Restoration Values: Methodology, Historic 1906 Masonry Structure

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This research reports on a four-year project to restore a 1906 structure designed by architect William Ellsworth Fisher (1871–1937), one of Denver and Colorado's most prominent architects and builders in the late 19th and early 20th centuries. It evaluates three competing decision-making process issues and the prioritization of each: restoration values (look and feel), integrated decision matrix (scope & process), and rules of thumb (architect's methodology). It focuses on infrastructure to provide safety, historical authenticity, and maximum utility in preserving the look and feel of the original architectural design. This two-story masonry house was acquired in a bank foreclosure; it was in derelict condition, condemned by the health/building departments, requiring immediate remedial action to prevent catastrophic collapse. A 1959 renovation compromised the historic character of the interior when the single-family structure was converted into a rooming house. Substantial completion of the restoration was in the summer of 2019.

In historic masonry structures with comparable heating degree days and cooling degree days, a similar, streamlined decision-making process can be developed to optimize the restoration outcome. Personal safety is always integral to this process. Standards relating to the treatment of historic properties—preservation, rehabilitation, restoration, and reconstruction should be maintained. Existing architectural features are recorded and preserved. False ceilings, chases, and the use of non-period materials and methods are avoided. There is a strong preference to remove and not encapsulate all environmental hazards. Masonry structures of the era are most at risk from poorly maintained or implemented moisture control systems. Intact roofs, gutters, and foundation drainage are prioritized. Sub-floor heating with a zoned, HE condensing boiler is the least disruptive process, maintaining the look and feel of the original structure. Ductless cooling is desirable. Development of an integrated prioritization matrix streamlines the decision-making process.

RESTORATION VALUES: A 1906 BRICK RESIDENCE

This research reports on a four-year project to restore a 1906 residence designed by architect William Ellsworth Fisher (1871–1937), one of Colorado's most prominent architects and builders in the late 19th and early 20th centuries.[1] The project began in the spring of 2015, and restoration was substantially completed in the summer of 2019.

Figure 1. William Fisher, Architect 1906. DPL Collection.[2]

The objective is to evaluate three competing decision making process issues and the prioritization of each: restoration values (look and feel), integrated decision matrix (scope & process), and rules of thumb (architect's methodology). It focuses on infrastructure strategies to provide safety, historical authenticity, and maximum utility in preserving the look and feel of the original architectural design.

In historic masonry structures with similar heating and cooling degree day characteristics, a streamlined decision-making process can significantly optimize rehabilitation outcomes. Personal safety is always integral to this process. The project generally followed standards relating to the treatment of historic properties, preservation, rehabilitation, restoration, and reconstruction. Strict compliance would result in a noticeable compromise to quality of life issues or exceeded any reasonable recovery of costs. From 1990 through 2015, the structure was partitioned off into livable and not livable. Existing architectural features were recorded; all existing structures and finishes were preserved to the extent possible with no further degradation to the original structure. It served as a residence throughout the preservation and restoration period.

While the estimated costs to rehabilitate the infrastructure was significant, it was anticipated that the appraised value of the residence would meaningfully increase with updated plumbing, heating, and electrical systems. Remodeled bathrooms, kitchen, millwork, and wall surfaces, plus the additional livable basement area (400 sq ft), would also increase value. The ancillary benefit (with the addition of an egress window), was that space was freed of the outdated, space-wasting furnace, heating ducts, and exposed plumbing waste and vent piping systems.

HISTORIC RECORD

The home is located in the Capitol Hill neighborhood in a single-family district (U-SU-B).[3] A newly built trolly system connected the neighborhood to the city center in 1906. The Insley subdivision lots are platted, 25-ft wide x 150-ft deep. As one of the earlier houses constructed, it is the only one on this block to sit entirely within a single 25 ft lot width.

Figure 2. 2019 & 1919 West Elevation

No construction plans are known to exist, nor is there is an original building permit. Research uncovered that a second, near duplicate to this design existed several blocks away and the accompanying 1906 plans by Architect Fisher and Thompson Olmsted Inv. Co are recorded in the Denver Public Library's archives.[4] Fisher's Swartout house on Emerson street has similar square footage, function, and style; its dimensions are mirrored and slightly adjusted to fit on its lot; it has a smaller back pantry, one foot wider footprint, and an offset front door.[5] The Emerson street revision also reduced the fireplace count from three to one; otherwise, the façade, interior function, front porch, and infrastructure are near identical. The Emerson Street property was built several months later and is now protected by historic district zoning codes.

The Lafayette street property appears to be an upscale prototype of an architect/developer attempt at a state-of-the-art show-home on a 25-ft lot. The original structure as-built was mostly sound, but there were notable shortcuts: no firebrick in the fireplaces, the finished hardwood floor in the basement was installed on dirt with wood sleepers. The lumber used for floor joists was structurally adequate, but it suffered significant dimensional shrinkage; the interior floors were about 1-inch lower in the middle than at the periphery.

The original brick structure, as built, had three finished floors. The first and second levels measured approximately 725 sq. ft. each, while the basement was divided, 40% finished, and 60% unfinished/utility. Built-in cabinetry flanked the fireplaces; finished wood floors were 7/8 inch douglas fir on a 7/8 inch pine subfloor. The living room was finished with oak parquet.

ACQUISITION

In 1990, this Lafayette Street house was in derelict condition, condemned by the building department, and required immediate remedial action to prevent catastrophic collapse. The roof had failed in several locations, allowing rainwater to flow through the second-floor kitchen, down partition walls, and into the dirt floor basement. The rear second-floor sleeping porch had detached from the structure. The front porch was absent, apparently from a fire more than 50 years earlier.

The bank owner of this repossessed property agreed to finance the sale once safety hazards were corrected and approved by the city's building department. The purchase followed the typical real estate transaction: take possession of a historic structure, and make it immediately livable through various limited and necessary improvements, then plan to rehabilitate some time in the future. At closing, there was no realistic construction loan option for restoration: The cost to update the outdated infrastructure would have exceeded the purchase price by several multiples. The house was purchased for $67,000 in 1990.

RAVAGES OF TIME

Three significant factors contributed to the degradation of this property: 1. failure to provide ongoing maintenance to prevent water infiltration; 2. a poorly executed 1959 multi-unit conversion; 3. unsafe conditions that were unknown at the time of construction, lead, asbestos, and radon gas.

Of the potential issues that would affect the preservation of a masonry structure, moisture control was the critical failure. Water damage from the failed roof and gutters and improper surface drainage compounded year over year damage to interior finish work. Plaster on ceilings and walls crumbled, plaster detached from the exterior walls, and the sheetrock was overlaid on the defective ceiling plaster.

Plaster surfaces do not just function as wall-finish, applied plaster surfaces are integral to the stiffness and strength of the overall structure, securing walls to ceilings and framing to structure. Plaster also forms an additional membrane to inhibit air infiltration. Lime-based plasters act as sacrificial substrates where salts and contaminants in the brick leach into the plaster, thereby protecting the brick and mortar from damage.

When water is not drained away from basement foundation walls, it can cause significant damage to the masonry, the plaster on those walls, mortar, and anything inside the building. By 1990, the hardwood floors and wood trim in the basement had degraded and were no longer usable. Hidden water damage can compromise wooden surfaces so that they rot, or worse yet, become substrates for mold and mildew. These can create serious health complications, especially for people with asthma, and for those susceptible to allergies.

Finished floors in the rest of the house suffered water damage but were mostly repairable. Window frames degraded, counterbalances jammed, and the frames were rotting because they were not repainted or calked.

In summary of all of the preservation techniques and tactics, moisture control from roof runoff and foundation drainage is the single most preventable environmental consideration in this preservation. Intact roofs, gutters, and foundation drainage are priorities. A masonry structure essentially has an unlimited lifespan if it is not subjected to water damage.

Architecturally, the attempt to contemporize the house in 1959 significantly compromised its historic character, but enough remained to make the preservation effort meaningful. Finally, the dangers of lead, asbestos, and radon gas were not known in 1906 and their removal is of the highest priority.

RESTORATION STANDARDS

This documentation and analysis is an aid in developing and implementing a strategy for the restoration of late 19th and early 20th-century brick housing, especially where freezing temperatures are a consideration. This renovation employs restoration standards developed by the U.S. Department of the Interior National Park's Technical Preservation Services.[6] In conjunction with these standards, it outlines coordinated implementation strategies to optimize, preserve, and restore residential brick and masonry structures.

The foundational document for historic restoration is The Secretary of the Interior's Standards for the Treatment of Historic Properties with Guidelines for Preserving, Rehabilitating, Restoring, & Reconstructing Historic Buildings (2017).[7] These Standards were codified in the Federal Register in 1995 and updated in 2017. 'Standards and Guidelines' was "produced in part to ensure that the National Park Service continues to fulfill its responsibility to promote the preservation of the historic buildings that are part of the nation's cultural heritage."[8]

"The Secretary of the Interior's Standards for the Treatment of Historic Properties address four treatments: preservation, rehabilitation, restoration, and reconstruction."[9] The Secretary of the Interior's Standards provides guidance to historic building owners and building managers, preservation consultants, architects, contractors, and project reviewers. "Only one category is to apply.: The Standards will be applied taking into consideration the economic and technical feasibility of each project." The document is advisory, and it lists "Recommended" and "Not Recommended" standards.

1. Preservation is defined as the act or process of applying measures necessary to sustain the existing form, integrity, and materials of an historic property. Work, including preliminary measures to protect and stabilize the property, generally focuses upon the ongoing maintenance and repair of historic materials and features rather than extensive replacement and new construction.

2. Rehabilitation is defined as the act or process of making possible a compatible use for a property through repair, alterations, and additions while preserving those portions or features which convey its historical, cultural, or architectural values. The Rehabilitation Standards acknowledge the need to alter or add to a historic building to meet continuing or new uses while retaining the building's historic character.

3. Restoration is defined as the act or process of accurately depicting the form, features, and character of a property as it appeared at a particular period of time by means of the removal of features from other periods in its history and reconstruction of missing features from the restoration period. The limited and sensitive upgrading of mechanical, electrical, and plumbing systems and other code-required work to make properties functional is appropriate within a restoration project.

4. Reconstruction is defined as the act or process of depicting, by means of new construction, the form, features, and detailing of a non-surviving site, landscape, building, structure, or object for the purpose of replicating its appearance at a specific period of time and in its historic location.[10]

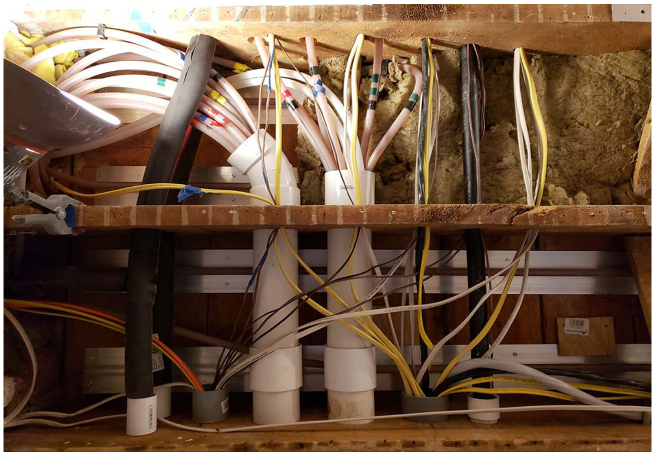
Of the four categories, Reconstruction does not apply since the underlying structure is intact. Preservation and Restoration do not apply because the original interior was substantially altered when living units were subdivided. Therefore the preservation standard that applies is Rehabilitation.

INTEGRATED DECISION MATRIX: SCOPE

Figure 3. Heating (radiant panels), plumbing, electrical, and controls.

"The Rehabilitation Standards acknowledge the need to alter or add to a historic building to meet continuing or new uses while retaining the building's historic character."[11] Under limited conditions, this approach might also apply to restoration. It is a decision primarily based on the ability to access ceiling space in an existing structure.

Figure 4. Heating (in-floor radiant) w/ sub-floor radon control.



The structure's condition dictates the method: the greater the scope of the rehabilitation, the greater the benefit of designing integrated systems around in-floor radiant heating. Trades areas are well defined; they are collectively made available by the general contractor. Unsafe lead, asbestos, radon, and mold are made readily accessible for their systematic removal.

The location of the project determines the viability of this radiant heat-centric approach. Extreme humidity levels may necessitate an alternative ducted air conditioning, best provided by an air-conditioning/hot air furnace. In Denver, there are two compatible options: central evaporative cooling, and zoned mini-split cooling.[12]

INTEGRATED DECISION MATRIX: REHABILITATION PLAN

Many unknowns confront the architect at the start of a rehabilitation project; nevertheless, the overall scope of the work can be ascertained by evaluating primary systems. The mechanical, electrical, and plumbing infrastructure in this 1906 house were outdated and unsafe in 2015. Plaster on the walls and ceilings had thoroughly deteriorated. Radon readings were at the upper limit of acceptable, and any tightening of the envelope would likely cause radon to exceed those levels.[13] The presence of lead, cadmium, asbestos, mold, and silica dust exposure would need to be tested and remediated.

Electrical, plumbing, heating, and radon remediation systems require access to the same locations for replacement and installation. Therefore the strategy was to provide common access to the trades workers was to identify horizontal and vertical chase locations: basement floor, basement, first-floor ceiling, and a vertical shaft.

The basement floor was excavated one-foot to allow the installation of sub-floor radon collection piping installed in a pea gravel base. The plumbing DWV waste system was installed below the gravel bed to permit the installation of a bathroom on this level. A copper water service (2008) replaced the lead pipe to the city street shutoff. A chemically inert vapor barrier was installed just below a reinforced four-inch concrete floor. A two-zone radiant heating system was installed within the concrete floor. Finally, the concrete floor was polished and sealed.

Removal of the partial basement ceiling and first-floor ceilings provided space for the installation of drain, waste and vent piping, cold and hot water feeds, space for 8-zones of radiant heating piping, aluminum heat-transfer pans throughout, gas piping, thermostat control wiring, bathroom exhaust piping, and sound insulation.[14] Recessed LED lighting was installed throughout. Ceiling plaster was replaced with 5/8-inch finished sheetrock.[15]

INTEGRATED DECISION MATRIX: DEMOLITION & REMEDIATION.

The original heating system was a gravity, automatic feed, coal-fired octopus configured, ducted furnace enclosed in a fire-resistant brick room. Return air was through the central vertical stair enclosure used as a return air plenum. The octopus, gravity-heating system was disassembled with careful attention to possible asbestos contamination: furnace, vent piping, ducts, trunk lines, gas piping, and room registers.[16] At the end of this process, none of the original or remodeled hot-air heating system remained.

The 1906 water service to the building from the street was a ¾" lead service connected to a ¾ inch galvanized house feed. The hot and cold water supply system material was galvanized iron pipe. Below and above floor waste piping was a combination of cast iron and galvanized piping. A three-fixture bathroom was added in a 1959 remodel. The original bathroom on the second floor was remodeled in 1959. The original water heater is unknown, but a stand-alone 40-gallon water heater was in service. As part of the demolition process, the lead water service and the interior galvanized piping were removed. The fixtures in both bathrooms (poor condition) and all service piping was removed, and no original or remodeled plumbing remained.

Electrical-gas utilities: In 1906, a dual gas light, knob and tube electrical wiring system was installed throughout the home. The gas-lighting option appears to have been abandoned. There was a 50 amp panel servicing the building. In demolition, the electrical panel, nob and tube wiring, light fixtures and switches were removed.

INTEGRATED DECISION MATRIX: HEALTH AND SAFETY

There is a strong preference to remove and not encapsulate hazards: lead piping, lead-cadmium contaminated paint surfaces, asbestos, free silica (deteriorating masonry), and mold-contaminated surfaces; they should be removed and not encapsulated or managed. Dangerous levels of radon (an unrecognized cancer agent in 1906) need to be remediated. Previous recommendations to encapsulate lead are inadvisable; the only genuinely safe environment is lead-free.

Lead is a threat to both adults and children, but children in particular experience what developmental issues that affect IQ, the rate of development, and overall well-being.[17] Adults and children are both especially at risk when this material is disturbed in any way.[18] The effect on adults may be less dramatic, but no less concerning. Heavy metal contamination may lead to early mental decline and neurological disease.

Even if the water is tested and found to be below acceptable legal lead limits, this does not mean that lead contamination is not a possibility; the Flint Michigan lead crisis demonstrates the potential threat of this invisible poison.[19]

"There is no safe level of lead exposure, as is widely agreed by public health authorities, including the Centers for Disease Control and Prevention (CDC), the World Health Organization, and the EPA."[20] "Dr. Kristi Pullen Fedinick released an analysis of EPA data showing that at least 5.5 million Americans were served between January 2015 and March 2018 by water systems that exceeded the EPA's weak (and not directly enforceable) lead action level."[21]

It is the position of this author that there is no safe way to manage lead contamination by leaving it in place. According to the non-profit group, NRDC, the rule (EPA regulations) needs to be overhauled to protect the enormous U.S. population served by at least six million lead service lines that remain in the ground. Canada recently set this as a maximum, and the EU recently recommended that its maximum lead level in drinking water be dropped from 10 to 5 ppb.[22] All lead piping and contaminated surfaces in this project were removed on demolition.

Radon gas is an invisible and dangerous threat in the home environment resulting from decaying uranium.[23] Radon enters buildings through gaps in the foundation and porous masonry materials. It is a colorless odorless noble gas that is heavier than air that collects in basements. A sub-floor radon system consists of 4-inch PVC perforated pipe embedded in gravel forming a collection system that is ducted above the roof. Four-inch high strength concrete floor is poured over the impermeable membrane.

Pre-construction radon levels over time ranged between 4.5 pCi/L + 5.5 pCi/L. The post-installation radon readings are preliminary since a full year cycle has yet to be recorded, but the results of the gravity bass system are very promising, 1-month 1.1 pCi/L. Radon levels have been reduced by approximately two-thirds. This lowers the radon reading from a high borderline to well below a requirement for mechanical ventilation.

Daily and hourly readings very substantially through two-day, weekly, and monthly readings. Variations are related to pressure imbalances inside the structure. At present, according to the results obtained, there is no requirement or need for additional remediation treatment.

REHABILITATION SUMMARY: INTEGRATED SYSTEMS (BY LEVEL)

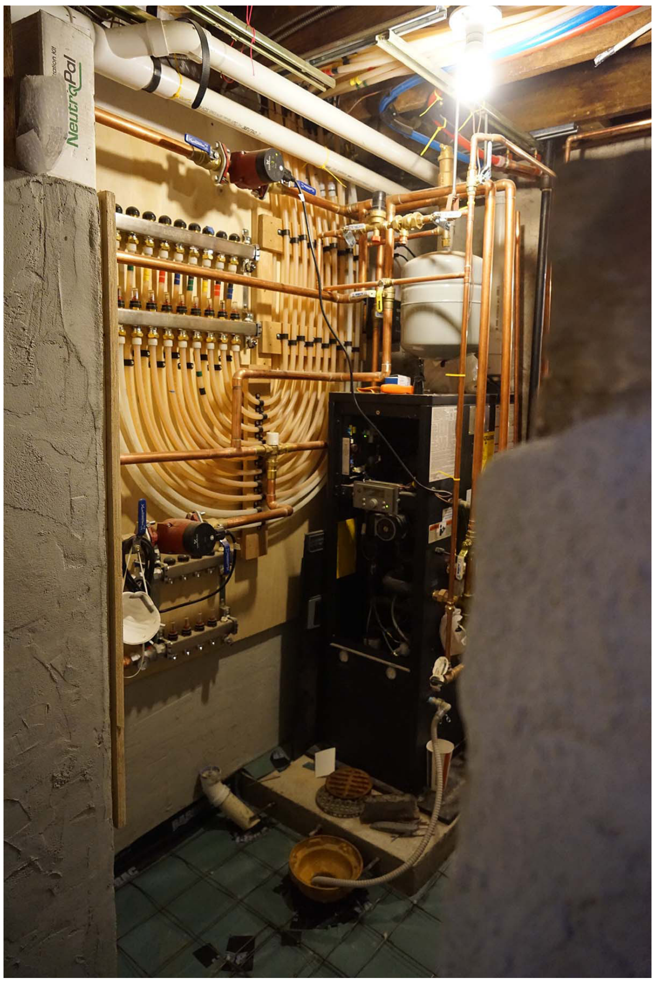
Sub-floor basement. Radon remediation and radiant heating and slab insulation were combined in a basement floor removal and replacement. The floor was excavated one-foot, and 4-inch PVC perforated pipe was embedded in gravel, this was topped with two-inch R-10 rigid insulation.[24] A 16-mil high-performance vapor retarder was placed directly on the insulating foam.[25] Reinforcing 4' x 8' remesh panels were installed directly on the vapor retarder. One-half inch proPEX piping was installed 12-inches on center, forming a 300-foot in-slab looped circuit to the boiler; 700 sq. ft. required two loops. Note, the maximum circuit length is 300 feet. Expansion joints were scored into the concrete. Piping should be installed in the entire area with 12-inch buffer at the external wall.

Basement and first-floor Ceilings. In order of installation, radiant extruded heating panels were attached (screws) to the wooden sub-floor 8-inches on-center.[26] In a brick structure it is recommended that the entire floor surface be covered; in this instance, it required four zones of one-half inch proPEX pipe for the first and second floors. Full floor coverage is recommended in historic brick structures. Each penetration of a wood-joists requires pipe guides to prevent expansion noise. Directly below the radiant system, four-inches of stone wool insulation is installed.[27] Below that, water, waste and vent piping is installed for plumbing fixtures; electrical and control wiring, exhaust vents, and recessed lighting is installed in this space. Five-eights sheetrock is attached to the ceiling joist; this provides greater stability and thickness that more closely matches the plaster that was removed. Four inches of rigid insulation is installed against the rim joist.

BOILER INSTALLATION.

Figure 5. HTP condensing boiler, manifold, and controls.

This system has 10-zones; the number of zones can be determined by the total count of 300-foot runs required to supply heat to the system. The 300-foot distance is a rule of thumb based on the flow resistance and the ability of the pipe to operate within industry temperature differential characteristics. While each zone may theoretically transfer 10000 BTUs, a more realistic estimate can be obtained with the delivery of 30-BTUs per square foot; zones may be thermostatically combined. The HTP Boiler is rated at 140,000 BTUs, but in this structure, the maximum heat delivery is limited to 70,000 BTUs. The HTP boiler prioritizes hot water generation and 140,000 BTUs. The boiler is 94% efficient and is directly vented directly to the outside.



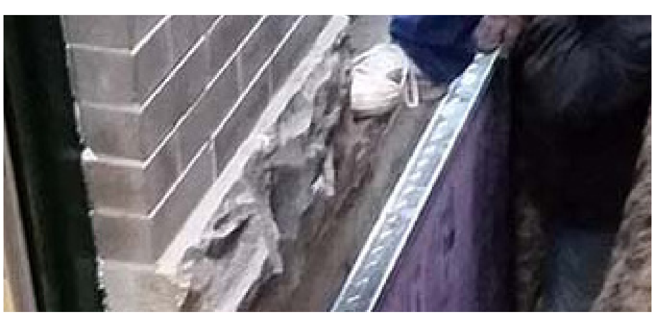


Figure 6. 2-inch rigid polystyrene below-grade perimeter insulation & drainage.

ENERGY AWARENESS

Insulation. All floors (including basement slab) are insulated with thermal/sound insulation. The attic is insulated to contemporary standards, R-38. Note that above-grade exterior insulation is aesthetically unacceptable, and interior insulation alters the wall's moisture/freeze location and compromises masonry integrity. The foundation wall was excavated and two-inches of polystyrene was installed.[28] A wood-framed sleeping porch and enclosed entry were upgraded to R-18 insulation.

Maintaining the look and feel of a 1906 structure requires judgment and compromise, a balancing of the craft of materials, restoration of the look and feel of life in 1906, plus the expectation of addressing contemporary energy standards. Carefully thought out, the restoration creates a much more comfortable, healthful, and efficient environment than existed in 1906, yet it maintains it's historic character and feel.

CONCLUSION

Code requirements will likely prohibit continued use or revisions of gas lights, coal furnaces, fused electrical service, revision to lead plumbing, un-vented appliances, and area occupancy with unsafe radon gas levels. The Secretary of the Interior's Standards for the Treatment of Historic Properties is the foundational guide. Prioritization of these factors is moderated by function, code compliance, health and safety, and costs; this complexity requires judgment and choice as to which systems must be altered and which can be preserved. Health and safety must be prioritized, even before preservation.

A large inventory of late 18th century and early 19th-century homes exists in designated and non-designated historic districts that may benefit from this streamlined approach. The factors considered in this paper will hopefully provide insight to make habitable structures that are safe, functional, affordable, maintenance-friendly, provide long-term value, and provide a sense of enduring satisfaction.

The author is an educator and registered architect and is licensed to design and supervise the installation of mechanical systems discussed in this restoration project.

ENDNOTES

1. History Colorado Center, Denver, CO. Colorado Architects Biographical Sketch. https://www.historycolorado.org/sites/default/files/media/document/2017/Architects_fisher.pdf
2. Denver Public Library. FISHER AND FISHER ARCHITECTURAL RECORDS, 1892-1997. The Denver Public Library EAD ProjectSwartout (Mrs. J.A.) residence, 618 Emerson Street
3. Denver Assessor's Office. 2019. L 22 BLK 23 INSLEES ADD AMD MAP https://www.denvergov.org/property/realproperty/summary/161092299/
4. Denver Building Permits File 1906-1914. Copied Page 28. 1906, 11.0#1236.02, brick residence, 30:8x22:8, $3000 (cost), Lafayette (st), between eighth and ninth (st), Fisher, W E (Architect), Thompson Olmsted Inv. Co. (developer builder).
5. Denver Public Library. FISHER AND FISHER ARCHITECTURAL RECORDS, 1892-1997. The Denver Public Library EAD ProjectSwartout (Mrs. J.A.) residence, 618 Emerson Street
6. The Secretary of the Interior's Standards for the Treatment of Historic Properties
7. The Secretary of the Interior's Standards for the Treatment of Historic Properties ... provides general guidance for work on any historic building. [1995]
8. The Secretary of the Interior's Standards for the Treatment of Historic Properties. P VI.
9. The Secretary of the Interior's Standards for the Treatment of Historic Properties ... provides general guidance for work on any historic building. [1995] https://www.nps.gov/tps/standards/treatment-guidelines-2017.pdf
10. The Secretary of the Interior's Standards for the Treatment of Historic Properties. p. 2.
11. The Secretary of the Interior's Standards for the Treatment of Historic Properties p. 2.
12. LG's line of heat pump duct-free split products. Condensation control, heat/cool application, external compressor. Under certain circumstances, this unit may be the only heat source needed. https://lghvac.com/residential-light-commercial/product-
13. Radon readings on site. Prior to construction a 4.5 avg. 48-hour radon readings recorded, ranging from 3.5-5.5 pCi/L.
14. ROXUL Mineral-Rockwool ® 60 Acoustic Insulation.
15. 5/8 sheetrock Plaster not a viable option since its installation cost is approximately five times the cost of sheetrock. ⅝" rather than ½" sheetrock with screws every 12" help restore the rigidity of the plaster.
16. United States Environmental Protection Agency. Asbestos. https://www.epa.gov/asbestos
17. United States Environmental Protection Agency. Lead. https://www.epa.gov/leadd States
18. Environmental Protection Agency. Lead. https://www.epa.gov/lead
19. NRDC. On April 25, 2014, officials looking to save money switched Flint, Michigan's drinking water supply from the Detroit city system to the Flint River. This new water was highly corrosive. Because city and state officials broke federal law by failing to treat the water properly, lead leached out from aging pipes into thousands of homes. https://www.nrdc.org/
20. NRDC. Here's What's Needed to Fix the EPA's Outdated Lead in Tap Water Rule October 09, 2019 Erik D. Olson
21. NRDC. Here's What's Needed to Fix the EPA's Outdated Lead in Tap Water Rule October 09, 2019 Erik D. Olson
22. NRDC. Here's What's Needed to Fix the EPA's Outdated Lead in Tap Water Rule October 09, 2019 Erik D. Olson
23. United States Environmental Protection Agency. Radon. https: www.epa.gov/radon.
24. Owens Corning® FOAMULAR® 250 Extruded Polystyrene (XPS) Insulation is a closed cell, moisture-resistant rigid foam board well suited to meet the needs for a wide variety of building applications. https://dcpd6wotaa0mb.cloudfront.net/mdms/dms/EIS/43522/43522-FOAMULAR-250-XPS-Insulation-Product-Data-Sheet.pdf?v=1474969868000
25. Interplus XM film. VB-350 (16 mil) Class A Vapor Retarder Exceeds astm e 1745 class a, b & c Retarder Specifications.
26. Radiant Engineering. ThermoFin 8-foot length extruded aluminum panels for 1/2" pex tubing. www.radiantengineering.com
27. ROCKWOOL COMFORTBATT is a stone wool insulation product for improved sound absorption and fire protection in residential wood and steel construction.
28. US Department of Energy. Measure Guideline: Installing Rigid Foam Insulation on the Interior of Existing Brick WallsH. Natarajan, S. Klocke, and S. Puttagunta Consortium for Advanced Residential Buildings (CARB) June 2012.