert material was injected into the hollow outrigger, permitting the outer wood to be retained and preserved.

Due to many early failures of substitute materials, some preservationist are looking abroad to find materials (especially stone) that match the historic materials in an effort to restore historic buildings accurately and to avoid many of the uncertainties that come with the use of substitute materials.

1. The unavailability of the historic material.

The most common reason for considering substitute materials is the difficulty in finding a good match for the historic material (particularly a problem for masonry materials where the color and texture are derived from the material itself). This may be due to the actual unavailability of the material or to protracted delivery dates. For example, the local quarry that supplied the sandstone for a building may no longer be in operation. All efforts should be made to locate another quarry that could supply a satisfactory match. If this approach fails, substitute materials such as dry-tamp cast stone or textured precast concrete may be a suitable substitute if care is taken to ensure that the detail, color and texture of the original stone are matched. In some cases, it may be possible to use a sand-impregnated paint on wood as a replacement section, achieved using readily available traditional materials, conventional tools and work skills. Simple solutions should not be overlooked.

2. The unavailability of historic craft techniques and lack of skilled artisans. These two reasons complicate any preservation or rehabilitation project. This is particularly true for intricate ornamental work, such as carved wood, carved stone, wrought iron, cast iron, or molded terra cotta. However, a number of stone and wood cutters now employ sophisticated carving machines, some even computerized. It is also possible to cast substitute replacement pieces using aluminum, cast stone, fiberglass, polymer concretes, glass fiber reinforced concretes and terra cotta. Mold making and casting takes skill and craftsmen who can undertake this work are available. Efforts should always be made, prior to replacement, to seek out artisans who might be able to repair ornamental elements and thereby save the historic features in place.

3. Poor original building materials.

Some historic building materials were of inherently poor quality or their modern counterparts are inferior. In addition, some materials were naturally incompatible with other materials on the building, causing staining or galvanic corrosion. Examples of poor quality materials were the very soft sandstones which eroded quickly. An example of poor quality modern replacement material is the tin coated steel roofing which is much less durable than the historic tin or terne iron which is no longer available. In some cases, more durable natural stones or precast concrete might be available as substitutes for the soft stones and modern terne-coated stainless steel or lead-coated copper might produce a more durable yet visually compatible replacement roofing.

Cast aluminum has been used as a replacement material for cast iron. Photo: NPS files.

4. Code-related changes.

Sometimes referred to as life and safety codes, building codes often require changes to historic buildings. Many cities in earthquake zones, for example, have laws requiring that overhanging masonry parapets and cornices, or freestanding urns or finials be securely re-anchored to new structural frames or be removed completely. In some cases, it may be acceptable to replace these heavy historic elements with light replicas. In other cases, the extent of historic fabric removed may be so great as to diminish the integrity of the resource. This could affect the significance of the structure and jeopardize National Register status. In addition, removal of repairable historic materials could result in loss of Federal tax credits for rehabilitation. Department of the Interior regulations make clear that the Secretary of the Interior's Standards for Rehabilitation take precedence over other regulations and codes in determining whether a project is consistent with the historic character of the building undergoing rehabilitation.

Two secondary reasons for considering the use of substitute materials are their lighter weight and for some materials, a reduced need of maintenance. These reasons can become important if there is a need to keep dead loads to a minimum or if the feature being replaced is relatively inaccessible for routine maintenance.

Cautions and Concerns

In dealing with exterior features and materials, it must be remembered that moisture penetration, ultraviolet degradation, and differing thermal expansion and contraction rates of dissimilar materials make any repair or replacement problematic. To ensure that a repair or replacement will perform well over time, it is critical to understand fully the properties of both the original and the substitute materials, to install replacement materials correctly, to assess their impact on adjacent historic materials, and to have reasonable expectations of future performance.

Many high tech materials are too new to have been tested thoroughly. The differences in vapor permeability between some synthetic materials and the historic materials have in some cases caused unexpected further deterioration. It is therefore difficult to recommend substitute materials if the historic materials are still available. As previously mentioned, consideration should always be given first to using traditional materials and methods of repair or replacement before accepting unproven techniques, materials or applications.

Substitute materials must meet three basic criteria before being considered: they must be compatible with the historic materials in appearance; their physical properties must be similar to those of the historic materials, or be installed in a manner that tolerates differences; and they must meet certain basic performance expectations over an extended period of time.

A waterproof coating is an inappropraite substitute material to apply to adobe as it seals in moisture and may result in spalling. Photo: NPS files.

Matching the Appearance of the Historic Materials

In order to provide an appearance that is compatible with the historic material, the new material should match the details and craftsmanship of the original as well as the color, surface texture, surface reflectivity and finish of the original material. The closer an element is to the viewer, the more closely the material and craftsmanship must match the original.

Matching the color and surface texture of the historic material with a substitute material is normally difficult. To enhance the chances of a good match, it is advisable to clean a portion of the building where new materials are to be used. If pigments are to be added to the substitute material, a specialist should determine the formulation of the mix, the natural aggregates and the types of pigments to be used. As all exposed material is subject to ultraviolet degradation, if possible, samples of the new materials made during the early planning phases should be tested or allowed to weather over several seasons to test for color stability.

Fabricators should supply a sufficient number of samples to permit onsite comparison of color, texture, detailing, and other critical qualities. In situations where there are subtle variations in color and texture within the original materials, the substitute materials should be similarly varied so that they are not conspicuous by their uniformity.

Substitute materials, notably the masonry ones, may be more water-absorbent than the historic material. If this is visually distracting, it may be appropriate to apply a protective vapor-permeable coating on the substitute material. However, these clear coatings tend to alter the reflectivity of the material, must be reapplied periodically, and may trap salts and moisture, which can in turn produce spalling. For these reasons, they are not recommended for use on historic materials.

Matching the Physical Properties

While substitute materials can closely match the appearance of historic ones, their physical properties may differ greatly. The chemical composition of the material (i.e., presence of acids, alkalines, salts, or metals) should be evaluated to ensure that the replacement materials will be compatible with the historic resource. Special care must therefore be taken to integrate and to anchor the new materials properly. The thermal expansion and contraction coefficients of each adjacent material must be within tolerable limits. The function of joints must be understood and detailed either to eliminate moisture penetration or to allow vapor permeability. Materials that will cause galvanic corrosion or other chemical reactions must be isolated from one another.

To ensure proper attachment, surface preparation is critical. Deteriorated underlying material must be cleaned out. Noncorrosive anchoring devices or fasteners that are designed to carry the new material and to withstand wind, snow and other destructive elements should be used. Properly chosen fasteners allow attached materials to expand and contract at their own rates. Caulking, flexible sealants or expansion joints between the historic material and the substitute material can absorb slight differences of movement. Since physical failures often result from poor anchorage or improper installation techniques, a structural engineer should be a member of any team undertaking major repairs.

Some of the new high tech materials such as epoxies and polymers are much stronger than historic materials and generally impermeable to moisture. These differences can cause serious problems unless the new materials are modified to match the expansion and contraction properties of adjacent historic materials more closely, or unless the new materials are isolated from the historic ones altogether. When stronger or vapor impermeable new materials are used alongside historic ones, stresses from trapped moisture or differing expansion and contraction rates generally hasten deterioration of the weaker historic material. For this reason, a conservative approach to repair or replacement is recommended, one that uses more pliant materials rather than high-strength ones. Since it is almost impossible for substitute materials to match the properties of historic materials perfectly, the new system incorporating new and historic materials should be designed so that if material failures occur, they occur within the new material rather than the historic material.

Performance Expectations

While a substitute material may appear to be acceptable at the time of installation, both its appearance and its performance may deteriorate rapidly. Some materials are so new that industry standards are not available, thus making it difficult to specify quality control in fabrication, or to predict maintenance requirements and long term performance. Where possible, projects involving substitute materials in similar circumstances should be examined. Material specifications outlining stability of color and texture; compressive or tensile strengths if appropriate; the acceptable range of thermal coefficients, and the durability of coatings and finishes should be included in the contract documents. Without these written documents, the owner may be left with little recourse if failure occurs.


The historic cornice was successfully replaced with a fiberglass cornice. Photo: NPS files.

The tight controls necessary to ensure long-term performance extend beyond having written performance standards and selecting materials that have a successful track record. It is important to select qualified fabricators and installers who know what they are doing and who can follow up if repairs are necessary. Installers and contractors unfamiliar with specific substitute materials and how they function in your local environmental conditions should be avoided.

The surfaces of substitute materials may need special care once installed. For example, chemical residues or mold release agents should be removed completely prior to installation, since they attract pollutants and cause the replacement materials to appear dirtier than the adjacent historic materials. Furthermore, substitute materials may require more frequent cleaning, special cleaning products and protection from impact by hanging window-cleaning scaffolding. Finally, it is critical that the substitute materials be identified as part of the historical record of the building so that proper care and maintenance of all the building materials continue to ensure the life of the historic resource.

Choosing an Appropriate Substitute Material

Once all reasonable options for repair or replacement in kind have been exhausted, the choice among a wide variety of substitute materials currently on the market must be made. The charts at the end of this Brief describe a number of such materials, many of them in the family of modified concretes which are gaining greater use. The charts do not include wood, stamped metal, mineral fiber cement shingles and some other traditional imitative materials, since their properties and performance are better known. Nor do the charts include vinyls or molded urethanes which are sometimes used as cosmetic claddings or as substitutes for wooden millwork. Because millwork is still readily available, it should be replaced in kind.

The charts describe the properties and uses of several materials finding greater use in historic preservation projects, and outline advantages and disadvantages of each. It should not be read as an endorsement of any of these materials, but serves as a reminder that numerous materials must be studied carefully before selecting the appropriate treatment. Included are three predominantly masonry materials (cast stone, precast concrete, and glass fiber reinforced concrete); two predominantly resinous materials (epoxy and glass fiber reinforced polymers also known as fiberglass), and cast aluminum which has been used as a substitute for various metals and woods.

Pros and Cons of Various Substitute Materials

Cast Aluminum

Material: Cast aluminum is a molten aluminum alloy cast in permanent (metal) molds or onetime sand molds which must be adjusted for shrinkage during the curing process. Color is from paint applied to primed aluminum or from a factory finished coating. Small sections can be bolted together to achieve intricate or sculptural details. Unit castings are also available for items such as column plinth blocks.

Application: Cast aluminum can be a substitute for cast iron or other decorative elements. This would include grillwork, roof crestings, cornices, ornamental spandrels, storefront elements, columns, capitals, and column bases and plinth blocks. If not self-supporting, elements are generally screwed or bolted to a structural frame. As a result of galvanic corrosion problems with dissimilar metals, joint details are very important.

Advantages:

- light weight (1/2 of castiron)
- corrosion-resistant, noncombustible
- intricate castings possible
- easily assembled, good delivery time
- can be prepared for a variety of colors
- long life, durable, less brittle than cast iron

Disadvantages:

- lower structural strength than castiron
- difficult to prevent galvanic corrosion with other metals
- greater expansion and contraction than castiron; requires
- gaskets or caulked joints
- difficult to keep paint on aluminum

Checklist:

- Can existing be repaired or replaced inkind?
- How is cast aluminum to be with other metals attached?
- Have full-size details been developed for each piece to be cast?
- How are expansion joints detailed?
- Will there be a galvanic corrosion problem?
- Are fabricators/installers experienced?

Cast Stone (dry tamped)

Material: Cast stone is an almost-dry cement, lime and aggregate mixture which is dry-tamped into a mold to produce a dense stone-like unit. Confusion arises in the building industry as many refer to high quality precast concrete as cast stone. In fact, while it is a form of precast concrete, the drytamp fabrication method produces an outer surface resembling a stone surface. The inner core can be either drytamped or poured full of concrete. Reinforcing bars and anchorage devices can be installed during fabrication.

Application: Cast stone is often the most visually similar material as a replacement for unveined deteriorated stone, such as brownstone or sandstone, or terra cotta in imitation of stone. It is used both for surface wall stones and for ornamental features such as window and door surrounds, voussoirs, brackets and hoods. Rubberlike molds can be taken of good stones on site or made up at the factory from shop drawings.

Advantages:

- replicates stone texture with good molds (which can come from extant stone) and fabrication
- expansion/contraction similar to stone
- minimal shrinkage of material
- anchors and reinforcing bars can be built in
- material is firerated
- range of color available
- vapor permeable

Disadvantages:

- heavy units may require additional anchorage
- color can fade in sunlight
- may be more absorbent than natural stone
- replacement stones are obvious if too few models and molds are made

Checklist:

- Are the original or similar materials available?
- How are units to be installed and anchored?
- Have performance standards been developed to ensure color stability?
- Have large samples been delivered to site for color, finish and absorption testing?
- Has mortar been matched to adjacent historic mortar to achieve a good color/tooling match?
- Are fabricators/installers experienced?

Glass Fiber Reinforced Concretes (GFRC)

Material: Glass fiber reinforced concretes are lightweight concrete compounds modified with additives and reinforced with glass fibers. They are generally fabricated as thin shelled panels and applied to a separate structural frame or anchorage system. The GFRC is most commonly sprayed into forms although it can be poured. The glass must be alkaline resistant to avoid deteriorating effects caused by the cement mix. The color is derived from the natural aggregates and if necessary a small percentage of added pigments.

Application: Glass fiber reinforced concretes are used in place of features originally made of stone, terra cotta, metal or wood, such as cornices, projecting window and door trims, brackets, finials, or wall murals. As a molded product it can be produced in long sections of repetitive designs or as sculptural elements. Because of its low shrinkage, it can be produced from molds taken directly from the building. It is installed with a separate noncorrosive anchorage system. As a predominantly cementitious material, it is vapor permeable.

Advantages:

- lightweight, easily installed
- good molding ability, crisp detail possible
- weather resistant
- can be left uncoated or else painted
- little shrinkage during fabrication
- molds made directly from historic features
- cements generally breathable
- material is firerated

Disadvantages:

- non-loadbearing use only
- generally requires separate anchorage system
- large panels must be reinforced
- color additives may fade with sunlight
- joints must be properly detailed
- may have different absorption rate than adjacent historic material

Checklist:

- Are the original materials and craftsmanship still available?
- Have samples been inspected on the site to ensure detail/texture match?
- Has anchorage system been properly designed?
- Have performance standards been developed?
- Are fabricators/installers experienced?

Precast Concrete

Material: Precast concrete is a wet mix of cement and aggregate poured into molds to create masonry units. Molds can be made from existing good surfaces on the building. Color is generally integral to the mix as a natural coloration of the sand or aggregate, or as a small percentage of pigment. To avoid unsightly air bubbles that result from the natural curing process, great care must be taken in the initial and longterm vibration of the mix. Because of its weight it is generally used to reproduce individual units of masonry and not thin shell panels.

Application: Precast concrete is generally used in place of masonry materials such as stone or terra cotta. It is used both for flat wall surfaces and for textured or ornamental elements. This includes wall stones, window and door surrounds, stair treads, paving pieces, parapets, urns, balusters and other decorative elements. It differs from cast stone in that the surface is more dependent on the textured mold than the hand tamping method of fabrication.

Advantages:

- easily fabricated, takes shape well
- rubber molds can be made from building stones
- minimal shrinkage of material
- can be load bearing or anchorage can be cast in
- expansion/contraction similar to stone
- material is firerated
- range of color and aggregate available
- vapor permeable

Disadvantages:

- may be more moisture absorbent than stone although coatings may be applied
- color fades in sunlight
- small air bubbles may disfigure units
- replacement stones are conspicuous if too few models and molds are made

Checklist:

- Is the historic material still available?
- What are the structural/anchorage requirements?
- Have samples been matched for color/texture/absorption? Have shop drawings been made for each shape?
- Are there performance standards?
- Has mortar been matched to adjacent historic mortar to achieve good color/tooling match?
- Are fabricators/installers experienced?

Fiber Reinforced Polymers (FRP, Fiberglass)

Material: Fiberglass is the most well known of the FRP products generally produced as a thin rigid laminate shell formed by pouring a polyester or epoxy resin gelcoat into a mold. When tack-free, layers of chopped glass or glass fabric are added along with additional resins. Reinforcing rods and struts can be added if necessary; the gel coat can be pigmented or painted.

Application: Fiberglass, a non load-bearing material attached to a separate structural frame, is frequently used as a replacement where a lightweight element is needed or an inaccessible location makes frequent maintenance of historic materials difficult. Its good molding ability and versatility to represent stone, wood, metal and terra cotta make it an alternative to ornate or carved building elements such as column capitals, bases, spandrel panels, beltcourses, balustrades, window hoods or parapets. Its ability to reproduce bright colors is a great advantage.

Advantages:

- lightweight, long spans available with a separate structural frame
- high ratio of strength to weight

- good molding ability
- integral color with exposed high quality pigmented gel-coat or takes paint well
- easily installed, can be cut, patched, sanded
- non-corrosive, rot-resistant

Disadvantages:

- requires separate anchorage system
- combustible (fire retardants can be added); fragile to impact.
- high coefficient of expansion and contraction requires frequently placed expansion joints
- ultraviolet sensitive unless surface is coated or pigments are in gelcoat
- vapor impermeability may require ventilation detail

Checklist:

- Can original materials be saved/used?
- Have expansion joints been designed to avoid unsightly appearance?
- Are there standards for color stability/durability?
- Have shop drawings been made for each piece?
- Have samples been matched for color and texture?
- Are fabricators/installers experienced?
- Do codes restrict use of FRP?

Epoxies (Epoxy Concretes, Polymer Concretes)

Material: Epoxy is a resinous two-part thermosetting material used as a consolidant, an adhesive, a patching compound, and as a molding resin. It can repair damaged material or recreate lost features. The resins which are poured into molds are usually mixed with fillers such as sand, or glass spheres, to lighten the mix and modify their expansion/contraction properties. When mixed with aggregates, such as sand or stone chips, they are often called epoxy concrete or polymer concrete, which is a misnomer as there are no cementitious materials contained within the mix. Epoxies are vapor impermeable, which makes detailing of the new elements extremely important so as to avoid trapping moisture behind the replacement material. It can be used with wood, stone, terra cotta, and various metals.

Application: Epoxy is one of the most versatile of the new materials. It can be used to bind together broken fragments of terra cotta; to build up or infill missing sections of ornamental metal; or to cast missing elements of wooden ornaments. Small cast elements can be attached to existing materials or entire new features can be cast. The resins are poured into molds and due to the rapid setting of the material and the need to avoid cracking, the molded units are generally small or hollow inside. Multiple molds can be combined for larger elements. With special rods, the epoxies can be structurally reinforced. Examples of epoxy replacement pieces include: finials, sculptural details, small column capitals, and medallions.

Advantages:

- can be used for repair/replacement

- lightweight, easily installed
- good casting ability; molds can be taken from building material can be sanded and carved.
- color and ultraviolet screening can be added; takes paint well
- durable, rot and fungus resistant

Disadvantages:

- materials are flammable and generate heat as they cure and may be toxic when burned
- toxic materials require special protection for operator and adequate ventilation while curing
- material may be subject to ultraviolet deterioration unless coated or filters added rigidity of material
- often must be modified with fillers to match expansion coefficients
- vapor impermeable

Checklist:

- Are historic materials available for molds, or for splicing-in as a repair option?
- Has the epoxy resin been formulated within the expansion/contraction coefficients of adjacent materials?
- Have samples been matched for color/finish?
- Are fabricators/installers experienced?
- Is there a sound substrate of material to avoid deterioration behind new material?
- Are there performance standards?

Summary

Substitute materials--those products used to imitate historic materials--should be used only after all other options for repair and replacement in kind have been ruled out. Because there are so many unknowns regarding the longterm performance of substitute materials, their use should not be considered without a thorough investigation into the proposed materials, the fabricator, the installer, the availability of specifications, and the use of that material in a similar situation in a similar environment.

Substitute materials are normally used when the historic materials or craftsmanship are no longer available, if the original materials are of a poor quality or are causing damage to adjacent materials, or if there are specific code requirements that preclude the use of historic materials. Use of these materials should be limited, since replacement of historic materials on a large scale may jeopardize the integrity of a historic resource. Every means of repairing deteriorating historic materials or replacing them with identical materials should be examined before turning to substitute materials.

The importance of matching the appearance and physical properties of historic materials and, thus, of finding a successful longterm solution cannot be overstated. The successful solutions illustrated in this Brief were from historic preservation projects involving professional teams of architects, engineers, fabricators, and other specialists. Cost was not necessarily a factor, and all agreed that whenever possible, the historic materials should be used. When substitute materials were selected, the solutions were often expensive and were reached only after careful consideration of all options, and with the assistance of expert professionals.

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Washington, D.C. September, 1988.

Home page logo: Cast alumnimum used as a replacement for cast iron. Photo: NPS files.

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APPENDIX B – PRESERVATION PRACTITIONER SURVEY & RESULTS

This appendix includes:

- **Preservation Practitioner Survey:** a printed version of the electronic survey, which was created using SurveyMonkey.com.

- **Complete Results of the Survey:** the results of all of the topic-based questions (1-10), including all open-ended responses and relevant figures; the respondents' reported areas of expertise; a list of respondents who provided optional contact information.

Substitute Materials for Historic Preservation

For the purpose of this study, replacement with a "substitute material" refers to any replacement that is not "in-kind." Substitutes can include anything from the replacement of deteriorated stone features with a different type of stone, to the replacement of a wood cornice with something altogether different, such as a fiberglass replica. While there are a wide variety of substitute materials available today, ranging from traditional to synthetic to emerging "green" materials, the question of how to evaluate them is usually left up to the individual practitioner. To supplement the relatively sparse literature on the topic, this survey seeks to gain insight into what criteria and methods contemporary preservation practitioners use for their evaluation and selection of substitute materials for historic buildings. This survey should take about 10 minutes.

1. Assuming you are dealing with an historic building, would you consider using a substitute material for the replacement of historic elements that cannot be repaired?

- ○ Yes
- ○ No

2. Under what conditions would you use a substitute material? (Check all that apply)

- ☐ Unavailability of the original historic material
- ☐ Unavailability of historic techniques or skilled labor
- ☐ Poor quality or inherent performance problems of the original material
- ☐ Toxicity, health or safety hazard associated with the original material
- ☐ Environmental hazard associated with the original material
- ☐ Code-related changes (i.e. life-safety or seismic codes)
- ☐ Cost: substitute material is less-expensive than the original material
- ☐ Durability: substitute material is more durable than the original material
- ☐ Maintenance: substitute material requires reduced maintenance
- ☐ Sustainability: substitute material is "greener" than the original material
- ☐ Other (please specify below)

3. Which classes of substitute materials would you use? (Check all that apply)

- ☐ Traditional materials (stone, wood, terra cotta, etc.)
- ☐ Synthetic materials (fiberglass, epoxies, etc.)
- ☐ "Green" materials (wood/plastic composites, etc.)
- ☐ Other (please specify below)

Substitute Materials for Historic Preservation

4. If you have worked on historic projects involving substitutes, do you use a similar set of criteria for every project or is each case unique?

- ◯ I use the same set of criteria for every project
- ◯ I use a unique set of criteria for each project
- ◯ I have not applied specific criteria

5. Of the following criteria, please rank those you consider essential from most to least important (do not rank non-essential criteria). Please note that this is a forced ranking, so you can mark only one criterion per column. If you have not applied criteria in practice, please skip this question.

	Most Important									Least Important
Matching appearance	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯
Compatible material properties (both physical and chemical)	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯
Service-life	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯
Maintenance	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯
Sustainability	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯
Initial cost	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯
Life-cycle cost	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯
Ease of installation	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯
Quality control	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯
Other	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯

(if "other" is selected, please specify below)

6. Do you utilize a specific method to evaluate substitute materials based on the criteria above? If so, what kind?

- ◯ No, I consider the criteria informally
- ◯ Yes, I use a checklist
- ◯ Yes, I use a decision matrix
- ◯ Yes, I use a decision tree
- ◯ Yes, I use another method

If you use an alternate method, please specify here. Also, if you use a method with a published source, please specify the source.

Substitute Materials for Historic Preservation

7. If you use substitute materials for historic projects, do you complete follow-up evaluations of in-situ performance?

- ◯ Yes, I usually complete a formal evaluation
- ◯ Yes, I usually complete a casual evaluation
- ◯ No

If not, why?

8. Have you used substitute materials successfully?

- ◯ Yes
- ◯ No

If so, which materials?

9. Are you aware of any failures of substitute materials?

- ◯ Yes
- ◯ No

If so, which materials? What went wrong? Do you think a more comprehensive selection method or list of criteria would have helped prevent the failure?

10. Any additional comments or questions?

Substitute Materials for Historic Preservation

11. What is your area of expertise? (Choose all that apply)

- ☐ Archaeologist
- ☐ Architect
- ☐ Architectural Historian
- ☐ Building Consultant
- ☐ Building Service Manager
- ☐ Conservator
- ☐ Consultant
- ☐ Contractor
- ☐ Crafts/Trades
- ☐ Cultural Historian
- ☐ Educator
- ☐ Engineer
- ☐ Geologist
- ☐ Historian
- ☐ Historic Preservation Consultant
- ☐ Historic Site Administrator
- ☐ Interior Designer
- ☐ Landscape Architect
- ☐ Landscape Consultant
- ☐ Librarian
- ☐ Manufacturer
- ☐ Museum Director
- ☐ Museum Staff
- ☐ Other
- ☐ Planner
- ☐ Project Manager
- ☐ Publisher
- ☐ Student
- ☐ Supplier

12. Optional Contact Information

Name ____

Title ____

Company ____

Telephone ____

Email ____

13. Would you be interested in discussing this topic further?

- ○ No
- ○ Yes, please contact me at:

____

14. Would you like to receive an announcement of the publication of this thesis?

- ○ Yes
- ○ No

Thank you!

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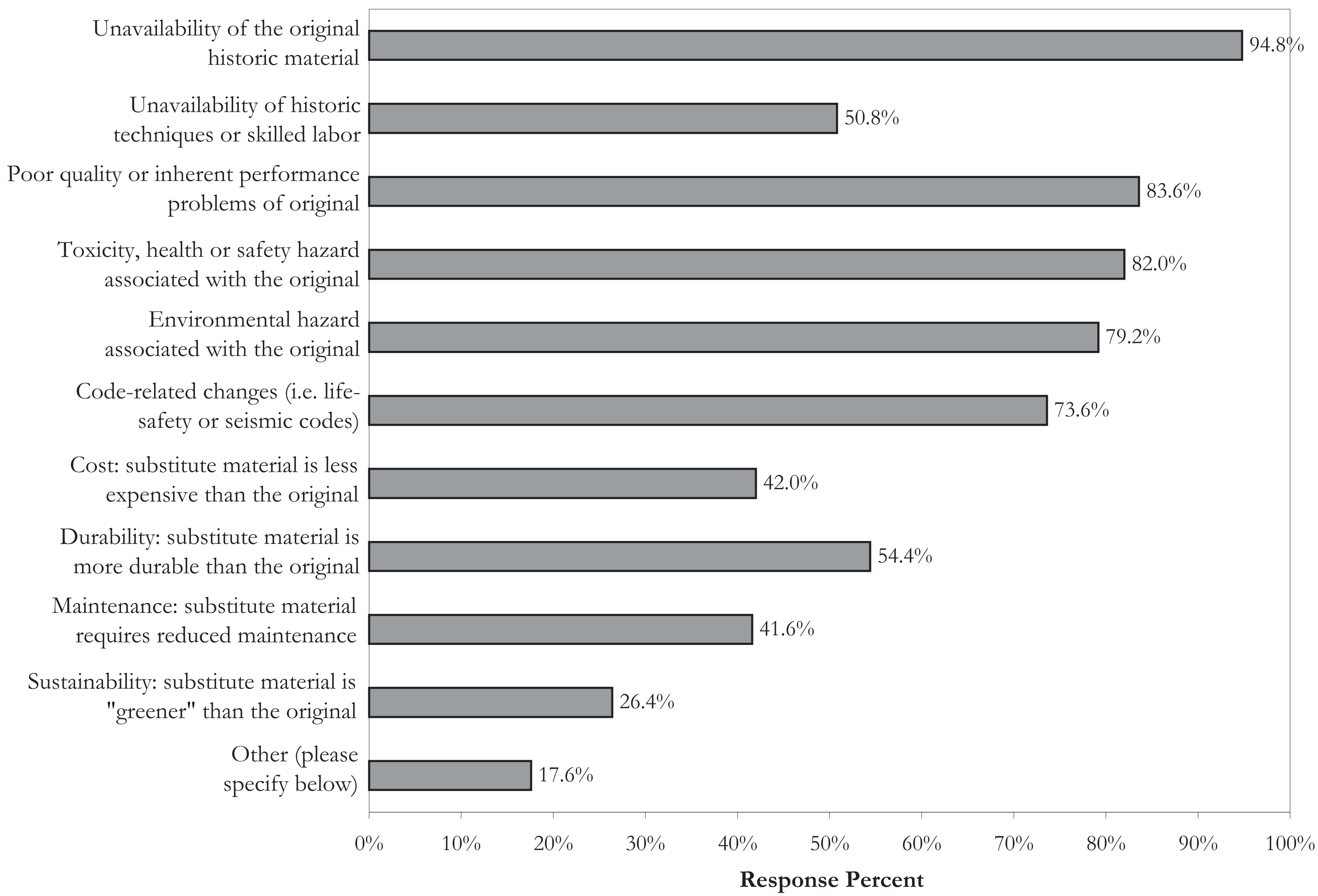
1. Assuming you are dealing with an historic building, would you consider using a substitute material for the replacement of historic elements that cannot be repaired?		
Answer Options	**Response Frequency**	**Response Count**
Yes	96.8%	242
No	3.2%	8
answered question		**250**
skipped question		**0**

2. Under what conditions would you use a substitute material? (Check all that apply)		
Answer Options	Response Frequency	Response Count
Unavailability of the original historic material	94.8%	237
Unavailability of historic techniques or skilled labor	50.8%	127
Poor quality or inherent performance problems of the original material	83.6%	209
Toxicity, health or safety hazard associated with the original material	82.0%	205
Environmental hazard associated with the original material	79.2%	198
Code-related changes (i.e. life-safety or seismic codes)	73.6%	184
Cost: substitute material is less-expensive than the original material	42.0%	105
Durability: substitute material is more durable than the original material	54.4%	136
Maintenance: substitute material requires reduced maintenance	41.6%	104
Sustainability: substitute material is "greener" than the original material	26.4%	66
Other (please specify below)	17.6%	44
	answered question	250
	skipped question	0

Number	Other (please specify below)
1	Note- all of the above are "possible" conditions, but would be applied on a project-by-project basis
2	Sacrificial repair in weaker material
3	When directed by client/owner when not in complete conflict with principles, for any number of reasons
4	Structural properties can be much better with subsitue materials.
5	Maintenance: Accessability becomes a maintenance issue
6	Very rarely have I used a substitute material over the past 20 years
7	I might consider issues such as skilled labor and code, but these can ususally be worked around and I'm hesitant to include them outright.
8	IF THE SUBSTITUTE MATERIAL IS COMPATIBLE WITH THE ORIGINAL MATERAIL AND HAVE NO DELETERIOUS EFFECTS ON PARENT MATERIAL WHICH IS THE MOST IMPORTANT
9	Unfortunately, cost usually becomes the deciding factor
10	Placement of substitute material is not visible to the viewer.
11	In regards to durabillity,maintenance and sustainability I think the answer is DEPENDS on the existing condition and the buildings use.
12	Lack of skilled labor can be a problem but sometimes training can overcome this hurdle
13	Subsitute materials, if an when used, must always considered in context
14	Short-term' for stabilisation or protection of original material for a period of 2-20 years pending future more extensive conservation works.
15	historic and architectural significance and prominence of the material / area in question
16	All of this assumes alot--if it is a very significant building some of the answers would change.
17	Lead time to obtain original material (e.g. terra cotta)
18	Money solves a lot of problems but I never have enough
19	Less invasive & reversible
20	May CONSIDER the use of substitute material, for all conditions, but not necessarily choose it - would balance the results with the project as a whole
21	If the owner insists
22	Operational requirements: I worked with an active military installation. There were times that I had to consult and make a decision based upon intended use of the building - similar to
23	Reduced maintenance needs of a substitute material would only be considered where difficult access is a contrubuter to material failure
24	If God had our technology, he would have used it
25	Except for the first item the other 3 need to be carfully evaluated for substitution

26	Structural problems require light-weight or hollow replacement (to hide structural reinforcement)
27	poor aesthetic match of new stone from the same quarry to the weathered material on the building
28	From a structural viewpoint, often the original has failed because it is not strong enough. Therefore substitute material could be stronger.
29	I would consider all of the above, but decisions would have to be made on a case-by-case basis. I would not say "yes" or "no" to any of these as a blanket statement.
30	Life safety of building.
31	Excessive timelines for replacement - like small orders of replacement terra cotta
32	Question is confusing - it seems that the question is about "when" to use a substitute material - not when to "substitute" the original material - is this correct ?
33	Question is "loaded"... given "toxcicity", "hazard", and "code", there may be no choice... except perhaps ACM encapsulation. Re "unavailability", I just don't believe this is so, unless it's 20th century manufacture.
34	if necessary to meet client's requirements for function/appearance/marketability/etc
35	substitute material in use under similar conditions for at least 5 yrs & independent testing, use by architects that I respect.
36	in order to clearly distinguish new work from original
37	we fabricate alternate materials
38	This is only in the case where the existing element is either missing or so deteriorated it must be replaced.
39	The "durability" and "maintenance" replies above pertain mostly to inaccessible or dangerous locations, such as church steeples, where replacement in-kind at relatively frequent intervals would be very difficult or costly.
40	maybe others above but not as a general rule - case by case
41	The items not checked do carry some weight in considerations, but less than the ones checked
42	I would consider--but not necessarily agree to use a substitute
43	But case needs to be carefully weighed and all alternatives considered
44	Substitute material has the same visual qualities as the original material.



Question 2. Conditions under which respondents to the Preservation Practitioner Survey use substitute materials

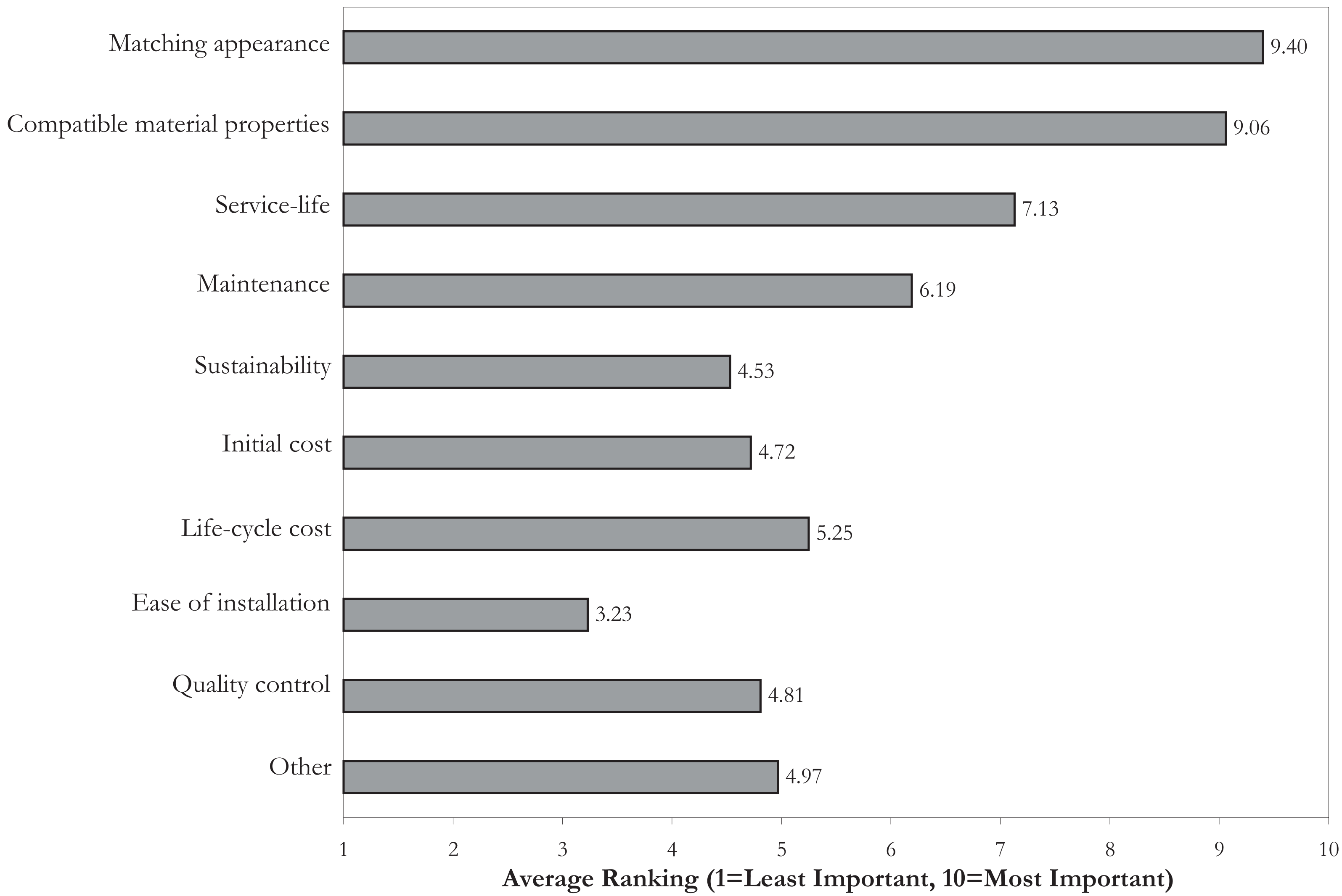
3. Which classes of substitute materials would you use? (Check all that apply)		
Answer Options	**Response Frequency**	**Response Count**
Traditional materials (stone, wood, terra cotta, etc.)	93.9%	232
Synthetic materials (fiberglass, epoxies, etc.)	67.6%	167
"Green" materials (wood/plastic composites, etc.)	61.5%	152
Other (please specify below)	15.8%	39
	answered question	247
	skipped question	3

Number	Other (please specify below)
1	something as close to the original as possible
2	I'd probably use any of them, but tend to favor the traditional materials & work with high-end clients who get that.
3	Completely dependent upon the situation, could be all of the above.
4	on a case by case basis, i might use a synthetic or green composite product.
5	One of the reasons I do not use sub materials is that the real thing is almost always available
6	I'd prefer this be a #1 (traditional materials), #2 (synthetic materials), and last resort #3 (other)
7	DEPENDS ON THE TYPE OF MATERIAL AND ITS COMPATIBILITY
8	concrete/cement-based materials are often the only option, particularly for masonry substution
9	cementitious repairs/replacements for stone
10	Sometimes a contrasting material will usefully highlight precisely what has been lost.
11	paints and finishes
12	better quality but similiar materials, ie copper rather than tin for finished architectual metal
13	As a general rule we would refrain from materials listed in choices 2 & 3 owing to their incompatiblilty and durability
14	My definition of green is different than yours.
15	Glass fiber reinforced concrete (GFRC) for terra cotta or stone
16	MEP are areas where we go as high tech as budget allows
17	Waxes and thremo-plastics
18	Would require testing and durability results
19	Depends upon application
20	cast stone
21	concrete, cast stone, cement-based composite patching materials
22	Difficult to say in general. It is all entirely dependant on the unique situation at hand.
23	Concrete, steel, engineered wood
24	see above comment
25	Work depend greatly of material and lack of avalibility.
26	precast concrete for terra cotta
27	Have used all of the substitute materials above - case by case basis depending on requirements.
28	Stone replacement repair products, such as JAHN
29	Steels (Galv. & SS), aluminum, brass, bronze, copper, Glass (cast & float)
30	Any appropriate material the use of which would meet the Secretary of Interior's guidelines.
31	Synthetics subject to track record and life-cycle cost.
32	green materials are very hard to choose once you get past the mfr hype
33	synthetic materials would have to be tested or used an a previous instance to showcase their durability and appearance on the historic fabric
34	Anything that would work in the absence of a better alternative.
35	Totally depends on the situation, client needs, etc.
36	finish techniques, application processes
37	I think I would consider--but not necessarily agree to use
38	Dependednt on the original and the issue at hand
39	Asphalt shingles

4. If you have worked on historic projects involving substitutes, do you use a similar set of criteria for every project or is each case unique?		
Answer Options	**Response Frequency**	**Response Count**
I use the same set of criteria for every project	13.2%	32
I use a unique set of criteria for each project	76.1%	185
I have not applied specific criteria	10.7%	26
answered question		**243**
skipped question		**7**

5. Of the following criteria, please rank those you consider essential from most to least important (do not rank non-essential criteria). Please note that this is a forced ranking, so you can mark only one criterion per column. If you have not applied criteria in practice, please skip this question.											
Answer Options	Most Important								Least Important	Rating Average	Response Count
Matching	113	88	19	6	5	3	2	3	1	1	9.40	232
Compatible material properties (both physical and chemical)	104	102	13	3	3	1	2	3	2	2	9.06	235
Service-life	6	15	94	47	22	13	9	3	3	2	7.13	214
Maintenance	2	5	30	65	45	39	11	9	5	0	6.19	211
Sustainability	1	5	8	26	37	23	35	24	30	15	4.53	204
Initial cost	0	3	16	27	27	34	38	34	26	4	4.72	209
Life-cycle cost	3	4	25	26	41	38	30	25	15	5	5.25	212
Ease of installation	0	2	3	5	10	21	38	53	47	31	3.23	210
Quality control	3	8	18	16	27	33	30	34	31	2	4.81	202
Other	5	3	5	2	2	3	3	1	2	12	4.97	38
(if "other" is selected, please specify below)												30
											answered question	243
											skipped question	7

Number	(if "other" is selected, please specify below)
1	Material History- how long has it been in use in similar installations? What is it's performance record?
2	need for sacrficial material
3	again this is very situation dependent
4	Original intent/functionality
5	Preservation of the building crafts & ongoing development of new crafts people
6	Location on Building
7	I would not use a flimsy-feeling material (i.e. sheet metal or fiberglass) in an area that can be touched.
8	No material last forever so maintenance is very important; what ever material you choose. The material which is maintenance free is not a good material at all.
9	From a client's perspective appearance and initial costs are their primary concerns, it can be very difficult to argue for life-cycle costs, performance, and compatibility, although these factors are key
10	It really depends on the speciifc project and the intent, SHOW NEW WORK CLEARLY or MAKE IT INVISI
11	Quality of replacement material
12	availability
13	whatever the circumstances dictate is the most important issue.
14	funds available
15	Do no harm to existing building especially if its a National Landmark
16	reversibility, non invasive/damaging
17	For modern materials: how long has the material been in use in the application I am considering
18	Operational requirements (see above)
19	This is a weird way of ranking. should be able to select any button
20	Structural adequacy
21	Many times each criteria should be of equal rank when judging the product.
22	Availability
23	Proven field performance of substitute material
24	Depends on "how historic" or demanding the situation is. Service life, and quality control are implied in other answers.
25	Client's and building's priority needs
26	I'm not sure what you mean by quality control?
27	Similar qualities to the original (i.e. concrete for cast-stone)
28	Patina, or matching appearance over time
29	see comments below
30	NA



Question 5. Essential criteria for the selection of substitute materials as reported in the Preservation Practitioner Survey

6. Do you utilize a specific method to evaluate substitute materials based on the criteria above? If so, what kind?		
Answer Options	**Response Frequency**	**Response Count**
No, I consider the criteria informally	67.9%	165
Yes, I use a checklist	6.6%	16
Yes, I use a decision matrix	11.9%	29
Yes, I use a decision tree	2.1%	5
Yes, I use another method	11.5%	28
If you use an alternate method, please specify here. Also, if you use a method with a published source, please specify the source.		43
	answered question	**243**
	skipped question	**7**

Number	If you use an alternate method, please specify here. Also, if you use a method with a published source, please specify the source.
1	Note- a matrix is used most often, but this will depend on the client and the review agencies that are involved- in the end this is a tool to inform others, less to help us make the decision.
2	I create criteria for each project. (Note: Consideration of substitute materials, except for wood species, sheet metal materials, and paint types, are very rare in our practice.)
3	This really depends on the project. Is it a rehab or a restoration? Is is a really great, one of a kind building or monument or whatever? What is the budget?
4	I look at each building on its own merits and do not systematize my approach - this would risk missing something!
5	Generally, we interview the owner once we have determined the parameters of the necessary repairs to understand their criteria (price, historical accuracy, service life, appearance etc) and then use their weighting to make recommendations. It is always the owner who selects the treatment based on these recommendations.
6	Discuss with Mfg. Reps and installing contractors
7	Material choices are based primarily on compatibility and durability. Evaluation is base my knowledge or research of the materials to be used.
8	Accelerated weathering to ASTM Standards
9	If the scope of a project is on the smaller side, I may consider the criteria more informally.
10	I also use a checklist and a decision matrix from time to time, depending on the nature of the material, situation and often, whether there are a number of options.
11	Evaluation based on type of project. What is budget of project. Is "museum quality" required? The importance of the building. Owner's objectives.
12	I consider compatibility with substrate/surroundings foremost--this must be and then I consider the other things: durability, appearance, reversibility, sustainability, LCA, etc.
13	Product material and possibly a Value Analysis.
14	I used my background in Material Physics and consult with my peers and other professionals
15	There is always a discussion between the owner, the engineer and the architect (assuming those professions are involved) and the criteria emerge during that process.
16	I also evaluate other examples.
17	A decision matrix sounds like something I would like to explore.
18	I use the methods outlined in the Park Service Preservation Briefs as well as Tech-Notes.
19	NA
20	I look at the material and its place in the overall project and budget, trying to be more holistic and dealing with all the compromises that need to be made on the project.
21	Performance on other sites and personal experience

22	The criteria for selection and testing depends in part on the nature of the project. For significant historic resources or sensitive projects, we are more likely to recommend or clients are more likely to request historically appropriate, traditional building materials installed by qualified craftspeople. That may include but not be limited to matching stone from the original quarry (dutchmen and replacement), historically-appropriate finishes (alkyd, casein, calcimine, gilding, glazes, etc.), wood species, etc. On the other side of the spectrum, rehabilitations which utilize federal investment tax credits, and specifically those which also employ low income housing tax credits, do not often have budgets which allow for high-end conservation. Those projects are more likely to employ substitute materials such as cementitious planking for deteriorated wood clapboards, milled-to match or aluminum windows to replace unsalvageable wood sash, cast stone to replace stone parapets, and molded fiberglass to replace deteriorated, non-bearing terra cotta in locations which cannot be easily accessed.
23	I try to weigh and balance the needs/desires of the owner with my best understanding of the Secretary of the Interior's Standards. I will ALWAYS opt for a substitute materials with "tried and true" performance.
24	laboratory testing
25	I reference the Secretary of the Interior's standards for rehabilitation.
26	Documentation, history of item, availability, matching appearance, durability
27	discussion with peers
28	All substitutes are reviewed by committee of architects and conservators.
29	use information based on past performance, similar applications, etc. I guess you would consider this "informal" but it isn't
30	I consider that finding a material as close to the original as possible - in appearance and performance - to be foremost. This is judged on a case-by-case basis. There is sometime only a very fine difference between ranking one criterion over another in th matrix above in practical application, because it is always a balance between suitability (appropriateness) for the work, cost and durability and factors such as sustainability can be an inherent factor of them, rather than being separate.
31	I use a qualified checklist of my own making, with extensive written statements reflecting research into each point, followed by a recommendation suited to project specifics.
32	NPS method called Value Analysis, Choosing by Advantages (CBA) methodology.
33	Each case is a bit different but we typically use some sort of a matrix.
34	Each instance has to be evaluated in a different way because of different circumstances. There is no one method other than thoroughly understanding all of the issues and using them to make an informed, educated decision.
35	Everything is project and client specific. Usually many options are necessary to cost out, design, weight the variables for in house decisions, client presentation, and public presentation
36	List available options for design solutions, rate appropriateness of solution, in duiscusiion with other heritage professional, propose to owner, AHJ
37	I use the Secretary of the Interior's Standards for the Treatment of Historic Properties and recommendation in the accompanying Guidelines
38	an decision matrix that is set up with the project in mind, not pulled out of a book.
39	Review substitute material for a number of criteria. Although there are similarities in the process each project is different.
40	The substitute material must have the same visual qualities as the original material and must behave (expansion/contraction) same.
41	Cost benifit analysis spreadsheet
42	Cost benifit analysis spreadsheet
43	formulate a method with the client

7. If you use substitute materials for historic projects, do you complete follow-up evaluations of in-situ performance?		
Answer Options	**Response Frequency**	**Response Count**
Yes, I usually complete a formal evaluation	14.5%	35
Yes, I usually complete a casual evaluation	74.7%	180
No	10.8%	26
If not, why?		36
	answered question	**241**
	skipped question	**9**

Numbe	If not, why?
1	Substitute materials have a history of performance prior to thier incorporation in to my projects
2	Well, I would guess that at least five years, an dprobably 10 years should be assumed for this follow-up - so that is pretty hard to accomplish.
3	The best evaluations of substitute materials come years after the project is complete. There is no money in projects to evaluate the job 5, 10 or more years down the road. Some preservationists pay close attention to older work, theirs and others.
4	Material performing in Lab may perform differently on site so very important to test and monitor on site before formal application.
5	Visual
6	not paid for this service
7	wherever possible. most project do not include follow up evaluations.
8	No, generally the contract is complete. There may be an opportunity to re-evaluate later, but generally you don't have the luxury to study work long term (unless you do it on a volunteer basis). I do not generally recommend substitute materials.
9	often no funds available
10	Follow-up evaluation is not part of my commissioned work for the project. If I am walking by a building on which I have worked, I typically do an informal review of how the work is holding up.
11	But this is often difficult due to the difficulties of accessing the exterior of a multi-storey building, which is the type of building I have most commonly worked on.
12	Work performed under my management has not been in place long enough to evaluate. That being said formal evaluations are part of protocol for repair work.
13	time = money, Typically a product or methodology that failed in the warranty period is revisited
14	I include the user and the maintenance staff.
15	N/A, but would complete a casual evaluation of a substitute material if I use one
16	No time or budget approved by the owner/client
17	Typically this is not my responsibility. I make recommendations but do not implement or monitor the repairs.
18	The products I use have been tested over time and work well in the conditions and situations tested.
19	Clients typically do not pay for monitoring or follow up.
20	Involvement in projects often does not equate with the amount of time that would be necessary to have the substitute material be weathered enough for evaluation.
21	NA
22	As a conservation consultant, my firm's role is often defined by the needs of the project team. Ideally, we are asked to see a project through from testing through planning, construction administration and final inspection, but that does not always happen. Sometimes, contracts last only through testing, survey, specifications and planning. It is unfortunate, but we do not always have the opportunity to review completed work.
23	I work for a SHPO so we inspect after work is done but after that checks are only done if there is a problem, if they do another project, or if we happen to be in the area and the project is visible from the street, we do drive-by inspections.

24	typically not part of the budget.
25	Casual evaluation due to time constraints.
26	Not in scope.
27	Have not had the chance to set up a protocol and act on it, other than "happen to be in the neighborhood" evaluations.
28	I am providing initial design services for Main Street design projects for many cities and projects each year. Only have time for follow-up if the project is grant-funded and requires post-evaluation.
29	My relationship to projects is as a reviewer for compliance with the Secretary's Standards. I do not have access to the properties beyond the initial project.
30	Each project is different, w/ different expectations and goals. Some get follow-up; others don't
31	As a government agency, the projects are not usually our own. In some instances we may have casual follow up when possible.
32	not sure what 'formal' is.
33	Hasn't been installed long enought to make a follow-up evaluation.
34	installations have varied maintenance cycles. Given that these are at different properties and different time lines, follow-up reviews are random and usually related to the demands of a new project with similar requirements.
35	we use substitute materials rarely, trying to maintain existing materials as benchmark. we have run into hazardous materials with historic situations that direct us to substitute materials.
36	This does not come up that much, usually wood, usually not involved after the work is done

8. Have you used substitute materials successfully?		
Answer Options	Response Frequency	Response Count
Yes	90.9%	219
No	9.1%	22
If so, which materials?		196
	answered question	241
	skipped question	9

Number	If so, which materials?
1	Steel lintels instead of wood lintels. LVL joists and beams instead of plain wood.
2	metals
3	FRP, GFRC, stone, mortar (as substitute for stone dutchman), cast aluminum (as substitute for terra cotta), laminate glass for float glass, aluminum for steel, etc
4	Oxysilanes have been particularly successful in my experience. Some epoxy consolidants have worked extremely well. There is a very wide range of materials which I have been able to use with great success. One more example would be structural steel in place of structural wood.
5	artificial slate, cast stone in lieu of brownstone, cast stone in lieu of sheet metal cornice
6	Composite woods, cast stone.
7	Mortar (lime-based) patch repairs on stone work
8	Synthetics
9	epoxy sealant for masonry crack
10	Limestone and/or glass fiber reinforced concrete as a substitute for terra cotta
11	red limestone in lieu of sandstone terra cotta in exterior application in lieu of original wood carved panel
12	In a situation where it was impractical to replace not-very-durable cast stucco ornament (BADLY deteriorated triglyphs & caps - forensics across the range needed even to figure out the original appearance) on ten stuccoed masonry chimneys, and the client was unwilling to bear the expense or time delay of replication in Indiana limestone (itself a more durable substitute) during a massive tile/leadcoted-copper reroofing of a beaux arts villa, we had the skilled metalworkers make up the detail in soldered LCC (already present all over the roof) to slide down over the rebuilt chimneys - it worked out very well, recreating a largely long-lost detail in an appropriate, if different material from the palette already on the house.
13	GFRC, Fiberglass, stone, cast stone
14	Cast stone as a substitute material for brownstone; cast stone as a substitute material for terra cotta; rot-resistant wood species in place of an species that is not rot-resistant; acrylic for linseed-oil based paint; fiberglass (FRP) cornice to recreate a missing wood cornice; aluminum replacement windows for wood windows in large rehabilitation project.
15	limestone for terra cotta
16	Reinforced fiberglass to replicate cast iron decoration. Reinforced Fiberglas to replicate decorative sheet metal.
17	Have had to use cast stone for stone; sometimes various types of wood for woods no longer available or not available in site's location
18	Vinyl clad windows, epoxy repairs of wood
19	Fiber-reinforced concrete with fiberglass reinforcing for traditional cast-in-place concrete with steel rebar.
20	Jahn patching mortars Cellular PVC trim and shutters
21	Type K and natural cement mortars as substitutes for lime mortars; cast replacements for terra cotta and stone elements
22	On certain projects, molded fiberglass makes a good substitute for pressed metal. In addition to being less expensive, it is easier to work, lighter to transport and can be easier to install.
23	Terracotta, stone repairs, mortar stains, prefinished metals, concealed waterproofing & drainage materials, materials with no less than 10-year proven service life
24	Concrete patching materials, exposed aggregate finish materials, replacement marble
25	cast stone in lieu of limestone

26	Define successfully. All of your criteria listed above are important and the individual job dictates the importance of each. In many (most) cases, the project would not get done if a substitution of something was not allowed. Money - which is time, material, labor, and skills is the single most important criteria. This may not be the way we practitioners want it, but that is the real world works. It is a very rare project that allows the practitioner virtual unlimited funds.
27	asphalt shingle roofs, bituthen (sp) roofing
28	moulding, light fixtures
29	What I have noticed more over the years is the complete lack of success of others' use of substitute materials.
30	So far, that is. Architectural pre-cast concrete for granite. Rubberized imitation slate. GFRP for wood and sheet metal. GFRC for cast iron. Closed-cell plastic for wood.
31	GFRC; new stone; windows; patching mortars; roof material (eg cement composition in lieu of slate)
32	GFRC, GFRP, Fiberglass (coated only), composite repairs for stone, veneers instead of full stone replacements. Probably others that I can't think of right now.
33	Enviroshake composite roofing
34	Cast stone as substitute for terra cotta
35	epoxies, hardiboard, trex, mostly composite woods
36	On earthen building in western himalayan region to protect against climate change and seismic vibrations.
37	Yes, with a "but". Among the terra cotta restoration work I have been involved with, invariably, the client does not want to extra expense or delay of in-kind replacement. I am highly unimpressed with the quality of "cast stone" (in reality, just molded concrete) that I have observed. Additionally, the quality of the replacement units tends to decline as a project progresses. When the last few weeks of a project are reached, it can be very difficult to convince the client that you are acting in his/her best interests by continually rejecting unacceptable cast stone units. I imagine this would be an issue for in-kind replacement materials as well, but my direct experience has been with cast stone. I have also used GFRC panels to replace areas of terra cotta, although the aesthetic results have been less than satisfactory.
38	fiberglass, alternate wood species, roofing sheet metal (Terne-coated)
39	Slate roof shingles to asbestos shingles. Now returning to slate. Wood shingles to architectural asphalt shingles. Now returning to wood on a few select structures.
40	Stone mortar patching, or cast stone patching with finishing pigments ; wood epoxies..both Abatron & Advanced Repair Technologies; Carbon Fiber Reinforcement in Wood Floor Joist;Wood species change from pine to oak, where excessive rot was occurring. and where concealed painted the wood.
41	patching, adhesive, coatings, metal alloys, hardware, lubricants, hardware assemblies, resins, alternative wood species, alternative stone sources, alternative stone types, cementitious compounds, synthetic materials
42	Hardie plank siding, Ecostar roofing, Fypon trim, EIPS, composition panel doors
43	faux plaster + decorative paint for guastavino tile. modern whitewash formula for traditional whitewash.
44	Cast stone for terra cotta. Cast stone for natural stone. Aluminum windows for wood windows. Fiberglass for cast iron.
45	Fiberglass for wood/metal cornices.
46	Design Cast 69 (a non-Portland cement); fiber glass reinforced kaolin modified Portland cement; caste Portland cement concrete; sandstone (one type for another); epoxy-modified cement (Conproco); Jahn mortars; Freedom Grey (for leaf coated copper and lead);non-historic paints (VOC compliant); and many others.
47	Composite patch materials in lieu of carving stone dutchman or fabricating new terra cotta units, concrete reinforced fiberglass in lieu of fabricating new cast iron (interior application)
48	masonry, caulking, flashings
49	Sandstone window sills. Wood trim. Metal cornice.
50	brownstone from a different, more durable quarry
51	Decking products, cementitious products, stone repair products, and sometimes metals and extruded plastics and foams where the detailing is at some distance

52	Alternative wood species, Alternative stone sources, Alternative "non-asbestos" products, Cast stone occasionally in lieu of natural stone, Occasionally metal clad windows in lieu of original wood windows.
53	Epoxies for wood, contemporary fasteners, polyurethane glues, etc, etc.
54	epoxy, catalyzed urethanes
55	fiberglass columns in place of wood, concrete cornice in place of stone
56	Sustainable woods for deteriorated woods that would have been unsustainable to replace in kind. Stainless steel for aluminum.
57	Cast stone, GFRC, fiberglass - these are typically used to replace sheet-metal or terra-cotta cornices.
58	Substitute stone for a different kind of stone, Cast stone replacement for Terra Cotta, GFRC replacement for stone, patching of existing terra cotta and stone with a patching mortar. Sealant installation at mortar joints instead of repointing.
59	Epoxies are perhaps my most widely used substitutes that I've used with much success in combination with the ability to retain maximum historic fabric. I've also substituted compatible or newer wood species for historic ones with success. For new work related to historic structures I use new wood composite materials for exterior applications due to their performance value as well as the fact that it is superior to most new woods. additionally, these products often match the appearance of the originals when detailed and installed correctly.
60	GFRC in lieu of the original terracotta (especially multi-colored terracotta). Cast stone (with subsequently applied patina/stain to effect weathering) in lieu of new brownstone. Fiberglass in lieu of copper/sheet metal cornice work (only where no load above).
61	Sandstone substituted with limestone Old growth lumber of any species substituted with standard lumber today Float glass substituted with annealed glass lead paint substituted with latex or acrylic
62	Mortars for masons putty Artificial stone (variety of types) for sandstone or granite Metal panel for stone Stainless steel for mild steel
63	gfrc, cast stone, Fiberglas, various metals
64	architectural metals, paints, roofing underlayments, roof cover materials, insulation, fasteners, lumber types, sealants, mortars, reformulated traditional materials etc.
65	synthetic wood trim, cast stone, fiberglass reproductions, fiber cement siding and roofing
66	Extira wood-resin composite for cornice and fascia trim. Fiberglass replicas of exterior plaster molds. Zinc coated stainless steel to replace lead coated tin for custom roofing and flashing.
67	As indicated in #3 above, we prefer to us traditional materials when substitutes are desired. We view most synethic materials as inappropriate in careful building conservation (physical incompatibility, limited duration, etc.). Instead we go to great lengths to use traditional albeit not identical materials when substitution is needed. (i.e. we might change specie of wood for greater longevity, or replace iron with stainless steel.)
68	Precast replacing sandstone - re: cost and difficulty of obtaining and installing matching material Fiberglass panels for terra cotta - re: cost and weight
69	when substituting painted assemblies, it's been generally successful to use a (completely) different material because the paint is the final aesthetic finish, not the substrate.
70	Epoxy consolidants and fillers, synthetic glazing compounds, modified lime mortars, latex paints
71	Epoxies, Wood
72	I don't have time to answer.
73	Fiberglass and GFRC for terra cotta
74	stone for terra cotta
75	Carbon fiber
76	Carrera Glass Tiles, Ceramic and Glazed Tiles, Window Glass, wood for many types of features, Bath Fixtures, Adobe, Brick, much more
77	Staying within materials we often decide on hard woods to replace soft woods in certain instances - generally related to the poor performance of today's pines.

78	Custom-molded fiberglass simulating painted exterior wood elements; Custom-molded fiberglass simulating painted exterior sheet metal elements; Custom-tinted epoxy simulating naturally-finished wood (for localized repair of existing material); Reinforced concrete simulating wood framing in direct contact with earth; Hydraulic lime or natural cement in place of hydrated lime in mortar and stucco mixes; Stainless steel in place of galvanized or tin-coated steel sheet metal in metal roof details, flashing, and rain conduction systems.
79	mostly wood species substitutions. And some epoxy use instead of wood patches, depends on the project.
80	cast stone and limestone for terracotta. fiberglass for terracotta. fiberglass for sheet metal cornices. veneer stone for full depth stone.
81	Your answers should have also included "sometimes." Some substitutes aren't and some like different forms of roofing might be OK. The general rule of thumb is that substitute materials tend to be problematic.
82	fiberglass
83	Countless Projects.. on interior and exterior stone & cementous works, metals,woods and polychrome coatings. waxes and thermo-plastics, Kevlar, carbon fiber, epoxies and resins. Silicates etc..
84	fiberglass, gfrc, gfrp, cast aluminum, cast stone,
85	#1. (frequently) Redwood or other quality outdoor wood on exterior exposed surfaces, rather than the original pine which has a very brief service life as grown today. #2. Custom molded 18' wide crown moldings to reproduce the original 100% lost interior plaster cornices
86	1. GFRC substitute for terra cotta cornice. 2. Fiber cement siding that mimics the wavy asbestos siding from the 1930s. OK for siding but see note below on roofing material.
87	Substitutes for wood and slate roofing materials
88	Lead-coated stainless flat seam roofing in lieu of historic multi-ply built-up roofing Lead coated copper or copper standing seam roofing in lieu of tin or tern Modern membrane in lieu of coal tar pitch (below grade) 4 inch stone veneer in lieu of historic full thickness stone Concrete in lieu of historic below-grade stone foundations Durable stone in lieu of historic non-durable stone Latex paint in lieu of historic oil-based paint. There are probably plenty more . . .
89	Epoxy and fiberglass in wood; lime in place of Portland for pointing, plastering; geosynthetic materials to augment surface and subsurface drainage; occasionally a consolidant; moderately hydraulic lime and microspheres for filling voids in adobe.
90	zinc-tin coated copper
91	Epoxy compounds for wood, metal, concrete repair.
92	Slate substituted for original tile roof
93	fiberglass; solid surface materials (Corian, etc.); plastic laminate; asphalt shingles; precast concrete;
94	GFRC for terra cotta cornice Lime based mortar for Portland cement Mahogony dutchman in historic white pine windows and doors
95	Window glazing (force protection issues) and introduction of another wood species (size matched original and with paint it was not noticeable).
96	Epoxy adhesives, Non-lead paint, coated steel rather than tin roofing, non-shrink grout
97	I have consistently used patching materials (Jahn etc) for stone substitutions , Fiberglass for stone spires and for wood cornices. Precast or cast stone for natural stone and terra cotta
98	Laminated veneer lumber (LVL), lime based mortars with some small amount of Portland cement, stainless steel (but only where buried in historic masonry)
99	Synthetic slates, Cast stone for terra cotta, PVC for particularly rot prone wood trim in difficult to access areas.
100	different wood species, fillers

101	Composites were used as trim molding material along eaves and look good and are holding up well. It was used where we knew the owner would not properly maintain the property.
102	Roofing tile, metal roofing
103	Cast stone as substitute for natural building stone, Zinc-tin coated copper as substitute for lead-coated copper, aluminum window frames as substitute for steel and bronze frames.
104	Jahn repair mortar for limestone/sandstone/granite.
105	Wood species
106	Jahn mortars for stone repair, epoxy
107	Epoxy products...West Systems
108	gfrc for plaster
109	GFRP, GFRC, Cast stone, Polymer concrete (epoxy, expanded polyurethane blended with graded minerals), Composite cement patches
110	On Guam our local hardwood, ifil, is a very slow growing, termite resistant hardwood. With the bombing devastation from US military during the liberation of Guam from the Japanese during
111	cast stone, epoxies, modern linoleums, stone, epdm
112	I have used composite wood materials, epoxy fillers, and cast stone products successfully on several historic projects.
113	Replicating a glazed finish on existing glazed brick. After several years, the inpainted material failed.
114	Though enough time has not elapsed for appropriate evaluation. Substitute materials in two cases were a Spanish cedar and an imported mahogany for an American 18th-century wood, and Hardy Plank for historic red oak wood siding.
115	Drywall for plaster, replacement masonry, replacement mortar, replacement plaster
116	GFRC for terra cotta; fiberglass for wood cornices and ornament; stainless steel for galvanized metal in cornices; cast stone for brick that we were unable to match.
117	New Terra cotta and mortar mixes using modern cements
118	Unreinforced cast stone to replace face-bedded sandstone. Cast fiberglass to replace cornice-level terra cotta on high-rises and skyscrapers. Composite repair materials for masonry. Cementitious planks (Hardi-Plank, Cem-plank) for rehabilitation of severely deteriorated clapboard houses.
119	GFRC for Limestone, precast concrete for terra cotta
120	PVC Trim in place of wood and metal, Cast Stone, Replacement brick
121	Stone patching and stone epoxy-type bonding materials.
122	Primarily for roofing, EPDM for flat roofs
123	cast stone, concrete, cement-based composite materials
124	Replacement stone when original material was performing poorly (i.e. could not be repaired or salvaged). Individual replacement of select terra cotta units with precast (cost-driven; locations not directly in public eye). Structural repairs to wood framing with new steel components (tie rods, etc.) Etc...
125	In dealing mainly with wood materials, I will sometimes substitute different wood species rather than a strict replacement in kind. The substitute material is clearly defined and often performs better. (read doesn't deteriorate)
126	Lead wool for mortar, latex paint for oil based
127	synthetic wood, plaster, stone
128	epoxy for repair of wood windows.
129	GFRC or cast stone replacements for poorly performing carved sandstone elements.
130	Castaluminum for cast iron GFRC for sheet metal cornice Stainless steel straps for mounting of copper cladding Aluminum cladding on wood windows in lieu of steel windows
131	Carbon fiber/epoxy matrix, fiberglass/epoxy matrix, thin shell replacement units (Polymer), cast stone, GFRC, sheet metal, engineered timber, steel, structural aluminum, reinforced concrete, wood epoxy repair, high strength steel post tensioning cables and anchorages,
132	Fiberglass for various materials (plaster, wood, terra cotta, stone) Cast stone for various materials (terra cotta, stone) Similar stone for replacement when original cannot be found Synthetic Slate for real slate

133	I have used silicon bronze with applied patina as a substitute for cast iron in a highly corrosive marine environment.
134	Replacement of Brownstone
135	Mainly relating to poor performance of originally installed material. One example is substitution of wood door sills with aluminum because of excessive water penetration into building even when properly maintained. Another would be the substitution of non original flat roofing material to lengthen expected life expectancy and limit fire risk at roof line during installation.
136	We sometimes approve substitute materials on non-primary facades, or, on a primary facade where the original material is missing. An example would be an aluminum cornice on a high rise where the original material was already missing.
137	too many to list
138	Chemically modified cast textile blocks for un-modified blocks which proved to be a maintenance nightmare.
139	Abatron for wood repairs; JAHN for masonry repairs; replacement "new" stone for no longer available "original" stone
140	glass, aluminum
141	"Z-brick" in place of brick in reconstructed chimney; block footings in place of brick/stone; TCS for terne in roofing.
142	epoxies, paints & finishes
143	FRP, cast stone, precast concrete
144	Cast stone in place of stone that is no longer commercially available. New manufactured terra cotta barrel tiles in place of historic, handmade terra cotta barrel tiles. Etc.
145	GFRC, Fiberglass, Polymer Modified Concrete
146	Stone, when original quarried material is not available, even in salvage or block form. Non corrosive materials for steel. Back up materials or on less visible facades-- more forgiving (budget-driven).
147	granite for marble fiberglass castings for high balusters rather than turned and painted wood cast aluminum for cast iron (old fence) cast cement for limestone new redwood for old growth hard pine (balustrade)
148	Fiberglass windows with aluminum "panning"; aluminum windows; fiber-cement siding; plastic repairs to stone (patching mortar); wood fillers for window repairs...
149	GFRC and Fiberglas replicas for Terra cotta
150	Abatron
151	Rarely recommend them and most projects don't get implemented.
152	GFRP and cast stone to replicate terra cotta, gfrc to replicate portland cement plaster
153	Precast for TC GFRC for TC Lime based patching mortar for limestone
154	Cathedral Stone stucco, ConServe epoxy for rotted wood
155	glass, stainless steel, aluminum, paints, composite wood products
156	But typically same type of basic material. Substituting steel for original wood structure has proven to be such a good idea, as the AIA building in DC has demonstrated~!
157	Alternative roofing materials.
158	cementitious castings and composites
159	GFRC and cast aluminum as a substitute for missing terra cotta cornices. Painted Wood and plastic as a substitute of ornamental interior cast iron.
160	fiberglass for wooden millwork outdoors, stone cornice
161	Pending; brick must be made to match a foreign type, probably Dutch. Historic Brick and New Brick do not fit the size or color; therefore, something new must be created.

162	Tropical or non-native hardwoods and softwoods to substitute for native softwoods. Non-local stone to substitute for local stone. Non-original (metal or asphalt) roof coverings to substitute for wood shingle roofing. Gypsum plaster to substitute for lime-sand-hair plaster. Titanium dioxide/alkyd paint or latex paint to substitute for non-available white lead and linseed oil paint. On a few occasions, for inaccessible locations, materials like cement-fiber board to substitute for softwood detailing.
163	Briarhill sandstone in place of Aquia sandstone
164	Jahn mortars
165	Substitute material: lead-coated copper Historic material: galvanized ferrous sheetmetal Substitute material: laminated glass Historic material: single or double-strength glass Substitute material: ice-and-water shield Historic material: tar paper Substitute material: oil-based primer and paint Historic material: lead-based white paint Substitute material: Type 316 stainless steel Historic material: ferrous metal anchors, wires, reinforcing, with and without pitch coating
166	Natural stone, Wood, Fiberglas, Artificial wood
167	Plastic
168	Fiber cement roofing for asbestos shingles, contemporary paints and coatings for original ones, modern mortars for original mixes
169	Composites for wood pieces such as balustrades.
170	Stone patching materials tend to discolor.
171	So far my clients have matched the original material, but it is almost always necessary to present alternate materials.
172	cast stone
173	GFRC, epoxy fillers
174	Jahn stone restoration mortars on outdoor situated limestones and marbles. Virginia Lime Works Natural Hydraulic Lime (NHL): A naturally occurring lime cement that is mixed with sand in specific ratios to produce a soft but durable restoration mortar. Virginia Lime Works: Mix N Go: A proprietary restoration mortar based on NHL and aggregates of sand and in the case of Mix N Go marble mortar, marble aggregate. AKEMI Akepox® 5010 epoxy: a water-white, two-part bulked epoxy adhesive that contains a UV stabilizer Stainless Steel, threaded rod, #304 or #316, either ¼" dia or ½" dia. Edison Coatings, Inc.: Custom System 45 restoration mortar. A two-part, latex and Portland cement based mortar mix. The Portland cement component is not more than 20% of the total aggregate. It is sometimes pigmented to achieve a better match with the original substrate. I have used this successfully on the repair of both sandstone and slate gravestones.
175	Where a marble cornice was being fractured by a truss which was differentially settling onto it, it was causing the marble to spall. The material in danger was removed and stored on site (a storage area beneath an historic stair) and a rubber moudling was cast, and faux painted to match. It took the compression and was undetectable. Another instance was where we used cast concrete "sandstone" where an exact sandstone could not be sourced.
176	Fypon to replace a missing balustrade on top of a 3-story building. Lamarite composite shingles. Cast stone for missing stone decorative pieces
177	Patching mortars for stone and concrete.
178	reproduced brick to match in all characteristics except that the reproduced bricks are high-fired and can be set in Portland mortars. Portland mortars can be manipulated to mimic type L mortars in appearance at a distance with some success. Acrylic exterior paint films in substitution for lead/oil paint films. More durable on exterior than current EPA approved oil exterior paint films. Mahogany for some exterior trim elements which will be painted as a substitute for heart pine. Heat treated/stressed glass in substitution of cylinder blown glass in post 1880 windows.

179	Cast materials (fiberglass, resinous, etc.) used in areas of limited weather exposure.
180	veneer plaster systems for flat plaster, low-VOC paint formulations, epoxy for repairs
181	Similar aged wood for species no longer available Different stucco mix and terra cotta roof tiles for different climate of moved historic structure Add structural steel to meet seismic code
182	Terra cotta substitutes of all kinds. Wood substitutes with painted finishes
183	wood, metal
184	Permeable epoxy wood patches Jahn mortars Specialized coatings for glazed terra cotta repairs
185	GFRC in lieu of stone or terra cotta Fiberglass in lieu of stone or terra cotta Fiberglass or GFRC in lieu of woodwork
186	Glass Fiber Reinforced Concrete in place of terra cotta and synthetic slate roofing
187	Ipe and dense mahogany in lieu of pine exposed to the elements for a replica domed skylight to limit differential movement relative to sealant/glazing material. Laminated (LVL) lumber where appropriate due to its greater strength/less deflection. Epoxy and fiberglas rods to reconstitute original exposed wood beam ends embedded in masonry. Steel angles, flitch plates, and channels when needed and hidden by finish materials. Salvaged architectural elements of appropriate period design when duplicating the original would be too expensive. Contemporary window sash tapes in lieu of replicating weights and pulleys in a new addition due to energy conservation. Stainless steel nails in lieu of steel nails. Abrasion-resistant Lucite in lieu of glass as a security measure.
188	GFRC, cast concrete, simulated slate.
189	GFRP, Fibrex wood products, Certain cast stone products (but definitely not most)
190	GFRC for sandstone; FRP for sandstone; FRP for terra cotta
191	Difficult to tell until more than 25 years has passed
192	Hardi-plank for wood siding; Fiberglas and poly decorative elements, columns
193	Aluminum half round gutters in place of galvanized half round gutters. Asphalt shingles in lieu of wood shingles. Rubberized slate shingles in lieu of real slate shingles. Fiberglass trim/casing in lieu of wood casing. Have also used cementitous siding in lieu of traditional siding (at previous employment) on tertiary facades and additions.
194	Freedom Grey for lead flashings Architectural Precast for specific stone replacement
195	Treated materials in moisture prone areas, where the material is not exposed; High performance windows that don't affect the character of the building
196	exterior work in white pine has been substituted with Spanish cedar, white cedar shingles with Alaskan yellow cedar shingles

9. Are you aware of any failures of substitute materials?		
Answer Options	Response Frequency	Response Count
Yes	61.9%	146
No	38.1%	90
If so, which materials? What went wrong? Do you think a more comprehensive selection method or list of criteria would have helped prevent the failure?		147
	answered question	236
	skipped question	14

Number	If so, which materials? What went wrong? Do you think a more comprehensive selection method or list of criteria would have helped prevent the failure?
1	The list is really enormous. Silicone water repellants come to mind immediately along with a number of masonry consolidants and patching materials. I think that any material can be used improperly, leading to premature failure. The problem is less the actual material than it is the application of that material.
2	fake slate, fiberglass not designed for exterior use. In both cases, accepting manufacturers assurances without field testing.
3	Typically the failure is accelerated aging that could only be determined after the material had been in a project for an extended period (10-15 years minimum)
4	GRP and GRC: see my publications on same in APT Bulletin and ASCHB Transactions, no
5	previous installation campaign utilized micro-cotta in lieu of terra cotta material. Surface finish deteriorated & substrate / body of replacement pieces deteriorated to the consistency of dust. Proper maintenance of mortar joints & surface monitoring. We replaced the micro-cotta pieces with new GFRC and used caulk joints for the differential in expansion/contraction of the original terra cotta. Some pieces of micro-cotta were reviewed for potentially installing a new terra glaze over - like Edison products, but the surface would not accept a new finish - mock-ups showed that the glaze easily peeled off.
6	Well, not in my own practice, but I see such failures all the time in buildings, and in some which I then have to correct. I see a GREAT many failures in brownstone patching, of all types - shoddy original workmanship, color fading, delamination, etc.. - this is a tough one, and the original stone is not technically of good quality, particularly when not bedded correctly.
7	Cast stone, concrete. Poor quality of replacement material, Poor workmanship
8	it is very important to have a history of service for materials being used as substitutes for historic materials. Life cycle testing should be performed at a minimum to gain insight into the possible long term performance of the materials.
9	In the 1970s, failure of stone patching materials that utilized stainless steel reinforcing wires (the SS corroded over time).
10	Many of our projects consist of replacing substitute materials that clients and other architects thought would work. Substitute materials should never be used unless you understand how the building works as a system.
11	Portland cement based mortars tend to fail when used in 19th century masonry construction.
12	Typically the reroofing of a historic building involves using substitute materials, often in the membrane or as the underlayment with a more "traditional" roof material. We have had failures using cured fluid-applied membranes, but I believe the problem would have occurred on new construction as well. Generally we have been fairly careful in selecting substitute materials and find that their failure rate is substantially less than the traditional systems they replaced. We are careful to match the physical and chemical properties of the original materials as closely as possible. We also stay away from evolving or untested technologies.
13	Composite material balustrades (different formulation from columns listed above). Touted as no paint finish required. Had problems with water absorption and failure of adhesives. Product was strongly pushed by client, so thorough vetting of material was not performed.

14	Precast concrete replacements for terra cotta elements weathered poorly over the medium term (10-20 years) resulting in poor aesthetics; color shift in fiberglass replacements for terra cotta. It is insufficient to evaluate appearance matching based on initial appearance - long term changes must be known and considered in the selection process.
15	In an effort to save costs, there have been projects where against our recommendations substitute materials have been used which ended up not being physically or chemically compatible with the original material. Sometimes when money is involved, there is nothing that can be said to persuade the contractor, architect or owner that the more expensive way is the correct way to go.
16	Patching materials. No. In many cases, the replacement material is intended to be sacrificial and will require periodic replacement over time.
17	Modern epoxies for monument repair. They look great initially, come back in 10-15 years. The UV also deteriorates them. Your criteria does not include considering the time that some of the substitutes have been marketed. For many building materials, you have to look longer than 5-10 years. The number of super great products in construction that are introduced is phenomenal. Very few of these new wonder products have lasted more than 5 or 10 years. Do not except manufacturers claims of just how durable these products are until you can see them in various climates for long periods of time. Modern construction excepts short lives. A true historic preservation project should be worked on with the idea in mind that this work should last at least as long as the original.
18	premade mortar mixes that are too hard for adjacent masonry substrates. unintended consequences of trapping moisture in buildings from artificial siding or poorly done insulation jobs.
19	flooring material
20	1. Masonry patch materials (i.e, that are not masonry) 2. Substitute mortar and plaster materials - anything that is not a match to what would have been used at the time of original construction - there is no excuse for substitution of real mortar and plaster. All of the materials are still readily available, they are cheap and easy to use. It is just aggressive salesmen & women from big companies and their PR departments wanting to make a buck that has caused these products to proliferate - it is endangering the future of the traditional masonry and plaster trades!!!!! 3. Fiberglass embellishments. 4. Various consolidants and "water proofers"
21	epoxy fillers - dramatic color changes; patching mortars - delamination and color changes all due to workmanship not the product;
22	I am aware of fiberglass failures from UV, but not on my projects (I have only used this material once, and it was well-coated). John Fidler wrote an article about this for the APT Bulletin, I believe in 2001.
23	GFRC as substitute for terra cotta. I've seen one instance where GFRC was installed like you would install terra cotta without any room for thermal expansion and contraction. GFRC failed in few years and we had to replace them with cast stone.
24	Generally the problem has had to do with the substitute materials being incompatible with the historic fabric.
25	Failures of substitute material are published extensively all over the world and definitely there should be a comprehensive STANDARD for SELECTING AND NOT SELECTING specific materials for certain repairs etc
26	Patching materials are a big offender; perhaps not the materials themselves but in installation. Many of the masonry and concrete patching materials are far too reliant on proper surface preparation, proper application of the product, proper weather conditions, and proper curing conditions. It has been my experience that although the Contractor will have one or two "certified" applicators on site, the workers installing the product day to day often have no experience or training. The weather is never ideal for patching, and manufacturer recommended curing procedures are never followed. None but the most talented workers (which are few and far between) can match color or texture of a natural building stone. Cracking, delamination, and shrinkage of patches are almost inevitable. My preference now is to replace masonry units rather than apply an inferior patch material. Again, I don't know that it is a problem with the materials per se, but in general complex installation requirements will negatively affect the final quality of the repairs.
27	early rubber slates - discoloration more comprehensive selection would not have helped as we used an early generation of the product
28	sometimes the stone patching materials...more so with the pigments allowing the patches to be visible where it wasn't supposed to be. I think a more thorough touch-up with breathable stains.

29	Failure can occur in all substitutions in ways that can include visual incongruity as well as in physical characteristics and long term performance. patching, adhesive, coatings, metal alloys, hardware, lubricants, hardware assemblies, resins, alternative wood species, alternative stone sources, alternative stone types, cementitious compounds, synthetic materials, yes if possible. I am assuming that this question relates to conditions I have observed not ones I have caused.
30	I think that long term test data on a substitute material as it is used in the historic assembly would be best. Building conditions vary dramatically and there is a lot of hearsay in the industry about how materials or assemblies perform. Dueling experts is a common problem.
31	Concrete and masonry patches that were inappropriately installed and need replacement.
32	What do you mean by failure? Nothing is perfect replacement. A color may fade, but the material is durable and compatible, unlike all other choices - is that a failure?
33	Composite patch material not installed properly has failed and sometimes discolors The Concrete reinforced fiberglass has been damaged by carts
34	quality control and understanding of original specs or nature of materials
35	Replacement of wood double hung windows with vinyl windows comes to mind... the newer windows do not last as long as they are a low-quality replacement.
36	Vinyl siding, is a cheap and cover-up product that when used tends to destroy original fabric and detail Vinyl products, most vinyls, tend to distort and become brittle over time Artificial stone and brick tends to let go from the substrate if in the event of moisture seeps behind Air barriers tend to solve the problem of air infiltration, but is not a substitute for a felt paper drain plane The use of substitute materials is a synonymous with a throw away society and yes a comprehensive selection method might help the industry to avoid the use of these materials, but there are strong lobbies including our petro industry that do not want to change. A change in the US oil production might very well be the key to controlling the synthetic industry.
37	Thermal glazing in lieu of single glazed windows with storm. The seals frequently fail and condensation occurs on the interior of the units. In this case, I do not think a comprehensive selection method or list of criteria would have helped prevent the failure.
38	All repairs, including those that utilize substitute materials, will eventually fail. For example, sections of a wooden column base that have rotted can be repaired with a premium wood epoxy. However the epoxy will not prevent future water damage - especially if the base is not properly designed or constructed to facilitate water drainage. Eventually the base will rot away and leave behind the epoxy repair. Reversible repair techniques and materials are ideal to facilitate future repairs.
39	Yes, many synthetics such as GFRC or GFGR have been substituted for stone - usually limestone or brownstone, and they have failed in both color retention and durability.
40	Cast stone performance versus original terra cotta. Cast stone is typically more porous than terra cotta and therefore performs differently than terra cotta, especially in wetting and drying. The Woolworth building is a good example of this. The utilization of a selection method or criteria list could be very helpful in assisting the preservation professional in selecting the right material for the job.
41	FRC
42	When epoxies, both fillers and consolidants, are not mixed and installed in the proper manner their bonding and structural capacities are compromised.
43	Cast stone in lieu of terracotta - hard to match the texture/surface glaze, absorbs water at different rates and therefore stands out in the rain, different expansion/contraction rates - we believe caused some micro-cracking in adjacent original terracotta pieces. Fiberglass in lieu of terracotta - again, hard to match the texture/surface glaze... and UV/weathering issues. Difficult to install in cases where the element is meant to support load from above (ie, in water tables, etc) - the shell itself cannot take any load and there was added unanticipated expense for extra reinforcing to support the loads above.
44	Generally systems based on polymers of some type; insufficient durability of the polymer system, or inadequate preparation of the substrate, or inadequate integration of the repair material with the substrate.
45	Lots of materials fail over time. Patches, castings, and poorly selected or detailed replacements can fail, regardless of the category of material selected on a particular project.

46	Many of the new engineered materials are necessarily experimental because we do not have the necessary long term in place experience with them especially as to weathering and compatibility with other construction components. Plastic and rubber based exterior materials have had color and dimensional stability problems. In location performance criteria is often different from testing experience. Improved selection methods and criteria would have to include long term use experience to expose limitations and problems that may result in failure. Many promotional efforts play to the desire to innovate, save money, and just curiosity without acknowledging or preparing the user for the risks.
47	dimensional instability of some synthetic materials as well as UV degradation. I have not personally had problems with fiber cement roof shingles but I know of others that have to the extent of complete removal and replacement.
48	Exterior elements replicated in fiberglass fade and polyester coating weathers away over a period of a decade. We used it several times in the 1970's, but are now reluctant to do so. Inappropriate application of epoxy coatings of epoxy on exterior wood leading to accelerated decay of substrate. Jahn patching of historic exterior brickwork fades and loses color match in just a couple of years.
49	Yes, stone patching failures, precast failures fiberglass - visual differentiation over time No, money and more time in the schedule would have helped. Costs are often driven by scaffolding. Longer lead time of stone and terra cotta push costs up sometimes more than materials. In that way, changes in product supply systems would sometimes make it more feasible to use original materials.
50	when the species, manufacturing process or cut of the substitution is a lesser quality than the original and fails prematurely.
51	Latex paints. EPA is requiring the use of latex paints because of low VOC emissions, yet latex paints have a short life span, trap moisture etc
52	Fiberglass - but it was a problem of design New wood, not well treated for outdoor use
53	I don't have time to answer well, but mostly it falls back to a problem of low skill in application/fabrication/installation.
54	Thin masonry veneers
55	See Above!
56	Multi-colored, custom-tinted epoxy for the repair of naturally-finished wood, is a substitute material that we have experimented with more recently. The matching of the color, grain, and growth rings has been remarkably successful on several projects. However, both epoxy and pigments have the potential to change color over time, especially with exposure to UV light. For this reason, we will be carefully monitoring the performance of these repairs over time, and will assess the use of different resin systems and pigments for their ability to withstand UV degradation. A substitute material that we have had some difficulty with is stainless steel sheet metal for use in roof and flashing details. Terne-coated stainless, which is often specified as a replacement for copper or galvanized sheet metal, does not accept solder with the same veracity as copper or galvanized steel. As a consequence, solder joints break more easily under forces of expansion and contraction. Aside from this, we have experienced no failure in the performance of any substitute material that we have used, to date.
57	Epoxy has failed before. There was some unseen moisture entering from above that ran down the window weight pocket and got under the sill. That moisture soaked up into the sill and the epoxy cracked and flaked off. I don't think a different selection method would have helped in this case.
58	early gfrc facade elements did not weather well. early facade stabilization anchors were to heavy and did not allow for thermal movement. patching mortars not breathable. waterproof coatings not breathable. patching mortar psi strength not equal to base material. the problem with evolving technology is that a list would be outdated quickly.
59	Rubber shakes which were designed to look like "real shakes." There was no rigidity to the product so it didn't want to lay flat.

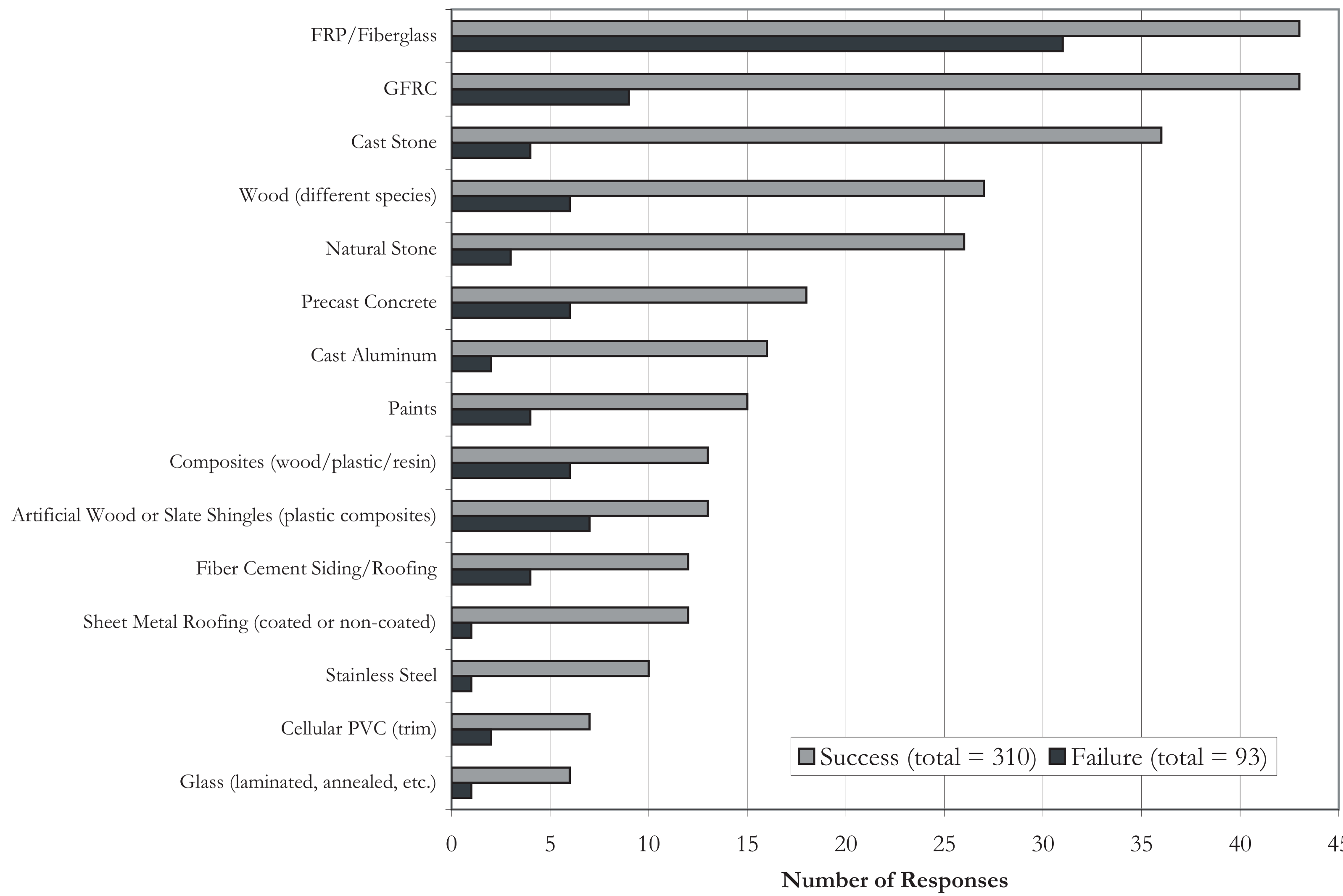
60	Fiberglass, resins and epoxies and coatings that were somehow imputed with qualities that made them immune to the laws of physics. ignorance of the products and improper mixing and application do to erroneous and otherwise poor judgments. lack of consultation with those more experienced in the field exposure to energies and chemicals and /or environments that degraded the stone, woods, metals, epoxies, coating and or resins improper preparation of surrounding surfaces. lack of engineering studies or stress analysis testing.
61	not on our projects.
62	Exterior fiberglass balusters which crack, have little strength, and fail to hold paint. Fake flooring painted to look like wood. Water leak ruined the floor as badly as if of wood. Replacement cost similar to wood, so why bother?? Epoxy patches on exposed wood trim and windows & w/sills. Crack loose at edges, water gets in, rest of wood rots.
63	1. The fiber cement roof shingles that mimicked the old asbestos hexagonal roof shingles were popular in the mid-1980s to early 1990s but did not hold up in field conditions in Florida. We eventually went to an architectural grade fiberglass shingle instead. This was an inherent failure of the material for that use and these products were discontinued for use on roofs.
64	The use of some wood substitute products (namely plywood and composites) for exterior siding and trim work does not hold up well when it is not maintained. As soon as the gutters clog and the water starts running against any of those products, they fail pretty quickly.
65	There is a long list of materials which have appeared on the market and disappeared a few years later leaving law suits behind: Masonite siding is one example. Koppers made an asphalt-based, multiply flashing tape (called, I believe, KMM) that was intended to substitute for metal flashing and counter flashing. It was a miserable failure and is now long gone but I still find it on a roof now and then. Most exposed elastomeric roofing systems have shorter lives than promised. (The life of the system is important, not the life of the membrane) The length of the list depends only on the length of one's memory, Latex paint over historic oil-based paint (massive pealing) (Criteria should have included similar use in past applications.) Artificial cementious shingles in lieu of historic slate (Breaking under impact loads) (Criteria should have included 40 yrs. min. of past use) EFIS, sometimes substituted for historic stucco, has suffered an inordinate number of failures. (Trapped moisture, rotting) (Criteria should have included expected life and training of applicators.) Many builders are now substituting poplar for historic durable woods for exterior trim. Poplar fails remarkably quickly.
66	Nothing lasts forever: wood will rot away from epoxies, geosynthetics can plug. The biggest failures I have see have all been with consolidants for stone, adobe and soft-fired brick.
67	plastics and composites which change appearance and degrade over time.
68	Product applications sometimes fail because the products are not installed according to instructions.
69	repointing with cement based mortar instead of original lime based mortar - which led to deterioration of the brick. A list of criteria may have not have prevented the failure in this case because a designer/preservation consultant was not involved and the decision was made by maintenance personnel
70	Not so much failures but deficiencies in performance and characteristics over time. For example, fiber glass tends to discolor over time. Precast concrete (imitation) stone is not as durable and ages differently than stone. Much depends on context.
71	Typically if you involve the manufacturers rep, a reputable one, you can avoid problems.
72	The failures were due to manufacturing defects. I have found that precast although a cheap alternative for natural stone is far inferior.
73	Artificial slate does not weather well (I have not used it but seen it used.) Hard Portland cement mortar is terrible with old brick (again, by observation, not my use.) Mild steel rusts like crazy in old masonry (same caution).
74	Not in my projects to date but I have seen FRP failures due to seams opening up across moldings and columns.
75	Polyurethane millwork substitutes shrink significantly. Some synthetic slates have not lived up to their life cycle projections.

76	Failures of metal roofing intended to emulate clay tile - metal coating failure and corrosion of base metal. Failure of repair mortar patches over natural building stone. In either case, an evaluation of the track record of the proposed substitute material in the intended application and environment would have indicated a high likelihood of failure.
77	certain castings can be problematic; fiberglass substitutes have had cracking problems or weathering problems; substitute problems more often have to do with durability rather than initial appearance - they often do not develop the same sort of patina over time as the real material and consequently reveal themselves as fakes.
78	If Jahn mortars are applied to horizontal (skyward-facing) surfaces, they will fail if exposed to water and freeze/thaw cycles.
79	I used epoxies in situations where compatibility was the issue.
80	Coal tar fillers for wood, epoxies for wood - the failures were the result of differential material properties, primarily shrinkage or moisture absorption.
81	Terra cotta substitutes typically fail visually within 5 to 10 years
82	Not that I've used
83	I would rather not like to leave the name of that product because I do believe that it was used in the wrong conditions.
84	Not necessarily used by me but aware of: Polymer concrete discolored Plastics CTE caused cracking (mine) Composite cement patches shrinkage cracks (mine) Composite ceramics structural failure
85	The failure of a cantilevered balcony built with the substitute Philippine mahogany was due to the owner's unapproved installation of an A/C condensing unit which constantly dripped water by the columns, leaving the wet wood as fiesta food for our tropical termites. The failure was not due to our material selection but due to owner's negligence.
86	I have witnessed wood epoxy failures on substrates subjected to significant sunlight-related thermal variation; specifically, epoxy fillers detaching from the substrate. My awareness of this phenomenon now informs my detailing wood repair and rehabilitation projects; and, indeed, this feedback is now incorporated into my criteria, albeit esoterically.
87	Fiberglass in exterior applications has been a dismal failure, as have plastic foam products such as Fypon. They cannot withstand degradation from UV and physical impacts.
88	Attempting to replicate historic, soft mortars sometimes fails, based on environmental conditions and not slaking the lime long enough. The end result is that the mortars weather quickly and flake away.
89	Spalling due to changes in moisture transport in new materials
90	Too soon to tell.
91	Staining and efflorescence of "brownstoning" and MIMIC for brownstone repair (this was an installation failure); delamination of "brownstoning"; separation of epoxy repairs from substrates due to differential thermal movement and poor surface prep; wear and excessive weathering of fiberglass elements under window a/c units. Failures would be prevented by more case studies showing how the material functioned in situ, rather than a list of criteria, since the failures occurred for different reasons.
92	Fiberglass for Terracotta - Cracking and Color loss plastics for wood - warpage Composite wood for wood - swelling and moisture absorption
93	Cast stone replacements for natural stone - deteriorated over time. Fiberglass replacements - finish oxidized and faded over time Epoxy matches failed due to differences in properties with original material Whether the selection criteria was formal or "seat-of-the-pants" informal, the largest problems are with lack of knowledge of aging properties of the substitute materials and failure to consider physical properties of replacement materials.
94	Composite patching materials (masonry) sometimes tend to flash or discolor soon after installation, despite best efforts at color-matching. Quality control is essential for cast stone and other replacement materials.
95	Fiberglass as a stand-in for terra cotta - finish deterioration. No.

96	Same answer as above, actually. I have seen many failures of stone patching materials, as well. In my experience the performance is manufacturer specific. In addition, it has much to do with the application of the product. The more manufacturer training and application steps required, the more likely your rate of failure with that product.
97	cement-based composite repairs - white efflorescence due to improper installation by mechanics
98	There are plenty of examples of failure of substitute materials or incorrect applications. Such as hard mortars in place of soft mortars, application of exterior sealers to brick masonry, vinyl windows for wooden windows.
99	Microcotta, FRP
100	We used a Type O mortar as a replacement for historic lime mortar; the material showed damage after 1 year service. The issue was freeze-thaw performance, on an historic retaining wall. In retrospect we should have used a mortar with better freezing performance.
101	Fiberglass can shred and discolor (decorative column capitals) but sometimes because of budget, schedule and lack of skilled craftsmen original material is impractical. It would be wonderful to have a comprehensive data base of substitute materials, their properties, relative costs, ease of installation, availability, life cycle, etc.
102	Replacement of historic wood windows with new wood windows. Modern wood is of poor quality. Construction techniques are also compromised due to quality of wood.
103	epoxies for stone patching, polyester resins for stone patching. No, this was a trial and error decision that there was no published info on its failure.
104	Epoxy log repairs
105	Epoxies, wood consolidants, composite trim materials.
106	JAHN. Suspected cause for failure was improper hydration of substrate.
107	Aluminum - paint finishes fail due to mfg. failure to remove mill scale prior to priming, damage in shipment and installation resulting in corrosion and NO to last question.
108	GRFC
109	paints- unknown cause of delamination no- what we need is performance information
110	There were problems with the older polymers but the manufacturers seem to have corrected them.
111	Wood... less durable species (poplar, finger-jointed) will not perform like better, more costly selection (cedar, cypress). In Australia it's huon pine that can't, and shouldn't, be exploited, therefore substitution must be inferior. Synthetics that don't weather like original: gfrc for terra cotta, stone. Benefit from life-cycle criteria considerations and better detailing... yes, improving on original details.
112	not necessarily, but certainly more first hand observations taken continuously over time about the weathering, durability, and/or failure of substitute materials would be helpful
113	Have heard of imitation slate that faded (but we know that some natural slates can fade as well). MDF generally won't last as long as real wood. Fiber-cement siding can get moisture damage if cut ends are not properly treated.
114	Not in my projects. However other architects told me of substituting caulk for traditional mortar and lead in masonry coping joints. Did not perform well and they went back to traditional method.
115	Generally discoloration on GFRP materials, typically due to UV degradation.
116	Cast in place polymer modified concrete for TC but this was conscious choice that balanced many factors - still likely to have made that choice at that time!
117	If epoxy repair is used on rotted wood, the cause of rot must be solved or rot will resume adjacent to the epoxy repair. BiGlass replacement of old window glass does not have adequate independent testing in my opinion to establish its thermal claim. Azek polyurethane exterior trim appears to have much more thermal movement that than the literature suggests, so I will not use it.
118	The fact is that every material will fail. It's more a matter of when and how and whether maintenance can prolong the serviceable life of the material. Different products perform differently under varied circumstances. Something that works well in Florida may fail after one harsh winter in Vermont. Finding a suitable replacement material can be difficult and a 'one-size-fits-all' approach is not going to work. A successful replacement is very dependent on the particulars of a project.

119	See note above. Also sine plastics have failed. Some coatings are not appropriate. Many substitute materials are rejected by state SHPOs on a routine basis, despite logical arguments for their use. We wanted to use substitute wood (resin synthetic) on an open train trellis that was over 30 feet away from anyone's eye. We wanted to use it because the client needed a more durable material than wood that would not need to be painted. AND we were replacing a wood trellis that was itself a 1980s replacement. The synthetic would match the historic paint color, and not fade or flake or peal. The substitute was rejected by the MD SHPO as not appropriate.
120	Alternative window materials, often fail in appearance. Some alternative roofing materials also fail to achieve the desired results in appearance.
121	I have heard of failures and discoloration of FRP used in an exposed location.
122	lots- a checklist of yes no maybe would be helpful.
123	Material compatibility problems.
124	fiberglass windows. could not withstand the same environmental exposure as original wood, paint and active maintenance
125	Masonry patching materials for stone and concrete. In my projects: application, workmanship. In brownstone patching projects, intrinsic flaw of trying to patch this material. Selection method and criteria would help make success possible. Specifications need to be well-informed, submittals to be rigorously checked, materials need to be available or substitutions will be forced on one. Manufacturer representatives need to be available for on-site review, instruction, and testing.
126	Not on my projects but I have noted the typical issues, such as resin materials not detailed properly or a natural stone weathering too differently from the adjacent original stone.
127	Material properties with regard to aging in service were not fully understood. No.
128	Vinyl-based substitute materials do not seem to be very durable.
129	Stone patching materials, replacement windows.
130	stucco
131	FRP ornamentation fades, warps, & finish wears off. Now only spec FRP for limited areas and to replicate painted metal.
132	I am aware of several materials which failed in use on historic gravemarkers: Milliput two part epoxy putty was used mixed with dyes sold by The Complete Sculptor in NY and inserted into very fine cracks. Unfortunately, nothing in the literature informed me that the dyes were fugitive in daylight, therefore the color matching faded. The putty however was useful for filling small cracks and with the right pigment might have been fine. As a result I had to paint the fills out to match using acrylic paints. In some areas of larger gap filling, the mixture of B72 and glass microballoons in solvent evaporated and left a gap which had to be filled again. (This will happen with a solvent based system) Also some milliput had been mixed with Liquitex paint in an effort to create a pigmented epoxy fill. However, this also shrank on drying, leaving a very small gap and had to be refilled. These were novel uses that worked in the lab but not in the more extreme climate of the outdoors. Restoration mortars must be carefully handled to avoid the formation of cracks. This involves following the instructions precisely and being aware of evaporation rates.
133	through papers presented at APT - eg, mortars, coatings etc More diagnostics of the compatibility and building science of the solution would have prevented a lot of the problems.
134	GFRC and GFRP in exterior applications will deteriorate in time - we are still learning. Synthetic materials respond differently to environmental changes than natural materials, and may be incompatible with surroundings.
135	EIFS; failure due to faulty materials and details, slate substitutes; warp from high heat and UV Wood replacement windows from a major manufacturer had to be replaced at 12 years; short-lived materials and detailing.
136	current paint formulations obviously do not have the longevity of earlier formulations, we've also experience some adherence issues in with coatings that relate to chemical composition and other issues, only other consequential problem is when contractors "substitute" "bond-o" for epoxy repair materials that we are not aware of
137	Plastic materials as substitutes for terra cotta that do not have color stability
138	wood, epoxies, stone, usually poor application/installation

139	Patching and coating of glazed terra cotta: lack of bond of patching mortars to substrate; unstable appearance in coatings. In general, the stability of the substitute material, and it's appearance over time, is a fundamental issue, since the substitute material may age differently than the original material.
140	Failure of substitute material to hold original color or texture of finish Failure of terra cotta used to substitute for stone generally because of ferrous anchor failure or poor joint detailing
141	If there are failures, I find it's due to improper preparation of the host material or in the manner of installation i.e. failure is due to the application or installation as opposed to the product itself. I find that it is important to read and follow the manufacturers recommendations.
142	None of my own material substitutions but know of others that have failed.
143	I try very hard to avoid recommending substitute materials, however, more easily accessible and understandable information on performance and physical/chemical compatibility between materials could help avoid bad decisions. We don't do a very good job at providing owners, developers, and architects with the information that could help them understand a recommendation that avoids substitute materials, while the manufacturers are very good at selling their products.
144	It depends how you define "failure". Only failures we've seen are color change in FRP.
145	Resins, Plastics, Aluminum, mortars, stone, fiberglass Virtually all materials have substitutes many of which are failures, this can be attributed to unsuitability of the material poor application amongst others A more comprehensive selection criteria would undoubtedly help, particularly for those that are not well versed in looking a risks as part of the process.
146	Poorly fabricated precast concrete
147	Substitute roofing products such as foam insulated roofing that failed quickly or became constant maintenance problems. Most substitute materials such as fiberglass in lieu of wood that were obvious substitutions



Questions 8 & 9. Substitute material successes and failures as reported in the Preservation Practitioner Survey

10. Any additional comments or questions?	
Answer Options	**Response Count**
	72
answered question	**72**
skipped question	**178**

Number	**Response Text**
1	I do think every case requires discretion and flexibility - building a building is always an exercise in chaos theory, and restoring a complex old one even more so...
2	Good luck!
3	If you asked more about our practice or type of client you might find some patterns that otherwise would not appear. Because most of our clients are institutions or historic sites, we rarely use substitute materials.
4	I'd be happy to send images of the several replications.
5	Historic Preservation has to be somewhat flexible. The substitution say of vinyl-clad windows of the same look can provide more energy efficient construction, more operable and usable conditions, while eliminating the need for non-historic and ugly storm windows. Historic preservation doesn't do anyone any good if it produces space that no one wants to live in. Bringing life and sustainability to buildings should be the priority. Preservation standards should guide change, not prevent change. In kind substitutions should always be the first choice, but professionals, commissions, and government agencies should be open to not just locking building in time, but actually making them better.
6	Excellent topic. I would definitely be interested in reading your final paper.
7	I did not rank your criteria, because of my comments listed above. Most important is that each project comes with its own set of priorities dictated by the owners, materials and crafts needed, time available, and money. You almost always have to at least consider substitutions for something. I would be interested in seeing the results of this survey to find out what other practitioners think.
8	I would suggest that lack of skilled labor is not a justification for using a substitute material, because we do have the skills to execute most traditional work in cost-effective ways in the US.
9	the drive for sustainability and LEED certification is wrecking havoc on original materials even more so than the deadly times of the 1970s.
10	Good luck!
11	Define criteria for your research and make a data base of failures and why specific materials failed.
12	Quality of both the replacement material and installation is truly key to making a substitute material successful. Especially with public projects were every little bit of the work must be bid out, it can be particularly difficult to weed-out contractors, sub-contractors, and manufacturers who continually return inferior results/products. Performance-based specifications are also insufficient to ensure quality for manufactured materials. Vigorous construction administration is probably the best insurance for proper installation/application of repair materials. It seems a little negative, but I hope this information is helpful. Good luck!
13	would love to see sample decision matrices or trees as per question 6, which my answer seems somewhat glib. we take this very seriously, but just don't have a formal method. I do have to say, that I believe the profession is far too conservative on substitute materials. I believe it is perfectly valid to be strict on NHLs and other extremely significant sites, but that for the vast majority of preservation projects, a substitute material - if cheaper, appropriate looking, and non-damaging to adjacent materials, allows preservation a greater impact on the resource, freeing $ for other areas of concern, which seems to me to be better for the resource and its surroundings.
14	The return to historic materials was based on authenticity to specific buildings and their function and use in regards to high visibility public structures.
15	For this study to be valuable you need to be more specific as to what constitutes substitute.
16	I generally try to avoid substitute materials - especially those that do not have a longer term track record. I have generally found that "new" materials can be have problems and I do not like the experimentation that can occur in the architecture industry regarding new or composite materials.
17	Interesting though somewhat constricted in face of the reality of practice.
18	Education

19	Our firm has only participated in museum quality restoration a few times. Among the rest of our clients, not very many want true restoration. Usually their desire for modern conveniences, especially air conditioning, force modifications. Many times budget constraints are a factor, and with most of my clients, the project needs to be done in phases or it won't get done at all. In my practice, we are faced with ensuring our clients' buildings will be self supporting, whether in business or government. To that end we generally have to introduce those nasty modern conveniences. While that frequently causes the lost of some artifacts, we make every effort to preserve the character of the historic structure. Every client and every structure are unique making a standardized checklist an impossibility. Good luck with your thesis.
20	Good luck
21	Good luck with your thesis!!!
22	Interesting research topic, difficult survey to answer in 5-10 minutes. Suggest that you might get some benefit from finding several professionals in your region and 'shadowing' them at their office when they are making this set of decisions on a project.
23	In most cases there is nothing that can replace the real thing however we need to consider alternatives as well.
24	We find more failures associated with the different repair and patching materials used with brick and stone masonry. Much of this is due to improper material selection and or installation. When replacing materials, even relatively poor quality replacement materials may have a maintenance free service life of over ten years making it hard to track. Many property owners do not keep appropriate long term records. Only at the highest levels of historical importance is good record keeping found. Many properties are run by management employees that care about correcting the issue at hand, often before the properties are considered to be of historic stature. Many years later they may remember that a substitute material was used but the manufacturer name may not be recorded or remembered. Some name brands, i.e. Fypon, are used generically for materials that may or may not be manufactured by Fypon. This obviously makes looking back on replacement materials and evaluating their performance difficult.
25	I think our technologically directed society places to great a reliance on "the most recent fix". A more profound understanding of historic building technology (both materials and craft techniques) is needed whenever intervention on an older structure is undertaken. With over 40 years of trial and error in the field my approach has become rather more conservative--striving to retrieve historic procedures when and where ever possible. In the long run this is proving to be a more successful approach. Beware of enthrallment with the latest revealed technological panacea!
26	Our approach to any building and any part of a building has a great deal to do with the stature of the building. Is it a National Historic Landmark? It is also has to do with the lesser of the evils. If a brownstone steeple is at risk or a life safety issue, than putting in precast stone instead of matching materials is hardly ideal, but it's better than loosing the steeple. Sometimes, we are just trying to protect something until a change in circumstances is possible. We always maintain original fabric as long as possible - often writing into the maintenance plan an expectation that a material may need to be replaced within a relatively short time, such as 10 years. I put matching appearance fairly high, but that is only after a decision to replace has been made. We try hard to help building owners appreciate and accept the aged appearance. I am deeply opposed to what I call "condo-preservation" which is the aggressive tidying up of old to make it look clean and new.
27	Every project is different and budgets are different. Most of all the philosophical approach to the project defines a lot of the issues. It is not something you can codify by a simple list. In some ways it is a feel and a balancing of all the issues added to time and material issues. I hope it helps.
28	This is a broad topic. We use substitute materials but staying within species is important....but that is our philosophy.
29	Your first question should also include "possibly". In most cases substitute materials are not appropriate, but it typically depends on the level of significance of the resource (national, state, local) as determined by the National Register criteria. If the building is of national significance or an NHL then the NPS would probably not consider a substitute material for a character defining feature or materials. An observation about your survey is that it doesn't address a significant number of upfront issues related to the decision tree such as the type of resource you're dealing with or how its historic significance (NR determined) factors in. If you aren't taking these into account you may find out a significant component of your survey is missing. Also, most of your questions don't allow for gray areas such as "Yes" or "No." Many decisions related to why a material might be used may not be this clear. Just a thought.
30	none

31	many product manufacturers over state the qualities of their products and those without true knowledge of the materials may specify a product that is under tested for an application. Installers or workers that are unaware of the specific needs for adherence to product specifications & environment at time of the work etc.
32	My attitude really is to stay with the original, especially if exposed to weather, except for using longer lasting wood for wood substitution.
33	Rigid foam molding on exterior - performed ok but lacked the crisp visual character of the sheet metal cornice that it replaced. Will not do that again.
34	I'm not sure what you mean by "maintenance" on your criteria list. Perhaps ease of maintenance? Cost of maintenance? Frequency of required maintenance? Required frequency is sometimes the most important criteria because each time a substitute material (say, roofing) fails it usually causes loss of some historic material. The chance of success of modern substitutes is very poor. The chief criteria we use when evaluating modern substitute materials is how long the material has been in use. If recently developed, we tend to reject a substitute because we have no true way to evaluate it under field conditions. It is difficult to develop a universal "rational" system for evaluation of substitutes because we need to consider the quality of the historic resource (somewhat subjective) and the owner's financial resources (usually unknown, even to the owner). Because of these and other subjective criteria, we usually "recommend" but the owner "selects." This makes educating the owner an important aspect (perhaps the most important aspect) of material selection. Good luck with your thesis! Good subject!
35	NA
36	The Client, NPS, SHPO, and local architectural review board can have a pretty substantial impact on what actually happens in the way of substitute materials. Your research hopefully will include decision makers at those levels who control legal and financial factors.
37	The biggest concern with synthetic materials for us is the unproven track record....we know what to expect of the original materials....and on a life cycle basis the original material is almost always the better choice. The only exception where first cost is not a factor is when the original material was a bad choice in the first place.
38	I restore wood windows (mainly double-hung). Any replacement is done with today's equivalent materials (meaning clear vertical grain fir with similar rings per inch, rather than salvaged fir of the same age as the original, etc.). I do not use substitute materials and tried to answer your questions as consistently as possible, but I believe the scope of my work is much more limited than that of your primary 'target.' I sometimes use epoxies to preserve elements that are deteriorating but expensive to replace (in kind). But strictly speaking that's not substituting.
39	While my bias in utilizing substitute materials is rooted in the appropriateness of the finished appearance, my checklist or criteria is ultimately client-driven. This is especially the case when Federal projects. I've found differing acceptance of substitute materials by the National Park Service to vary from one historic park to another, even within the same regional office. And in pursuit of historic tax credits, this acceptance is largely the call of the individual charged with deeming the proposed and finished work's appropriateness to the Secretary of the Interior's Guidelines. The matter of sustainability remains tricky in historic preservation. Because the field is primarily concerned with saving or re-using already existing construction, it is inherently 'sustainable'; however, it is possible for specific treatments stray wildly from such goals. In general, lead must be avoided; replacement materials of a sustainable nature must be encouraged, especially from a budgetary standpoint, and elimination of environmental hazard, be it mold on-site or dangerous material disposal are always considered.
40	Although appearance is important, we should remember that we should not be creating "Disneyland" replicas. We are at a point in our history when the "real thing" is rapidly disappearing. In the not-too-distant future, real wood will be a thing of the past - literally. We should take pains to preserve what we can for future generations. They will thank us.
41	Modern and sustainable materials are wonderful, and have many useful properties. Great care is needed to avoid unintended consequences when modern materials or practices (such as insulation) impact historic materials. Use of insulation and membranes such as air and vapor retarders and coatings can have a huge impact on aged materials. Most problems I have seen result from moisture control problems in exterior walls. In northern climates this can have disastrous consequences with freeze thaw cycles. It can be difficult to find remediation contractors for environmental issues such as lead paint or asbestos that protect aging substrates. Modern lighting can fade pigments and textiles.

42	I am a recent graduate and have been working for seven months in my position so I'm sure more substitute materials have been used than I am aware of. Our tax credit person deals with much more of the planning stages for projects and the decisions regarding substitute materials.
43	For Question 11: Category "Other" I am a chemist.
44	Be careful
45	It would be nice to have a set of criteria developed for replacement materials. I could use two components: one listing compatibility criteria (with limits also: for example, when choosing replacement masonry materials we know we want similar water vapor transmission, but how similar must it be?) and another more philosophically based component: when are replacement material acceptable, from a preservation theory standpoint? It would be useful to show such criteria to client to help them make the right decisions, instead of cost being their main criterion.
46	Good luck with your thesis!
47	In structural work, more often than not, one requires the use of substitute materials. The reason for the need for structural intervention is usually because the original has failed or is not adequate to carry required loading. Thus replacement in kind will not be sufficient. The Secretary's standards are not adequate in covering these structural issues that require replacement material.
48	The issue is not simple. For us, an important criteria is where on the building the material is located. If it is on the non-visible back facade it is much easier to meet the Secretary of Interior's Standards and use a substitute material. Or at the cornice level of a high-rise when the original cornice is missing.
49	This is a broad survey.
50	NA
51	Re question 2, I've considered all checked criteria at one time or another, always contingent on situation, never as a checklist, usually in hidden work. Ease of installation has mattered only when disrupting existing fabric is an issue.
52	In very demanding historic situations, I replaced failed original materials with in-kind materials even knowing that it's life was limited and would need replacing yet again (galvanized steel roof on a farm building or thin marble "glazing" that will only warp again). Less demanding situations, synthetic painted "wood" was OK where subjected to exposure. The closer to the eye (say below 30 feet up) or where it can be touched, authentic in-kind materials are more critical. Many times, life-cycle costing proved desirability of original (slate, terra cotta). But what if your Client just can't afford it, or would have to cut something else out of the job? I say to institutions, "If you can't afford doing it well, how can you afford doing it twice?" (cheap metal or shingle roofing instead of copper) In the end you may only be able to inform the client of the risks and limitations... they only have so much money to invest. I'd rather postpone the whole solution than spend good money on the wrong solution. Beware of substitutions with little or no track record (rubber "slate"). If you can't find a successful installation 25 years old, how can you confidently specify something intended to last 50 years or more?!
53	Recommend that APT and AIC and state historical commissions as well as any granting bodies require at least a one-year from completion, and a five year from completion report with photos, and possibly lab work, to inform potential users of actual performance of substitutes
54	Generally I feel that substitute materials are not a good idea. However most of my buildings are 1-3 stories so they are visually close to the sidewalk pedestrians and cannot successfully conceal the substitute on upper floors as taller buildings do in larger cities. Also most projects do not have contractors experienced with historic projects so quality control is a problem even with traditional materials.
55	Please send a copy of your survey results and any lists or matrices that you develop.
56	The National Park Service recently published new guidance on the use of substitute materials in rehabilitation projects. The new guidance can be found at http://www.nps.gov/history/hps/tps/tax/guidance.htm under the heading 'Modern requirements and new technologies and materials.' It may be helpful.
57	everything has its place based on project criteria
58	I think what you are doing is admirable but it is a big topic. I think that the way it is typically thought of the answers above work, but what about the substitution of latex paint for oil based paints? or drywall with a skim coat of plaster vs. traditional 3 coat plaster etc.? I would be happy to discuss it at some point on the phone.

59	In any preservation projects over which the New Hampshire Division of Historical Resources has involvement or control, we strive to use traditional and period-appropriate methods and materials. By statute, we must apply the Secretary of the Interior's Standards for the Treatment of Historic Properties. Increasingly, our preservation efforts involve bridges rather than buildings, and the Standards were written with buildings principally in mind. We therefore often find that application of the Secretary's Standards to bridges is difficult. Engineering structures often pose problems (including structural and safety concerns) that are not so pronounced in most buildings. Some of the issues of substitute materials must therefore be addressed differently in engineering structures than in buildings.
60	Question 2, above. Most of these are a matter of degree. Lead paint in the nursery. Float glass in high-rise double-hung windows. Sustainability: Of course one wouldn't replace an unsustainable material in good shape, though one might not replace it in kind if were deteriorated or missing (ivory curtain rings, say.)
61	It is very difficult to respond to these issues in survey format because every situation is unique. Different criteria should be used in different circumstances - how significant is the structure? how much money does the client have to work with? how much of an emergency is the situation in question? what quality of workmanship can you expect? etc.
62	Sorry, but this isn't even close to a "10-Minute" survey. Questions 5, 8, and 9 are by themselves fairly complex issues, where the words you use must be carefully defined to yield any usable information. In addition they each should take a significant amount of time to answer. As I'm sure you know, the professional circumstances of each practitioner will affect the answers s/he is able to give, and of course the answers to 2, 3, 5, and 7 will also vary according to the circumstances of the treatment location (original material, accessibility/visibility of treatment location, exposure to harmful conditions, etc.). I understand the effort you are making but I am not sure you'll get the information you're looking for by this survey. To the limited extent that I can, I'm happy to correspond with you further about this if you wish.
63	This is an important topic.
64	Will the results of this survey be available prior to completion of your thesis?
65	MEP systems are hell on renovations and qualified consultants in this area are hard to find.
66	The poor durability of modern painted wood materials in exterior use is creating a huge problem. There is very little old growth wood available for renovations. We have seen new wood members rot out in 4, 7 and 15 years.
67	I sense an interest in a question of sustainability.... This issue is in every decision I make and has been for decades but I do not see how to bring it into your survey.
68	A fundamental decision factor in selection of substitute materials is the location on the building with respect to the building environment, the user, and the environment. Visual character is an important aspect of building character. For example, the visual and tactile qualities of a material at the ground level within contact with people is usually more important than a material at the roof level where a change in material and finish is not as easy to detect.
69	1) Are you addressing the problems associated with replacement wood? In my experience, wood produced from "tree farms" is a poor substitute for old growth wood and yet it is not considered a substitute material. This new wood lacks the characteristics of old growth wood, thereby making it not only a substitute material but a poor substitute. 2) What about issues of sustainability globally? Have you come across any studies that address the issue of depletion of natural materials, such as stone and slate? 3) As preservationists, we don't do a very good job at providing owners, developers, and architects with the information that could help them understand a recommendation that avoids substitute materials, while the manufacturers are very good at selling their products.
70	We've really only considered substitute materials when they can be installed in such locations that are not readily visible to the lay person as a substitute material. As you'll note, most are roof related, thus installed up high. Though not sure asphalt is truly considered a substitute material any longer since it is ubiquitous and just about universally accepted.
71	This is a difficult and timely topic, and a great subject for a thesis. It's an issue that I struggle with every day. Good luck with your thesis and your career.
72	Fabrication and assembly is as important as the actual original materials and substitute materials. Climate and interior conditions that may change over the life cycle for the building or material most be considered. Also is the substitute material if the same quality as the original material. Is it really the same for example white pine, wrought iron and stone can have the same name but are considerably different from the original source to today's source. And lets not forget the "Green" in green.

11. What is your area of expertise? (Choose all that apply)		
Answer Options	**Response Frequency**	**Response Count**
Archaeologist	2.0%	5
Architect	50.6%	126
Architectural Historian	16.5%	41
Building Consultant	14.5%	36
Building Service Manager	1.6%	4
Conservator	20.1%	50
Consultant	19.7%	49
Contractor	13.3%	33
Crafts/Trades	9.6%	24
Cultural Historian	3.2%	8
Educator	6.0%	15
Engineer	12.0%	30
Geologist	0.4%	1
Historian	2.4%	6
Historic Preservation Consultant	40.6%	101
Historic Site Administrator	2.8%	7
Interior Designer	0.8%	2
Landscape Architect	0.4%	1
Landscape Consultant	0.0%	0
Librarian	0.4%	1
Manufacturer	2.4%	6
Museum Director	0.4%	1
Museum Staff	2.0%	5
Other	3.6%	9
Planner	1.2%	3
Project Manager	19.3%	48
Publisher	0.4%	1
Student	1.2%	3
Supplier	0.4%	1
	answered question	249
	skipped question	1

12. Optional Contact Information

Name	Title	Company
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Elwin Robison		Wiss, Janney, Elstner
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Whitney Powers	President	Studio A, Inc.

APPENDIX C – INVENTORY OF CONSIDERATIONS & METHOD FLOWCHART

This appendix includes:

- Inventory of Considerations for the Evaluation and Selection of Substitute Materials
- Flowchart of Suggested Method for the Evaluation and Selection of Substitute Materials

Preservation Philosophy

Significance of Building	Amount & Location of Substitute	Proposed Use
Significance of Element or Material	Physical Condition of Original	Goal of Intervention

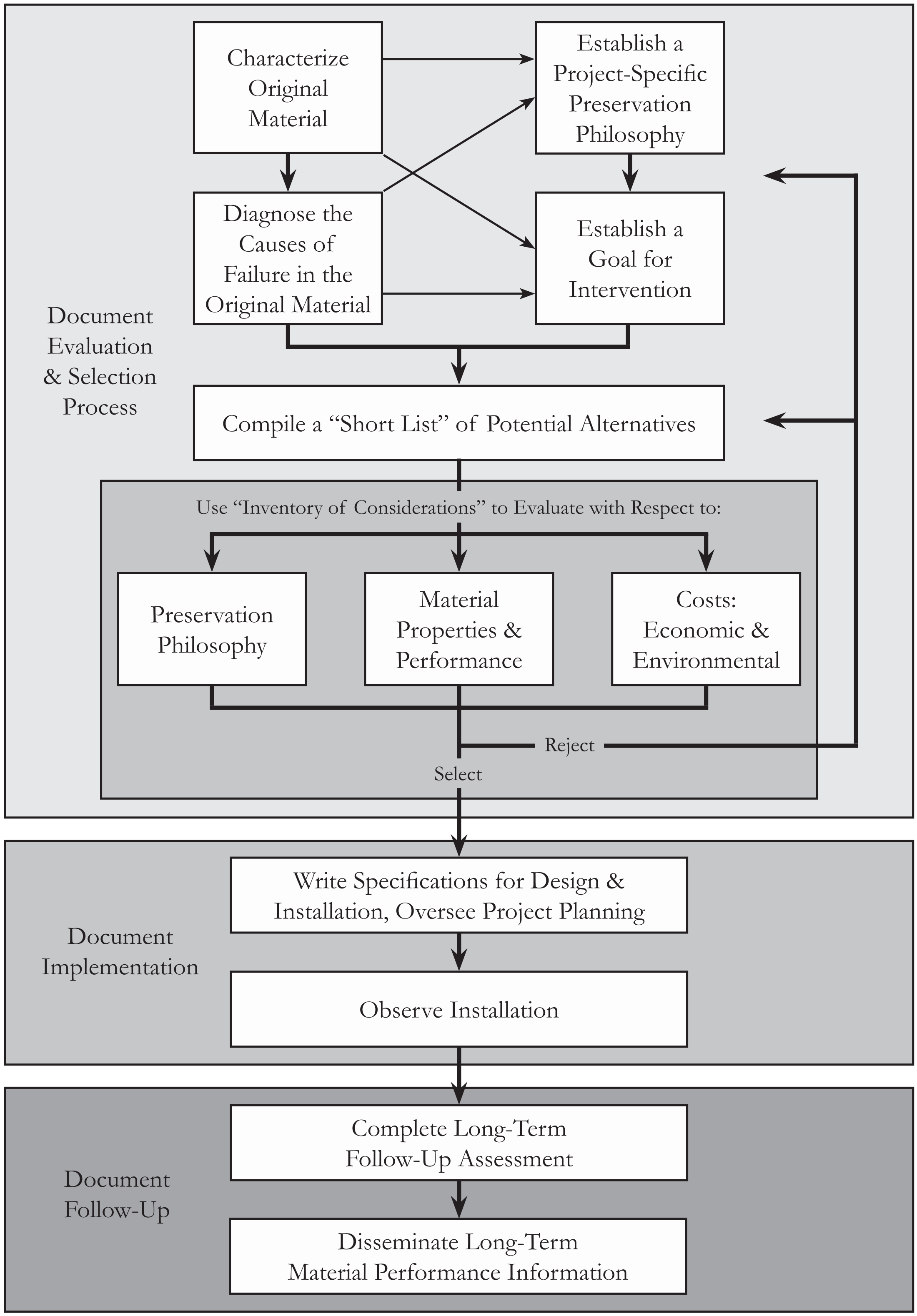
Material Properties & Performance

- Material Properties
  - Aesthetic Properties
    - Color
    - Texture
    - Finish
    - Reflectivity
    - Size & Shape
    - Detailing
    - Patina, Corrosion & UV Degradation
    - Static Charge & Response to Pollutants
  - Physical, Mechanical, Thermal & Chemical Properties
    - Weight
    - Strength
    - Flexibility
    - Hardness
    - Creep
    - Curing or Drying Shrinkage
    - Porosity & Permeability
    - Hygroscopic Expansion
    - Vapor Permeability
    - Thermal Expansion
    - Other Thermal Properties
    - Fire Resistance
    - Corrosion Resistance
    - Galvanic Corrosion
    - UV Degradation
    - Inertness
    - Rot & Fungal Resistance
    - Toxicity
- Design & Detailing
  - Knowledge Base
  - Attachment & Joining
  - Invasiveness or Reversibility
  - Relative Integration or Isolation
- Fabrication & Installation
  - Fabricator Experience
  - Material Fabrication Properties
  - Installer Experience
  - Transportation Requirements
- Functionality
  - Structural Serviceability
  - Fire Safety
  - Habitability
  - Maintainability
  - Code Acceptability
- Durability
  - Long-Term Performance Data
  - Weathering Prediction
  - Performance Standards
  - Testing Methods

Costs: Economic & Environmental

- Economics
  - Raw Material Cost
  - Fabrication or Manufacturing Cost
  - Transportation Cost
  - Installation Cost
  - Lead-Time
  - Operation & Maintenance Costs
  - Potential Repair Costs
- Environmental Sustainability
  - Durability
  - Energy Efficiency
  - Future Recyclability
  - Maintainability
  - Recycled Content
  - Embodied Energy
  - Local or Regional Materials
  - Hazardous Natural Chemicals
  - Synthetic Chemicals

Inventory of Considerations for Evaluation & Selection of Substitute Materials



Suggested Method for the Evaluation & Selection of Substitute Materials

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