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Vaults Speak: A History and Material Analysis of Guastavino Akoustolith Tile

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Abstract
Since antiquity, reverberation has been linked to monumental interiors. Roman temples and medieval Gothic cathedrals produced a recognizable soundscape that was considered as natural as gravity. Vaults, domes, pendentives, and other large concave surfaces produced reverberant spaces that enriched the medieval Latin chant but was detrimental to the clarity of the modern Protestant sermon. At the turn of the twentieth-century, Wallace Clement Sabine and Rafael Guastavino Jr. responded to a demand to quiet Protestant cathedrals. Together, they patented two acoustical products, a clay-based tile named “Rumford” and an artificial stone named “Akoustolith.” These were structural, imitated traditional masonry, and absorbed the mid and high pitches. They were bonded as a soffit to the vaults and domes of interlocking structural clay tiles. The Akoustolith was not only specified in religious buildings, but enjoyed success in secular buildings: banks, auditoriums, libraries, museums, classrooms, courthouses, laboratories, gymnasiums, swimming pools, and railroad stations. This thesis broadens the history of the origins, development, and application of Akoustolith tile. It presents a material analysis on the following properties: water absorption, particle size distribution, compressive strength, and mineralogical composition. This thesis demonstrates that the Akoustolith tile presented variability in composition across commissions and within individual tiles, modifying its acoustical behavior by changing particle size, angularity, sorting, and binder-to-aggregate ratio. It presents evidence that the degree of sorting is inversely correlated with compressive strength. This informs the hypothesis that sorting is proportional to sound absorption.

Keywords
Guastavino, acoustical tile, reverberation, porosity, artificial stone

Disciplines
Historic Preservation and Conservation

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VAULTS SPEAK: A HISTORY AND MATERIAL ANALYSIS OF GUASTAVINO AKOUSTOLITH TILE

José Carlos Hernández Cruz

A THESIS

in

Historic Preservation

Presented to the Faculties of the University of Pennsylvania
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En memoria de mamá y papá.
Preface

When one thinks of Guastavino vaults, what often comes to mind are ceramic tiles arranged in a signature herringbone pattern in vaults and domes of monumental public palaces: railroad stations, libraries, museum galleries, cathedrals, and auditoriums. The contributions of the R. Guastavino Company on architectural acoustics remained largely unnoticed until the publication of a 1999 paper in the *APT Bulletin* by Richard Pounds, Daniel Raichel, and Martin Weaver.

During my undergraduate studies at NYU, I remember visiting the Met Cloisters in Fort Tryon Park as part of a "Sketch & Mingle" session organized by the NYU Urban Design & Architecture Society. What struck the group’s attention the most was hearing the clarity of our voices in the Gothic Chapel. A few years later, in the summer of 2021, I experienced the acoustics at Princeton University Chapel as part of a summer internship at Historic Building Architects, where I was helping photograph the conditions of the vaulted ceiling. My exposure to these two interiors furnished with Guastavino acoustical tile went unnoticed.

The excellent scholarship that has been written on Akoustolith tile had addressed its use in cathedrals and temples, discussing issues of aesthetics, reverberation, and treatments to seal it. This thesis elaborates on its material properties and sheds light on its use in lesser known building typologies. I hope this effort opens new avenues of research for future scholars to build on.
# Contents

Acknowledgements ................................................................. ii
Dedication ................................................................... v
Preface ........................................................................ vi

1 Introduction ........................................................................ 1
  1.1 Historical Background ................................................. 2
  1.2 The Conservation Problem ........................................... 4
  1.3 Central Questions ...................................................... 4
  1.4 Limitations and delimitations ....................................... 4
  1.5 Methodology ............................................................ 6
    1.5.1 Archival Research ................................................ 6
    1.5.2 Data Collection ................................................... 6
    1.5.3 Material Analysis and Performance Testing .......... 7
    1.5.4 Petrographic Analysis ......................................... 7

2 Literature Review ................................................................ 8
  2.1 Principles of Architectural Acoustics ............................. 8
  2.2 Guastavino Tile Vaulting ............................................. 10
    2.2.1 Rumford and Akoustolith Tile ............................. 11
  2.3 Treating the Akoustolith ............................................. 11
    2.3.1 Riverside Church ................................................ 12
    2.3.2 St. Thomas Church ............................................. 12
    2.3.3 National Cathedral ............................................ 13
    2.3.4 Cathedral of St. John the Divine ......................... 13
    2.3.5 Duke University Chapel .................................... 14
    2.3.6 Cathedral of St. Philip ....................................... 14
    2.3.7 National Academy of Sciences ......................... 15

3 Origins and Development ................................................ 16
  3.1 Solving a Centuries Old Problem ................................. 16
  3.2 La Cerámica ............................................................ 18
  3.3 Scientist and Ceramic Worker ..................................... 20
  3.4 Rumford Tile .......................................................... 20
  3.5 Akoustolith Tile ...................................................... 22
  3.6 Akoustolith Plaster ................................................... 23
  3.7 Castacoustics and Plastacoustics ................................. 24
3.8 Quiet and Dignified for Sale ................................................. 26
3.9 Competition ................................................................. 30
3.10 Data and Standardization ............................................... 31
3.11 Application ................................................................. 32

4 Cathedrals, Churches and Temples ........................................ 35
4.1 Cathedral of St. John the Divine ......................................... 35
4.2 Washington National Cathedral ......................................... 36
4.3 Church of Notre Dame ..................................................... 38
4.4 Temple Emanu-El ........................................................... 39

5 Civic and Institutional Projects ............................................. 42
5.1 Triumvirate: Bertram Goodhue, Rafael Guastavino, and Hildreth Meière ................................................. 42
5.2 National Academy of Sciences ............................................ 43
5.3 Nebraska State Capitol ..................................................... 45
  5.3.1 Great Hall .............................................................. 46
  5.3.2 Memorial Hall ......................................................... 46
5.4 Egyptian Wing, University of Pennsylvania Museum ............... 48
5.5 New Delhi Legislative Chamber .......................................... 49

6 Commercial Projects .......................................................... 52
6.1 Iron and Steel ............................................................... 52
6.2 Salmon Tower .............................................................. 53
6.3 Federal Reserve Bank of New York ...................................... 54
6.4 Natatorium, Smith College .............................................. 54
6.5 Offices and Schools ....................................................... 56
6.6 Hospitals ..................................................................... 57

7 Infrastructure ....................................................................... 59
7.1 Buffalo Central Terminal ................................................... 59
7.2 79th Street Rotunda ......................................................... 62
7.3 Pedestrian Underpass ....................................................... 64
7.4 Ventilation Units, Industrial Flues, and Military Facilities .......... 64
7.5 Airplane Hangars ............................................................. 67
7.6 The End of an Era ........................................................... 67

8 Petrified Sponges: Material Analysis ....................................... 68
8.1 Definition ........................................................................ 68
  8.1.1 Akoustolith Tile ........................................................ 72
  8.1.2 Akoustolith Plaster ..................................................... 75
8.2 Sample Collection ........................................................... 77
8.3 Water Absorption by Complete Immersion ......................... 79
  8.3.1 Purpose .................................................................. 79
  8.3.2 Specimen Preparation ................................................. 79
  8.3.3 Methods ................................................................. 79
8.4 Gravimetric Analysis and Particle Size Distribution ............... 80
A.1.12 International Commissions ........................................... 121
B.2 List of Advertisements ..................................................... 123
C.3 Specimen Profiles .......................................................... 135
    C.3.1 Buffalo Central Terminal ........................................... 135
    C.3.2 Eglise de Notre Dame .............................................. 136
    C.3.3 Cathedral of St. John the Divine ............................... 140
    C.3.4 Nazareth Hall, University of Northwestern ................. 143
    C.3.5 Nebraska State Capitol .......................................... 147
    C.3.6 Washington National Cathedral ............................... 150
D.4 Description of Petrofabrics of Akoustolith Tiles ............... 155
    D.4.1 Microstructure ................................................... 155
    D.4.2 Groundmass ..................................................... 156
E.5 Compressive strength data ............................................. 159
F.6 Sound absorption coefficient of different materials ........... 162
G.7 Drawings for other commissions ..................................... 163
# List of Figures

<table>
<thead>
<tr>
<th>Figure</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.1</td>
<td>Diagram of Guastavino assembly showing location of acoustical tile as soffit (author)</td>
<td>3</td>
</tr>
<tr>
<td>3.1</td>
<td>1918 Map of Woburn (Sanborn Map Company, May, 1918)</td>
<td>19</td>
</tr>
<tr>
<td>3.2</td>
<td>Rumford tile at B’Nai Jeshurun Temple <em>(The Brickbuilder, 24, no. 1 306)</em></td>
<td>21</td>
</tr>
<tr>
<td>3.3</td>
<td>Sound absorption of Rumford and Akoustolith tile (Guastavino/Collins Collection)</td>
<td>22</td>
</tr>
<tr>
<td>3.4</td>
<td>A classical molding in <em>Castacoustics</em> (Guastavino/Collins Collection,)</td>
<td>24</td>
</tr>
<tr>
<td>3.5</td>
<td>Section through a decorative rib, Tiferith Temple (Guastavino/Collins Collection)</td>
<td>25</td>
</tr>
<tr>
<td>3.6</td>
<td>Castacoustics used in a classical impost (Guastavino/Collins Collection)</td>
<td>26</td>
</tr>
<tr>
<td>3.7</td>
<td>Akoustolith Sales Manual (Guastavino/Collins Collection)</td>
<td>28</td>
</tr>
<tr>
<td>3.8</td>
<td>Relationship between pitch and sound absorption on different grades of Akoustolith tile and plaster. Source: Scatter data points from 1926 test by the U.S. Bureau of Standards. Trendlines and graph by the author.</td>
<td>33</td>
</tr>
<tr>
<td>3.9</td>
<td>Histogram of number of commissions with Akoustolith by year (Illustration by author)</td>
<td>34</td>
</tr>
<tr>
<td>4.1</td>
<td>Section through south transept of the National Cathedral showing locations with Akoustolith tile. (Washington National Cathedral Construction Archives Collection, National Building Museum Collection.)</td>
<td>37</td>
</tr>
<tr>
<td>4.2</td>
<td>Drawing of a pendentive showing the location of Akoustolith tile at the Church of Notre Dame (Guastavino/Collins Collection)</td>
<td>39</td>
</tr>
<tr>
<td>4.3</td>
<td>Detail of Akoustolith tile in metal strip jointing (Guastavino/Collins Collection)</td>
<td>40</td>
</tr>
<tr>
<td>4.4</td>
<td>Half elevation of the sanctuary arch at Temple Emanu-El with Akoustolith tiles (magenta) in metal strip jointing. Source: Guastavino/Collins Collection.</td>
<td>41</td>
</tr>
<tr>
<td>5.1</td>
<td>Half-section of dome at Great Hall, National Academy of Sciences. (Guastavino/Collins Collection)</td>
<td>44</td>
</tr>
<tr>
<td>5.2</td>
<td>Advertisement showing north vestibule dome, Nebraska State Capitol. (Guastavino/Collins Collection)</td>
<td>46</td>
</tr>
<tr>
<td>5.3</td>
<td>Section through dome of Memorial Hall, Nebraska State Capitol (Guastavino/Collins Collection)</td>
<td>47</td>
</tr>
<tr>
<td>5.4</td>
<td>Section through roof of the Egyptian Wing, Penn Museum (Guastavino/Collins Collection)</td>
<td>48</td>
</tr>
</tbody>
</table>
5.5 Section through the Assembly Chamber of the Legislative Building, New Delhi, with proposed Akoustolith tile (magenta). Source: Hope Bagenal and Alex Wood, Planning for Good Acoustics (London: Methuen Co Ltd, 1931). Original drawing in the Bagenal Family Archives. 50

6.1 Detail drawings of vestibule at Salmon Tower (Advertisement in Sweet's Architectural Catalogue (1939)). 53


6.3 Akoustolith tile applied underneath a slab and laid in the herringbone pattern. 56


6.5 Difference in sound absorption between Akoustolith stone (Line 1), Plastacoustics at 1/4" thick (Line 2) and Plastacoustics at 1/2" thick (Line 3). C3 corresponds to middle C on the piano. Source: Line 1 corresponds from an advertisement on Akoustolith tile in Pencil Points. Line 2 corresponds to results from the Bureau of Standards in 1926. Line 3 corresponds to results from Jefferson Laboratory at Harvard. All results available in Box 4, Folder 1, Guastavino/Collins Collection. Diagram by author. 58

7.1 Half cross section of the passenger concourses with Akoustolith tile on the vaulted ceilings (magenta), Buffalo Central Station, Alfred Fellheimer and Steward Wagner, Architects. Source: Fellheimer & Wagner architectural drawings of railroad stations in the United States and Canada, 1915-1931, Avery Architectural and Fine Arts Library, Columbia University. 60

7.2 Arcade of the 79th street Rotunda with Akoustolith tile on the vaults. Source: Guastavino/Collins Collection. 62

7.3 Typical section for a rotunda bay with Guastavino vaults finished in Akoustolith (magenta), 79th street rotunda. Source: Guastavino/Collins Collection. 63

7.4 Section through a concrete bridge with Akoustolith soffit (magenta). Source: Akoustolith Sales Manual, Guastavino/Collins Collection. 64

7.5 Diagram of a flue cast in Akoustolith (Guastavino/Collins Collection). 65


8.1 Micro-CT scan of Akoustolith tile. 70

8.2 Textures of Akoustolith. 71

8.3 Absorptive power of formula variations. (author) 73

8.4 Photomicrographs of specimen from the Nebraska State Capitol showing a lump of pigment in the binding medium. Photo courtesy Center for the Analysis of Archaeological Materials, Penn Museum. 74
8.5  a) Coarse plaster as a heavy-scratch base coat b) Wall c) Fine Plaster as binder coat d) Akoustolith material e) Filling back of sound absorbing material.  
Source: U.S. patent 1,563,846.
8.6  Overview of all specimens collected. For individual photographs and microphotographs of impurities, see Table C.3.6
8.7  Sand profile plotted in a logarithmic scale. Graph by author.
8.9  Capping cubes with plaster of Paris using plastic petri dishes to create parallel and smooth surfaces. Photo by the author.
8.10  Photomicrograph of the microstructure of Akoustolith showing a decreased interconnection of voids with a higher use of binding medium.
8.11  A representative force vs. displacement graph on Akoustolith stone (END.T3, Eglise de Notre Dame) with recognizable features: an elastic phase that culminates in a Yield Point, an intermediate phase of plastic deformation that culminates in a peak compressive strength, and a descending phase with a slight inflection at the fracture point. For the full data of each cube, see section E.5 Graph by author.
8.12  Relationship between compressive strength and sorting. Scatter points represent the average of the compressive tests on 3 cubes per commission, with an error bar indicating variability in the tests. Graph by author.
8.13  Specimen containing an assembly of Guastavino vaulting from the ceiling of the Egyptian Wing at the Penn Museum. Photo courtesy Marie-Claude Boileau, Center for the Analysis of Archaeological Materials (CAAM), Penn Museum.
8.14  Typical microstructure of Akoustolith showing angular pumice grains (P) bonded with cement (C) at close points of contact to create interconnected air voids (AV). Note the isotropic behavior of the volcanic glass in the pumice makes it look opaque on XPL. In addition, the natural voids within the vesicles of the pumice grains rarely connect with the larger network of voids. The brownish-golden color of the binder in XPL indicate the carbonation of the Portland cement. (GA5, PPL and XPL, 50x) Photo courtesy of Center for the Analysis of Archaeological Materials, Penn Museum.
8.15  A grain of biotite (right) is partially enclosed with cement. The mineral is identified for its single cleavage and fractures (GA3, 50x, PPL and XPL). Photo courtesy of Center for the Analysis of Archaeological Materials, Penn Museum.
8.16  An isolated rock of andesitic basalt with euhedral phenocrysts of plagioclase feldspar (magenta arrows) and pyroxene (yellow arrow) in a glassy groundmass within the rock. (GA3, 100x, XPL and PPL) Photo courtesy of Center for the Analysis of Archaeological Materials, Penn Museum.
8.17  Concentration of blue pigment within the angular cavities of a pumice grain (cyan arrows). Phenocrysts of quartz and feldspar (magenta arrows) are present in the cement groundmass. Of notice is the gradation of the groundmass from light on the top left to dark on the bottom right (dashed green arrow), indicating an active gradual carbonation of the Portland cement(GA3, 50x, XPL). Photo courtesy of Center for the Analysis of Archaeological Materials, Penn Museum.
8.18 **Closing of pores** The linter presents a lump of aggregate and binder absent of the interconnected voids. (423C 25X PPL and XPL). Photo courtesy of Center for the Analysis of Archaeological Materials, Penn Museum. .............................. 96

9.1 Deterioration mechanisms associated with Akoustolith tile: biological growth (top left), cracking from external stresses (top right), detachment from the laminating/bedding mortar (bottom left), and accumulation of dirt and pollution within the pores (bottom right). Photos courtesy of Barbara A. Campagna. Microphotograph (bottom right) courtesy Architectural Conservation Lab, University of Pennsylvania. ................................. 99

9.2 3D surface topography of a specimen from the Nebraska State Capitol. Photo courtesy of Center for Analysis of Archaeological Materials (CAAM), Penn Museum. .............................. 101

9.3 Graph by author. ................................................. 102

9.4 Graph by author. ................................................. 103

9.5 Graph by author. ................................................. 104

B.2.1 Draft of an advertisement featuring a graph of sound absorption. Source: Box 4, Folder 2, Guastavino/Collins Collection. .............................. 123

B.2.2 Akoustolith Ad for Church of Notre Dame in Morningside Heights, New York City. Printed in *Architectural Forum* (January 1922). .............................. 124

B.2.3 Akoustolith Ad for Nazareth Hall Chapel, University of Northwestern at St. Paul. Printed in *Pencil Points* (March 1922). .............................. 125

B.2.4 Sweet’s Catalogue, 1932 ......................................... 126

B.2.5 Akoustolith Ad for Riverside Church in *Architectural Record*, August 1931. Reprinted in the Akoustolith Sales Manual, Guastavino/Collins Archive (Box 4, folder 2), Avery Library, Columbia University. .............................. 127

B.2.6 Akoustolith Ad for the New York Federal Reserve Bank, printed in *Pencil Points* (1925). ................................................. 128

B.2.7 Types of materials made by Guastavino, printed in the 1931 edition of *Sweet’s Catalogue* Volume B, page 2657. .............................. 129

B.2.8 Ad, printed in *Architectural Forum* (June 1934) ................................................. 130

B.2.9 Ad, printed in *Architectural Forum* (January 1921) ................................................. 131

B.2.10 Ad, printed in *Architectural Forum* (June 1923) ................................................. 132

B.2.11 Akoustolith ad for Leslie Lindsey Memorial Chapel, printed in *Architectural Forum* (June 1923) ................................................. 133

B.2.12 Advertisement of Akoustolith with metal strip jointing. Source: Guastavino/Collins Archives. .............................. 134

D.4.13 Grouping and sub-grouping of thin sections. Collection at the Center for the Analysis of Archaeological Materials, Penn Museum. .............................. 155

D.4.14 Grain size distribution of 40 inclusion particles in Group 1A in mm. .............................. 157

E.5.15 Force (Newtons) vs displacement (mm/mm) graphs ................................................. 160

E.5.16 Force (Newtons) vs displacement (mm/mm) graphs ................................................. 161

G.7.17 Drawing showing the placement of Akoustolith tiles, University of Chicago Chapel, Bertram Goodhue Associates, dated September 24, 1927. .............................. 163
# List of Tables

<table>
<thead>
<tr>
<th>Table</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.1</td>
<td>Products used in sealing the Rumford at St. Thomas Church by Klepper Marshall King Associates.</td>
<td>12</td>
</tr>
<tr>
<td>3.1</td>
<td>Patents held by Rafael Guastavino Jr. for acoustical products</td>
<td>27</td>
</tr>
<tr>
<td>3.2</td>
<td>Cost per square foot of Akoustolith tile and plaster</td>
<td>29</td>
</tr>
<tr>
<td>3.3</td>
<td>Cost per square yard of Akoustolith plaster. Source: Box 4, folder 1. Guastavino/Collins Collection</td>
<td>30</td>
</tr>
<tr>
<td>3.4</td>
<td>Material profile of Akoustolith tile with historical tests.</td>
<td>32</td>
</tr>
<tr>
<td>8.1</td>
<td>Minimum thickness of Akoustolith. Source: Advertisement on Sweet’s Catalogue</td>
<td>75</td>
</tr>
<tr>
<td>8.2</td>
<td>Water absorption coefficient of 5 specimens. END = Eglise de Notre Dame SJD = Cathedral of St. John the Divine NH = Nazareth Hall, University of Northwestern NSC = Nebraska State Capitol WNC = Washington National Cathedral</td>
<td>80</td>
</tr>
<tr>
<td>8.3</td>
<td>Sorting Classification proposed by Füchtbauer (1959)</td>
<td>82</td>
</tr>
<tr>
<td>8.4</td>
<td>Results of gravimetric analysis by acid digestion.</td>
<td>82</td>
</tr>
<tr>
<td>8.5</td>
<td>Sorting results for the coarse aggregate. full data available in section E.5 ND = No data</td>
<td>83</td>
</tr>
<tr>
<td>8.6</td>
<td>Summary of results for compressive testing. full data available in section E.5 ND = No data</td>
<td>86</td>
</tr>
<tr>
<td>8.7</td>
<td>Origins of thin sections</td>
<td>90</td>
</tr>
<tr>
<td>9.1</td>
<td>Criteria for an ideal sealant</td>
<td>105</td>
</tr>
<tr>
<td>C.3.1</td>
<td>Data for specimen BCT.T1</td>
<td>135</td>
</tr>
<tr>
<td>C.3.2</td>
<td>Data for specimen END.T1</td>
<td>136</td>
</tr>
<tr>
<td>C.3.3</td>
<td>Data for specimen END.T2</td>
<td>137</td>
</tr>
<tr>
<td>C.3.4</td>
<td>Data for specimen END.T3</td>
<td>138</td>
</tr>
<tr>
<td>C.3.5</td>
<td>Data for specimen END.T1</td>
<td>139</td>
</tr>
<tr>
<td>C.3.6</td>
<td>Data for specimen SJD.T1</td>
<td>140</td>
</tr>
<tr>
<td>C.3.7</td>
<td>Data for specimen SJD.T2</td>
<td>141</td>
</tr>
<tr>
<td>C.3.8</td>
<td>Data for specimen SJD.T3</td>
<td>142</td>
</tr>
<tr>
<td>C.3.9</td>
<td>Data for specimen NH.T1</td>
<td>143</td>
</tr>
<tr>
<td>C.3.10</td>
<td>Data for specimen NH.T2</td>
<td>144</td>
</tr>
<tr>
<td>C.3.11</td>
<td>Data for specimen NH.T3</td>
<td>145</td>
</tr>
<tr>
<td>C.3.12</td>
<td>Data for specimen NH.T4</td>
<td>146</td>
</tr>
<tr>
<td>C.3.13</td>
<td>Data for specimen NSC.T1</td>
<td>147</td>
</tr>
</tbody>
</table>
C.3.14 Data for specimen NSC.T2 ................................................. 148
C.3.15 Data for specimen NSC.T7 ................................................. 149
C.3.16 Data for specimen WNC.T1 ................................................. 150
C.3.17 Data for specimen WNC.T2 ................................................. 151
C.3.18 Data for specimen WNC.T3 ................................................. 152
C.3.19 Data for specimen WNC.T4 ................................................. 153
C.3.20 Data for specimen WNC.T5 ................................................. 154
D.4.21 Inclusions of the Coarse Fraction of Group 1 ......................... 156
D.4.22 Data for specimen WNC.T1 ................................................. 158
F.6.23 Sound absorption coefficient (SAC) for different materials at 512 Hz per square foot. Source: Box 4, folder 1. Guastavino/Collins Collection, Avery Architectural and Fine Arts Library, Columbia University. .................. 162
CHAPTER 1: Introduction

The Akoustolith solved a problem we no longer have. The introduction of electroacoustical systems in the 1930s rendered porous materials that diminished reverberation in cathedrals, churches, and synagogues obsolete. Clarity and intelligibility of speech, rarely found in monumental vaulted spaces, was now possible with time-delayed systems. Today, the Akoustolith tile prevents the enrichment of organ and choral music at a moment in history where low rates of church attendance are placing many sacred spaces in danger.

This thesis broadens the history of the origins, development, and application of Akoustolith tile. It expands the known list of commissions with Akoustolith tile to 150 buildings. It provides a material analysis on the following properties: water absorption, particle size distribution, compressive strength, and mineralogical composition. This thesis demonstrates that the Akoustolith tile presented variability in composition across commissions and within individual tiles, modifying its acoustical behavior by changes in particle size, angularity, sorting, and binder-to-aggregate ratio. Furthermore, it presents evidence that the degree of sorting is inversely correlated with compressive strength. This informs the hypothesis that sorting is proportional to sound absorption.

The origins and development of Guastavino Akoustolith are discussed in chapter 3, followed by a discussion on representative commissions from different building typologies: religious (chapter 4), civic and institutional (chapter 5), commercial (chapter 6), and infrastructure (chapter 7). Chapter 8 discusses the results from experiments measuring water absorption, compressive strength, particle size distribution (sorting), and petrographic analysis using specimens from 5 different representative commissions: the Nebraska State Capitol (1916-1928), Cathedral of St. John the Divine (1882-1941), National Cathedral (1906-1988), Buffalo Central Terminal (1927-1929), and Church of Notre Dame (1909-1928).
findings between compressive strength and particle size distribution serve as evidence to prove that compressive strength is inversely correlated with sorting. The discussion in material analysis then informs a discussion on repair, consolidation, and reversible sealing in chapter 9. Finally, chapter 10 expands on suggestions for further research and testing.

1.1 Historical Background

Since antiquity, reverberation and echo have been linked to monumental vaulted spaces. Classical Roman temples and medieval Gothic cathedrals produced a recognizable soundscape. This relationship was considered as natural as gravity. Vaults, domes, coves, pendentives, and other large concave surfaces were conducive to reverberation, echo, and focusing of sound that enriched the medieval Latin chant but was detrimental to the clarity of the modern Protestant sermon. To diminish the blurring of syllables, architects and engineers of the nineteenth-century clothed the interior surfaces of monumental spaces with acoustic felts at the detriment of architectural expression. These corrections not only were ad-hoc interventions to the original design and construction, but were vulnerable to fire and vermin.¹

At the turn of the twentieth-century, physicist and Harvard professor Wallace Clement Sabine (1868-1919) and master builder Rafael Guastavino Jr. (1872-1950)² responded to a demand to quiet Protestant cathedrals. Together, they invented two acoustical products: a clay-based porous tile named "Rumford" (1914) and an artificial cast stone named "Akoustolith" (1916). Both imitated traditional masonry, and were effective at absorbing mid and high pitches of the musical scale. Sabine and Guastavino Jr. created a unitized material that not only reduced reverberation and echo, but was structural, incombustible, and imitated traditional masonry construction.³ Both products were bonded to the ancient constructive

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²To be consistent with the naming convention of George Collins and John Ochsendorf, I refer to Rafael Guastavino i Moreno as "Rafael Guastavino Sr." and his son, Rafael Guastavino i Expósito as "Rafael Guastavino Jr."
technique of self-supporting vaults of interlocking structural clay tiles that Guastavino Sr. patented in the U.S. as "timbrel vault construction" (Figure 1.1).

The Akoustolith enjoyed a tremendous success as an acoustical and structural tile for traditional early 20th-century American architecture. It delivered a clear soundscape to major buildings designed by leading early 20th-century American architects: Bertram Grosvenor Goodhue (1869–1924) and Ralph Adams Cram (1863–1942); John Russell Pope (1874–1937); Frank Ray Walker (1877–1949) and & Harry E. Weeks (1871-1935); Horace Trumbauer (1868-1938); and Edward York (1863–1928) and Phillip Sawyer (1868-1949).

Figure 1.1: Location of Rumford or Akoustolith tile as a soffit layer to the larger Guastavino timbrel arch construction assembly. Illustration by author.

The Roaring Twenties saw an increase in building typologies with Akoustolith. It was applied on interior walls and ceilings of buildings of institutional, civic, or commercial use: legislative chambers, bank rooms, auditoriums, libraries, museum galleries, classrooms, courthouses, laboratories, gymnasiums, natatoriums, memorials, and railroad stations. Commissions ranged from the small music room at St. Mark’s school in Southborough,
MA (Bigelow Wadsworth, 1919) to the monumental Buffalo Central Terminal in Buffalo, NY (Fellheimer Wagner, 1929).

1.2 The Conservation Problem

Over the past 50 years, clergymen and organ directors of many cathedrals, churches and temples with Akoustolith tile have demanded to treat the porous material to increase the reverberation time so as to enrich ecclesiastical music. This treatment often comes at the detriment of irreversibility and change in finish. Furthermore, many buildings furnished with Akoustolith tile and plaster are reaching their centennial, where the material is deteriorating, cracking, soiling, and detaching.

While this thesis does not study in-depth the conservation challenges and the formulation of an effective treatment, it fills a gap in the literature by providing a history of technology on secular buildings and provides new insights on its material properties.

1.3 Central Questions

Was the Akoustolith applied on other structures other than religious? If so, on which building typologies and assemblies? How was Akoustolith manufactured? Did it experience changes in its composition and formula across projects and how do these differences impact its conservation? Has there been a variation in composition ratios, manufacturing, and application methods across different projects? If variation between projects is present, how do these differences impact the approaches for conservation? What testing protocols and products have been used to clean the Akoustolith?

Answering these unknowns will inform the next stages of conservation, including stabilization, consolidation, and related treatments.

1.4 Limitations and delimitations

The following limitations were encountered:

- Restrictions related to the COVID-19 pandemic prevented conducting an exhaustive
archival research on the Guastavino/Collins Collection at Avery Architectural & Fine Arts Library.

- The standardized thickness of the tiles limited the dimensions of specimens for compressive strength testing.

- The time required to procure specimens from different locations and the time for preparing thin-sections did not allow to do a comparative petrographic analysis of multiple commissions.

- The results from tests on water absorption and gravimetric analysis by acid digestion are not representative of all existing Akoustolith. Quality control issues in the manufacturing, the way the Akoustolith was installed, and the accumulated soiling on certain specimens, are potential sources of noise in the data.

- The Akoustolith samples acquired only represent 6 commissions of a list of more than 150. These may not be deemed representative of all the permutations that the R. Guastavino Company may have developed.

- Time constraints did not allow for product development for a reversible sealant, but an outline on formulating coatings is provided in chapter 10.

The following delimiters define the scope of the thesis:

- This study does not conduct an in-depth material analysis of other Guastavino acoustical products, such as its predecessor, the Rumford tile, the Akoustolith plaster, nor the gypsum-based acoustical plaster products known as Plastacoustics and Casta-coustics.

- This thesis does not consider the larger field of architectural acoustics in the early 20th century, nor does it trace the history and development of all the Guastavino acoustical products.⁴

• The study of the behaviour of the Akoustolith as part of a larger assembly of laminating mortar and structural clay tiles (the Guastavino system) is excluded.

1.5 Methodology

Archival Research

Archival research at the Guastavino/Collins Collection at Avery Architectural and Fine Arts Library was conducted remotely. This was supplemented with material provided by archivists and professionals from relating architects. The R. Guastavino Company was hired as a contractor or sub-contractor in many of these commissions, and material from the architect’s or builder’s archives proved invaluable on specific commissions.

In expanding the list of known commissions with Akoustolith, two primary sources—the Project List of the Guastavino/Collins Collection and advertisements in professional journals—verified and expanded the list published in.

Data Collection

This thesis uses mixed methods (qualitative and quantitative). The history of technology (chapter 3) relies primarily on qualitative methods: interviews with conservation professionals and interpretation of archival material from primary sources (patents, original archives, ) and secondary sources (technical papers, journal articles, thesis, academic papers). I crowd-sourced research leads by posting on the Facebook group “Historic Preservation Professionals.” I gathered leads to contact architects, consultants, and contractors involved in the conservation of Akoustolith. Material that was used as primary source material include conference proceedings, records of building specifications mentioning Akoustolith, unpublished theses, and conditions assessments from commissions with Akoustolith.

I interviewed 5 professionals: Jaume Soler, acoustician at SoundArts Consulting for

5. My special thanks go to my friend Kevin Tang, a Columbia student at the time this thesis was written, and to Pamela Casey, archivist at Avery Library, for providing scans of specific items in the collection.

his advice on formulating research questions; Michael Kramer, founder and president of The Gilders’ Studio, for his experience in restoring the Akoustolith stone at the National Academy of Sciences in Washington D.C.; Laura Buchner, senior conservator at Building Conservation Associates for her experience in restoring Akoustolith tile at the Cathedral of St. John the Divine; Marlene Goeke, conservator at Building Conservation Associates, for her work in sealing the Akoustolith at the National Cathedral; and Joseph W. A. Myers, principal consultant at Kirkegaard Associates, for his insights on the relationship between acoustics and porosity of Akoustolith tile at the National Cathedral and the Cathedral of St. John the Divine.

Material Analysis and Performance Testing

In comparing specimens from different projects, the following questions were formulated. What do these samples tell about the evolution of Portland cement? What do they tell on the standardization industry? What is the dimension of each layer? Do they confirm the specifications in the trade literature? What is the thickness and material composition of the bonding material?

Performance testing was performed concurrently, not sequentially. Each testing followed the corresponding ASTM guidelines. The quantitative data was then synthesized to draw conclusions, formulate new questions, and inform the formulation of consolidation and sealing in the future.

Petrographic Analysis

Analysis and interpretation of thin sections was conducted as part of a class in ceramic petrography instructed by Dr. Marie-Claude Boileau of the Center for the Analysis of Archaeological Materials (CAAM) at the Penn Museum. The thin sections were produced off-site as 30 microns thin sections with blue epoxy to clearly distinguish the voids in the interconnected pores and within the pumice particles. These were observed in polarized light (PPL) and cross-polarized light (XPL) at the Ceramics Lab at CAAM. Petrographic analysis addresses questions of composition, provenance, manufacturing, and preservation.
CHAPTER 2: Literature Review

This thesis is primarily informed by three bodies of literature: two books, The Art of Structural Tile (Ochsendorf, 2010) and The Soundscape of Modernity: Architectural Acoustics and the Culture of Listening in America, 1900-1933 (Thompson, 2002), and the Master’s thesis Guastavino Acoustical Tile and Plaster: A History of Development and Conservation Issues (Pounds, 1995). The intersection of the subjects architectural acoustics and the R. Guastavino Company are considered for the literature review. Literature on the origins of the catalan vault system, structural performance of the cohesive tile construction, or material analysis of the terra-cotta are excluded. The review will address three topics: (a) the history of Principles of Architectural Acoustics in the first decades of the 20th century, (b) the history of technology of Guastavino Tile Vaulting, (c) the study of development of the Rumford and Akoustolith Tile, and (d) empirical studies and technical reports on Treating the Akoustolith.

2.1 Principles of Architectural Acoustics

Vaults, domes, coves, pendentives, and other large concave surfaces produce a certain soundscape that is dependant on the interior’s shape, size, finishing surface, and –to a lesser extent– climatic conditions.\(^1\) Four major acoustical phenomenons arise in these large vaulted spaces: reverberation, echo, resonance, and interference. These are deeply inter-related: minimizing reverberation reduces resonance at a similar ratio (Swan, 1921).

The combination of these four produce a signature acoustical "footprint" that may be desired for one use but detrimental for another (Sabine, 1923). A church may wish \(^1\)It is known that refraction of sound occurs when the density of air changes by heating and cooling systems. These changes are negligible to the human ear.
the music from choirs and organs to be enriched with a reverberating ceiling. A railroad company may seek to quiet the mumbling and tapping of footsteps from public concourses. A bank may desire to quiet the clickety-clack of typewriting and the ringing of telephone bells. A transportation authority may want to reduce the noise of vehicle engines in an underground tunnel for the commodity of its users.

Reverberation is how long a pitch can be prolonged by multiple reflections before it becomes inaudible. It is defined as the time it takes for a pitch to lose half its intensity. Playing a tune releases a series of waves of a specific frequency and intensity that gets mostly reflected as they reach a surface. Some of the initial energy is lost in transmission and absorption. As the wave of a pitch bounces across a room, it continues to lose energy until it dissipates.

The higher a pitch is, the shorter the wavelength. As these wavelengths decrease, they start to interact with surfaces that vary to the scale of inches and fractions of an inch. When the energy of a high-frequency sound wave hits a rough and porous surface, it is partially absorbed and partially scattered (Neville, 1963). The microstructure of a material then plays an important role in absorbing, transmitting, reflecting, and diffracting sound waves of mid and high frequency. The more porous and lightweight the material is, the more it will absorb sound on every interaction, reducing the reverberation time in large interiors.

Too much reverberation blurs and overlaps syllables. It creates a cacaphony of sound that diminishes the clarity and intelligibly of speech. On the other hand, too much absorption creates dead and unnatural soundscapes. These may prevent attendants to hear a sermon if they are sitting at the back. A necessary and sufficient amount of absorption supports and amplifies successive syllables to a large mass.

The geometry of ceilings affects reverberation and focusing of sound. A coffered ceiling mitigates the focusing of sound by scattering the incoming waves. Lower ceilings, recesses, protrusions, and felt furniture all decrease reverberation (Swan, 1921).

Monumental interiors with concave ceilings present acoustical challenges. It puzzled architects, engineers, and designers for centuries. The problem of attaining "good acoustics"
in monumental interiors were a matter of trial and error, an empirical gambling with the laws of physics (Orcutt, 1933). To mitigate it, architects introduced coffers and semi-domes and reluctantly used felts after construction (Pounds et al., 1999).

In 1898, Harvard professor Wallace Clement Sabine brought the subject of architectural acoustics from empirical state to a reasoned, quantifiable science. He defined reverberation time with a sound absorption coefficient formula, making the unknown quantifiable, predictable, and easily controlled (Thompson, 2002). In 1900, Sabine published in *The American Architect* what would be known as the "Sabine formula". His equation gave architects the power to attain what the scholar Emily Thompson calls a "mastery over the soundscape" (Thompson, 2004).

\[
T = \frac{0.164V}{\Sigma A}
\]

where \(T\) is the reverberation time in seconds, \(V\) is the interior volume in \(m^3\), \(\Sigma A\) represents the cumulative absorption of the objects in a room in \(m^2\) or sabins, and 0.164 is a constant in s/m.

While large interior surfaces increased reverberation and echo, materials with high Sound Absorption Coefficient (SAC) would decrease it, breaking the age-old relationship between sound and space (Thompson, 2004).

### 2.2 Guastavino Tile Vaulting

**Rumford and Akoustolith Tile**

The reverberation time in religious buildings changed depending on the denomination. A Christian Scientist church may prefer the spoken word while a Roman Catholic church may prefer organ music. (Pounds, 1995)

The Rumford tile presented great variability in porosity, density, water absorption, and sound absorption (Pounds, 1995). This was sufficient reason for Sabine and Guastavino Jr. to formulate a more consistent material.

The practice to seal the Rumford tile dates back to the same architects who demanded its formulation. Bertram Goodhue had expressed his dissatisfaction of the tile and had considered sealing it (Pounds, 1995).

### 2.3 Treating the Akoustolith

Before treating the Rumford or Akoustolith tile, other interventions can be done to improve the reverberation time, including moving the organ, installing hard wainscotting panels, and painting organ chambers with vinyl masonry paint (Pounds, 1995).

Disadvantages of sealing the Akoustolith to restore reverberation include reversibility and change in finish (Soler-Bertrolich, 2012). The dichotomy of choosing between creating a space for church music enriched with reverberation or delivering intelligible speech was resolved with the invention of electro-acoustical devices in the 1930s (Thompson, 2002), where speakers and amplifiers can integrate time delays to mitigate the reverberation. It was now possible to hear perfectly well the sermon and experience an enlivened church music.

Many ecclesiastical spaces, increasingly relying on choir and other ecclesiastical music for public programming, grew unsatisfied with the acoustics. Solutions have been conducted to seal the pores of Akoustolith ceilings with transparent coats at multiple churches, synagogues and cathedrals. Modern sound speaker devices (usually column loudspeakers) with varying time delays addressed the problem of speech intelligibility in many of these ecclesiastical spaces.
Riverside Church

The practice of sealing the Akoustolith dates back as early as 1952 at Riverside Church (Pounds, 1995). Designed by Pelton, Allen & Collens, Riverside Church was a modern structure clad in the Guastavino acoustical masonry (Figure B.2.5). Akoustolith was installed at the soffit of the narthex ceiling and the vaults of the nave.

Under the direction of restoration architect Gerald P. Allen (- 2015), buckets of Okon® acrylic sealer were applied in multiple coatings, increasing the reverberation time to 4 seconds.²

St. Thomas Church

The installation of electro-acoustical systems to minimize reverberation of the spoken word has been done at St. Thomas Church in New York (Rumford) where 4 coatings of Kyanize® sealer were employed under the supervision of Klepper Marshall King Associates (Table 2.1).³

<table>
<thead>
<tr>
<th>Product</th>
<th>Material</th>
<th>Manufacturer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coronado 70-200</td>
<td>Aquaplastic urethane</td>
<td>Coronado Paint Company</td>
</tr>
<tr>
<td>Kyanize L-0560 sealer with L-0561 flat finish</td>
<td></td>
<td>Hudson-Shatz Painting Company</td>
</tr>
<tr>
<td>M.A.B. HydroClear</td>
<td>Acrylic latex</td>
<td>M.A.B. Paints and Coatings</td>
</tr>
<tr>
<td>Okon four-times-solid-density sealer</td>
<td></td>
<td>Okon, Inc.</td>
</tr>
<tr>
<td>Pratt and Lambert acrylic latex varnish dull Z-39</td>
<td></td>
<td>Pratt and Lambert</td>
</tr>
<tr>
<td>UVS Sealer</td>
<td></td>
<td>ProSoCo</td>
</tr>
</tbody>
</table>

Table 2.1: Products used in sealing the Rumford at St. Thomas Church by Klepper Marshall King Associates.

In instances where reverberation was restored, electro-acoustical systems have been employed as a corrective to deliver time-delayed feedback so speech intelligibility is ensured. This has occurred at St Thomas Church (New York, NY), Duke University Chapel (Durham, NC), and Riverside Church (New York, NY).(Pounds, 1995)

National Cathedral

In 2013, the National Cathedral engaged Building Conservation Architects, Inc. (BCA) and Kirkegaard Associates - an acoustics design firm - to regROUT, clean, and seal the Akoustolith. BCA and Kirkegaard established a temporary laboratory for product testing in a non-public area of the triforium for cleaning and sealant testing. A squeegee was used for applying a Golden® gel medium, ensuring it penetrated the substrate well enough. The Crossing area was prioritized, since this was on the path of sound waves originated from the organ at the Great Choir.4

It was suspected that the Akoustolith was losing its bonding strength with the terracotta substrate. This became clearly evident after the 2011 Virginia earthquake, where the Akoustolith cracked, loosened, vibrated, and sometimes detached from the terracotta substrate.5

A bond-breaker was used in regrouting Akoustolith tiles with the laminating mortar. The tiles themselves were not friable, but the bedding and joint mortar had lost its bonding strength. It is unknown if this loss of mortar cohesion with the structural clay tiles and the Akoustolith tiles was due to workmanship during construction, the 2011 earthquake, normal vibration from construction, or other unknown mechanisms.

Cathedral of St. John the Divine

Akoustolith tile was found out to be used at St. John the Divine between 2005 and 2008 when some of these tiles detached from the terracotta layers. It was suspected that when Guastavino masons applied the soffit layer, the porous substrate of Akoustolith absorbed moisture from the laminating mortar, so the bond between the Akoustolith and the rough structural clay tiles were weakened.

In the recent restoration, BCA performed injection grouting so the Akoustolith was safe and secured.6 In cleaning the Akoustolith, several treatments were discarded. The porous

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4 James Shepherd (principal at Smith Group) in discussion with the author, January 2022.
6 Laura Buchner (senior conservator at BCA) in discussion with the author, February 2022.
substrate absorbed too much of the chemical cleaners and the aggregate particles were
dislodged under the action of micro-abrasives. During hot summer days, the ceiling of the
cathedral became warm and humid, which made poorly-formulated sealants melt, drip,
and run down the ceiling. Douglas Hunt, Organ curator of the cathedral, settled with an
acrylic emulsion to seal the Akoustolith.7

Several samples were replicated on-site to match the visual appearance, but not the
acoustical requirements. The formula was changed so the binder was greater, creating a
denser and less porous product.8

Duke University Chapel

At Duke University Chapel (Horace Trumbauer, 1932), the reverberation time was increased
from three seconds at 500 cycles per seconds to almost seven seconds by applying four coats
of sealant. A new organ was donated under the conditions that the interior surfaces were
treated for organ music. The firm Bolt, Beranek, & Neuman outlined a method to correct
the Chapel’s dry acoustics with the application of up to 6 coats of an acrylic sealer. In the
end, four coats were applied, effectively increasing the mid-frequency reverberation time
from 3 seconds to 6 seconds.9

Cathedral of St. Philip

Following the sealing work at Duke University Chapel, Robert Neuman was consulted to
address the acoustics at the Cathedral of St. Philip (1960-62). The ceiling was sealed in

Like at St. Thomas Church in New York City, concern over the high absorption of
Akoustolith were raised in its early years. In a letter dated April 28, 1960, the President of
the Aeolian-Skinner Organ Company expressed his distress on the use of the Akoustolith
tile because of its limitation to absorb only high and mid-high frequencies.

7Ibid.
8Ibid.
From June 2010 through June 2012, the domes at the National Academy of Sciences were restored by the firm Quinn Evans and The Gilders’ Studio. The scope of work included cleaning, restoring, and regrouting of the Akoustolith at the Great Hall, where certain tiles were loosening. Active water leaks on the ceiling demanded repairs. Jablonski Building Conservation, addressed the repair protocols for the Akoustolith ashlar on the walls.

Wet-cleaning was discouraged since it would ruin the plaster decoration. The sponge-jet system was explored, but there was concern that the sponges would get stuck in the substrate, so it was all dry-cleaned by hand with sponges that acted as big erasers.

Some of the Akoustolith tile at the Great Hall was stained from dissolved plaster. To remove the spilled-over plaster into the Akoustolith, wet rags were used, vacuuming the plaster stuck in the pores of the substrate.

Nearly 1,000 square feet of damaged historic plaster was substituted with new plaster. Dry pigments were mixed into the watercolor to match the original finish of the historic plaster. To clean the historic gilded surfaces, a wet system that consisted of cotton balls was used.
CHAPTER 3:
Origins and Development

3.1 Solving a Centuries Old Problem

Since antiquity, reverberation and echo have been linked to monumental spaces. Roman temples and Gothic cathedrals produced a recognizable soundscape, an association that was assumed as natural as gravity. The soundscape of a medieval Gothic cathedral determined the type of activities inside. High vaulted ceiling created a reverberation time that was as high as 10 seconds. This limited religious activities to delivering sermons in Latin or chanting. Understanding the contents of the speech was not as important as joining the spiritual experience of mass.

The Italian Renaissance saw a renewed interest in Greek architecture, where auditoriums were designed in the image of Greek amphitheaters. An interest in Roman classicism introduced domes and vaults as the preferred forms for covering theaters and auditoriums.\(^1\) The adoption of the Greek amphitheater in plan and the Roman dome in section produced reverberant rooms that was detrimental to musical activities, especially when the focus of the curvature of domes was near the audience.

In the New World, the 1893 World’s Columbian Exposition in Chicago re-introduced monumental domes and vaulted ceilings in the classical vocabulary of public monuments. The desire for such architecture was fortuitous for Rafael Guastavino Sr., who imported a technique of constructing domes and vaulted ceilings that was cost-effective, required no centering, was faster to build than the traditional voussoir arches, and demanded little buttressing to accommodate the horizontal thrust.

When Guastavino Sr. erected monumental vaults and domes, the density and rigidity

of the structural clay tiles unintentionally reflected sound at a high degree, producing long reverberation times in large interiors. The furnishing of the soffit with hard, glazed ceramic tiles or smooth plaster, made the interiors even more reverberant, a condition that was detrimental to court houses, theaters, and –most importantly– Protestant churches. A need for a sound-absorbing material that imitated traditional masonry emerged (Figure 1.1).

At the turn of the twentieth century, architect Ralph Adams Cram (1863-1942) was unable to meet the demands of Protestant congregations, who desired sanctuaries of medieval character. Unlike the churches of medieval Europe, Protestant denominations favored the clarity of the spoken word. This warranted a demand for monumental interiors with little reverberation time.

The problem of reverberation in public spaces could not be quantified until the pioneering work of Harvard professor Wallace Clement Sabine (1868 – 1919), who in 1895 had addressed the acoustical problems of the Lecture Hall of the recently completed Fogg Museum in Cambridge, Massachusetts. His research and experimentation at the Lecture Hall allowed him to formulate quantifiable principles that proved useful in correcting the acoustics of Boston Symphony Hall by McKim, Mead & White. A few years later, in 1900, Sabine offered advice to Charles McKim to discuss the issue of reverberation at the Rhode Island State Capitol.

Sabine was interested in the sound absorption coefficient of several materials. He discovered that sand was particularly effective at absorbing mid and high-pitches, and the key to this was the interconnection of voids. He measured the sound absorption of regular beach sand in a laboratory room at Harvard, where he experimented with grain size and thickness on wooden frames laying on the cement bed. These experiments led him to hypothesize the preferred grain size and thickness for a high pitch.

Like many builders of his day, Guastavino Sr. was concerned with improving the

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5 Thompson, The Soundscape of Modernity: Architectural Acoustics and the Culture of Listening in America, 1900-1933, 69.
6 Orcutt, Wallace Clement Sabine: A Study in Achievement, 207.
acoustical performance of interiors. However, he was concerned with the transmission of sound from exterior to interior and between rooms, not the sound that propagated within a single room. This was evident in his 1891 patent for a "Cohesive Ceiling-Floor", where improvements were made to reduce the transmission of sound, but not the reverberation and echo that occurred within large, vaulted interiors.

3.2 La Cerámica

Guastavino Sr. arrived to New York with his 9-year-old son in 1881 with $40,000 in cash. He and his son travelled to Colorado and North Carolina in search of local deposits of clay, and eventually established a small and improvised plant in North Carolina. His financial adviser, William Edward Blodgett (1864-1931), suggested to establish a tile factory in his hometown Woburn, Massachusetts. Blodgett had been hired by Guastavino as a bookkeeper in 1889 when he was only 25 years old, and served as major of Woburn at the time of the proposition.

A small plant was established near the Horn Pond between Greene and Fowle Streets on a plot of land that was previously occupied by the old wooden St. Charles Church. It was situated immediately east of the Boston and Maine Railroad, facilitating the supply of clays and shipping of tiles. Establishing the factory cemented a life-long relationship between Guastavino Sr. and Blodgett, who remained as the company’s business manager and treasurer until his death in 1931.

As demands for tile production increased with more commissions, Guastavino Sr. and

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9 Ibid., 28.
10 Ibid., 21.
11 Ibid., 15.
13 New Tile Factory Formally Opened, Mayor Blodgett Greeted Visitors at the Plant all Day, Yesterday, June 8, 1907.
Blodgett built a secondary factory behind a Fire Station (Engine 3) at 660 Main Street in Central Square, Woburn. The new factory opened in 1907 and was named "La Cerámica". The facility boasted a brand new laboratory, a show room, two baking kilns, a glazing room, and a clay shed (Figure 3.1).

Although the factory was primarily equipped to produce structural clay tiles, it also manufactured the finishing tiles (glazed and unglazed) of all possible colors, in addition to the acoustical products that Guastavino Jr. would co-invented with Sabine in 1914 and 1916.\textsuperscript{15} Interestingly, the factory did not store surplus of tiles for future clients or

commissions, since each project demanded specific sizes and colors.  

3.3 Scientist and Ceramic Worker

When Guastavino Sr. died in 1908, his son succeeded him as head of the company. He wanted to address the problem of reverberation and focusing of sound. He eventually found the work of Wallace Sabine. In March 1911, a letter of introduction by architect Ralph Adams Cram (1863-1942) of Cram, Goodhue & Ferguson led to a private meeting between Sabine and Guastavino Jr. They discussed the properties of a theoretical tile that was fireproof and had the character of traditional masonry.

Describing his relationship with Sabine as that between a "scientist" and a "practical ceramic worker", Guastavino Jr. worked to formulate a ceramic-based acoustical tile. Sabine began testing samples of regular clay tiles from the Woburn factory destined to be used at the Chapel at the West Point Military Academy (Cram, Goodhue & Ferguson, 1911). After making suggestions on improving the composition, Guastavino Jr. and William Blodgett experimented with it, and a new set of tiles were used at the ceiling of the First Baptist Church in Pittsburgh. These new tiles were a prototype for what Guastavino and Sabine eventually patented in February 1913 as "Rumford tile".

3.4 Rumford Tile

The Rumford tile was the first unitized product to be fireproof, structural, and sound-absorbing. In an article for The Brickbuilder, Sabine wrote that the tile had "over six-fold the absorbing power of any existing masonry construction" (Figure 3.3).

Ralph Adams Cram, Bertram Goodhue, and Frank Ferguson hired Guastavino Jr. to furnish the soffit course of the vaulted ceilings with Rumford tile at St. Thomas Church.

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16 Guastavino/Collins Collection, Box 4, folder 1.
17 Thompson, “Shaping the Soundscape of Modernity”, 338.
18 Orcutt, Wallace Clement Sabine: A Study in Achievement, 209.
19 Thompson, The Soundscape of Modernity: Architectural Acoustics and the Culture of Listening in America, 1900-1933, 182.
20 Ibid., 182.
21 For the etymology and origin of Rumford tile, see Thompson, “Shaping the Soundscape of Modernity”, 338n40.
The work at St. Thomas would later impress architect Harold Lea Fetherstonhaugh (1887-1971), who visited New York City in 1929 for inspiration in designing the Church of St. Andrew and St. Paul in Montreal, Canada. In the subsequent years of its construction, St. Thomas was described as being "dead as a door-nail" and choir members complained that the church was a "pillow factory".

Following the application at St. Thomas, the Rumford tile had its fullest application at another project by Bertram Goodhue, the First Congregational Church in Montclair, N.J. (Bertram Goodhue, 1920).

The Rumford tile would be used in a dozen commissions, including the B’Nai Jeshurun Synagogue in Newark, NJ (Albert S. Goetlieb, 1914, demolished) (Figure 3.2), where Sabine advised architect Albert S. Goetlieb on the design and material selection.

In Philadelphia, the Harrison Auditorium at the University of Pennsylvania Museum (1915, Wilson Eyre & McIlvaine, Day Bros. & Klauder, Stewardson & Page) featured Rumford tile on the largest dome supporting a full floor slab. In New York City, the Rumford tile was used at St. Thomas Church (Cram, Goodhue & Ferguson, 1914), St. Bartholomew’s Church (Bertram Goodhue, 1919), and Church of St. Vincent Ferrer.

Figure 3.2: 1915 photo of Rumford tile on the interior wall at the West End of B’Nai Jeshurun Temple in Newark, N.J. (now demolished). Source: The Brickbuilder, 24, no. 1 (December 1915), 306.

Note:
23 Guastavino/Collins Collection, Box 4, folder 1.
The success of this clay-based tile, however, was short-lived. The Rumford tile was costly and unpredictable: it varied in color, density, porosity, and acoustical performance. Some units came out from the kilns warped, overly vitrified, or under fired. The interconnected pores was variable and unstable, ranging from 21% to a high of 52%.

### 3.5 Akoustolith Tile

Guastavino Jr. and Sabine went back to the drawing board and sought an artificial stone instead of a fired clay product. The discovery by Sabine that sand beach was very effective at absorbing mid and high frequencies led them to formulate a product that mimicked the arrangement of sand grains. The key to its absorption was the interconnection of voids within well-graded grains of angular shape. Guastavino Jr. and Sabine then began experimenting with Port-

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27Ibid., 51.

28Ibid., 26.

29Ibid., 25.
land cement and pumice grains.

The first successful samples were produced in September 1915, with subsequent improvements that culminated in a patent granted the following year on September 12, 1916 and reissued in July 24, 1918, listing Sabine as co-inventor. The sound absorption coefficient was a considerable improvement from that of the Rumford tile (Figure 3.3). A key departure was the use of well-graded or uniformly-graded aggregate of angular shape that reduced contact to a minimum, increasing the interconnection of voids.

3.6 Akoustolith Plaster

The R. Guastavino Company formulated a plaster variant of the Akoustolith tile almost a decade after the cast stone. Patented in 1925, its invention responded to the desire to compete with Sabinite, an acoustical plaster developed by the U.S. Gypsum Company. The company was unable to offer a competing plaster product during the bidding process for correcting the acoustics of the dome of the Legislative Chamber of the Parliament House in New Delhi (Herbert Baker, 1921-27).

The problem in formulating an acoustical plaster was in maximizing the thickness of a single application without losing the interconnection of voids and without plaster matter falling off. Applying multiple coats of plaster rendered all the previous layers useless, as a new coat sealed the previous one. Using an effervescent substance that generated gas was only effective at creating isolated bubbles.

After several experiments, it was determined that the maximum thickness of the plaster was $\frac{1}{2}$ inch. Like the tile, the plaster consisted of pumice powdered in Portland cement and was packed in 100-pound burlap bags. It was calculated that a ton of plaster (200 pounds) covered more than 100 square yards at $\frac{1}{2}$ inch thick.

30 Orcutt, Wallace Clement Sabine: A Study in Achievement, 209.
32 Guastavino/Collins Collection, Box 4, folder 1.
33 See subsection 8.1.2 for a further discussion on the manufacturing and application
3.7 Castacoustics and Plastacoustics

Akoustolith plaster, and the subsequent development of a gypsum-based casting product named "Castacoustics" enabled the construction of continuous surfaces with acoustical treatment, regardless of the presence of moldings and related detailing. Unlike Akoustolith plaster, Plastacoustics and Castacoustics were gypsum based. Yet they also used Italian pumice as aggregate.

Like the Akoustolith plaster, Plastacoustics was specified to be \( \frac{1}{4} \) inch or \( \frac{1}{2} \) inch in thickness as a finishing coat. The first coat was applied to a dry base coat. A second coat was applied 24 hours after the last coat. It was finished with steel trowel.\(^{34}\) The relative thinness of the plaster and the use of angular particles of Italian pumice helped preventing cracks from drying shrinking.\(^{35}\) Plastacoustics was not dependant on the cohesive tile construction and could be applied to wire lath, wood lath, brick, or hollow tile walls.

To reduce the amount of casting material, Castacoustics was usually backed with wood so the product would be cast at a minimum thickness. Examples where Akoustolith tile and Castacoustics were both used include the banking room of the New York Stock Exchange (1929, Trowbridge Livingston; George B. Post) and the Tiferith Temple in Cleveland, Ohio.


(1923-25, Charles R. Greco) (Figure 3.5).

*Plastacoustics* was only specified on smooth, continuous surfaces. Moldings, coffers, and other architectural detailing were specified with ordinary plaster. In the subsequent years, the Company invented and patented *Castacoustics*, a fine-grained gypsum plaster for casting ornamental or coffered surfaces (Figure 3.4 and Figure 3.6).

Akoustolith tile, Akoustolith plaster, *Castacoustics*, and *Plastacoustics* represented four of the five patents for acoustical products held by Guastavino Jr., of which the first two were the result of a close collaboration with Sabine (Table 3.1).
3.8 Quiet and Dignified for Sale

The R. Guastavino Company branded the Akoustolith with Greek origins. \((\text{ἀκρωτήριον})\) – meaning hearing, and \((\text{λίθος})\) – meaning rock. Advertised to ensure "wherever a quiet and dignified atmosphere is desired", the Company highlighted its acoustical, structural, and fireproof qualities (Figure B.2.6). They argued that acoustic materials should have architectural character. "If a plaster interior is desired," they argued, "the material should carry out this effect." Unlike felts and sugar-cane fiber boards, the Akoustolith tile and plaster contained no organic matter that was combustible or attracted insects. Unlike fiber boards and felts, the Akoustolith tile did not warp or buckle under damp conditions. Unlike perforated fiber boards, the voids in the Akoustolith tile were not large enough to be nesting

\(^{36}\)“Akoustolith - What it is, and its uses,” The Rafael Guastavino Company, advertisement, *Pencil Points* 2, no.3 March 1921, 37.

places for vermin. Unlike competing porous materials, the Akoustolith was cheaper per unit of sound absorption and could be washed.

<table>
<thead>
<tr>
<th>U.S. Patent</th>
<th>Name</th>
<th>Trade Name</th>
<th>Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>1,119,543</td>
<td>Wall and Ceiling of Auditoriums and the Like</td>
<td>Rumford tile</td>
<td>Dec. 1, 1914</td>
</tr>
<tr>
<td>1,197,956</td>
<td>Sound Absorbing Materials for Walls and Ceilings</td>
<td>Akoustolith tile</td>
<td>Sept. 12, 1916</td>
</tr>
<tr>
<td>1,440,073</td>
<td>Acoustical Facing Material for Interiors</td>
<td>Castacoustics</td>
<td>Dec. 26, 1922</td>
</tr>
<tr>
<td>1,563,846</td>
<td>Sound Absorbing Plaster and Method of Applying Same</td>
<td>Akoustolith plaster</td>
<td>Dec. 1, 1925</td>
</tr>
<tr>
<td>1,917,112</td>
<td>Acoustical product</td>
<td>Unknown product</td>
<td>July 4, 1933</td>
</tr>
</tbody>
</table>

Table 3.1: Patents held by Rafael Guastavino Jr. for acoustical products

Furthermore, the addition of pigments on the cement rendered unnecessary the use of paints to achieve a good light reflection, a common practice with other acoustic materials. In fact, the Portland cement gave the Akoustolith a light reflection factor of 62%, according to test results from a laboratory at the Massachusetts Institute of Technology.38

The company displayed Akoustolith tile specimens at the Architects Samples Corporation in 101 Park Avenue, New York, an exhibit display created by Edwin Lockwood (-1972) that served as a catalogue of building materials to architects and engineers.

The company also published advertisements for Akoustolith tile on prominent publications: Sweet’s Catalogue and the professional journals Pencil Points, Architectural Record, Architecture and Architectural Forum39 (See section B.2) Advertisements boasted that "there is more Akoustolith installed than any other cast masonry acoustic product." These full-page ads featured technical drawings by Philip George Knobloch (1893-1964).40

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38 Guastavino/Collins Collection, Box 4, folder 1.
39 Ibid., Box 4, Folder 1.
40 Knobloch was praised by architect Thomas Hastings (1860-1929), who wrote the preface for a treatise by Knobloch on good practice in construction in Pencil Points.
The company assembled an internal Sales Manual to brief sales representatives on the principles of architectural acoustics and the commercial benefits of their products (Figure 3.7). The manual advised representatives to highlight the ability to wash the surfaces after installation and the less surface area required to achieve equal reverberation time compared with competing products.\footnote{Guastavino/Collins Collection, Box 4 folder 1.}

Interestingly, the company actively collected pamphlets published by the U.S. Bureau of Standards on architectural acoustics so as to be updated with latest research and product development on acoustical treatments.

On the matter of business and consulting, the R. Guastavino Company hired an acoustical engineer that was at the disposal of the architect. The acoustical engineer advised in calculating the amount of Akoustolith tile or plaster to install in a given design.\footnote{Ibid.} The tile, being more absorptive than the plaster, required less surface area to achieve similar results.

It was often stressed the difference between the correction of reverberation within an interior space and the prevention of transmission of sound between rooms.\footnote{Ibid.} Emphasis was given on gearing the specifications towards a desired reverberation time over maximizing the specific sound absorption coefficient of materials. This allowed flexibility in calculating the surface area and location of treated surfaces. Furthermore, maximizing sound absorp-
tion was not necessarily advantageous: spaces with very low reverberation time (below 0.5 seconds) created unnatural soundscapes that produce psychological distress.

<table>
<thead>
<tr>
<th>Product</th>
<th>Cost per square foot</th>
<th>Sound absorption C₄ 512 Hz</th>
</tr>
</thead>
<tbody>
<tr>
<td>Akoustolith tile as soffit</td>
<td>$1.65 - 3.15</td>
<td>38%</td>
</tr>
<tr>
<td>Akoustolith ashlar*</td>
<td>$3.00</td>
<td>38%</td>
</tr>
<tr>
<td>Akoustolith tile not as soffit**</td>
<td>$0.70</td>
<td>38%</td>
</tr>
<tr>
<td>Akoustolith plaster</td>
<td>$0.35</td>
<td>29%</td>
</tr>
</tbody>
</table>

Table 3.2: Approximate cost per square foot of acoustical treatment.
* Dimensions up to 15 x 30 inches.
** On concrete slabs, masonry, metal lath, etc.

The tile was priced at least 400% more than the plaster, but absorbed an additional third at 512 cycles per second than the plaster (Figure 3.8). Price for bags of Akoustolith plaster depended on the order tonnage. In addition, the company charged for the labor cost of troweling the scratch coat, brown coat, binder coat, and the Akoustolith plaster at approximately $4.00 per square yard. ⁴⁴

They charged more for the installation of Akoustolith tile as a soffit to the Guastavino timbrel arch construction, but the sound absorption was equal on either system, since the bedding mortar behind the tile sealed the pores and rendered all preceding layers unable to absorb sound. (Table 3.2 and Figure 1.1)

The company was typically responsible for supplying, setting, and cleaning Akoustolith surfaces. They refused to install Akoustolith tile on imitations to their timbrel vault construction. ⁴⁵ However, it was not uncommon for architects and builders to use competing acoustical products. For instance, at the Chapel of Intercession (New York City, 1914) and the Fourth Presbyterian Church (Chicago, 1912), Cram, Goodhue & Ferguson specified acoustical products by the Johns-Manville Company alongside Akoustolith stone. The Gymnasium of Smith College (1923, Northampton MA, J.W. Ames E.S. Dodge) featured Akoustolith tile on the ceiling of its swimming pool and Acousti-Celotex on the gymnasium.

⁴⁴Guastavino/Collins Collection, Box 4, folder 1.
⁴⁵Ibid., Box 4, folder 1.
### Table 3.3: Cost per square yard of Akoustolith plaster.
*Source: Box 4, folder 1. Guastavino/Collins Collection*

<table>
<thead>
<tr>
<th>Tons ordered</th>
<th>Price per ton</th>
<th>Cost per square yard $\frac{1}{2}$&quot; thick</th>
<th>Cost per square yard $\frac{1}{4}$&quot; thick</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-20 tons</td>
<td>$150.00</td>
<td>$1.43</td>
<td>$0.88</td>
</tr>
<tr>
<td>20-50 tons</td>
<td>$140.00</td>
<td>$1.33</td>
<td>$0.82</td>
</tr>
<tr>
<td>50-80 tons</td>
<td>$130.00</td>
<td>$1.24</td>
<td>$0.76</td>
</tr>
<tr>
<td>80-100 tons</td>
<td>$120.00</td>
<td>$1.14</td>
<td>$0.71</td>
</tr>
<tr>
<td>100 tons or more</td>
<td>$115.00</td>
<td>$1.10</td>
<td>$0.68</td>
</tr>
</tbody>
</table>

3.9 Competition

Wallace Sabine was known to share his research with the public, and often did not take credit in the commercial products that applied his principles. This altruistic and self-effacing trait of Sabine change when Jacob Mazer ([?]-1954) attempted to patent an acoustical material incorporating Sabine’s published articles and recommendations Sabine gave Mazer two years earlier while addressing the acoustics of a synagogue in Pittsburg.\(^{46}\) Mazer was hoping to patent a felt and commercialize its application with the Johns-Manville Company.

The Johns-Manville Company, seeking to make ammends with Sabine, offered to promote Sabine’s work in architectural acoustics. Sabine recommended to open an acoustics department and place a student of his, Clifford Melville Swan (1877-1951), as head of the division.\(^{47}\) This forced the reissuing of the patent for the Rumford tile that included Sabine’s name.\(^{48}\) Johns-Manville Company created a highly-absorptive felt trade named *Akoustikos Felt*, which would be applied their acoustical products to nearly 800 buildings.\(^{49}\)

The introduction of Akoustolith on the market in the early 1920s led to an explosion of competing acoustical products. These were no longer only felt-and-membrane and board-and-tile systems, but also artificial stones and plasters.\(^{50}\) Johns-Manville was among

\(^{46}\) Thompson, *The Soundscape of Modernity: Architectural Acoustics and the Culture of Listening in America, 1900-1933*, 176.

\(^{47}\) Thompson, “Shaping the Soundscape of Modernity”, 336.

\(^{48}\) Orcutt, *Wallace Clement Sabine: A Study in Achievement*, 243-244.

\(^{49}\) Ibid., 243.

the leading competitors for the R. Guastavino Company, who produced the trade names *Akoustikos* (asbestos felt), their own *Akoustolith* (artificial stone), and *Nashkote*. The Celotex Corporation introduced *Acousti-Celotex* and *Calicel*. Johns-Manville produced *Nashcote* and *Kribble Kloth*. The National Gypsum Company produced *Acoustex* and *Macoustic* plaster. Other products were the *Acoustone*, *Sanacoustic Tile*, and *Sprayo-Flake*.51

After the death of Wallace Sabine, his cousin Paul E. Sabine (1879-1958), who was also interested in architectural acoustics, was hired as a consultant by the U.S. Gypsum Corporation, which sold the competing acoustical plaster *Sabinite*. Interestingly, *Sabinite* was also primarily made of pumice grains but was gypsum-based with dolomite in the aggregate.52 and was patented by the Riberbank Laboratories, Wallace Clement Sabine’s own laboratory.53 In addition to *Sabinite*, the U.S. Gypsum Company commercialized similar acoustical products that were branded as *Acoustone*, *Perfatile*, and *Quitile*.

### 3.10 Data and Standardization

In the 1920s, performance testing of building materials was becoming a standard practice as government agencies began to enforce building codes. With increasing regulations in the Architecture, Engineering and Construction industry, the professionalization of disciplines, and standardization of methods, Rafael Guastavino Jr.’s role changed from master-builder to sub-contractor.54

To convince clients of the effectiveness of Akoustolith, the Company conducted scientific tests on the mechanical and physical properties of Akoustolith (primarily in sound absorption) on the tile, plaster, and the gypsum-based *Plastacoustics*. The results in sound absorption were often graphed as empirical figures included in their advertisements (Figure B.2.1 in Appendix), but the other properties were often excluded from advertisements.

In 1926, Malcolm S. Blodgett (1897-1956) submitted samples of Akoustolith tiles of...
<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
<th>Test Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight</td>
<td>4-5 lbs/$ft^2$</td>
<td>Test by U.S. Bureau of Standards (1926). See Figure 3.8</td>
</tr>
<tr>
<td>Sound absorption</td>
<td>33-59% from C4 to C7</td>
<td>Test by U.S. Bureau of Standards (1926). See Figure 3.8</td>
</tr>
<tr>
<td>Fire Resistance</td>
<td>Incombustible</td>
<td>N/A</td>
</tr>
<tr>
<td>Light Reflection</td>
<td>57.6%</td>
<td>Test on white No. 40 by Incandescent Lamp Department, General Electric Company (1937)</td>
</tr>
<tr>
<td>Compressive</td>
<td>1,000 psi</td>
<td>M.I.T. (1927)</td>
</tr>
<tr>
<td>Strength</td>
<td>525psi</td>
<td>The Thompson &amp; Lichtner Co. (1935)</td>
</tr>
<tr>
<td>Freeze-thaw</td>
<td>Durability less than 5 years</td>
<td>The Thompson &amp; Lichtner Co. (1942)</td>
</tr>
</tbody>
</table>

Table 3.4: Material profile of Akoustolith tile with historical tests.

different grades and a plaster for sound absorption testing to the U.S. Bureau of Standards in Washington, D.C.\(^{55}\) These tests revealed a normal distribution of absorption with highest performance between C4 and C\(_7\) (Figure 3.8). The Bureau of Standards published these results and compiled them with other acoustical products, as well as ordinary materials (Table F.6.23 in Appendix).

The following year, Malcolm Blodgett submitted samples of Akoustolith plaster to the Jefferson Physical Laboratory at Harvard,\(^{56}\) where they were being tested by Clifford M. Swan, the former pupil of Wallace Sabine.

3.11 Application

When Akoustolith was introduced, it was primarily used in the opening decades of the twentieth century in the cathedrals and churches of Cram, Goodhue & Ferguson, where the Akoustolith was laid in horizontal courses of regular heights and variable lengths, imitating the natural stone in the rib-vaulting and the ashlar walls.

The application of Akoustolith peaked in the first years of the Roaring Twenties. Commissions decreased after the Great Depression in 1929, and expanded in building use from religious to secular and utilitarian (institutional, commercial, cultural, infrastructure) (Figure 3.9). Commissions with Akoustolith concentrated in the cities of New York (27), Washington, D.C. (12), Boston (10), Philadelphia (5), Pittsburgh (5), and Buffalo (4). It was

\(^{55}\)Guastavino/Collins Collection, Letter from George K. Burgees to Malcolm Blodgett, April 28, 1926. Box 4, folder 1.

\(^{56}\)Ibid., Box 4 folder 1.
Figure 3.8: Relationship between pitch and sound absorption on different grades of Akoustolith tile and plaster. 
Source: Scatter data points from 1926 test by the U.S. Bureau of Standards. Trendlines and graph by the author.

the preferred acoustical material of the architectural firms of Cram & Ferguson (6 commissions), Bertram Goodhue & Associates (6), York & Sawyer (4), John Russel Pope (4), Maginnis & Walsh (4) and Cram, Goodhue & Ferguson (3). They ranged from the small music room at St. Mark’s school (1919, Bigelow & Wadsworth), to the monumental Buffalo Central Terminal (Fellheimer & Wagner, 1929), the largest installation of Akoustolith tile.
Figure 3.9: Histogram of number of commissions with Akoustolith overlayed on total tile production (including structural and glazed/decorative clay tile) at Woburn Factory. The data on the histogram is organized by date of building completion and categorized by building use. Date of building completion is used as a proxy to estimate the production of Akoustolith tile. The number of tiles differs from project to project.

 CHAPTER 4:  
Cathedrals, Churches and Temples

Akoustolith tile was primarily used in cathedrals and churches, including the two largest religious structures in the United States. This chapter discusses a representative building of religious use with Akoustolith tile: the Cathedral of St. John the Divine (Ralph Adams Cram, 1916-41), the National Cathedral (George Frederick Boodley, Philip Hubert Frohman, 1906-1988), the Church of Notre-Dame (Cross & Cross, 1909-1928), and Temple Emanu-El (Kohn, Butler, & Stein, 1928-1930).

4.1 Cathedral of St. John the Divine

Conceived as the “American Westminster Abbey”, the Cathedral of St. John the Divine (1892-1941) was built on the former site of an orphanage in the neighborhood of Morningside Heights in New York City.1 It was constructed in several phases, spanning almost half a century. The R. Guastavino Company had been involved in the construction since 1898, constructing vaults for a period of 42 years that culminated in 1940.2

The first phase (1882-1907) was carried out in a design by the architecture firm Heins & La Farge. It consisted of a Gothic exterior with Romanesque and Byzantine decoration in the interior. Guastavino’s timbrel arch construction was used at the ceiling of the original great choir and the Byzantine dome resting on pendentives at the crossing. No acoustical treatment was given to the original Romanesque design, creating a very bright and reverberant interior. The choir and crossing were built, but the central nave and west


end of the original design were never executed.

A few years after the death of architect George Lewis Heins (1860-1907), the trustees of the Cathedral made good use of a clause that allowed them to choose a different architect.\(^3\) By that time, the taste of the bishop and the trustees changed from a Romanesque aesthetic to the purer Gothic. They scratched the design of Heins & La Farge and appointed the Boston architect Ralph Adams Cram as Cathedral Architect, who had extensive experience in designing neo-Gothic cathedrals.\(^4\)

Designed in the spirit of a 14\(^{th}\)-century French cathedral, the new scheme called for the reconstruction of the great choir and specified Akoustolith tiles on newer vaults.\(^5\) Cram believed in the honest expression of structure, following the tenets proposed by John Ruskin (1819-1900) and Augustus Pugin (1812-1852). However, the use of an artificial stone that imitated the aesthetics and tectonics of heavy-weight masonry did not represent a problem for Cram.

The vaults with Akoustolith tile required traditional centering and light formwork, so there was no need to use a quick-setting gypsum mortar in the Guastavino assembly.\(^6\) Construction began in 1916 and continued until 1941.

### 4.2 Washington National Cathedral

Designed in the spirit of 14th-century French Gothic, the second largest cathedral in the United States stands on the highest point of Mount St. Alban at the nation’s Capitol. It was designed by architects George Frederick Bodley and Henry Vaughan, and was built in 6 phases for a period that spanned 83 years. Construction began in 1906, a decade before Akoustolith was patented, and concluded in 1988, 27 years after the closure of the R. Guastavino Company.

Faithful to 14\(^{th}\)-century construction methods, the architects specified gray Indiana

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\(^3\)Stern, New York 1900: Metropolitan Architecture and Urbanism 1890-1915, 402.


\(^5\)Douglas Hunt (Organ Curator at the Cathedral of St. John the Divine) in discussion with the author, February 24, 2022.

\(^6\)Murphy, Michiels, and Trelstad, “Forging the link among shape, formwork, and mortar assemblies in Guastavino vaulting”, 153.
limestone for most of the masonry walls, using minimal steel. The roof of the choir was suspended from a hidden truss.\textsuperscript{7}

During its 84 years of construction, the National Cathedral suffered long construction holds. In between bursts of construction, the interiors of newly built sections were left

\textsuperscript{7}T. Robins Brown, \textit{The Cathedral Church of Saint Peter and Saint Paul}, Nomination Form, United States Department of the Interior, National Parks Service May 1974, 5.
exposed to the environment, including those furnished with Akoustolith tile. Religious activities were held, and parishioners noted the deadened space, pleading not to furnish the newer sections of the cathedral with this material.⁸

The Akoustolith was only applied on certain areas, including the ceilings of the crossing, the side aisles, the triforium, the north transept, some walls at the triforium level (Figure 4.1), a few bays of both side aisles of the nave, and at the organ chambers behind the pipes.⁹ Some of these surfaces were decorated by the Art-Deco mural painter Hildreth Meière (1892–1961).

### 4.3 Church of Notre Dame

Located just a block north of St. John the Divine, the Church of Notre Dame (1914-1928, Cross & Cross) was modeled after the Saint-Louis des Invalides (Jules Hardouin Mansart, 1677-1706) and the Pantheon in Paris (Jacques-Germain Soufflot, 1768-1771). It was designed in the French Neo-classical style by the firm Cross & Cross. The church enclosed an older chapel built in 1909 and designed by Daus & Otto.¹⁰ The church was the only religious building by Cross & Cross.¹¹ Its original scheme called for a crowning dome featuring a colonnade at its drum, surmounted by a statue. This was never built.¹²

The interior was furnished with colossal marble columns from which arches sprung, creating a barrel vault at the altar and pendentives that support a central dome. The R. Guastavino Company was hired in March 31, 1914 to erect the central dome, a barrel vault at the church sanctuary, the ceilings of the basement, a tympanium over the altar, and an exterior semi-circular apse at a cost of $23,600.¹³ The basement was furnished with

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⁸Douglas Hunt (Organ Curator at the Cathedral of St. John the Divine) in discussion with the author, February 24, 2022.
¹²Huckins, *Church of Notre Dame and Rectory*, 2.
¹³Guastavino/Collins Collection; Huckins, *Church of Notre Dame and Rectory*, Letter from The Norcross Brothers Co. to R. Guastavino Co., March 31, 1914.
Rumford tile\textsuperscript{14} while the central dome and barrel vaults with Akoustolith tile (Appendix S). The Akoustolith was laid in varying sizes (4”, 6”, and 8” wide) and colored to match the caen stone of the walls below. At the pendentives, four sculptural angels crowned a simplified medallion set with Akoustolith tile (Figure 4.2).\textsuperscript{15}

\textbf{4.4 Temple Emanu-El}

If St. John the Divine was the largest cathedral in America, Temple Emanu-El (New York City, 1928-30) was meant to become the largest synagogue. Designed in the Romanesque Revival, Architects Clarence Stein (1882-1975), Robert D. Kohn (1870-1953), and Charles Butler (1871-1953) paid special attention on the acoustical treatment.

Guastavino Jr. worked with the Art-Deco muralist Hildreth Meière, an artist whom Guastavino previously collaborated at the National Academy of Sciences and the Nebraska State Capitol. Meière covered the walls of the sanctuary and the main arch with decorative

\textsuperscript{14}Guastavino/Collins Collection, Letter from The Northcross Brothers Co. to R. Guastavino Co., December 11, 1914.

\textsuperscript{15}Ibid., Letter from Lewis P. Fluhrer to R. Guastavino Co., June 20th, 1920.
mosaics. Guastavino finished the central dome, the sanctuary arch, and most of the walls with Akoustolith tile, where it was set in portrait and within a grid of metal-strip jointing (Figure 4.3). This detailing would be later employed in office lobbies (Figure B.2.12 in Appendix).

In treating the acoustical environment, a felt was introduced behind the Akoustolith walls. Drawings indicate that the Akoustolith tiles were meant to be pigmented in shades of brown from the lighter ones near the floor to darker tones near the ceiling, so as to produce a mysterious aura that evoked the Seven Heavens. However, the actual arrangement of the tiles was randomized. Detailing on the stone was reduced to a minimum, since the acoustical performance was more important than decoration.

The Akoustolith walls at Temple Emanu-El impressed the German architect Jacob W. Sherman (1881-[?]), who was on the Building Committee for a new Manhattan Beach Jewish Center in the Modern style. Conceived as one of the first Modernist synagogues, the new center would embody principles of the Bauhaus, departing from the traditional European synagogue. The R. Guastavino Company would later furnish its ceilings with Akoustolith tiles in half a dozen colors to create a light scheme at the interior walls.

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18 Guastavino/Collins Collection, Letter from Jacob W. Sherman to Malcolm Blodgett, September 17, 1951.
19 National Register of Historic Places Registration Form for Manhattan Beach Jewish Center, prepared by Anthony Robbins. Available online at https://npgallery.nps.gov/GetAsset/e23ef217-b7b7-4e1e-86df-599e3110286a
20 Ibid.
Figure 4.4: Half elevation of the sanctuary arch at Temple Emanu-El with Akoustolith tiles (magenta) in metal strip jointing.
Source: Guastavino/Collins Collection.
CHAPTER 5:
Civic and Institutional Projects

The Akoustolith imbued a soundscape of clarity, deliberation, and rationality to civic spaces. A representative commission for government and institutional use of Akoustolith is discussed: an academy of sciences, a capitol building, a museum gallery, a seminary, and a legislative chamber.

5.1 Triumvirate: Bertram Goodhue, Rafael Guastavino, and Hildreth Meière

The history of decoration goes back to the beginnings of recorded civilization, whether as murals in caves or carvings in rock.

—Richard Guy Wilson, in The Art Deco Murals of Hildreth Meière

Having been called "the Greatest of American Gothicist", architect Bertram Grosvenor Goodhue (1869-1924) did not believe in adhering to a particular style. Unlike his partner Ralph Adams Cram, Goodhue found styles too constraining for creative invention. Whether it was the inevitable verticality of the neo-Gothic or the rigid symmetry of French classicism, they predetermined language and form. Goodhue advocated for a type of Gothic that was massive and simplified. This was evident in his design submission for a Cadet Chapel at West Point (1911), where Akoustolith and the cohesive-tile construction eliminated the need for buttressing. Goodhue searched for creative invention, and this led to a rupture from his partners Ralph Adams Cram and Frank Ferguson (1861-1926).

Goodhue believed in a collaboration between architect, painter, and stone-maker on equal terms. In a letter (Unknown date) to the Philadelphia architect Paul Philippe Cret

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(1876-1945), he wrote:\textsuperscript{2}

\begin{quote}
\textit{I should like to turn the ornament (whether sculpture or not makes no difference) over to a perfectly qualified sculptor, and the colour and surface direction (mural pictures or not as the case may be) to an equally qualified painter. I grant it is hard to find such. I do think I know the sculptor, and I have not yet despaired of finding the painter.}
\end{quote}

It was a fortunate circumstance for Goodhue to encounter the artistic spirit of Hildreth Meière and the inventive entrepreneurship of Rafael Guastavino Jr. In 1921, Goodhue met Meière, then a twenty-nine-year-old muralist who was trained in the Beaux-Arts, a rare education typically reserved to men. Goodhue sought to bring Meière’s sensible and inventive decoration using Guastavino’s Akoustolith as an artistic medium.

\section*{5.2 National Academy of Sciences}

When Goodhue was commissioned to design the National Academy of Sciences (Washington, D.C., 1922-24), he reluctantly adhered to the neoclassical language imposed by the McMillan Plan of 1901-2 and the strict guidelines imposed by the Commission of Fine Arts.\textsuperscript{3} To comply with the classical grammar of the nation’s Capitol, he proposed a Greek cross in plan. The elevations were articulated in what Goodhue called an "Alexandrian" style: an ahistorical term that merged Greek and Egyptian motifs.\textsuperscript{4} The ambiguity of the term referred to no archaeological precedent, and effectively made it difficult to criticize.\textsuperscript{5}

This move gave Goodhue some artistic leeway on the exterior. However, it was the interior where freedom was enjoyed. The Great Hall, centered within the Greek cross plan, was articulated in a Byzantinian dome resting on pendentives (Figure 5.1). Neither the Great Hall nor any of the interior spaces featured any columns, pilasters, vaults, ribs, or cornices that referenced a particular style.


\textsuperscript{5}\textit{Ibid.}, 45.
Acoustics was of great importance at the Great Hall. Conceived as a space for lectures, it was essential that the space delivered clarity of speech and an even distribution of sound.\(^6\) The ability to control the soundscape would be a clear statement of the scientific mastery over the laws of nature.

Guastavino was initially asked to cover the dome with Akoustolith plaster.\(^7\) The plaster, however, proved too expensive. Given its lower sound absorption coefficient at 512 cycles compared to the tile (Figure 3.8), it would have required greater surface area of exposed and untreated plaster, restricting any possible decoration beyond mere spray-painting. The tiles, by contrast, allowed Meière to cover as much as 50% of the surface area of the tile. To fund for the Akoustolith tiles, the Building Committee reallocated funds from furniture.\(^8\)

The National Academy of Sciences was first large commission. She proposed a series

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\(^7\)Ibid., 16.
\(^8\)Ibid.
of artistic decoration narrating the history of science at The Great Hall. A limited budget
prevented to use glazed ceramic tiles of varying shapes inset within the matrix of Akous-
tolith. As an alternative, Goodhue requested to instead cover the Akoustolith surface with
raised gesso—a mixture of calcium carbonate and glue, which proved to be a challenging
medium. The gesso was then painted and gilded. The effect was to simulate a finish of
glazed ceramic tiles from the ground floor.

After the successful work at the National Academy of Sciences, Goodhue entrusted to
decorate the ceilings of the Senate Chamber and the Hall of Representatives at the Nebraska
State Capitol.

5.3 Nebraska State Capitol

A more generous budget enabled the use of glazed ceramic tiles for the designs by Meière.
She specified custom-glazed tiles to the Woburn Factory.

The Capitol project made use of all the available acoustical products offered by the R.
Guastavino Company. Akoustolith plaster was applied to the four domes of the Supreme
Court Law Library. The Rumford tile was specified at the corridors, probably used from
a surplus at the Woburn Factory and sold at a lower cost than the Akoustolith tile.

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10For a full description of the design process and the iconography of the dome and pendentive at the Great Hall, see
11Ibid., 43.
12Guastavino/Collins Collection.
Great Hall

The dome at the Great Hall was covered in Akoustolith tile, serving as a matrix where glazed ceramic tiles were inserted and flushed. Just like at the National Academy of Sciences, the glazed ceramic tiles could only cover as much as half of the total surface area of the Akoustolith to preserve the degree of sound absorption.\(^{13}\) resolved this by consolidating her work in multiple vignettes (Figure 5.2).

The dome at the Great Hall had a radius of 19'-0" to the finish tile. Four courses of rough tile were supported with a metal lath behind and concentric reinforcing rods of \(\frac{1}{2}\)" and \(\frac{3}{4}\)" at different elevations.

Memorial Hall

The decoration scheme of the ceilings at Memorial Hall evoked the evening sky.\(^{14}\) Guastavino specified the Akoustolith to be pigmented in light blue and cut into different shapes to resemble a cloudless sky with gilded rays running down the apex to represent the sun. Its walls were furnished in black marble-Black Belgian, Italian Porto Oro, and Vermont

\(^{13}\) Brawer and Skolnik, The Art Deco Murals of Hildreth Meière.

Verde Antique.

Following Bertram Goodhue’s death in 1924, the collaboration between Meière, Guastavino Jr., and the succeeding firm of Bertram Goodhue Associates continued at the University of Chicago Chapel (1928, today known as Rockefeller Chapel) (See ad in Appendix). Goodhue himself designed the chapel in 1919 but never saw it completed. Building on her success at the Nebraska State Capitol, set glazed ceramic tiles within the Akoustolith tiles
at the vaulted ceilings with great skill.\textsuperscript{15} \textit{Sabinite} plaster from the U.S. Gypsum Company was used on the walls.\textsuperscript{16}

The flexible budget for the Chapel enabled to execute her designs in glazed Guastavino tiles, many of which were gilded. enriched the transverse ribs of the nave with panels and medallions representing 14 subjects of study: Bird, Beast, Fish, Reptile, Sun, Moon, Star, Tree, Flower, Man, Earth, Air, Water, Fire.\textsuperscript{17} Her last project with Guastavino Jr. was at the Mary Immaculate Center (Northampton, PA; 1939).

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{figure5.4.png}
\caption{Section through roof at the Egyptian Wing with Akoustolith tile as soffit (magenta). Source: Guastavino/Collins Collection.}
\end{figure}

\section*{5.4 Egyptian Wing, University of Pennsylvania Museum}

Plans for a University Museum were drafted in 1892 when the archaeological collection outgrew the limited space at Fisher Fine Arts Library.\textsuperscript{18} The construction of the University

\begin{footnotesize}
\begin{itemize}
\item \textsuperscript{15}Brawer and Skolnik, \textit{The Art Deco Murals of Hildreth Meière}, 82.
\item \textsuperscript{16}Reinhold Martin, “The Dialectic of the University: His Master’s Voice”, \textit{Grey Room} no. 60 (Summer 2015), 82–109.
\item \textsuperscript{17}Edward Goodspeed, \textit{The University Chapel}, (Chicago, Illinois: University of Chicago Press, 1921), 8.
\item \textsuperscript{18}Alexandra Fleischman Alessandro Pezzati Jane Hickman, “A Brief History of the Penn Museum”, \textit{Expedition Magazine} 54, no. 3 (Summer 2012), 8.
\end{itemize}
\end{footnotesize}

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Museum was phased in multiple periods, each successive campaign responding to financial support and demands for more space.

The original design for the Museum was conceived by Philadelphia firms Cope & Stewardson and Frank Miles Day under the lead of architect Wilson Eyre (1858-1944). Funds allowed for an initial phase of construction from 1893 to 1899.

In 1910, Vice President Charles Curtis Harrison (1844-1929) made great efforts to build the central Rotunda, an auditorium, and the Egyptian Wing, the next phases of the original master plan. Construction for the Rotunda and Auditorium began in 1913, but the Egyptian Wing had to be postponed. The dome of the rotunda, spanning an impressive 90 feet, was furnished with Rumford tile.

The Egyptian Wing was completed in 1922. The construction of the Egyptian Wing followed the design of the same team of architects, this time with slightly different names: Wilson Eyre & Mellvaino, Stewardson & Page, Day & Klauder.

5.5 New Delhi Legislative Chamber

In the early 1920s, the R. Guastavino Company was invited to bid for finishing the dome of the new Legislative Chamber in New Delhi with an acoustical treatment. Under the master planning of Sir Edward Lutyens (1869-1944), the Parliament Building was designed by Sir Herbert Baker (1862-1946), who was a close friend of Bertram Goodhue.

Unlike previous commissions, the R. Guastavino Company was not hired to construct the dome of the Legislative chamber, but to merely supply their acoustical tiles. In designing the ceiling for the Legislative Chamber, Baker was reluctant of the presence of joints in the Akoustolith tiles, and preferred a smooth, continuous surface. He considered plaster products from competing companies, including the Sabinite. To win the bid, William Blodgett suggested a lime jointing mortar that blended with the Akoustolith tile. Baker

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19 Alessandro Pezzati, *The First Century of the Harrison Rotunda*.
was not convinced and preferred the uniform and neutral finish of *Sabinite* gypsum plaster.  

The relationship between William Blodgett and Herbert Baker was increasingly fraught in mutual mistrust. Baker was not convinced of the veracity of the scientific data in the marketing material of the R. Guastavino Company. He was skeptical of the ability of the Company to manufacture, supply, and install the Akoustolith at the Legislative Chamber and pushed the government of India to demand the British government to establish an independent factory in England.

Baker’s desire was conceded in 1923, when the government of India officially requested the British Government by way of the Department of Scientific and Industrial Research (DSIR) to investigate the acoustical problems at the Assembly Chamber in the newly built

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22. Vegas and Mileto, “Guastavino in India”.  
A new research center and a laboratory was established under the direction of Henry Owen Weller (1880-1948) and named the Building Research Station (BRS). Some of the earliest work of the BRS studied the behaviour of reinforced concrete, and the development of the British Standard for bricks.

To verify the scientific data that the R. Guastavino Co. promoted, the British Building Research Board was asked to perform acoustical tests on both the Sabinite plaster and the Akoustolith tile. Fearing that the R. Guastavino Company would lose the contract, the company adapted the original composition to formulate a material that could be sold as powder and effectively troweled. It was patented two years later in December 1925 (U.S. Patent No. 1,563,846).

Akoustolith plaster, and the subsequent development of a gypsum-based casting product named "Castacoustics" enabled the construction of continuous surfaces with acoustical treatment, regardless of the presence of moldings with enriched motifs.

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26 Ibid.
28 Vegas and Mileto, "Guastavino in India".
CHAPTER 6:
Commercial Projects

The Akoustolith advanced productivity, efficiency, and well-being in commercial interiors. Office workers could now ignore the mumbling of their fellow co-workers in open-floor spaces. Banks were able to quiet the clickety-clack of typewriting and the ringing of telephone bells. Swimmers could understand the instructions given by their coaches. Patients could find tranquility in the quietness of hospital hallways. This chapter discusses four representative commissions of commercial character: an office building, a Federal Reserve building, a swimming pool, and a hospital. The last project discusses the technical advantages of the plaster variant over the tile.

6.1 Iron and Steel

The integration of iron and steel in building construction was among the most important innovations since antiquity. The 1871 Chicago Fire was an opportunity for architects William Le Baron Jenney (1832-1907), Burnham and Root, and Louis Sullivan (1856-1924) to rebuild the old city with iron and steel. The opening decades of the 19th century saw a wide adoption of the concrete slab over a steel frame, placing the Guastavino system at odds with innovative ways of construction. The patented timbrel arch construction was unable to compete as a structural system, so it was increasingly seen as a decorative finish with sound-absorbing qualities (Figure 6.4).

The 1920s marked a turning point in the nature of commissions with Akoustolith (Figure 3.9). The tile and plaster were increasingly used for utilitarian and secular buildings, including commercial lobbies, banks, auditoriums, libraries, museums, classrooms, courthouses, laboratories, natatoriums, memorials, and railroad stations.
6.2 Salmon Tower

The Salmon Tower (1927), located north of Bryant Park at West 42\(^{th}\) street in New York, was designed by Joseph Kleinberger, who worked for architects Edward York (1865-1928) and Phillip Sawyer (1868-1949). At the vestibule and first-floor corridors, York & Sawyer specified Guastavino vaults. The ground lobby opened to the streets of New York, exposing the Akoustolith to an exterior environment.

Unlike previous commissions with cohesive tile construction, the vaults were installed after the steel frame and concrete slabs were in place. The underside of the concrete floor slab was connected to the Guastavino vault by I-beams, with the upper flange buried in the concrete slab and the lower flange resting between layers of structural clay tiles, with Akoustolith furnished at the soffit (Figure 6.1). It is worth noting that the I-beams supporting the Guas-

![Figure 6.1: Detail drawings of the vestibule at the Salmon Tower with Akoustolith tile (magenta). Source: Advertisement in Sweet’s Architectural Catalogue (1939).]
tavino vault were redundant, as
the system was self-supporting. The connection, however, may have addressed concerns
from structural engineers or the spatial limitations of an office building where a Beaux-Arts
architect wished to maximize a public interior space for monumental effect.

6.3 Federal Reserve Bank of New York

The First World War had caused a short recession in 1918–19, and confidence in the Amer-
ican economic institutions was dwindling. To ameliorate this, the Department of Treasury
wanted to communicate confidence and economic security in the design of several branches
of the Federal Reserve. These buildings were often modeled as Florentine palazzos from
the Italian Renaissance to project security and institutional stability. The New York firm of
York & Sawyer were prepared to deliver such aesthetics.

The Department of Treasury, functioning as a supervising architect, wished to quiet
the activities within the banking spaces on new branches of the Federal Reserve in Boston,
New York, Philadelphia, Lousville, and Richmond. The noise produced by typesetting and
ringing of bells was a detriment to productivity, and so the Akoustolith was ideal to absorb
the high-pitched noises (Figure B.2.6) At the main banking room of the New York City
branch (York & Sawyer, 1919), the Akoustolith tiles were randomized in color and used in
connection with stone ribs in groin vaults.

6.4 Natatorium, Smith College

Akoustolith tile and plaster were applied in natatoriums, shower rooms, steam kitchens,
and other interiors with damp conditions in schools, colleges, clubs, and the like. The
moisture-resistant property of the Portland cement made the Akoustolith a preferable
choise to the gypsum-based Sabinite and other related products, since these dissolved on
the presence of moisture.¹

In these damp interiors, water vapor tends to condense when the temperature drops to

MS Thesis Columbia University Graduate School of Architecture, Planning and Preservation 2015, 48.
the Dew Point, creating droplets of water on smooth walls and ceilings. The porous fabric of the Akoustolith tile and plaster allowed moisture to flow through the void matrix and reduced the formation of droplets.

The construction of the ceiling at the natatorium at Smith College was entirely based on the Guastavino system (Figure 6.2). 4-inch thick dwarf bridge walls spaced at 25 inches on center leveled the flat surface of the floor slab above, helping distribute the loads to the Doric arcade. These dwarf walls created channels that were ideal for running heating and
ventilation ducts. The vaulted ceiling at the natatorium served two practical purposes: it supported the floor slab above while quieting the activities at the swimming pool below (Figure 6.2).

![Figure 6.3: Akoustolith applied underneath a slab and laid in the herringbone at the Harris-Forbes Banking Building in Boston, MA. Executive offices of Lockwood, Greene & Co., Architects and Engineers. Source: Advertisement in Architectural Forum (June 1923)](image)

6.5 Offices and Schools

The Akoustolith tile was nailed under concrete slabs in office interiors and classrooms. This occurred as early as 1923, when the Akoustolith was specified to be nailed on the underside of a slab at the Harris Forbes Banking Building in Boston, MA (Figure 6.3). The Westwood Senior High School (Coletti Brothers, 1956-57) featured Akoustolith stone bonded with a bedding of Portland cement mortar underneath a concrete slab (Figure 6.4)

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6.6 Hospitals

Akoustolith plaster absorbed a higher spectrum of sound frequencies compared to the tile (Figure 3.8). The tile was ideal for spaces with musical programming, such as churches, auditoriums, and theatres. The Akoustolith plaster, by contrast, was preferred in broadcasting studios, hospitals, and courthouses, where it was most efficient at absorbing the higher pitches. This was probably due to smaller grain sizes in the plaster variant and the cross-section thinness of the plaster (a quarter of the 1-inch thick tile).

It was in hospitals where the Akoustolith plaster enjoyed its greatest success. Architects Edward Fletcher Stevens (1860–1946) and Frederick Clare Lee (1876-1936) from Stevens & Lee specified the plaster on at least 4 different hospitals. The Akoustolith plaster was effective at diminishing the noise of slamming doors, conversations from across hallways, and the clatter of utensils and dishes. Furthermore, the use of Portland cement made it washable, a necessity for sanitation protocols.
Figure 6.5: Difference in sound absorption between Akoustolith stone (Line 1), Plastacoustics at 1/4" thick (Line 2) and Plastacoustics at 1/2" thick (Line 3). C3 corresponds to middle C on the piano.

Source: Line 1 corresponds from an advertisement on Akoustolith tile in *Pencil Points*. Line 2 corresponds to results from the Bureau of Standards in 1926. Line 3 corresponds to results from Jefferson Laboratory at Harvard. All results available in Box 4, Folder 1, Guastavino/Collins Collection.

Diagram by author.
CHAPTER 7:
Infrastructure

The Akoustolith mitigated the noise pollution of modern society. Railroad companies could quiet the mumbling and foot tapping of patrons wandering on public concourses. Municipal authorities were able to contain the noise of vehicle engines in underground tunnels. Companies could dampen the noise of chimneys on industrial facilities.

This chapter discusses three representative infrastructure commissions with Akoustolith tile: a railroad terminal, a vehicular rotunda, and a pedestrian underpass. It then addresses the application of Akoustolith in industrial flues and airplane hangers, concluding with a discussion on the role of the acoustical line in the decline of the R. Guastavino Company after the Second World War.

7.1 Buffalo Central Terminal

The golden age of the railroad drew to a close as the 1920s gave way to the 1930s. Despite the decline of the use of the railroad, the New York Central Terminal constructed a new monumental station in the city of Buffalo between 1927 and 1930. Dubbed the “Queen City the Great Lakes”, Buffalo was already an industrial node that connected the Great Lakes and the Atlantic Ocean through the Eerie Canal.¹

The terminal was designed by the regional firm of Fellheimer & Wagner, who were experienced in designing railroad stations. It was among the last of a series of monumental railroad stations that responded to a bygone era of transportation. Designed in the Art Deco style, the Buffalo Central Terminal recalled the aesthetics of traditional classicism: monumental vaulted spaces and an emphasis on symmetry, repetition, and proportion.

¹Claire L. Ross, New York Central Terminal Complex, Buffalo, Erie County, Nomination Form, National Register of Historic Places Nomination Form Aug. 1984, Item 8, page 2.
However, the station did not echo the soundscape of Roman imperial baths, present at Union Station in Washington D.C. (Daniel Burnham, 1908); the Pennsylvania Railroad Terminal (McKim, Mead & White, 1910) or the Grand Central Terminal (Reed & Stem; Warren & Wetmore, 1913) in New York City.

![Figure 7.1: Half cross section of the passenger concourses with Akoustolith tile on the vaulted ceilings (magenta), Buffalo Central Station, Alfred Fellheimer and Steward Wagner, Architects. Source: Fellheimer & Wagner architectural drawings of railroad stations in the United States and Canada, 1915-1931, Avery Architectural and Fine Arts Library, Columbia University.]

While the decoration of the terminal was Art Deco, the massing and spatial arrangement referenced Ancient Roman architecture. There were no classical columns or cornices, but the spaces were monumental and arcuated, much like the imperial Roman baths. The Baths of Caracalla (AD 216) and Diocletian (298 AD-306 AD), which informed the design of McKim, Mead & White’s Pennsylvania Station (1910) and Reed & Stem’s Grand Central Terminal (1913), indirectly influenced the design of the Buffalo Central Terminal. The Roman imperial bath was efficient at handling the circulation of large groups between
interiors, and so it was seen as appropriate model for the modern railroad station.

Special attention was given to quieting the monumental concourse. The foundation columns were laid on vibration mats made of layers of asbestos and lead, mitigating the transmission of vibration from the trains below. The marble floors were placed on top of 2-inch cork slabs. The six-story barrel-vaulted concourse and the upper interior walls were clad in Akoustolith tile (Figure 7.1). The use of coffers on the vaulted ceiling helped in mitigating focusing of sound. The floors and the wainscotting were finished with hard and reflective materials: polished Botticino marble that imitated the decorative patterns of the Roman Pantheon.

The terminal was among the last railroad stations of traditional forms in America when air travel became the dominant form of inter-state travel in the ensuing decades. Furthermore, the 1932 International Style exhibition at the Museum of Modern Art, organized by architect Philip Johnson (1906-2005) and architectural historian Henry-Russell Hitchcock (1903-1987), marked a turning point in what architects desired: an increasing preference for clean, horizontal surfaces expressed in clear honesty of material (predominately steel and glass). Theorists and critics often denounced the theatricality and falsity of plaster vaults hung from hidden trusses. This philosophy may have been at odds with the aesthetics of traditional masonry of the Guastavino system, despite expressing honesty in tectonics and structure. Yet, most of the domes and vaults associated with the Beaux-Arts and Art-Deco movements were plaster or cast concrete hung from steel trusses, and so a disdain for domes and vaulting was generalized.

After the 1929 financial crash of Wall Street, architects were no longer designing for private corporations. Unemployed, they found themselves at the mercy of public projects. Franklin Delano Roosevelt’s New Deal funded public work projects through the Civil Works Administration (CWA). Trends in building construction shifted from commercial architecture to public projects. Like many architects, the R. Guastavino Company was now building for government-funded infrastructure projects.

2Ross, New York Central Terminal Complex, Buffalo, Erie County.
3The last train was pulled in 1979 and in the following years the owner went bankrupt, transferring ownership to the Central Terminal Restoration Corporation.
7.2 79th Street Rotunda

The 79th Street Rotunda (1937) and Boat Basin was the crowning jewel of what Parks Commissioner Robert Moses (1888-1981) envisioned for the west side of Manhattan as a young Yale graduate.4 He imagined a combination of a marina, a riverside restaurant, and a pedestrian promenade overlooking the Hudson and the Palisades. It was part of a larger development known as the West Side Improvement project that would eventually extend from 72th street to the Riverdale in the Bronx. The improvement called for extending the waterline and cover the existing New York Central railroad tracks with a promenade.5

The original design of the complex was outlined by McKim, Mead & White. Robert Moses and his architectural engineer Clinton Lloyd revised it to feature a sunken plaza underneath a vehicular roundabout. The open-air plaza was free of views from the highway above, and a central fountain precluded the noise from vehicles above.

The concrete rotunda was surrounded by a vaulted arcade finished in Guastavino acoustical tile (Figure 7.2 and Figure 7.3). The R. Guastavino Company worked with engineer Michael John Madigan (1894-1981), president of the Madigan-Hyland Consulting Engineers for the West Side Improvement in New York City.

The son of an Irish impoverished bartender, Michael "Jack" Madigan entered the construction industry at the age of thirteen. He rose through the ranks of construction gangs until he became a personal aide to Moses. Moses found in Jack a financial intelligence and business shrewdness, and Jack was charged with negotiating with Wall Street bankers to sell bonds to fund a toll highway on the Hudson River. This earned Jack public contracts for Long Island projects, making him a millionaire.

Figure 7.3: Typical section for a rotunda bay with Guastavino vaults finished in Akoustolith (magenta), 79th street rotunda. Source: Guastavino/Collins Collection.


For a full discussion on the role that Madigan played in financing the construction of the West Side Improvement by selling bonds from the Hudson River Parkway Authority to Wall Street bankers, see *ibid.*, 535–539.
7.3 Pedestrian Underpass

Jack Madigan’s engineering firm, Madigan-Hyland, enjoyed multiple contracts from Robert Moses, including the construction of major bridges, highways and other public projects that spanned four decades. Madigan entrusted the R. Guastavino Company to install and furnish Akoustolith arches for pedestrian underpasses north of the West Side Highway in Manhattan (Figure 7.4). On both the 79th street rotunda and the pedestrian underpasses, the Akoustolith was applied on an exterior environment and attached to a system of poured concrete, much like the Salmon Tower (1927, York & Sawyer).

![Figure 7.4: Section through a concrete bridge with Akoustolith soffit (magenta). Source: Akoustolith Sales Manual, Guastavino/Collins Collection.](image)

7.4 Ventilation Units, Industrial Flues, and Military Facilities

The Akoustolith was also used in other projects commissioned by Robert Moses to Madigan-Hyland, including the vehicular Brooklyn-Battery tunnel (1944-48), the New Jersey ventilation units (1955-56) and ceilings for the third tube of the Lincoln Tunnel (1954), as well as the ventilation units for the George Washington Bridge (1949-51).

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The industrial use of Akoustolith extended in military facilities in the United States. The effectiveness of the Akoustolith in quieting stacks, flues, and other industrial fixtures demanded it to be cast in shapes with special jointing to create unitized assemblies (??). The Akoustolith was not only able to attach as tiles on concrete walls, but was now cast into full modules that interlocked to create chimney flue walls. These walls of Akoustolith were

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**Figure 7.5:** Installation details for flue quieting ribbon wall construction.  
*Source: Akoustolith Sales Manual, Box 4, Folder 2, Guastavino/Collins Collection.*
secured with I-beams and special channels. The modules of Akoustolith were bonded with acoustical cement (Figure 7.5), ensuring its cohesiveness.9

The same year Nazi Germany annexed Czechoslovakia in 1938, the Hamilton Standard Propeller Company, an American aircraft manufacturing company that would later provide propeller parts for the Allies, had requested the installation of Akoustolith in its new facility in East Hartford, Connecticut. In 1941, the U.S. Navy commissioned the construction of a major naval facility in a small peninsula in Narragansett Bay, Rhode Island. Akoustolith was applied in quieting exhaust and intake stacks in airplane engine test houses.10


10Ibid.
7.5 Airplane Hangars

Towards the end of his life, Guastavino Jr. continued to make the case for vaulted spaces, despite the prevalence of concrete and steel frame construction that generated orthogonal spaces (Figure 7.6). He continued to design airship hangars with Akoustolith tile. In these spaces, Guastavino Jr. imagined that the high-pitch noise generated from the propulsion systems, undesired noise for the individuals boarding and disembarking, could be reduced with the Akoustolith.

7.6 The End of an Era

In the 1930s, the emergence of the International Style, the rising costs of hand labor, the introduction of thin-shell concrete, and the Great Depression, the Guastavino system went into disfavour. Akoustolith still enjoyed wide adoption, but increasingly divorced from the cohesive tile system. The R. Guastavino Company was moving away from master builders of domes and vaults to mere suppliers of tiles.

The introduction of electro-acoustical systems from the experimental stage to the market in the 1930s rendered the Akoustolith in ecclesiastical spaces obsolete. The Chapel at Girard College (Philadelphia, 1931-1933) was among the first large interiors to employ an electro-acoustical system alongside Akoustolith tile as part of their design. The tile was specified for the clerestory walls of the main auditorium, rising from the base of the columns to the slope of the ceiling. (Figure B.2.10) It was tinted in buff to match the Indiana limestone. Clifford M. Swan, the M.I.T. physics professor and former pupil of Sabine, was the acoustics engineer.

The professionalization of the building trades meant that the architect was no longer responsible of construction. The R. Guastavino Company went from being master builders to mere sub-contractors, closing its branches and consolidating in the Woburn Factory.

12 Walter H. Thomas and Sydney E. Martin, “The Girard College Chapel, Philadelphia”, Architectural Record 73, no. 6 (June 1933), 382.
13 T. F. Bludworth, “The Electro-Acoustical System in the Girard College Chapel”, Architectural Record 73, no. 6 (June 1933), 385.
CHAPTER 8:

Petrified Sponges:

Material Analysis

In the knowledgeable realm, the form of the good is the last thing to be seen, and it is reached only with difficulty.

— Plato, Parmenides

The the interconnection of voids in a matrix of uniform or well-graded aggregate is the defining characteristic of the Akoustolith tile and plaster. This property makes it similar to pervious concrete, porous asphalt, pumice-crete, and related porous cast-stone products. To distinguish Akoustolith tile and plaster from materials of similar composition and microstructure, a discussion on the essential and secondary properties is discussed. The sample collection from 5 representative commissions is discussed, followed by findings in three tests: water absorption, particle size distribution by acid digestion, and compressive strength. The chapter ends with an interpretation of petrographic analysis from specimens of Memorial Hall at the Nebraska State Capitol and the Egyptian Wing at the Penn Museum.

8.1 Definition

The U.S. Patent 1,197,956 states that Akoustolith tile is at its essence a network of voids created with uniform grains that touch at points of contact (Figure 8.1). This creates an interconnected network of air capillaries that absorb the vibration of air molecules at specific frequencies, transforming their kinetic energy into heat as the waves of air vibration "bounce" across the network. The result is that subsequent reflections are lower in energy, decreasing the reverberation time. Grain size is proportional to void size; this
then determines the range of frequencies absorbed.\textsuperscript{1} Larger well-graded grains increase the void size, targeting frequencies of longer wavelength (lower pitch).

The defining properties of Akoustolith are:

- interconnected pores at close points of contact,
- well-graded particles of angular shape,
- expansion and contraction of pore channels that absorb a range of sound frequencies

Secondary attributes that are not discussed in the patent, but are evident in actual specimens include:

- Portland cement as a binding medium,
- a lightweight aggregate (usually Italian pumice),
- a lightweight product
- cement pigments,
- texturing of the finishing surface (Figure 8.2),
- use as a soffit tile in the larger Guastavino assembly,
- the manufacture in standardized sizes 3x6, 3x12, 4x8, 5x10, 6x12, 6x15, 8x16, 10x20, and 12x20 inches at 1 inch or 7/8 of an inch in thickness
- the grading of aggregate from large to small from the finishing surface

The patent does not discuss geometric shape, so the material is an amorphous medium that takes the shape of its mold. The Akoustolith was cast in standardized dimensions of 3x6, 3x12, 4x8, 5x10, 6x12, 6x15, 8x16, 10x20, and 12x20 inches. These tiles were usually 1 inch, $\frac{7}{8}$ inch, or $\frac{3}{4}$ inch thick. They weighed on average 4 pounds per square foot (Table 8.1). The large ashlar tiles for wall installation could be as large as 30x60 inches, from 1.5

Figure 8.1: Micro-CT scan of Akoustolith from Cathedral St. John the Divine in New York City. Density is visualized by white intensity. Portland cement (denser) coats light-weight pumice grains (porous). Photo courtesy of the McKay Orthopaedic Research Laboratory, Perelman School of Medicine, University of Pennsylvania. (Scale: 3/4” width of image)

to 2 inches thick, weighing 5 pounds per square foot. Certain commissions called for large ashlar tiles installed on walls, not unlike thin stone veneer. In these instances, the ashlars

2J. Ralph Dalzell and James McKinney Air Conditioning, (Chicago: American Technical Society, 1937); Vegas and Mileto, “Guastavino in India”, 49–50,
could be as large as 30x60 inches, from 1.5 to 2 inches thick, weighing 5 pounds per square foot. Thicker tiles increased the sound absorption coefficient at the expense of increased weight and price of production.

The composition was not restricted to Portland cement nor pumice. The binder could also be lime or gypsum. The aggregate could be crushed rock, brick, or natural sand, as

\cite{RichardPoundsWeaver.2011}
is observed from specimens from Buffalo Central Terminal (BCT.T1) and Nazareth Hall, University of Northwestern (NH.T2). However, pumice was preferred as an aggregate for its low weight and angularity of the grains. Portland cement was preferred to gypsum for its compressive strength and stability under damp conditions, a condition necessary for its application in the ceilings and walls of natatoriums, baths, kitchens, and other interior damp spaces.

**Akoustolith Tile**

The Akoustolith tile was manufactured at the Woburn Factory. William Blodgett specified Italian pumice stone as aggregate and Portland cement as the binder. Pumice particles were probably crushed and sieved to produce a well-graded aggregate. To diminish waste, it is likely that factory workers used the particles from adjacent sieves. The elongated shape with angular edges of the grains increased the surface area for points of contact at the detriment of workability (Figure 8.14). To increase the cohesiveness between aggregate and binder, the pumice may have been powdered in dry Portland cement before wetting it. Activating the Portland cement with water beforehand would have created air bubbles between the binder and the glassy pumice particles. The binder then formed a thin coat around the individual grains of pumice. It is estimated that binder-to-aggregate ratio was probably between 1:3 to 1:4. A closer ratio (more binder) would have decreased the voids and create impermeable lumps (Figure 8.18).

The use of Italian pumice reflected a desire to produce a lightweight product. This practice dates back as early as Ancient Rome, when the Romans extracted pumice from Pozzuoli (now in the metropolitan area of Naples) to produce lightweight concrete. Pozzolani (Latin *pulvis puteolanus* which translates as "dust of Puteoli") was famously used at the dome of the Pantheon, where the volcanic aggregate was sorted by weight and then used to create different graduations of concrete, becoming lighter as the dome reached

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4 Parks, “Documenting the Work of the R. Guastavino Company: Sources and Suggestions”.  
7 Ibid.
The Italian pumice created a lightweight tile that weighed a third of natural stone. Its application to imitate mass masonry construction preceded the popularization of thin-stone veneer in Modernist buildings.

Changes in the formula modified its acoustical behavior. An increase in grain size is correlated with an increase in void size and a decrease in the frequencies absorbed (Equation 8.1).

\[ P_s \propto V_s \propto \frac{1}{f} \quad (8.1) \]

where \( P_s \) is grain size, \( V_s \) is void size, and \( f \) frequency.

It is hypothesized that the range of sound frequencies could be modulated with grain size: larger grains targeted lower frequencies. The layering of beds with different grain size expanded widened the range of frequencies.

Improving the interconnection of voids increased the percentage of absorption. This was achieved by strictly using angular and uniform-sorted grains with the necessary and sufficient binder (Figure 8.3). However, a maximization of the interconnection of voids was at the expense of increased friability and a lesser compressive strength. Furthermore, the strict use of uniform grain size could prove too expensive, since the similarly sized particles would

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Figure 8.3: Absorptive power of formula variations. The horizontal axis indicates octave intervals of pitch. A 100% absorption is equivalent to emitting sound to an open window. Line 1 shows the absorptive power of the original formula. Line 2 indicates maximization of interconnection of voids with a high ratio of binder-to-aggregate (at least 1:4), the narrow use of particle size (uniform) with angular particles. Line 3 indicates the use of graduated layers of different grain size. Source: Diagram by author.

---

Cement pigments were used to imitate natural stone, ranging from grey white to various shades of buff, brown, and blue (Figure 8.4). They enabled polychromatic schemes of the decorated ceilings of St. Francis de Sales in Buffalo, the Art-Deco designs of Hidrelth Meière at the Nebraska State Capitol (Bertram Goodhue, 1928) and the National Academy of Sciences (Bertram Goodhue, 1924), the Stars of David at the dome of Temple Isaiah in Chicago (Alfred A. Alschuler, 1924), the buff-colored with gold and varicolored trim at the Slovak Girls Academy in Danville (1929, Harry Sternfeld; Henry D. Dagit & Sons, Architects).\(^9\)

Portland cement mortar was used for the laminating beds between courses of tiles and

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<table>
<thead>
<tr>
<th>Size of block</th>
<th>6 x 12” and under</th>
<th>12”x12”</th>
<th>10”x20”</th>
<th>12”x24”</th>
<th>18”x40</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimum thickness</td>
<td>7/8”</td>
<td>1”</td>
<td>1 1/2”</td>
<td>2”</td>
<td>3”</td>
</tr>
</tbody>
</table>

Table 8.1: Minimum thickness of Akoustolith.

*Source: Advertisement on Sweet’s Catalogue*

at the joints. When the Akoustolith was applied to concrete slabs, it was specified with 1/4” joints.\(^{10}\) When applied on metal lath ceiling, it was specified to have 1 inch standard channels set 12 inches on center.\(^{11}\)

Like the tile, the acoustical plaster was lightweight and was used as a finishing surface coat. While both the tile (cast stone) and plaster shared the same primary attributes, they differed in the secondary attributes. The plaster was typically troweled on wire or wood lath, concrete slabs, or fiber boards, and was rarely specified as a soffit finish to the timbrel arch construction. In rough and irregular surfaces, a heavily-scratched coat was applied behind the binder coat and the acoustical product (Figure 8.5). The plaster, unlike the regular tile or felt, required specialized experience in its application. If improperly mixed and applied, the degree and range of sound absorption could be severely compromised. This was usually caused by applying more than a single coating and not following the specified binder-to-aggregate ratio or water-to-cement ratio. Too much cement and water could completely seal the pores.

*Akoustolith Plaster*

The heavy scratch coat (or base coat) could be made of Portland cement, gypsum, or lime. Guastavino Jr. did not consider the ability of moisture to travel through the porous layers and disintegrate the gypsum or lime base coat. When Portland cement was specified for the scratch coat, the composition for the binder changed. Once it was set, the finishing surface was scratched in preparation for the application of the binder. These scratches improved the mechanical interlocking between the scratch and binder coat. Finally, the base coat was sufficiently pre-wetted to facilitate a soft and sticky binder and insure a slow setting time of both the binder and acoustical product.

\(^{10}\)Company, “Advertisement”.

\(^{11}\)Ibid.
The binder coat consisted of a fine plaster that was specified at a thickness no greater than $\frac{1}{8}$ inch. It bonded the scratch coat with the Akoustolith plaster and was specified to be either hydrated lime with sand or these two with Portland cement. Unslaked lime was discouraged. In both cases, the hydrated lime could be either "Finish" or "Masons hydrated".

When Portland cement was used on the base coat, the binder layer had to follow a ratio of 5 parts Portland cement, 2 parts hydrated lime, and 10 parts sand by weight.\(^\text{12}\) On the interior walls of natatoriums and other damp interiors, the binder coat was specified to follow a ratio of 5 parts Portland cement, 2 parts hydrated lime, and 10 parts of sand.\(^\text{13}\)

The last coat of acoustical product was specified to be prepared in a dry, granulated consistency and troweled to a thickness of $\frac{1}{2}$ or $\frac{1}{4}$ inch. Thickness was dependant on the budget of the client and the desired degree of sound absorption. A $\frac{1}{2}$ inch-thick coat produced a higher curve of absorption, but covered less surface. In either case, exactly 4.5 gallons (20.45 L) of water were specified for a 100-pound

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\(^{12}\text{Guastavino/Collins Collection, Box 4, folder 1.}\)

\(^{13}\text{Company, "Akoustolith (Sound Absorbing) Plaster", B2661.}\)
The mix had to be in such consistency so that only the necessary amount of water activated the setting of the Portland cement without sealing the pores. Once the plaster was activated and thoroughly mixed, it was recommended to screen it through a $\frac{1}{4}$-inch sieve so as to remove any lumps. Once activated, the acoustical plaster had to be troweled within an hour before the mix got too dry and started to set. After an hour, the plaster would become useless since it would be unable to bond with the binder. Re-tempering was prohibited.

The relative thinness of the plaster and the use of angular particles of Italian pumice helped preventing cracks from drying shrinkage. In addition, the Company believed that applying more than a single coat of the acoustical product rendered useless the previous one, since a new layer would seal the pores of the preceeding one.

Just like the stone, the plaster could be colored with mortar pigments or by spray painting. Interestingly, the R. Guastavino Company preferred to spray paint the plaster as they believed that mortar pigments had a tendency to fade. Acoustolight, an independent product, was often specified as a spray-paint.

The company did not trust in the expertise of the average plasterer, so they demanded to be involved in its application. The interconnection of voids of the Akoustolith plaster was dependant on the level of suction of moisture from the binding coat and the strict adherence of applying a single coat of acoustical product. They also asked to oversee the application of finishing paints, as they were worried that thick paint or improper technique (particularly brushing) could seal the pores.

8.2 Sample Collection

Representative specimens from the Nebraska State Capitol, the Washington National Cathedral, Nazareth Hall at the University of Northwestern, sec:buffalo-terminal]Buffalo Cen-
Samples from the Nebraska State Capitol were spare tiles from the dome of Memorial Hall. They were once placed in the colored tile band immediately above the spring line of the dome (Figure 5.3). Samples from the Cathedral of St. John the Divine were ex-

Figure 8.6: Overview of all specimens collected. For individual photographs and microphotographs of impurities, see Table C.3.6

20Special thanks goes to my advisor, Roy Ingraffia, and Joe Alonso, head stonemason at the National Cathedral, for specimens from the Washington National Cathedral; to Matt Hansen from the Capitol Preservation Office of the for specimens from the Nebraska State Capitol; to Monica Pellegrino Faix, Executive Director of the Central Terminal Restoration Corporation, for a tile from Buffalo Central Terminal; to Laura Buchner, senior conservator at BCA, for specimens from the Cathedral of St. John the Divine; and to Mark Baden for samples of Nazareth Hall at University of Northwestern.
tracted from an unused stock of Akoustolith tiles wrapped in 1927 newspaper and saved underneath a wooden floor. These were believed to be used for the construction of the north transept, which was not completed.\textsuperscript{21} Samples from the Eglise de Notre Dame were extracted in a site visit in February 2022, where access was provided to the upper dome and roof of the building.

8.3 Water Absorption by Complete Immersion

Purpose

To reveal the water absorption coefficient of Akoustolith specimens to inform the future formulation of re-grouting and sealants for restoring reverberating spaces. It has been observed that the high permeability of the cast stone presents a problem for stabilization of loose tiles by re-grouting, since the Akoustolith tends to absorb the moisture from the grouting mortar.

Specimen Preparation

The specimens were stored in dry area of the Architectural Conservation Lab at the University of Pennsylvania. The dry area had a stable temperature of 21 °C (± 3 °C throughout the day) and relative humidity of 23%. The thickness of each sample was taken with an OEM Dial caliper with a precision of 0.001in.

Methods

The water absorption by total immersion testing was conducted in accordance to the standard practices described in ASTM C1195-21. A \( \frac{1}{4} \) metallic mesh was placed on top of \( \frac{3}{16} \) diameter glass rods so that the specimens above would be exposed to water at the bottom. The tank was filled with sufficient deionized water so it covered at least 4 inches above the top surface of the test specimens. Test specimens from each of the 5 commissions were weighted on a scale sensitive to 0.01g and its weight rounded to the nearest 0.1g and

\textsuperscript{21} Phone conversation with Douglas Hunt
recorded. They were then oven dried at a temperature of 110 °C (230 °F) for 42 hours, when they lost less than 0.2% of their weight. The specimens were then cooled in desiccators at a constant temperature of 21 °C (69 °F) and relative humidity at 22%. During the drying process, the specimens lost on average 2.3% of their initial weight, with the sample from Nebraska State Capitol loosing the least (1.6%).

<table>
<thead>
<tr>
<th></th>
<th>END</th>
<th>SJD</th>
<th>NH</th>
<th>NSC</th>
<th>WNC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water absorption (%)</td>
<td>39.56</td>
<td>33.81</td>
<td>21.22</td>
<td>27.98</td>
<td>26.22</td>
</tr>
</tbody>
</table>

*Table 8.2: Water absorption coefficient of 5 specimens.*

END = Eglise de Notre Dame  
SJD = Cathedral of St. John the Divine  
NH = Nazareth Hall, University of Northwestern  
NSC = Nebraska State Capitol  
WNC = Washington National Cathedral

### 8.4 Gravimetric Analysis and Particle Size Distribution

**Purpose**

To determine the approximate sorting of the aggregate and the approximate proportion by weight of the aggregate, binder, and soluble matter. This experiment consists in microscopic examination of the samples, acid dissolution of the binder, and mechanical separation between the fines and aggregates. The resulting data serves two goals: to inform replication efforts of Akoustolith with the binder-to-aggregate ratio and to understand the relationship between sorting and compressive strength. It is assumed that the acid soluble material and the insoluble fines constitute the binder.

**Methodology**

The sieve analysis was in accordance to the standard protocols described in ASTM C136-84a (Standard Method for Sieve Analysis of Fine and Coarse Aggregates).

Approximately 30 grams from a representative specimen per commission (BCT.T1, SJD.T3, NH.T3, NSC.T10, WNC.T2) were extracted, weighted, and crushed with a clean mortar and pestle.
To dissolve the binder, each powdered specimen was dried in a chemically untreated oven at 60 °C for 24 hours. They were then placed in a desiccator, weighed, and recorded. Each of the powdered samples was then placed in a 600 mL beaker. To dissolve the binder, each was moistened with deionized water and then applied 250 mL of 14% solution of hydrochloric acid. The 6 beakers were then placed on a mechanical stirring plate and a Teflon stir bar placed inside each beaker, leaving it to agitate at a low speed for 12 hours.

To separate, filtrate, and sieve the aggregate, a 4 grade filter paper was placed on a funnel resting on a funnel support mounted on an instrument stand. The funnel was placed so as to drain directly into a large 500 mL Erlenmeyer flask. The filter paper was then pre-wetted with deionized water to decrease the surface tension. Each beaker was swirled to levigate the fines and slowly poured onto the funnel. Water was added to the beaker so as to extract as many fine particles, repeating the process until the water became clear. The coarse grains collected at the bottom of the beaker were then relocated onto individual petri dishes. The funnels were left to pour over for 24 hours. Then the filter papers with the collected fines and the petri dishes with the collected aggregates were oven-dried for 24 hours at 60 °C. The weight ratio of the fines, soluble, and aggregate are presented in Table 8.4.

To quantify the relationship between degree of sorting and compressive strength, a coefficient proposed by the geologist Parker Davies Trask (1899-1961) was adopted. Tresk’s sorting coefficient is calculated as the square root of the ratio of the 75<sup>th</sup> and 25<sup>th</sup> percentiles of grain size distribution (Equation 8.2).

\[ S_c = \sqrt{\frac{D_{75}}{D_{25}}} \]  (8.2)

Fuechtbauer (1959)<sup>22</sup> proposed a qualitative interpretation of Trask’s sorting coefficient based on a study of 505 samples and 122 sorting determinations (Table 8.3).<sup>23</sup>

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<sup>22</sup>Füchtbauer, Hans. “Zur Nomenklatur der Sedimentgesteine.” The percentiles of each analysis were visually calculated by the graph method. *Erdöl und Kohle* Vol. 12, No. 8 (1959): 605-613.

# Sorting Coefficient and Qualitative Designation

<table>
<thead>
<tr>
<th>Sorting coefficient</th>
<th>Qualitative designation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.0 - 1.23</td>
<td>Uniformly sorted</td>
</tr>
<tr>
<td>1.23 - 1.41</td>
<td>Well sorted</td>
</tr>
<tr>
<td>1.41 - 1.74</td>
<td>Moderately sorted</td>
</tr>
<tr>
<td>1.74 - 2.0</td>
<td>Poorly sorted</td>
</tr>
<tr>
<td>&gt; 2.0</td>
<td>Very poorly sorted</td>
</tr>
</tbody>
</table>

**Table 8.3:** Sorting Classification proposed by Füchtbauer (1959)

<table>
<thead>
<tr>
<th>Specimen ID</th>
<th>% Fines</th>
<th>% Aggregate</th>
<th>% Soluble</th>
</tr>
</thead>
<tbody>
<tr>
<td>BCT.T1</td>
<td>27.32%</td>
<td>39.90%</td>
<td>32.78%</td>
</tr>
<tr>
<td>SJD.T3</td>
<td>13.25%</td>
<td>52.39%</td>
<td>34.36%</td>
</tr>
<tr>
<td>NH.T3</td>
<td>25.77%</td>
<td>35.36%</td>
<td>38.87%</td>
</tr>
<tr>
<td>NSC.T10</td>
<td>56.03%</td>
<td>9.19%</td>
<td>34.77%</td>
</tr>
<tr>
<td>WNC.T2</td>
<td>11.88%</td>
<td>44.84%</td>
<td>43.28%</td>
</tr>
<tr>
<td>END.T2</td>
<td>70.30%</td>
<td>0.00%</td>
<td>29.70%</td>
</tr>
</tbody>
</table>

**Table 8.4:** Results of gravimetric analysis by acid digestion.

**Figure 8.7:** Sand profile plotted in a logarithmic scale. Graph by author.
<table>
<thead>
<tr>
<th>Building</th>
<th>Specimen ID</th>
<th>75th pctl (µm)</th>
<th>25th pctl (µm)</th>
<th>Sorting coefficient</th>
<th>Qualitative designation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Buffalo Central Terminal</td>
<td>BCT.T1</td>
<td>980</td>
<td>420</td>
<td>1.52</td>
<td>Moderately sorted</td>
</tr>
<tr>
<td>St. John the Divine</td>
<td>SJD.T3</td>
<td>1015</td>
<td>450</td>
<td>1.50</td>
<td>Moderately sorted</td>
</tr>
<tr>
<td>Nazareth Hall</td>
<td>NH.T3-A</td>
<td>800</td>
<td>260</td>
<td>1.75</td>
<td>Poorly sorted</td>
</tr>
<tr>
<td>Nebraska State Capitol</td>
<td>NSC.T10</td>
<td>775</td>
<td>145</td>
<td>2.31</td>
<td>Very poorly sorted</td>
</tr>
<tr>
<td>National Cathedral</td>
<td>WNC.T2</td>
<td>880</td>
<td>420</td>
<td>1.44</td>
<td>Moderately sorted</td>
</tr>
</tbody>
</table>

Table 8.5: Sorting results for the coarse aggregate. Full data available in section E.5

Results and Discussion

All specimens presented a high degree of reaction/effervescence when a few droplets of 14% solution of hydrochloric acid was applied, indicating a considerable presence of binding medium.

The specimen from Eglise of Notre Dame was the only one that presented a complete dissolution of the aggregate, so the sieve analysis for this sample was not performed. This indicates that the aggregate used at the tiles of Notre Dame were not based on pumice, but potentially based on siliceous materials, such as marble dust.

The gravimetric analysis by acid digestion is not sufficient to determine the binder-to-aggregate ratio, since the distinction between fines and coarse grains does not necessarily translate into a distinction between binder and aggregate. Furthermore, it does not account for soluble matter in the aggregate (especially when the pumice was mixed with a calcareous material). In addition, the crushing process with the mortar and pestle may have pulverized some grains of the aggregate into fine particles, mixing them with the binder.
8.5 Compressive Strength

Historical Tests

Historical laboratory tests were conducted in 1927 and 1935 at the Massachusetts Institute of Technology showed that the Akoustolith had a compressive strength of 1,000 psi (6.89 MPa). In 1937, the Thompson and Lichther Company conducted compression and shear tests on Akoustolith prisms. Test on a 4" x 3-3/4" x 12" prism revealed a compressive strength of 525 psi (3.61 MPa), almost half the results at M.I.T. (Figure 8.8). This great difference may indicate that the material presents variable mechanical properties. To confirm this variability, additional tests on specimens from the collection were completed.

Contemporary Test

The purpose of a contemporary test is to explain the great variability presented in the historical records. If the standard deviation of the compressive test results proves to be small (results are in close-range), then the data could prove useful for structural and civil engineers when evaluating the conditions of wall and ceiling assemblies furnished with Akoustolith. It has been reported at the Buffalo Central Terminal, for instance, that the 24Guastavino/Collins Collection, Box 4, folder 1.
Akoustolith has been subject to differential settlement and complete detachment from the laminating or bedding mortar that bonds with the Guastavino structural clay tiles, effectively supporting itself.

However, if the new data points present a high standard deviation and high variability, no inductions or generalizations can be made on the material. Furthermore, it could lead to research questions on the manufacturing process to explain the variability.

In both cases, any structural analysis would require to consider the mechanical properties of the mortars and structural tiles within a specific entire assembly, as it has been discovered that mortars with different composition and formula were used at different locations on Guastavino domes and vaults across commissions.\textsuperscript{25}

**Methodology**

Compressive strength testing was conducted in May 2022 at the Laboratory for the Research of Structure of Matter (LRSM) at the University of Pennsylvania using an Instron 4206 universal testing machine with a 5kN load cell. The test was conducted in accordance to the standard protocols described in ASTM C617/C617M-15. An uniaxial compressive load was applied to individual cubes of 1in\(^2\) or 0.75in\(^2\) on 3 representative samples per commission (15 cubes total). (Full report available in section E.5)

\textsuperscript{25}Murphy, “Deconstructing Guastavino Vaulting”.
Samples were placed below the center of the upper bearing block on the static testing machine. The Instron machine was programmed with a 15,000 lb load limit at a speed of 0.05 inches per minute. The data on force vs displacement were logged at five scans per second and saved in a CSV file. The data was then processed and plotted.

**Sample Preparation**

Specimens were cut with a wet-saw table to produce cubes with side length equal to the thickness of the tile. Most of the tiles were 1.00” ± 0.04” thick. Those from the Nebraska State Capitol and a tile from the Eglise de Notre Dame were cast as 0.75” ±0.4” thick.

<table>
<thead>
<tr>
<th>Origin</th>
<th>Parent Specimen ID</th>
<th>Compression Strength [psi]</th>
<th>Compression Strength [MPa]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eglise de Notre Dame</td>
<td>END.T1-A</td>
<td>734.78</td>
<td>5.06</td>
</tr>
<tr>
<td></td>
<td>END.T2-A</td>
<td>363.33</td>
<td>2.50</td>
</tr>
<tr>
<td></td>
<td>END.T3-A</td>
<td>348.47</td>
<td>2.40</td>
</tr>
<tr>
<td>St. John the Divine</td>
<td>SJD.T1-A</td>
<td>732.56</td>
<td>5.05</td>
</tr>
<tr>
<td></td>
<td>SJD.T3-A</td>
<td>281.08</td>
<td>1.93</td>
</tr>
<tr>
<td></td>
<td>SJD.T3-B</td>
<td>212.34</td>
<td>1.46</td>
</tr>
<tr>
<td>Nazareth Hall</td>
<td>NH.T3-A</td>
<td>705.78</td>
<td>4.86</td>
</tr>
<tr>
<td></td>
<td>NH.T3-B</td>
<td>488.39</td>
<td>3.36</td>
</tr>
<tr>
<td></td>
<td>NH.T3-C</td>
<td>500.66</td>
<td>3.45</td>
</tr>
<tr>
<td>Nebraska State Capitol</td>
<td>NSC.T5-A</td>
<td>1307.95</td>
<td>9.01</td>
</tr>
<tr>
<td></td>
<td>NSC.T5-B</td>
<td>1571.54</td>
<td>10.83</td>
</tr>
<tr>
<td></td>
<td>NSC.T5-C</td>
<td>1600.51</td>
<td>11.03</td>
</tr>
<tr>
<td>National Cathedral</td>
<td>WNC.T1-A</td>
<td>1037.40</td>
<td>7.15</td>
</tr>
<tr>
<td></td>
<td>WNC.T2-A</td>
<td>476.81</td>
<td>3.28</td>
</tr>
<tr>
<td></td>
<td>WNC.T3-A</td>
<td>832.45</td>
<td>5.73</td>
</tr>
</tbody>
</table>

Table 8.6: Summary of results for compressive testing. full data available in section E.5
ND = No data

All cubes were capped on the top and bottom surface with plaster of Paris and squeezed between a glass sheet below and plastic petri dishes above. The petri dishes were moved in a circular motion to spread out the plaster of Paris across the entire surface of the cube. The capping on both surfaces helped distribute the applied load evenly throughout the microstructure (Figure 8.9).
Figure 8.10: Photomicrograph of the microstructure of Akoustolith showing a decreased interconnection of voids with a higher use of binding medium.

Results and Discussion

During the test, it was observed that when the specimens reached their failure point, and the cell was unloaded and the specimen was extracted, the cubes presented few cracks. However, when the cubes were subject to a slight tensile force using the fingers and in a direction parallel to the direction of the compressive load, the cube fractured along very irregular fracture planes. It was observed that these fracture planes had the cement binder completely pulverized. Interestingly, the fragments themselves remained sound, with no loss of friability. This may be explained by the fact that the fracture occurred in regions where the binder coating the aggregate grains was too thin.

The results for compressive strength displayed a great variability between commissions, with a minimum value of 212 psi (St. John the Divine) and a maximum of 1,600 psi
Figure 8.11: A representative force vs. displacement graph on Akoustolith stone (END. T3, Eglise de Notre Dame) with recognizable features: an elastic phase that culminates in a Yield Point, an intermediate phase of plastic deformation that culminates in a peak compressive strength, and a descending phase with a slight inflection at the fracture point. For the full data of each cube, see section E.5. Graph by author.

(Nebraska State Capitol). It is worth noting that the specimens from St. John the Divine are the least dense from the entire collection and present the highest permeability. These specimens also appear to have a higher ratio of aggregate in relation to the binder on visual inspection. By contrast, the specimens from the Nebraska State Capitol are pigmented, present a lower grain size and appear to have a greater proportion of binding medium (Figure 8.10).

All specimens presented a similar curve with recognizable features for brittle materials: an elastic phase, a plastic deformation, a descending phase, and a fracture point (Figure 8.11). The elastic phase, which follows Hooke’s Law, reached an average yield point of 216 psi (1.48 MPa), with a standard deviation of 182 psi (1.25 MPa). The mean compressive strength of all 15 specimens was found at 746 psi (5.14 MPa) and standard deviation of 449 psi (3.09 MPa).

The high standard deviation indicates that the material presents high variability composition and microstructure, as was suggested in the two data points from the historical data. The variability between commissions may be explained by variations in formula (binder-
to-aggregate ratio, grain size, and use of natural sand instead of pumice). However, it is worth noting that variability within specimens of the same project is also considerable.

### 8.6 Relationship between compressive strength and sorting

![Graph showing the relationship between compressive strength and sorting](image)

Figure 8.12: Relationship between compressive strength and sorting. Scatter points represent the average of the compressive tests on 3 cubes per commission, with an error bar indicating variability in the tests. Graph by author.

Tresk’s coefficient (Equation 8.2) was used to quantify the relationship between compressive strength and degree of sorting. It was found that, despite the variability in the results of compressive strength, there was a linear relationship between compressive strength and sorting. The greater the sorting coefficient, the more poorly sorted the aggregate, and the greater the resulting compressive strength (NSC.T10). Conversely, the closer the sorting coefficient is to 1.00, the more uniformly graded the aggregate is, and the lesser the compressive strength (SJD.T3).

These results demonstrate that increasing the interconnection of voids of the Akous-
tolith comes at the expense of decreasing compressive strength, since a high interconnection is correlated with a high sound absorption coefficient, which is achieved with the use of well-sorted or uniformly sorted aggregate with only the necessary and sufficient amount of binder that brings the grains at close points of contact.

### 8.7 Petrographic Analysis

**Materials and Methodology**

On January 2022, the author received several Akoustolith samples from the Memorial Chamber of the Nebraska State Capitol (Figure 5.3). In addition, Professor Marie-Claude Boileau, Ph.D, Director of the Center for the Analysis of Archaeological Materials (CAAM), provided a hand specimen of a Guastavino assembly from the Egyptian Wing at the Penn Museum in February 2022. These were used for petrographic analysis as part of a semester project during the Spring 2022 term.

The central questions for petrographic analysis were: what other binders and aggregates besides pumice and Portland cement were used? What other inclusions are present in the pumice aggregate? What do these inclusions tell about their origin or manufacturing? What is the morphology of the interconnected voids?

<table>
<thead>
<tr>
<th>ID</th>
<th>Material</th>
<th>Provenance</th>
<th>Delivered by</th>
</tr>
</thead>
<tbody>
<tr>
<td>GA.1</td>
<td>Akoustolith (blue)</td>
<td>Memorial Hall, Nebraska State Capitol</td>
<td>Matt Hansen, the Capitol Preservation Architect of the Nebraska State Capitol</td>
</tr>
<tr>
<td>GA.2</td>
<td>Akoustolith (blue)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>GA.3</td>
<td>Akoustolith (blue)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>GA.4</td>
<td>Akoustolith (blue)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>GA.5</td>
<td>Akoustolith (blue)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>423C</td>
<td>Akoustolith</td>
<td>Egyptian Wing, Penn Museum</td>
<td>Dr. Marie-Claude Boileau</td>
</tr>
<tr>
<td>424A</td>
<td>Structural clay tile</td>
<td></td>
<td></td>
</tr>
<tr>
<td>424B</td>
<td>Bedding mortar</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 8.7: Origins of thin sections

In both cases, the thin sections were sampled across the thickness of the tile (Figure 8.13). These were then polished to achieve a thickness of 30 microns. The friability of the Akoustolith samples required the application of a low-viscosity blue-dyed epoxy resin.
The epoxy was tinted in blue to clearly distinguish voids, pores, and cracks from the glassy texture of the Italian pumice.

Two subgroups, one of 5 samples and a loner, are distinguished by their differences in microstructure (Figure D.4.13).

The description of thin-sections follows a qualitative approach and heavily relies on visual observation. Qualitative data is restricted to the measuring of inclusions and the identification of the mode of inclusion size. To measure the frequency of coarse inclusions, semi-quantitative frequency labels proposed by Quinn (2013) were adopted (see Appendix D.4). The author made an effort to describe the petrofabrics independently from the author’s research in the manufacturing and assembly so as to critically interpret the petrography.

\footnote{Coincidentally, the sub-grouping corresponds to different commissions.}
Figure 8.14: Typical microstructure of Akoustolith showing angular pumice grains (P) bonded with cement (C) at close points of contact to create interconnected air voids (AV). Note the isotropic behavior of the volcanic glass in the pumice makes it look opaque on XPL. In addition, the natural voids within the vesicles of the pumice grains rarely connect with the larger network of voids. The brownish-golden color of the binder in XPL indicate the carbonation of the Portland cement. (GA5, PPL and XPL, 50x)
Photo courtesy of Center for the Analysis of Archaeological Materials, Penn Museum.

Discussion and Interpretation

On all thin sections (Memorial Hall at the Nebraska State Capitol and Egyptian Wing at the Penn Museum), the Akoustolith is identified as a mix of well-sorted pumice grains bonded with Portland cement at close points of contact. The pumice grains are about 1 millimeter in size and very angular. Other inclusions are present and share the same volcanic origin. The binding medium is identified as regular Portland cement. Just enough binding medium was added so as to connect the pumice grains at close points of contact, and the binder-to-aggregate ratio is estimated to be between 1:3 and 1:4.

The aggregate is poorly graded rather than well or uniformly graded that the patent
suggests. It is predominately white or grey pumice displaying isotropic behavior (transparent in PPL, opaque in XPL). It is identified as a porphyritic igneous rock, with few phenocrystic inclusions of mafic and felsic origin. The white color of the pumice indicates a rhyolite and trachyte variant, with few to no iron oxides, which also indicates its mafic origin.27

Figure 8.15: A grain of biotite (right) is partially enclosed with cement. The mineral is identified for its single cleavage and fractures (GA3, 50x, PPL and XPL).
Photo courtesy of Center for the Analysis of Archaeological Materials, Penn Museum.

The glass pumice constitutes as much as 95% of the coarse aggregate. Other inclusions of similar size include andesite (Figure 8.17), biotite and basalt (Figure 8.15) (See Table D.4.21 in Appendix for a full description of inclusions).

The mechanical crushing of the pumice may have produced very angular and irregular particles, which may have improved the volume of interconnected voids at the expense of

workability. Furthermore, the irregularity and sub-angular shape of the grains may have helped reducing drying shrinkage.\textsuperscript{28} It is possible that including grains of adjacent sieves instead of restricting to a uniform-graded mix helped in reducing waste.

![Image of rock sample](https://example.com/rock_sample.jpg)

**Figure 8.16:** An isolated rock of andesitic basalt with euhedral phenocrysts of plagioclase feldspar (magenta arrows) and pyroxene (yellow arrow) in a glassy groundmass within the rock. (GA3, 100x, XPL and PPL) Photo courtesy of Center for the Analysis of Archaeological Materials, Penn Museum.

*Properties of pumice*

Pumice is a silica-rich pyroclastic product originating as lava that when ejected and cooled, certain elements become gaseous, creating vesicles that run parallel to the flow of the magma. This produces a vesicular texture in parallel view and fibrous in cross-section. The pumice and inclusions share the same volcanic origin. The chemical composition of pumice and the rock inclusions are both of silica (SO\textsubscript{4}) and aluminium oxides, just like

volcanic ash.

During a volcano eruption, a gas-saturated lava (containing silicon dioxide and aluminum oxide) is exposed to the atmosphere, forming into pumice and volcanic ash. The amorphous silica in the pumice may have formed a strong bonding with the calcium hydroxide in the cement clinker of the Portland cement in underwater conditions, which is known as pozzolanic behavior.²⁹

![Image](image)

**Figure 8.17:** Concentration of blue pigment within the angular cavities of a pumice grain (cyan arrows). Phenocrysts of quartz and feldspar (magenta arrows) are present in the cement groundmass. Of notice is the gradation of the groundmass from light on the top left to dark on the bottom right (dashed green arrow), indicating an active gradual carbonation of the Portland cement (GA3, 50x, XPL).

Photo courtesy of Center for the Analysis of Archaeological Materials, Penn Museum.

The groundmass is identified as a binding medium of regular Portland cement. No other cements are identified. The cement is an isotropic matrix of calcium silicate hydrates of portlandite (calcium hydroxide) crystallites. Rare unhydrated portland cement pockets

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²⁹The physics of formation of pumice is very similar to that of the foam in a glass of beer. When the beer is stored and sealed, the inner pressure keeps the carbon dioxide dissolved in the fluid. When it is served in a glass, the pressure is released, leaving the carbon dioxide to form into bubbles.
are present. Darker regions of groundmass indicate carbonation of the Portland cement. Very few pumice particles are coated with undissolved blue pigment (Figure 8.17)

Figure 8.18: Closing of pores
The loner presents a lump of aggregate and binder absent of the interconnected voids. (423C 25X PPL and XPL). Photo courtesy of Center for the Analysis of Archaeological Materials, Penn Museum.

The mineralogical composition of the Akoustolith at the Egyptian Wing (Penn Museum) is similar to that of the Nebraska State Capitol. However, an impermeable lump indicates either poor workmanship or a region where the material is in contact with an adjacent laminating or joint mortar. The darker opaqueness of the binder indicates a higher degree of carbonation compared to that of the Nebraska State Capitol (Figure 8.18)
CHAPTER 9:
Conservation and Restoration

"The whole point is when we go away it doesn’t look like we’ve been here."
-Gerald Allen, restoration architect of Riverside Church, quoted in the New York Times (August 26, 1995)

Sealing the pores to increase reverberation times is the most frequent treatment in Akoustolith tile (Introduction). Treatments are almost inevitably irreversible, since any coating or sealant would need to penetrate the substrate to adhere. The preservation of the mate finish is an added challenge.

Deterioration mechanisms associated with Akoustolith tile on interiors include detachment from the laminating mortar, friability, collection of dirt and pollution, cracks from external stresses, and carbonation of the binder (Figure 9.1). Deterioration mechanisms associated with exterior environments include biological growth, erosion from freeze-thaw, and soiling. Conservation tasks may include the repointing of mortar joints, cleaning of the Akoustolith, application of a consolidant, regrouting to the laminating mortar bed, and replacement/replication of tiles. Each of these tasks are briefly discussed.

9.1 Philosophical framework

In assessing the importance of conserving Akoustolith tile and plaster, a values-based framework can identify non-economic attributes. These values can be grouped in heritage (aesthetic, historic, artistic, scientific) and societal values.1

The significance of the material may be clarified by considering its heritage values. The imitation of natural masonry is an aesthetic quality. In commissions where Hildreth

Meière used the Akoustolith as a medium for her decorative ceilings, its artistic value becomes evident. The historic value resides in its association with the R. Guastavino Company and Wallace Clement Sabine, the father of architectural acoustics. Its scientific value relies in being an innovative early 20th-century acoustical material that combined structural, fireproof, and aesthetic qualities at a time when architectural acoustics was in its early infancy.

Heritage values enter into conflict with societal values in religious buildings with Akoustolith tile, where the interior activities are of great importance. The invention of electroacoustics and the introduction of modern corrective sound systems in the 1930s made the Akoustolith tile obsolete. Furthermore, the decline in church attendance and membership in the United States in the last few decades have cornered congregations to sell off their structures to developers or find creative ways to adaptively reuse them. Donations and access to funding are decreasing nationwide, and the cost of maintaining houses of worship are increasingly prohibitive.

Organ and church music programming play a vital role in raising funds. This source of capital not only offsets the cost of operations and maintenance, but the music activities play a larger societal role. In many cases, the sound-deadening effects Akoustolith tile has proven a detriment to music directors who rely on reverberant spaces to enliven their music. The technological dimension places the heritage and societal values of religious structures with Akoustolith tile at odds with each other, bringing relevance the importance of formulating a sealant that is both reversible and invisible.

9.2 Cleaning

When increasing the reverberation time is desired, modifying the existing conditions of the Akoustolith tile may in fact decrease the reverberation. For instance, cleaning it from accumulated dirt and pollutants contributes in opening the void network to its original state. A thorough study of the deterioration mechanisms and performing a conditions assessment of the Akoustolith tile is of vital importance before intervening.

Open pores collect dirt and germs. Soot and other dirt particles (nicotine smoke, diesel
Figure 9.1: Deterioration mechanisms associated with Akoustolith tile: biological growth (top left), cracking from external stresses (top right), detachment from the laminating/bedding mortar (bottom left), and accumulation of dirt and pollution within the pores (bottom right).
Photos courtesy of Barbara A. Campagna. Microphotograph (bottom right) courtesy Architectural Conservation Lab, University of Pennsylvania.

fuel, coal fire residue, atmospheric pollution, burning of candles, etc.) has been observed in the specimens collected and may contribute to the closing of the pores (BCT.T1, NH.T3, WNC.T2). Before cleaning, soiling must be characterized so the right product is used. The Akoustolith may be cleaned using chemical sponges, water poultice, the Sponge-jet method, or with skin-forming latex paste that peels off when cured. At Temple Emanu-
El, for instance, the Akoustolith was cleaned with large erasers instead of using water or chemical treatment.²

Commercial products for the later include Arte Mundit®, and the latex-based cleaners by Cathedral Stone Products® and PROSOCO®. These skin-forming peel-off latex paste has been previously used at St. John the Divine, where conservators used the commercial product Arte Mundit®.³ It has been reported that the thickness of the latex influences the curing time and easiness to peel-off. Thinner layers make it more difficult to remove, in addition to an increased absorption of sound by vibration.

Peel-off latex paste for cleaning may be be applied by spray, brush, or trowel. The selection of one application over another depends on time and labor required, training, curing time, and safety considerations. When latex is sprayed, air-born particles may cause a safety hazard, so special scaffolding may be required to compartmentalize and install special air-circulating systems.

Cleaning of the Akoustolith may serve as surface preparation for the application of a sealant or consolidant. Not doing so can entrap the the dirt particles with the application of sealants or consolidants. The surfaces need to be vacuumed to extract any loose particle matter. The substrate must then be in dry conditions and relative humidity may need to be controlled to specified ranges.⁴

9.3 Sealing

Concern for restoring reverberation in Guastavino’s acoustical tiles is documented as early as 1915, when architect Bertram Goodhue considered filling the pores of the Rumford tile to restore a degree of reverberation.⁵

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²Conversation between the author and Mark H. Heutlinger, Administrator of the Congregation Emanu-El of the City of New York, February 11, 2022
⁴Ibid.
⁵Richard Pounds and Weaver, “The Unseen World of Guastavino Acoustical Tile Construction: History, Development, Production”. 100
Speech clarity is affected by late arriving sound reflections. In increasing the reverberation time in large interiors, an acoustical engineer may offer a range of solutions before considering sealing the Akoustolith. Hard surfaces that are currently hidden can be exposed. Convex acrylic-based ceiling reflectors can be introduced to increase the early reflections. The tile itself can be plastered over, covered with new masonry, or entirely replaced.

Treatments on the Akoustolith may need to be graduated. For instance, an acoustician may recommend a desired acoustical signature that demands degrees of sound absorption at multiple locations with Akoustolith, demanding a variation in thickness of the treatment. Raytracing the sound paths in plan and section from intended sources could inform these decision.

The problem of formulating an effective sealant is to make it hold up to the Akoustolith substrate with a minimal number of applications so as to create a sealed surface with little to no pinholes. The treatment would contribute in increasing reverberation time of desired frequencies, minimize future maintenance, and consolidate the friable substrate.
The preservation of the matte finish of exposed Akoustolith can be achieved with a reduced number of thin coatings or by applying matte particles in a finishing coating. The product would need not to seep into the cracks or deposit in the cratering or spall zones, that is, the film must have a close range of thickness throughout the surface.

Figure 9.3: Graph by author.
Surface treatments can be categorized in three broad groups (Figure 9.5):

- **Impregnation surface treatment**
  A thin layer that penetrates the crown of the Akoustitolith and preserves the rough and bumpy surface, scattering high-frequencies.

- **Film-forming surface coating**
  Multiple layers of coating that create a thick and relatively smooth surface.

- **Surface consolidant** A deep penetration into the network of voids so as to reduce the friability of the stone.

Sealers normally penetrate more than paint due to their relative thinness. Of all three groups, the impregnation treatment is more desirable, since it preserves the bumpy surface.
This allows a degree of scattering at very high frequencies, preventing the effect of focusing. However, if the coating is too thin, it may lose adherence and start vibrating at certain frequencies, preventing the increase in reverberation time at certain frequencies.

In addition, the treatment would need to provide a sound-tight surface to reflect mid and high frequencies. To reflect high-frequency waves, the finish may follow the bumpy/rough surface of the Akoustolith, where variations in depth can go as high as 4-5mm (0.15-0.2in) (Figure 9.2). A coating can also prolong the cleaning periods from years to decades, since it prevents dirt and soiling particles from entering the matrix.

To prevent the yellowing effect (observed years after its application at Riverside Church in New York and Rockefeller Chapel at the University of Chicago), any acrylic-based sealant would need to have ultra-violet stability. These properties are all summarized in Table 9.1.

The reduction in number of applications must be of great importance so as to reduce labor costs. Furthermore, the coating must adhere enough to the substrate so as it does not
Durability | High
---|---
Fire Resistance | Remain adhered to the substrate under high temperatures (>90 F)
Moisture control | Permeable to water-vapor
Reversibility | Dissolution with a chemical that does not damage the Akoustolith substrate
Sound reflection | High
Maintenance and cleaning | Minimal
Ultra-violet stability | High (to prevent yellowing)
Sheen | Low (matte finish)
Number of coatings | 1 or 2
Surface continuity | Uniform, no pinholes

Table 9.1: Criteria for an ideal sealant

"run" down the walls and vaults. It is also desirable for the treatment to be permeable to moisture particles so as to allow the ceiling to "breathe", however, this may prove impossible.

9.4 Regrouting

The complete detachment of Akoustolith tiles have been observed at the passenger concourse of Buffalo Central Terminal and the Legislative Chamber in New Delhi. In both interiors, several Akoustolith tiles lost their adhesion to the laminating mortar (Figure 9.1). At the Buffalo terminal, cracking from external stresses was present on many tiles.\(^6\)

In both cases, the complete detachment may be associated with a loss of adhesion between the tile and the laminating mortar behind. Tiles that loose adhesion can be caused by a lack of provision for differential movement, inappropriate formulations on the laminating mortar, or poor workmanship.\(^7\) However, a more plausible explanation is the reduction of bond strength between the laminating mortar and the Akoustolith, given the high water absorption coefficient of the Akoustolith (section 8.3). Other factors may include variations in the grain size that cause uneven bonding between the laminating mortar and the Akoustolith, an improper trowelling technique during installation, and unexpected stresses from external forces (seismic, differential settlement, vibration from railroads, etc.).

A thorough sounding survey with a non-sparking deadblow hammer can map out

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\(^6\) Jim Shepherd (Smith Group) in discussion with the author, February 2022.
\(^7\) Ingham, *Geomaterials Under the Microscope*, 168.
the conditions of the individual tiles and determine which ones are at risk of detaching from the laminating mortar. Those that are loose or vibrating may require grout injection. Special attention needs to be given to the moisture content and viscosity of the grouting material, given the high water absorption coefficient of the Akoustolith.

9.5 Replication

When grout injection becomes too expensive or impractical, replacement of the tiles may be pursued.

The Akoustolith tiles behave like petrified sponges. They tend to absorb moisture from the laminating mortar during installation, reducing the bonding strength. Petrographic and/or chemical analysis need to be performed to determine the binder-to-aggregate ratio, the particle size distribution, and the composition of the aggregate.

Improvements in the manufacturing process can be made to ensure a proper adhesion. It may be necessary to partially or completely seal the pores facing the laminating mortar. This can be achieved by casting the tiles on a thin layer of binder and assign the skyward-facing surface of the mold as the soffit surface. Furthermore, it may be necessary to pre-wet and saturate the bedding face of the cast tiles before attaching them to the laminating mortar so as to reduce the amount of water absorption from the mortar.
CHAPTER 10: 
Conclusion and Future work

Referring to the Central Questions, archival research revealed that the Akoustolith was not exclusively an interior acoustical tile for churches and cathedrals. Akoustolith was applied on buildings of institutional, civic, or commercial use: legislative chambers, bank rooms, auditoriums, libraries, museum galleries, classrooms, courthouses, laboratories, gymnasiums, natatoriums, memorials, and railroad stations. Commissions ranged from the small music room at St. Mark’s school to the monumental Buffalo Central Terminal. The product was not exclusively specified for building interiors to diminish reverberation, but was also applied on exteriors (Salmon Tower, 79th Street Rotunda, West Side Highway Pedestrian Underpass). This leads to consider deterioration mechanisms associated with the environment (biological growth, efflorescence, freeze-thaw damage, etc.) The Akoustolith was not exclusively installed within the United States, but was exported to a few projects in Canada, India and the United Kingdom. It was not only cast into tiles of specific dimensions and thickness, but was also cast in large modules for uses beyond the soffit layer in timbrel arch construction assembly. The Akoustolith tile not only differs in material composition throughout commissions, but its mechanical properties vary between individual tiles.

This thesis argues that the range of sound frequencies is controlled with grain size: coarser grains target lower frequencies. The layering of beds with different grain size widens the range of frequencies. Improving the interconnection of voids increased the percentage of absorption, which is achieved by strictly using angular and uniformly-sorted grains with a minimal sufficient amount of binder.

However, a maximization of the interconnection of voids comes at the expense of increased friability and reduced compressive strength. The observed relationship between the sorting coefficient and compressive strength of representative specimens are evidence
that sorting is inversely correlated with compressive strength. Experimental work needs to be done to prove or disprove the hypothesis that sorting is a causal factor to sound absorption.

10.1 Future Work

This thesis is a first attempt to describe the material composition of Akoustolith, outline its large range of applications, analyze its mechanical and petrographic properties, and outline its deterioration mechanisms. This work is certainly not the last. What follows is a set of recommendations for future scholars to build upon this work.

Archival Research

Deeper archival research on the Guastavino/Collins Collection at Avery Library and records of the associated primary architects on each of the identified commissions will continue to shed new light on the application of Akoustolith tile and stone, and potentially reveal hitherto unknown Guastavino interiors. Further archival research may reveal whether the Akoustolith plaster or the gypsum-based Plastacoustics was specified as a soffit layer to the Guastavino timbrel arch construction.

Petrography

A comparative petrographic analysis with Akoustolith stone from any of the 150 reported commissions is required before generalizing findings in its microstructure, mineralogical composition, and particle size distribution. This work can potentially reveal a clear evolution of the material throughout the years. It can offer qualitative evidence on the estimated binder-to-aggregate ratio of Akoustolith stone across commissions. These findings could be assembled in a material atlas that serve as reference to conservators.

Conservation of Hildreth Meière decorative work

At the domes and vaults of the Great Hall at the National Academy of Sciences, the interaction between the raised gesso and the Akoustolith tile deserves greater attention. Further
archival research on the relationship between Meière, Guastavino Jr., and Bertrand Good-hue may shed light on unknown uses of Akoustolith as a medium for artistic expression.

**Mechanical properties**

The 5.8 magnitude Virginia earthquake in 2011 made clear the relevance of the seismic considerations for Akoustolith in the Guastavino cohesive tile. It was reported that after the 2011 earthquake, the Akoustolith at the National Cathedral behaved very differently than the limestone, leaving cracks and detaching from the structural clay tiles.¹ Further testing on tensile, flexural and shear strength will reveal key insights of its performance during seismic events. Furthermore, the deterioration mechanisms observed in Akoustolith in the outdoors (Salmon Tower, 79th Street Rotunda, West Side Highway Pedestrian Underpass) demand a deeper study of its performance under freeze-thaw, thermal cycling, and efflorescence. Freeze-thaw testing can compared with copies of historical tests in the Guastavino/Collins collection.

**Consolidation**

In addition to the formulation of a sealant, consolidation may be desired. It is suggested to investigate inorganic consolidants in lieu of traditional and bulky organic consolidants of Volatile Organic Compounds (VOC) like nanolime, mineral silicate or potassium silicate. This avenue of research in product development may be complemented with the search for a sealant that increases the reverberation time.

**Soiling and Cleaning**

At the National Cathedral, the tiles have been heavily soiled with alkali stains, dust, and soot from cigarette and candle smoke.² Further research on characterizing the soiling and testing cleaning products without damaging the substrate is recommended.

Additional material analysis on the mortars used at the Buffalo Central Terminal and the Cathedral of Learning may inform the understanding of the impact of differential

¹Phone conversation with Jim Shepherd.
²Conversation between the author and Jim Shepherd, February 2, 2022
settlement in Akoustolith surfaces. It is known that mortar composition and formula used to bond the tiles on Guastavino assemblies changed between projects and within different domes/vaults in a same project (Murphy, 2020).

**Regrouting**

A common problem of Akoustolith tile is its detachment from the laminating mortar in timbrel arch construction. Buchner (2010) discusses the use of Jahn M30 (Cathedral Stone Products®) for regrouting and suggests testing low-viscosity grouts with high adhesion properties.

**Mechanical testing**

In conducting the compressive strength testing, it was observed that a possible source of noise that could affect the highly-variable results are the relatively small specimens (1 inch cubes), the thickness of the capping plaster, and the sealing of the pores when cutting the cubes with a wet-saw. The saw pulverized the aggregate and binder into wet dust and partially sealed the pores of the cutting surface. On some specimens, drops of plaster of Paris dripped on the surfaces. It is recommended to use high-strength gypsum plaster instead of plaster of Paris for the capping of the specimens. Furthermore, a minimum thickness of the plaster ought to be followed, and these should be leveled-off using a three-axis bubble level.

The friability of the Akoustolith presents particular challenges in the preparation of small cubes for compressive testing and thin slices for equi-biaxial flexural testing. The results of both compressive and equi-biaxial flexural testing are very sensitive to specimen preparation and testing procedures. Due to multiple factors involved in sample preparation (cutting at exact thicknesses with parallel surfaces, capping, and avoiding sealing the pores), the compressive test may not have been entirely satisfactory. Given that the standardized thickness of historic specimens limit the dimensions of the cubes, it may be worth pursuing the replication of Akoustolith formulas into larger casts to diminish noise.

The data from the compressive strength could be complemented and correlated with
testing on equi-biaxial flexural strength, permeability, and water-vapor transmission. This would yield important information on the effect of changes in the formula on the mechanical properties of Akoustolith, as well as in the formulation of sealants and consolidants.
Alessandro Pezzati Jane Hickman, Alexandra Fleischman, “A Brief History of the Penn Museum”, Expedition Magazine 54, no. 3 (Summer 2012), 4–19.


Bludworth, T. F., “The Electro-Acoustical System in the Girard College Chapel”, Architectural Record 73, no. 6 (June 1933), 385–386.


Guastavino/Collins Collection.


Martin, Reinhold, “The Dialectic of the University: His Master’s Voice”, Grey Room no. 60 (Summer 2015), 82–109.


Murphy, Erin, “Deconstructing Guastavino Vaulting”, Columbia University, Graduate School of Architecture, Planning and Preservation May 2020.


New Tile Factory Formally Opened, Mayor Blodgett Greeted Visitors at the Plant all Day, Yesterday, June 8, 1907.


Thomas, Walter H. and Sydney E. Martin, “The Girard College Chapel, Philadelphia”, Architectural Record 73, no. 6 (June 1933), 381–384.


Appendices

A.1 List of Commissions with Akoustolith

Aggregate of data from Richard Pounds’s masters thesis, the Guastavino Project List at Avery Library, and Advertisements in Pencil Points, Architectural Record, Architectural Forum, and Sweet’s Catalogue. They are organized by building use and sub-organized by year of completion. These show extant buildings with Akoustolith tile. Commissions with only Akoustolith plaster are excluded.

Banks

Malden Savings Bank
48 Pleasant St
Malden, MA
Monks & Johnson
1919-1921

Federal Reserve Bank
230 S. LaSalle St.
Chicago, IL
Graham, Anderson, Probst & White
1922

Harris-Forbes Banking Building (Federal Street Building Trust)
24 Federal Street
Boston, MA
Lockwood-Greene & Co
1922

Federal Reserve Bank
30 Pearl St
Boston, MA
R. Clipston Sturgis
1922

Bowery Savings Bank
110 East 42nd St
New York, NY

York & Sawyer
1921-1923

Harris Forbes Banking Building
14-24 Federal St
Boston, MA
Lockwood-Greene & Co
1921-1923

Federal Reserve Bank
1 Federal Reserve Bank Plaza
St Louis, MO
Sill, Buckler and Fenhagen
1922-1924

Federal Reserve Bank
114 East Lexington St
Baltimore, MD
Parker, Thomas & Rice
1927-1928

Federal Reserve Bank (now Supreme Court of Virginia)
100 N 9th St
Richmond, VA
Parker, Thomas & Rice
1927-1928

New York Stock Exchange
18 Broad St
New York, NY
Trowbridge and Livingston
1921-1929

Detroit Stock Exchange
415 Griswold St
Detroit, MI
Odell & Diehl
1930-1931

Federal Reserve Bank
925 Chestnut St
Philadelphia, PA
Paul Philippe Cret
1931-1935

Classrooms

Physics Building,
Wellesley College
Wellesley, MA
Day & Klauder
1918

St. Mark’s School
25 Marlboro Rd
Southborough, MA
Bigelow & Wadsworth
1919
<table>
<thead>
<tr>
<th>School/Building</th>
<th>Location</th>
<th>Architect/Designers</th>
<th>Year(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>George Washington High School</td>
<td>New York, NY</td>
<td></td>
<td>1924</td>
</tr>
<tr>
<td>Chambers Memorial Building, Davidson College</td>
<td>Davidson, NC</td>
<td>H. C. Hibbs</td>
<td>1928-1929</td>
</tr>
<tr>
<td>New Stone Hall, Wellesley College</td>
<td>Wellesley, MA</td>
<td>Charles Zeller Klauder</td>
<td>1930</td>
</tr>
<tr>
<td>Students’ Activity Building, Worcester Polytechnic Institute</td>
<td>Worcester, MA</td>
<td>Appleton &amp; Stearns</td>
<td>1939-1940</td>
</tr>
<tr>
<td>Westwood Senior High School</td>
<td>Westwood, MA</td>
<td>Coletti Brothers, Architects</td>
<td>1956-1957</td>
</tr>
<tr>
<td>McKinley Elementary and Technical High School</td>
<td>Boston, MA</td>
<td>Thomas F. McDonough</td>
<td>1959-1960</td>
</tr>
<tr>
<td>Ottawa Hills High School</td>
<td>Grand Rapids, MI</td>
<td></td>
<td>1932</td>
</tr>
<tr>
<td>Advanced Twin Engine School</td>
<td>Seymour, IN</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Churches</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>House of the Good Shepherd</td>
<td>Grand Rapids, MI</td>
<td>Joseph C. Huber, Jr.</td>
<td>1907</td>
</tr>
<tr>
<td>St. Lawrence Basilica</td>
<td>Asheville, NC</td>
<td>Rafael Guastavino</td>
<td>1908</td>
</tr>
<tr>
<td>North Woodward M.E. Church</td>
<td>Detroit, MI</td>
<td>Malcolmson and Higginbotham</td>
<td>1911-1912</td>
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<tr>
<td>St. Thomas Church</td>
<td>New York, NY</td>
<td>Cram, Goodhue &amp; Ferguson.</td>
<td>1914</td>
</tr>
<tr>
<td>Hennepin Avenue M. E. Church</td>
<td>Minneapolis, MN</td>
<td>Hewitt &amp; Brown</td>
<td>1914-1915</td>
</tr>
<tr>
<td>Toledo First Congregational Church</td>
<td>Toledo, OH</td>
<td>Mills, Rhines, Bellman &amp; Nordoff</td>
<td>1914-1915</td>
</tr>
<tr>
<td>First Congregational Church</td>
<td>Montclair, NJ</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Churches</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Morgan Memorial, Church of all Nations</td>
<td>Boston, MA</td>
<td>Frank A. Bourne</td>
<td>1917</td>
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<tr>
<td>Church of St. Vincent Ferrer</td>
<td>New York, NY</td>
<td>Bertram Goodhue</td>
<td>1918</td>
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<tr>
<td>St. Bartholomew’s Church</td>
<td>New York, NY</td>
<td>Bertram Goodhue</td>
<td>1917-1919</td>
</tr>
<tr>
<td>Church of Our Lady of Presentation</td>
<td>Brighton, MA</td>
<td>Maginnis &amp; Walsh</td>
<td>1913-1921</td>
</tr>
<tr>
<td>Shrine of the Sacred Heart</td>
<td>Washington, DC</td>
<td>Murphy &amp; Olmstead; Maginnis &amp; Walsh</td>
<td>1922</td>
</tr>
<tr>
<td>Eglise De La Nativite D’Hochelaga</td>
<td>Montreal, Canada</td>
<td>Vieu &amp; Venne</td>
<td>1922-1923</td>
</tr>
<tr>
<td>Emanuel Church</td>
<td>Boston, MA</td>
<td>Allen &amp; Collins</td>
<td>1924</td>
</tr>
</tbody>
</table>
St. Mary’s Seminary  
28700 Euclid Ave  
Cleveland, OH  
Franz C. Warner  
1924

St. Vincent’s Church (now Montante Cultural Center, Canisius College)  
Canisius College, 2001 Main St, Buffalo  
Buffalo, NY  
Comes, Perry & McMullen  
1924-1925

Chapel of the Incarnate Word  
4503 Broadway  
Houston, TX  
Maurice J. Sullivan  
1925

St. George’s Chapel  
73 Chapel Dr  
Newport, RI  
Cram & Ferguson  
1925

St. John’s Ecclesiastical Seminary  
127 Lake St  
Brighton, MA  
O’Connell & Shaw  
1925

Church of our Lady of Perpetual Help  
526 59th St  
Brooklyn, NY  
F. Joseph Untersee  
1925-1927

St. Francis de Sales Church  
407 Northland Ave  
Buffalo, NY  
Murphy & Olmstead, Geo. J. Dietal, Assoc. Architects  
1926-1927

Christ Church  
17 Sagamore Rd  
Bronxville, NY  
Mayers, Murray & Phillip; Bertram Goodhue Associates  
1925-1927

Church of Notre Dame  
40 Morningside Drive  
New York, NY  
Dans & Otto (1910-1915), Cross & Cross (completion 1928)  
1909-1928

Epworth Euclid M.E. Church  
1919 E 107th St  
Cleveland, OH  
Bertram G. Goodhue (1924 design); Walker & Weeks (1928); Mayers, Murray and Phillip  
1925-1928

Church of the Heavenly Rest  
90th street  
New York, NY  
Hardie Phillip of Mayers, Murray & Phillip  
1929

First Church of Christ Scientist  
13 Waterhouse Street  
Cambridge, MA  
Bigelow, Wadsworth, Hubbard & Smith  
1924-1930

Riverside Church  
490 Riverside Drive  
New York, NY  
Henry C Pelton, Allen & Collens, Architects  
1930

Church of St Andrew and St Paul  
3415 Redpath St  
Montreal, PQ  
H.L. Fetherstonhaugh  
1929-1932

Madison Avenue Methodist Episcopal Church  
60th street  
New York, NY  
Cram & Ferguson  
1930-1932

St John’s Church  
627 Pike St.  
Covington, KY  
1931-1932

East Liberty Presbyterian Church  
116 S. Highland Avenue  
Pittsburgh, PA  
Cram & Ferguson  
1932-1935

Sisters of Saints Cyril and Methodius Chapel  
1002 Railroad St  
Danville, PA  
1939

Cathedral of Christ the King  
2699 Peachtree Road  
Atlanta, GA  
Henry D. Dagit  
1937-1939

Cathedral of Saint John the Divine  
1047 Amsterdam Ave  
New York, NY  
Heins & La Farge (1892-1911), and Ralph Adams Cram (1916-1941)  
1892-1941
Christ Church, Methodist
524 Park Ave
New York, NY
Cram & Ferguson
1948

Chapel, St. Anthony’s Convent
1024 Court St
Syracuse, NY
Napoleon H. La Vaute
1949-1950

Cathedral Basilica of the Sacred Heart
89 Ridge Street
Newark, NJ
Jeremiah O’Rourke; Isaac E. Ditmars; Paul C. Reilly
1898-1954

First M. E. Church
906 Grand Ave
Asbury Park, NJ
Lucian E. Smith, Harry E. Warren
1953-1955

St. Alban’s Episcopal Church
3001 Wisconsin Avenue NW
Washington, DC
Frohman, Robb & Little, Architects
1957

National Shrine of Immaculate Conception
400 Michigan Avenue, NE
Washington, DC
Maginnis & Walsh, Architects
1919-1959

Cathedral of St. Philip
2744 Peachtree Rd NW
Atlanta, GA
Ayers & Godwin
1960-1962

National Cathedral
3101 Wisconsin Ave NW
Washington, DC
George Frederick Boodley, Philip Hubert Frohman
1906-1988

Grace Cathedral
1100 California St
San Francisco, CA
Lewis P. Hobart; Cram & Ferguson
1927-1930

Christ Church, Cranbrook
70 Church Rd
Bloomfield Hills, MI
Mayers, Murray, and Phillip, Bertram G. Goodhue Associates
1928-1929

Civic

Federal Reserve Bank
33 Liberty Street
New York, NY
York & Sawyer
1924

Nebraska State Capitol
1445 K St
Lincoln, NE
Bertram Goodhue
1916-1928

County Office Building
542 Forbes Ave
Pittsburgh, PA
Henry Hornbostel & Edward B. Lee
1929-1931

Common Council Chamber, Buffalo City Hall
65 Niagara Square
1930-1931

U.S. Post Office & Custom House, Oklahoma City
Oklahoma City, OK
Treasury Department (Supervising architect)
1931

Herbert C. Hoover Federal Building
1401 Constitution Ave, NW
Washington, DC
Louis Ayres of York & Sawyer
1927-1932

National Archives
700 Pennsylvania Avenue NW,
Washington, DC
John Russell Pope
1932-1935

U.S. Post Office, Custom House and Courthouse
515 W 1st St
Duluth, MN
Treasury Department (Supervising architect)
1928-1930

College Chapels

Nazareth Hall, University of Northwestern
3003 Snelling Ave. N
St. Paul, MI
Maginnis & Walsh
1922

Notre Dame Chapel, Trinity College
125 Michigan Ave. NE
Washington, DC
Maginnis & Walsh
1920-1924

Our Lady of Victory Chapel, St. Catherine University
2004 Randolph Ave
St. Paul, MI
H. A. Sullwold
1924

Princeton University Chapel
Princeton, NJ
Cram & Ferguson
1927

Rockefeller Chapel, University of Chicago
5850 S Woodlawn Ave
Chicago, IL
Bertram Goodhue
1925-1928

Copley Crypt Chapel, Georgetown University
Copley Hall
Washington, DC
1930

St Aedan’s: The Saint Peter’s University Church
800 Bergen Ave
Jersey City, NJ
Edward A. Lehmann
1929-1931

Duke University Chapel
401 Chapel Drive
Durham, NC
Horace Trumbauer
1929-1932

Girard College Chapel
2101 S College Ave
Philadelphia, PA

Thomas, Martin, and Kirkpatrick
1931-1933

Chapel of the Immaculate Conception, Rosemont College
Bryn Mawr
Rosemont, PA
Henry D. Dagit & Sons
1939-1941

Copley Hall

Cultural

Minneapolis Institute of Arts
2400 3rd Ave S
Minneapolis, MN
McKim, Mead & White
1913-1914

University of Pennsylvania Museum
3260 South St
Philadelphia, PA
Wilson Eyre & McIlvaine, Day Bros. & Klauder, Stewardson & Page
1915

Rochester Chamber of Commerce
55 St Paul Street
Rochester, NY
Claude Fayette Bragdon and Charles Evans
1916

National Academy of Sciences Building
2101 Constitution Avenue, N.W
Washington, DC
Bertram Goodhue
1922-1924

Hershey Community building

Hershey, PA
Cassius Emlen Urban; Paul Philip Cret
1931-1932

Franklin Institute
222 N 20th St
Philadelphia, PA
John T. Windrim
1932-1933 Frick Art

Reference Library
10 East 71st
New York, NY
John Russell Pope
1934

The Met Cloisters
New York, NY
Allen, Collins and Willis
1936-1937

Cathedral of Learning, University of Pittsburg
4200 Fifth Ave
Pittsburgh, PA
Charles Zeller Klauder
1937

Glencairn Museum
1001 Cathedral Rd 0757
Bryn Athyn, PA
1936-1938

Memorials

Albert Pike Memorial
700–724 Scott Street
Little rock AR
Mann & Stern
1921-1924

Military

Naval Aircraft Factory
Philadelphia, PA
1937

Motor Test Stand Building
Pensacola, FL
1940
Engine Test Building, Naval Air Station
Quonset Point, RI
1941

Engine Test Building, Southeast Naval Air Depot
Mobile, AL
1941

Boston Army Base
Boston, MA

Synagogues and Temples
Beth Am Synagogue
(Formerly Chizuk Amuno Temple)
2501 Eutaw Place
Baltimore, MD
Joseph Evans Sperry
1922

Kehilath Anshe Ma’arav
Isiah Temple
1100 East Hyde Park Boulevard
Chicago, IL
Albert S. Altschuler
1924

Temple Emanu-El
840 Fifth Avenue
New York, NY
Robert D. Kohn, Charles Butler, and Clarence S. Stein; Mayers, Murray & Phillip; 1928-1930

Manhattan Beach Jewish Center
60 West End Avenue
Brooklyn, NY
Jacob W. Sherman
1951-1961

Swimming Pools
Scott Gym, Smith College
106 Lower College Ln
Northampton, MA
J.W. Ames & Edwin S. Dodge
1923-1924

Columbia High School
South Orange, NJ
Guilbert & Betelle
1926-1927

Cadet Gymnasium, U.S. Military Academy
West Point, NY
Delano & Aldrich
1946-1948

Brooklyn College of the City of New York
New York, NY
Randolph Evans, Architects; Corbett, Harrison & MacMurray
1922-1925

Transportation
Central Railroad Terminal
Buffalo, NY
Fellheimer and Stewart Wagner
1927-1929

Water Brake Test House
Hartford, CT
1938

Brooklyn Battery Tunnel
New York, NY
1948

George Washington Bridge, Ventilation Unit
New York, NY
1950

International Commissions
Eglise De La Nativite D’Hochelaga
1855 Dezery Street
Montreal, Canada
Viau & Venne
1922-1923

Pathology Building, McGill University
3775 Rue University
Montreal, PQ, Canada
Nobbs & Hyde
1923

Thorvaldson Building, University of Saskatchewan
Saskatoon, Canada
David R. Brown
1924

Assembly Chamber, Legislative Building
Sansad Marg, Gokul Nagar, Janpath, Connaught Place
New Delhi, India
Edwin Lutyens
1923-1925

Ironmonger’s Company
Shaftesbury Place, near Barbican
London, United Kingdom
Sydney Tatchell
1925

U.S. Base in Trinidad
Trinidad
Walsh Construction Co., and Geo. F. Driscoll Co. Contractors
<table>
<thead>
<tr>
<th>Year</th>
<th>Building Name</th>
<th>Location</th>
<th>Architect</th>
<th>Year</th>
</tr>
</thead>
<tbody>
<tr>
<td>1941</td>
<td>Alberta Medical Building</td>
<td>Edmonton, Canada</td>
<td>Nobbs &amp; Hyde</td>
<td>1920?</td>
</tr>
</tbody>
</table>
B.2 List of Advertisements

Figure B.2.1: Draft of an advertisement featuring a graph of sound absorption.
Source: Box 4, Folder 2, Guastavino/Collins Collection.
AN ACOUSTICAL INSTALLATION

Pendentives and Chancel Vault of Guastavino Construction with AKOUSTOLITH SOUND-ABSORBING TILE FINISH

WE DO WORK ANYWHERE IN THE UNITED STATES AND CANADA

R. GUASTAVINO CO.
40 COURT STREET  FULLER BUILDING
BOSTON, MASS.  NEW YORK

Figure B.2.2: Akoustolith Ad for Church of Notre Dame in Morningside Heights, New York City. Printed in Architectural Forum (January 1922)
Figure B.2.3: Akoustolith Ad for Nazareth Hall Chapel, University of Northwestern at St.Paul. Printed in Pencil Points (March 1922)
ONE OF MANY MONUMENTAL BUILDINGS HAVING
Guastavino Timbre Arch Construction, and obtaining good
acoustics, permanence and beauty by using
GUASTAVINO ALL MASONRY ACOUSTIC MATERIALS
Figure B.2.5: Akoustolith Ad for Riverside Church in *Architectural Record*, August 1931. Reprinted in the Akoustolith Sales Manual, Guastavino/Collins Archive (Box 4, folder 2), Avery Library, Columbia University.
Figure B.2.6: Akoustolith Ad for the New York Federal Reserve Bank, printed in Pencil Points (1925).
Figure B.2.7: Types of materials made by Guastavino, printed in the 1931 edition of Sweet’s Catalogue Volume B, page 2657.
Wherever it is desired to carry out the effect of a stone ashlar, AKOUSTOLITH sound-absorbing artificial stone can be made to match very closely the color and texture of the natural stone. The above illustration shows clerestory walls of large AKOUSTOLITH blocks in perfect combination with the natural building stone.

R. GUASTAVINO COMPANY
500 FIFTH AVENUE, NEW YORK, N. Y. 40 COURT STREET, BOSTON, MASS.

R. GUASTAVINO CO. OF CANADA, Ltd., Architects Building, Montreal, P. Q.
AKOUSTOLITH, a masonry material, has a sound absorbing or acoustical value approximately ten times that of ordinary plaster (see graph) and comparable with felt treatment as usually applied. It can be made in a variety of textures, usually of a fine granular appearance imitating caen stone almost perfectly (see illustration of Chapel in Notre Dame Church, New York) and is made in a wide range of colors—ranging from gray white through various shades of buff, gray, and the stronger blues, etc., it desired.

AKOUSTOLITH can be manufactured in any size from the smaller tile dimensions, 3' x 12', 4' x 8', 5' x 10', 6' x 12', 6' x 15', 8' x 16', 10' x 20', and approximately one inch thick to the larger ashlar forms up to 12' x 30' by 1 1/2" thick, and can be moulded or carved in usual ornamental architectural forms. Owing to its light weight and facility of manufacture AKOUSTOLITH can be easily adapted to simple or elaborate architectural treatment. Its adaptability as an acoustical agent is unique and of a wide range starting with the more obvious purpose of insuring correct acoustics in churches and auditoriums. It is being used in rooms wherever a quiet and dignified atmosphere is desired. Its success where installed in banking rooms or offices where typewriters and adding machines are used has been proved conclusively.

AKOUSTOLITH used on ceilings has primarily been installed in connection with our regular Guastavino arch construction, using it as a soffit course of tile and backing up the same with two or more layers of rough tile. It is, however, being largely used applying it directly on the soffit of the concrete floor slabs, or wire lath and cement plaster ceiling.

For side walls the installation can be made directly on any of the many masonry surfaces without scratch coat if surface is reasonably true, or applied on a wire lath backing as described for ceilings.

*We do work anywhere in the United States and Canada*

R. GUASTAVINO CO.

40 COURT STREET
BOSTON, MASS.

60 FULLER BUILDING
NEW YORK

*Figure B.2.9: Ad, printed in Architectural Forum (January 1921)*
ACOUSTICAL - INSTALLATION

The ceiling is finished in AKOUSTOLITH sound absorbing tile. It is the most efficient masonry material used for acoustical correction for either walls or ceilings.

R. GUASTAVINO CO.
BOSTON, MASS.
40 COURT STREET
NEW YORK
1133 BROADWAY

Figure B.2.10: Ad, printed in Architectural Forum (June 1923)
Figure B.2.11: Akoustolith ad for Leslie Lindsey Memorial Chapel, printed in *Architectural Forum* (June 1923)
Figure B.2.12: Advertisement of Akoustolith with metal strip jointing.

Source: Guastavino/Collins Archives
C.3 Specimen Profiles

Buffalo Central Terminal

Object ID        BCT.T1
Collection       Architectural Conservation Laboratory Materials Database Collection
Commission      Buffalo Central Terminal
Thickness (avg)  0.931 in (1.986 cm)
Weight           175.23 g
Color            Munsell code (approximate)
Observations     No cracks or efflorescence are visible. Water droplets applied to the surface tend to bead. It has been reported that the Akoustolith surfaces were not pigmented, weighted 24.4 lb per sq ft and had a thickness of 1-1/4”.

Table C.3.1: Data for specimen BCT.T1
Table C.3.2: Data for specimen END.T1

<table>
<thead>
<tr>
<th>Object ID</th>
<th>END.T1</th>
</tr>
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<tbody>
<tr>
<td>Collection</td>
<td>Architectural Conservation Laboratory Materials Database Collection</td>
</tr>
<tr>
<td>Commission</td>
<td>Eglise de Notre Dame (New York, NY)</td>
</tr>
<tr>
<td>Thickness (avg)</td>
<td>0.931in (1.986cm)</td>
</tr>
<tr>
<td>Weight</td>
<td>175.23g</td>
</tr>
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</table>
Object ID       END.T1
Collection      Architectural Conservation Laboratory Materials Database Collection
Commission     Eglise de Notre Dame (New York, NY)
Thickness (avg) 0.931in (1.986cm)
Weight          175.23g

Table C.3.3: Data for specimen END.T2
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<thead>
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<th>Object ID</th>
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<tr>
<td>Commission</td>
<td>Eglise de Notre Dame (New York, NY)</td>
</tr>
<tr>
<td>Thickness (avg)</td>
<td>0.931in (1.986cm)</td>
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<tr>
<td>Weight</td>
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**Table C.3.4:** Data for specimen END.T3
Object ID  
Collection  
Commission  
Thickness (avg)  
Weight  

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<tr>
<th>Table C.3.5: Data for specimen END.T1</th>
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<tr>
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<tr>
<td><strong>Commission</strong></td>
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<tr>
<td><strong>Thickness (avg)</strong></td>
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<tr>
<td><strong>Weight</strong></td>
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</tbody>
</table>

*Table C.3.6:* Data for specimen SJD.T1
Object ID | SJD.T2
---|---
Collection | Architectural Conservation Laboratory Materials Database Collection
Commission | Eglise de Notre Dame (New York, NY)
Thickness (avg) | 0.931in (1.986cm)
Weight | 175.23g

**Table C.3.7:** Data for specimen SJD.T2
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<tbody>
<tr>
<td>Collection</td>
<td>Architectural Conservation Laboratory Materials Database Collection</td>
</tr>
<tr>
<td>Commission</td>
<td>Eglise de Notre Dame (New York, NY)</td>
</tr>
<tr>
<td>Thickness (avg)</td>
<td>0.931in (1.986cm)</td>
</tr>
<tr>
<td>Weight</td>
<td>175.23g</td>
</tr>
</tbody>
</table>

**Table C.3.8:** Data for specimen SJD.T3
Object ID  NH.T1
Collection  Architectural Conservation Laboratory Materials Database Collection
Commission  Eglise de Notre Dame (New York, NY)
Thickness (avg)  0.931in (1.986cm)
Weight  175.23g

Table C.3.9: Data for specimen NH.T1
<table>
<thead>
<tr>
<th>Object ID</th>
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</tr>
</thead>
<tbody>
<tr>
<td>Collection</td>
<td>Architectural Conservation Laboratory Materials Database Collection</td>
</tr>
<tr>
<td>Commission</td>
<td>Nazareth Hall, University of Northwestern (St. Paul, MN)</td>
</tr>
<tr>
<td>Thickness (avg)</td>
<td>0.931in (1.986cm)</td>
</tr>
<tr>
<td>Weight</td>
<td>175.23g</td>
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**Table C.3.10:** Data for specimen NH.T2
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<td>Architectural Conservation Laboratory Materials Database Collection</td>
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<tr>
<td><strong>Commission</strong></td>
<td>Nazareth Hall, University of Northwestern (St. Paul, MN)</td>
</tr>
<tr>
<td><strong>Date</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Location</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Thickness (avg)</strong></td>
<td>0.931 in (1.986 cm)</td>
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<tr>
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**Table C.3.11:** Data for specimen NH.T3
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<tr>
<td>Thickness (avg)</td>
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**Table C.3.12:** Data for specimen NH.T4
Nebraska State Capitol

<table>
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</tr>
<tr>
<td>Commission</td>
<td>Nebraska State Capitol</td>
</tr>
<tr>
<td>Location</td>
<td>Memorial chamber, lower band</td>
</tr>
<tr>
<td>Thickness (avg)</td>
<td>0.931in (1.986cm)</td>
</tr>
<tr>
<td>Weight</td>
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Table C.3.13: Data for specimen NSC.T1
<table>
<thead>
<tr>
<th>Object ID</th>
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<tbody>
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<td>Collection</td>
<td>Architectural Conservation Laboratory Materials Database Collection</td>
</tr>
<tr>
<td>Commission</td>
<td>Nebraska State Capitol</td>
</tr>
<tr>
<td>Location</td>
<td>Memorial chamber, lower band</td>
</tr>
<tr>
<td>Thickness (avg)</td>
<td>0.931in (1.986cm)</td>
</tr>
<tr>
<td>Weight</td>
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**Table C.3.14:** Data for specimen NSC.T2
<table>
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<tr>
<th>Object ID</th>
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<tbody>
<tr>
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<td>Architectural Conservation Laboratory Materials Database Collection</td>
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<tr>
<td>Commission</td>
<td>Nebraska State Capitol</td>
</tr>
<tr>
<td>Location</td>
<td>Memorial chamber, lower band</td>
</tr>
<tr>
<td>Thickness (avg)</td>
<td>0.931in (1.986cm)</td>
</tr>
<tr>
<td>Weight</td>
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**Table C.3.15:** Data for specimen NSC.T7
### Object ID
BCT.T1

### Collection
Architectural Conservation Laboratory Materials Database Collection

### Commission
Buffalo Central Terminal

### Thickness (avg)
0.931in (1.986cm)

### Weight
175.23g

**Table C.3.16:** Data for specimen WNC.T1
Object ID: WNC.T2
Collection: Architectural Conservation Laboratory Materials Database Collection
Commission: National Cathedral (Washington, D.C.)
Thickness (avg): 0.931 in (1.986 cm)
Weight: 175.23 g

**Table C.3.17:** Data for specimen WNC.T2
<table>
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<td>Architectural Conservation Laboratory Materials Database Collection</td>
</tr>
<tr>
<td>Commission</td>
<td>National Cathedral (Washington, D.C.)</td>
</tr>
<tr>
<td>Thickness (avg)</td>
<td>0.931in (1.986cm)</td>
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<tr>
<td>Weight</td>
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*Table C.3.18: Data for specimen WNC.T3*
<table>
<thead>
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<td>Architectural Conservation Laboratory Materials Database Collection</td>
</tr>
<tr>
<td>Commission</td>
<td>National Cathedral (Washington, D.C.)</td>
</tr>
<tr>
<td>Thickness (avg)</td>
<td>0.931in (1.986cm)</td>
</tr>
<tr>
<td>Weight</td>
<td>175.23g</td>
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</tbody>
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**Table C.3.19:** Data for specimen WNC.T4
Table C.3.20: Data for specimen WNC.T5

<table>
<thead>
<tr>
<th>Object ID</th>
<th>WNC.T5</th>
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<tbody>
<tr>
<td>Collection</td>
<td>Architectural Conservation Laboratory Materials Database Collection</td>
</tr>
<tr>
<td>Commission</td>
<td>National Cathedral (Washington, D.C.)</td>
</tr>
<tr>
<td>Thickness (avg)</td>
<td>0.931in (1.986cm)</td>
</tr>
<tr>
<td>Weight</td>
<td>175.23g</td>
</tr>
</tbody>
</table>
D.4 Description of Petrofabrics of Akoustolith Tiles

Group 1
Akoustolith

Group 2
Structural ceramic tiles

Group 3
Mortars

Figure D.4.13: Grouping and sub-grouping of thin sections. Collection at the Center for the Analysis of Archaeological Materials, Penn Museum.

Microstructure

Predominately interconnected angular meso-vughs that expand and contract at irregular intervals. Meso-vughs and micro chambers are enclosed within the groundmass and dispersed. The voids between the thinly-coated grains constitute on average 30% (not including the voids within the pumice grains formed during their geological origins).
Frequency | Mineral or rock | Properties
--- | --- | ---
**Predominant (>70%)** | Pumice | va-sa, irregular to elongate and flaky, < 1.1mm, tubular or vesicular microstructure. Grains are equant to sub-equant with an average aspect ratio of 2:1, though very rare grains are as much as 3:1 (Figure 8.14) The glass of the pumice is colorless in PPL and predominately isotropic in XPL.

**Few (5-15%)** | Andesite | Felsic magma - silica rich (SiO₂). Glassy groundmass with phenocrysts of lathy and tabular plagioclase feldspar, alkali feldspar, orthopyroxene, clinopyroxene, biotite, and quartz. Some plagioclase phenocrysts are zoned. (Figure 8.16)

**Basalt** | Rare (0.5-2%) | Felsic and silica rich (SiO₂) but contains less silica than andesite

**Biotite** | Very rare (<0.5%) | Sr-r, tabular and euhedral exhibiting one cleavage plane. Yellow in XPL and transparent in PPL. (Figure ??)

**Unidentified blue pigment**

| Table D.4.21: Inclusions of the Coarse Fraction of Group 1 |

Distribution of the particle size behaves like a bell-curve, with high percentage between 0.5 and 1.0mm, meaning the aggregate is well-sorted (Figure D.4.14). The pumice presents filament voids when cut obliquely, while elongated voids that create a flow texture when cut parallel to the flow of volcanic activity. Interconnection between voids within the pumice particles and the larger network of voids rarely occur, since the pumice grains are predominately coated with the groundmass/binding medium.

**Groundmass**

Homogeneous binding medium. Brownish dark in PPL. Groundmass goes darker in certain regions in XPL. The groundmass creates a thin coat around the very angular pumice grains, diminishing the angular outline of the network of voids. Some phenocrysts of quartz and feldspar from the pumice are mixed in the groundmass (Figure ??).
Figure D.4.14: Grain size distribution of 40 inculsion particles in Group 1A in mm.
Object ID: 423C (Egyptian Wing, Penn Museum)
Polarized: PPL and XPL
Imaging: Buffalo Central Terminal
Microscope: Zeiss AX10
Trinocular magnification: 175.23 g

Table D.4.22: Data for specimen WNC.T1
<table>
<thead>
<tr>
<th>Origin</th>
<th>Parent Specimen ID</th>
<th>Surface Area [in²]</th>
<th>Yield point (Newtons) [N]</th>
<th>Ultimate strain (Newtons) [N]</th>
<th>Compression Strength [psi]</th>
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<tbody>
<tr>
<td>Eglise de Notre Dame</td>
<td>END.T1-A</td>
<td>0.56</td>
<td>1474.31</td>
<td>1838.42</td>
<td>734.78</td>
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<tr>
<td></td>
<td>END.T2-A</td>
<td>0.56</td>
<td>631.00</td>
<td>1616.09</td>
<td>363.33</td>
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<tr>
<td></td>
<td>END.T3-A</td>
<td>1.00</td>
<td>777.27</td>
<td>1550.00</td>
<td>348.47</td>
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<tr>
<td>St. John the Divine</td>
<td>SJD.T1-A</td>
<td>1.00</td>
<td>693.45</td>
<td>3258.44</td>
<td>732.56</td>
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<tr>
<td></td>
<td>SJD.T3-A</td>
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<td>ND</td>
<td>1250.26</td>
<td>281.08</td>
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<td></td>
<td>SJD.T3-B</td>
<td>1.00</td>
<td>611.05</td>
<td>944.49</td>
<td>212.34</td>
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<td>Nazareth Hall</td>
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<td>1244.19</td>
<td>1765.88</td>
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<td>NH.T3-B</td>
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<td>1095.79</td>
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<td>NH.T3-C</td>
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<td>976.72</td>
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<td>500.66</td>
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<tr>
<td>Nebraska State Capit-ol</td>
<td>NSC.T5-A</td>
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<td>600.27</td>
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<td>NSC.T5-C</td>
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Figure E.5.15: Force (Newtons) vs displacement (mm/mm) graphs
Figure E.5.16: Force (Newtons) vs displacement (mm/mm) graphs
### F.6 Sound absorption coefficient of different materials

<table>
<thead>
<tr>
<th>Material</th>
<th>SAC</th>
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<tr>
<td>Open window</td>
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<tr>
<td>Plaster</td>
<td>0.025-0.034</td>
</tr>
<tr>
<td>Concrete</td>
<td>0.015</td>
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<tr>
<td>Brick set in Portland cement</td>
<td>0.025</td>
</tr>
<tr>
<td>Marble</td>
<td>0.01</td>
</tr>
<tr>
<td>Glass, single thickness</td>
<td>0.027</td>
</tr>
<tr>
<td>Wood, sheathing</td>
<td>0.061</td>
</tr>
<tr>
<td>Wood, varnished</td>
<td>0.03</td>
</tr>
<tr>
<td>Cork tile</td>
<td>0.03</td>
</tr>
<tr>
<td>Linoleum</td>
<td>0.03</td>
</tr>
<tr>
<td>Carpets</td>
<td>0.15 to 0.29</td>
</tr>
<tr>
<td>Cretone cloth</td>
<td>0.15</td>
</tr>
<tr>
<td>Curtains in heavy fold</td>
<td>0.50 to 1.00</td>
</tr>
</tbody>
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*Table F.6.23*: Sound absorption coefficient (SAC) for different materials at 512 Hz per square foot. Source: Box 4, folder 1. Guastavino/Collins Collection, Avery Architectural and Fine Arts Library, Columbia University.
G.7 Drawings for other commissions

Figure G.7.17: Drawing showing the placement of Akoustolith tiles, University of Chicago Chapel, Bertram Goodhue Associates, dated September 24, 1927.
Index

Castacoustics, 24
Plastacoustics, 24, 25, 31

Acousti-Celotex, 29
acoustic felts, 2
acoustical cement, 66
acoustical materials
  felts, 26
  fiber boards, 26
  vibration mats, 61
aggregate
  grading, 23
Akoustikos Felt, 30
Akoustolith, 2
  advertisements, 27, 31
  aggregate, 71
  Akoustolith product, by
    Johns-Manville, 31
building use, 32
cleaning, 13, 15, 29, 98
coloring, 74
colors, 39, 40
compressive strength, 73, 84, 88
decoration, 43
deterioration mechanisms, 97, 99
doors, 65
formula, 14
friability, 73, 90, 110
heritage value, 98
market, 30
metal-strip jointing, 40
permeability, 79, 88
pigments, 27, 67
plaster, 23, 28, 44, 45, 51, 52, 57, 68, 75
  ratios, 76
  spray painting, 77
pricing, 29
regrouting, 13, 15, 105
replication, 14, 106
sales manual, 28
sealing, 97, 100
seismic performance, 109
sorting, 108
sound absorption, 22, 33
staining, 15
testing, 51
tests, 31
tile, 22, 24, 28, 46, 49, 52, 63, 67, 68, 79
  thickness, 69
  weight, 70
water absorption, 105

Baker, Sir Herbert, 49, 50
Blodgett, Malcolm S., 31
Blodgett, William E., 18–20, 49, 50, 72
bond breaker, 13
Boston Symphony Hall, 17
Buffalo Central Terminal, 59

Castacoustics, 51
Cathedral of St. John the Divine, 13, 35
Cathedral of St. Philip, 14
cement pigments, 69, 74, 77
Chapel of Intercession, 29
church
  Christian Scientist, 11
  music, 11
  Protestant, 17
  Roman Catholic, 11

Church of Notre Dame, 38
Church of St. Andrew and St. Paul in
  Montreal, 21
Civil Works Administration, 61
clay
  deposits, 18
tiles, 17, 19
compressive strength, 80
concrete slab, 52, 56
cracks, 13
Cram, Goodhue & Ferguson, 20, 29, 32
Cram, Ralph Adams, 3, 17, 20, 36, 42
Cret, Paul Philippe, 42
Cross & Cross, 38
density, 22
Dew Point, 55
dolomite, 31
domes, 16, 40
drying shrinkage, 24, 94
Duke University Chapel, 12, 14
electro-acoustical system, 1, 11, 12
Federal Reserve Bank of New York, 54
felts, 10
First Congregational Church, 21
Fisher Fine Arts Library, 48
Fogg Museum, 17
Fourth Presbyterian Church, 29
Girard College Chapel, 67
Goodhue, Bertram, 3, 11, 20, 21, 42, 47, 100
Gothic cathedrals, 2
Guastavino Jr., Raphael, 2, 20, 22, 39, 47
Guastavino Sr., Raphael, 17, 18
gypsum, 24, 25, 31, 71, 75
Harrison Auditorium, 21
Heins & La Farge, 35
Horace Trumbauer, 3
Johns-Manville Company, 29, 30
La Ceramica, 19
latin chant, 2
light reflection, 27
lime, 75, 76
Lutyens, Sir Edward, 49
Madigan-Hyland, 63, 64
McKim, Charles Follen, 17
McKim, Mead & White, 17, 60, 62
Meière, Hildreth, 38, 39, 43–48, 98
micro- abrasives, 14
Modern architecture, 61, 67
mortar
  bonding strength, 13, 106
gypsum, 36
laminating bed, 13, 29, 105
lime-based, 49
Moses, Robert, 62, 63
natatorium, 54, 55
National Academy of Sciences, 15, 39, 43
  Great Hall, 44
National Cathedral, 37
nave, 12
Nebraska State Capitol, 39, 45
  Memorial Hall, 46
Nebraska State Capitol, Great Hall, 46
Nebraska State Capitol, Hall of Representatives, 45
Nebraska State Capitol, Senate Chamber, 45
neo-Gothic, 42
Neuman, Robert, 14
New Deal, 61
New Delhi Legislative Chamber, 23, 49, 50
New York Central Terminal, 59
New York Stock Exchange, 24
organ, 14, 38
particle
  angularity, 69, 72, 73, 93
  size, 17, 57, 73
  sorting, 68, 73, 80, 90
patents, 18
Penn Museum
  Egyptian Wing, 49
  Harrison Auditorium, 49
Pope, John Russell, 3
porosity, 22
  interconnection, 22
  sealing, 29
Portland cement, 23, 57, 69, 71, 72, 75–77, 92, 95
  carbonation, 96
Protestant, 2
pumice, 23, 24, 31, 69, 72, 91, 92
geological formation, 95
properties, 94

R. Guastavino Company, 10, 23, 28, 35, 38, 49–51, 67, 98
business, 51
railroad station, 9, 59
reversibility, 11
Rhode Island State Capitol, 17
Riverside Church, 12
Roman architecture, 2, 72
imperial baths, 60
Pantheon, 72
Rumford tile, 2, 11, 20, 22, 30, 39, 49, 100

Sabine, Paul E., 31
Sabine, Wallace Clement, 2, 10, 17, 20, 22, 25, 30, 31, 98
Sabinite, 23, 31, 48, 50, 51, 54
Salmon Tower, 53
sand, 17
sealant, 11, 12, 14
Smith College, 29
soffit, 17
sorting coefficient, 81
sound
absorption, 9
echo, 2, 16, 18
focusing, 2
frequency, 9, 73
high frequency waves, 9
intensity, 9
pitch, 9
reverberation, 2, 9, 11, 12, 14, 16–18, 28, 35, 100
soundscape, 2, 9

transmission, 9, 18, 28, 61
sound absorption coefficient, 10, 17, 28, 71, 90
speech intelligibility, 9, 11, 12, 17
St. Thomas Church, 12, 20
steel frame, 52
Swan, Clifford Melville, 30, 32, 67

Temple Emanu-El, 39
Tiferith Temple, 25
Trumbauer, Horace, 14

U.S. Bureau of Standards, 28, 32
underground tunnel, 9, 59
University of Chicago Chapel, 47

vaults, 12, 16, 18, 35, 53
vermin, 2
voids
expansion and contraction, 69
interconnection, 17, 23, 89
interconnection of, 73
network, 68

Walker & Weeks, 3
Washington National Cathedral, 13, 36
water absorption, 79
water vapor transmission, 54, 75
West Point Military Academy, 20, 42
West Side Improvement, 62
wire lath, 24
Woburn Factory, 45, 67, 72
Woburn, MA, 18
wood lath, 24

York & Sawyer, 3, 53, 54