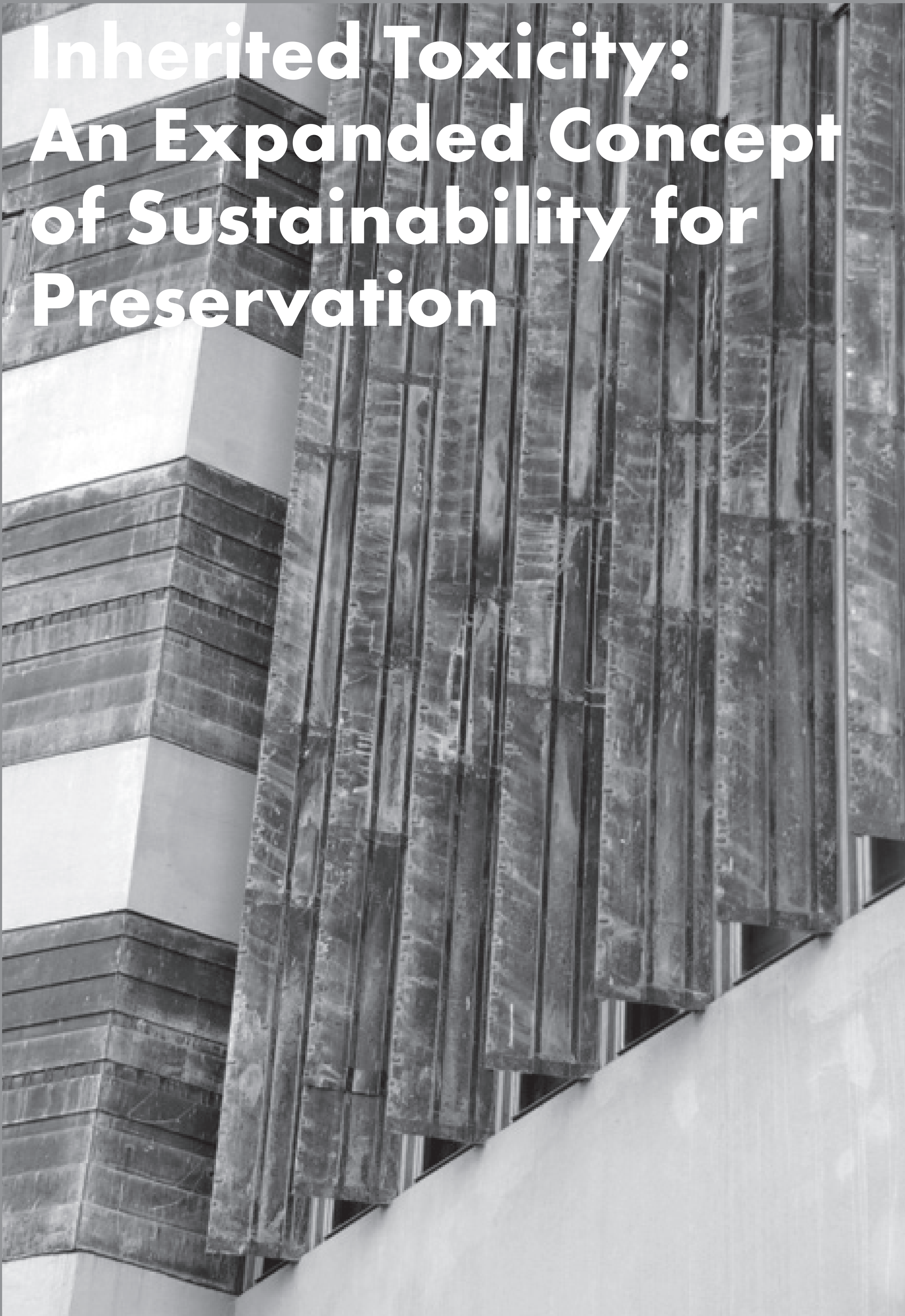
Inherited Toxicity: An Expanded Concept of Sustainability for Preservation



SUSTAINABILITY is a concept that has been accepted as a foundation for professional practice, and toxicity of materials is gaining concern. While the topic of material toxicity is generally addressed with regard to new materials, the built environment represents a history of embedded toxins. However, this aspect of 'inherited toxicity' is scarcely addressed. Considering the toxic potential associated with 20th century building materials, this will grow more critical for the preservation field to address in coming years.

In response to the increasing regulation of copper in both Europe and the US, the case study at Frank Lloyd Wright's Price Tower (1956) is an exploration of whether or not an acute environmental impact from the building's exterior copper elements exists, the results of which are assessed based on an expanded toxicology of copper.

By Amy Swift

WITH the general increase in universal environmental concerns, preservationists are now called on to not only serve as custodians of history, but to serve additionally as stewards of the environment. Concurrent with the general tides of an enlightening environmentalism, material toxicity is an issue that is gaining attention. While much of the toxicity research and advocacy today focuses on the regulation of the production of new materials,[1] 'inherited toxicity' refers to the embodied material hazards already present in the built world, and their potential to impact human and environmental health. In regards to preservation, the term refers to the hereditary condition in which toxic or hazardous materials are embedded in historic buildings or sites and left to the current generation to manage. Inherited toxicity poses significant consequences, yet is often overshadowed by energy concerns when the topic of sustainability is discussed.

At the beginning of the 20th century there were less than one hundred chemically different materials used in common building construction, but by the end of the century there were over 50,000, a number that continues to grow today with industry advancements.[2] Considering only 6 percent of the existing building stock in the United States was constructed prior to 1920, much of the built world is comprised of these chemically varied modern industrial materials.[3] But the concept of inherited toxicity is not exclusive to 20th century materials. Although these materials may serve to exasperate the issue, materials that have been used for centuries may also hold a toxic potential, highlighting the relevance of the topic to preservationists involved with any building vintage. Lead and asbestos are materials that are already heavily regulated internationally, and the general difficulties these materials present to preservation projects are often a topic of discussion within the profession. But there are potentially many other materials that pose similar concerns, including heavy metals and many commonly used plastics and foams. As awareness of the embedded risks associated with in–situ materiality develops, regulation is likely to follow. Therefore, it will only grow more critical for preservationists to examine and adapt their practice in coming years.

This adaptation may happen in two ways. Preservation can either simply comply with expanding regulation as it has done with lead and asbestos, or it can opt for a more proactive approach. The preservation field as it stands has an extensive knowledge of building materials and has the potential to guide suitable regulation and treatment guidelines of such materials. Yet, to date, there has been little official effort by the national and international preservation constituencies to address the concerns of embodied toxins. The US NPS Guiding Principles for Sustainable Design (1993) is one of the few doctrines that approach the subject, stating:

> *In some instances toxic materials... are inherited. Toxic materials that exist in many historic buildings must be removed and properly disposed of. Unfortunately, some of the inherited toxic materials are significant features of historic structures or sites... The problem of inherited toxins will need to be addressed in all proposed management and development projects in the future.*[4]

This brief and vaguely outlined passage is the only instance where inherited toxicity is explicitly addressed in preservation guidelines, and indeed, nearly two decades after this directive was penned, the position on inherited toxins has hardly been developed, either theoretically or in practice, beyond a black–and–white adherence to regulation. This is perhaps not entirely surprising considering the inherent ideological conflict between material authenticity and these environmental health concerns.

Further, there is a dearth of research on materials that are being targeted for regulation within the context of architecture. This lack of appropriate knowledge stands out as a gap in understanding.

Frank Lloyd Wright's Price Tower was used as a case study in order to explore the potential of an acute environmental impact from the building's exterior copper elements. This study also outlines a proactive environmental method of material research that identifies and addresses the risks associated with embodied hazards. By using this method to develop an empirical research base and a suitable response, the preservation community has the opportunity to contribute to the current sustainability discourse as it stands.

Copper: A Hazardous Material?

Copper is a naturally occurring material and is considered to have a number of sustainable qualities, such as durability and ease of recyclability. However, copper is considered a heavy metal and aquatic toxicant whose urban runoff sources are becoming increasingly regulated in Europe, California, and other coastal US states. While much of the regulation is targeted at antifouling paints and copper brake pads in the US, there is precedent for the regulation of architectural copper in both Europe and Palo Alto, CA. Both of these regulations address historic properties differently: in Palo Alto there are exemptions granted to landmarks and buildings contributing to historic districts, while in Europe there are no exemptions granted to historic properties.

In Europe this means that mitigation is deemed necessary during all relevant restoration projects, putting material authenticity, and ultimately historic integrity, at risk while adding potential costs and complications to restoration projects. On the other hand, by offering an exemption to historic properties, as is the case in Palo Alto, any potential environmental contamination would be allowed to persist, underscoring the intrinsic ethical dilemma in not addressing these risks. By moving beyond a simple response to regulation to a progressive place–based understanding of material hazards, the preservation community can begin to build up a comprehensive material management model that considers both historic and environmental concerns.

Significance of Case Study

No other public studies measuring architectural copper runoff relative to acute impacts on historic sites were found during this research. Since architectural copper in urban runoff is a non–point source pollutant, the studies performed to date observe cumulative copper levels in municipal effluence and are therefore unable to isolate the individual impacts associated with specific buildings. On the other end of the spectrum, the studies that measure copper released into runoff over time by architectural applications utilize simulated weathering and deal more specifically with rates of copper release as opposed to the potential impact of such releases. In short, acute site–specific environmental impacts of architectural copper are untested and therefore largely speculative.

The Price Tower designed by Frank Lloyd Wright (1956) was chosen as an ideal case study to test for the acute impacts of copper runoff onto a site. It was important to choose a landmarked historic building, whose material integrity was reliant upon major copper elements integral to its design. This is an instance where preservation and environmental goals exist in conflict; whereas the replacement of a potentially hazardous architectural element would severely jeopardize the historical integrity of the structure.

Price Tower: Historic Significance

Frank Lloyd Wright is commonly known for his Prairie Style designs using long, low horizontal lines, but his many unrealized towers were equally as stunning. Built during the city's petroleum boom era for Harold C. Price, Sr. of the H.C. Price Company,[5] the multi–use Price Tower in Bartlesville, Oklahoma, stands as the only fully realized conception of Wright's planning model for Broadacre City.[6] After 1930 Wright began to promote his notion that a tower's rightful place was in the country where its vertical expression and formal beauty were liberated from the visual cacophony of the city. Wright believed, "as trees crowded in the forest have no chance to become themselves (as they could if they stood alone) so the skyscraper needs to be freestanding in the countryside to become a human asset."[7]

It was serendipitous then that in 1952 Price contracted Wright to build a tower embodying this nascent expression of decentralized urbanism in the Midwestern petroleum boom town of Bartlesville, home to just 22,000.[8] Wright based the design for Price Tower on his unrealized St. Mark's–on–the–Bouwerie housing project in New York City designed in 1929 [figure 3]. The St. Mark's Tower design was reinterpreted to accommodate a new mixed–use program reflective of the Broadacre model for development. The Bartlesville city center at that time was still largely tree–lined with views of rolling hills beyond, lending an apt setting for the deep–green louvered tower to rise over the horizon of the one and two–story downtown development; a metaphor for "the tree that escaped the crowded forest [figures 1, 2].[9]

The cantilevered structure departed from the traditional rectilinear cage of the typical urban tower, relying in-

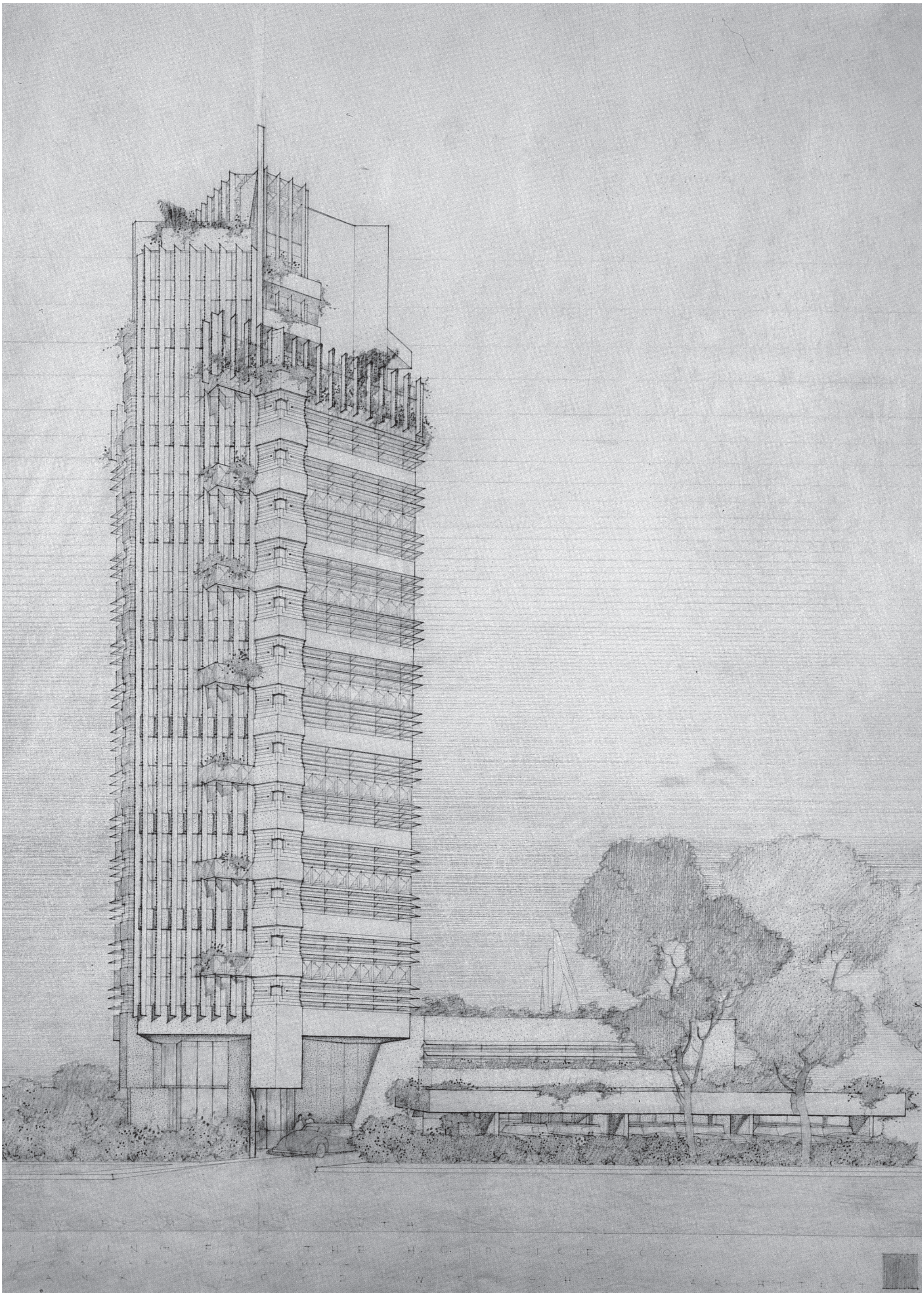


Figure 1. Price Tower, Bartlesville, Oklahoma, 1952–1956. Perspective drawing, 30 September 1952. Pencil and color pencil on tracing paper, 43x34. FLWF 5215.004. Copyright © 2011 The Frank Lloyd Wright Foundation, Taliesin West, Scottsdale, AZ.

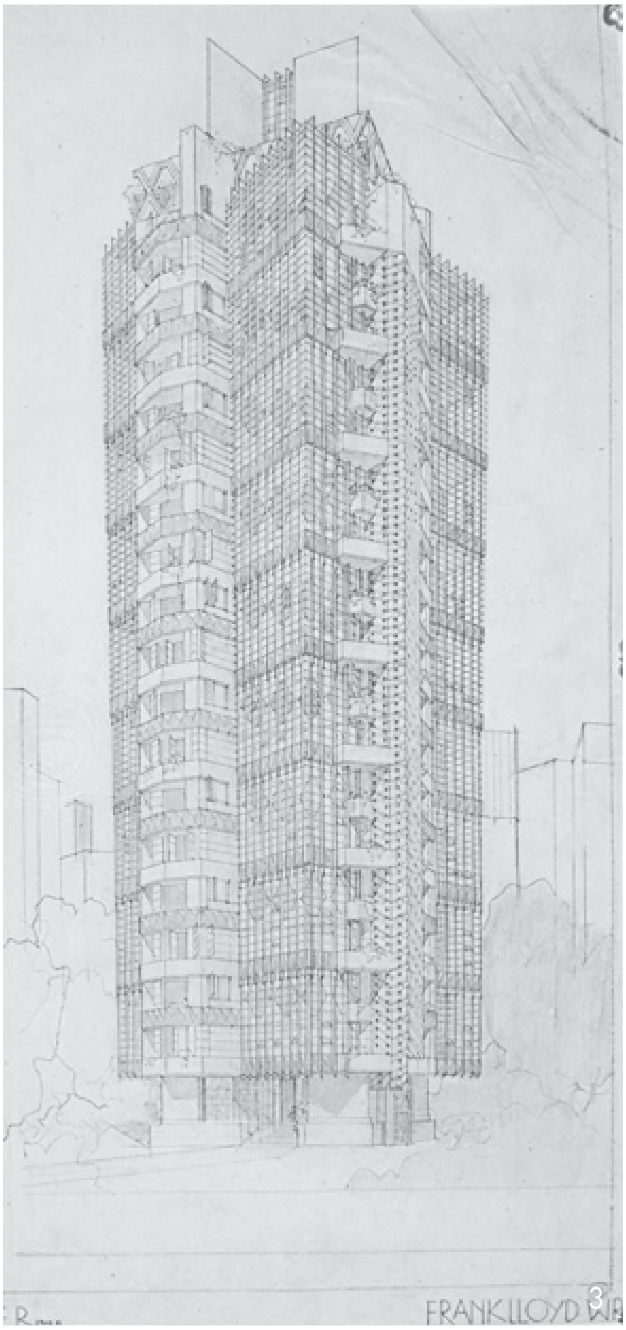


Figure 2. Image of tower taken January 29, 2011.
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Figure 3. Perspective view of the St. Mark's Tower, New York City, revised project, 1929. FLWF 2905.041.
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Figure 4. Still image of a film made by **Joe Price** of **Frank Lloyd Wright** using a prairie flower to explain the 'taproot' construction method of the Price Tower. PTAC 2004.15.

stead on a deep core foundation that works to anchor the vertical spine from which the floor slabs are suspended. Wright referred to the core as a 'taproot' structure, comparing the building's nature to that of a living organism fed by the soil [figure 4]. All four elevations of the 16-storey tower are designed with its own unique variation of vertical and horizontal louvers, and decorative copper panels. In constructing the tower, copper sheets were first pressed into master dies [figure 5], and then placed into formwork before the concrete slabs were poured. After the concrete cured, workers removed the forms [figure 6] and patinated the fresh copper using an acid bath.[10] The resulting green copper elements [figures 7, 8] combined with the singularity of the tower certainly render the project the ultimate metaphor. Thus patinated copper is an essential element to the building's nature.

In 2007 the tower was placed on the National Register of Historic Places, 51 years after its completion. It is also included as part of a serial nomination that has been submitted to the UNESCO World Heritage List for outstanding works by Frank Lloyd Wright, including such iconic structures as Fallingwater, the SC Johnson and Sons buildings, the Guggenheim, and the Robie House.[11] The building underwent an extensive renovation in 2003, during which the copper panels were not in need of any major repair.[12] In sum, there can be no objection raised as to the architectural significance and overall integrity of the tower and its copper elements.

Soil Testing for Copper

Since testing for copper in runoff from the site's gutters and hardscapes is costlier and requires a more arduous sampling process than soil testing, it was decided to first perform exploratory testing of the soil in order to gauge if further runoff testing would be necessary. Copper (Cu) testing in soil is common in agricultural sciences, and is performed in order to monitor the effect of cropping practices on soil fertility. Soil tests can also be used to identify if Cu or other nutrients are present at levels that may be toxic to plants or other organisms. Cu is a difficult nutrient to test because thresholds tend to be comparably lower than other micronutrients. The element is highly immobile, but different chemical speciations of copper result in varying levels of mobility and must be considered when assessing the risk to surface water and groundwater contamination.[13]

Methodology

The testing location was chosen where runoff drains directly into the soil from the north and west façades. These façades receive the prevailing winds, which is an important factor as these façades receive the highest volume of rain impinging the surface, resulting in elevated volumes of runoff. Also important to note is that the panels were originally patinated on site, so these layers of patina are brittle and much less stable in their formation than a naturally formed patina, resulting in increased loss of patina product to runoff. With all of these factors combined, if Cu toxicity was to be found in the soil, the chosen sampling site was the most likely place.[14]

Samples were collected on a visit to the site on January 29, 2011, and represent both a control and experimental set. The control samples represent a measure of the naturally occurring levels of copper in the soil and were taken from the south lawn of the property. This area of the site does not receive runoff from the building or from any other perceivable source (refer to samples SW-1, SW-2, and SW-3 in figures 10, 11). The experimental samples were taken from directly under the cantilevered southwest corner of the louvered façade where heightened copper levels were most likely to be found (refer to samples A-3, A2-3, B-2, B-3, C-2, and C-3 in figures 10, 12). Cu from both the control and experimental samples was measured to assess if there was any significant increase in Cu content in the soil as a result of the building runoff.

Procedure

Surface vegetation was first removed with a clean trowel. All samples were dug from a depth of 0-6″ at distances of 5′ or 10′ apart, collected, tagged, and mapped.[15] To prevent cross-contamination, between each sample collection the trowel was cleaned in a clean water bath, dried with a clean towel, and new rubber gloves were applied. The samples were double-bagged separately and stored at room temperature before being sent to the University of Minnesota's Research Analytical Laboratory,[16] which specializes in soil testing.

Testing

Each sample underwent two testing procedures:

1. The DTPA (diethylenetriamine pentaacetic acid) extract test is the most commonly used chelating test for extracting Cu from soil. The test is designed to simultaneously extract Zinc (Zn), Iron (Fe), Magnesium (Mn), and Copper (Cu).[17] The results can be used to estimate the readily available Cu levels in soils, and are best suited to determine Cu deficient, near-neutral, and calcareous soils.[18]

2. The microwave digestion test is a hot nitric acid leach of the soil done under pressure in a Teflon vessel. This method comes closest to being a measure of the total copper in the soil, as it is able to measure the chemically bound copper that is missed by the DTPA test.

Results

The results of the testing show that there is a clear increase in Cu content in the experimental samples collected from under the building's eaves as compared to the control samples. Of the 6 experimental samples collected, toxic levels of Cu over 100 ppm were found at two sites. The control samples collected in the SW lawn show a range of copper content from 4.8–6.0 ppm and 15.7–21.0 ppm in the DTPA and microwave digestion tests, respectively. The values found in the experimental group are clearly elevated but vary greatly, indicating a sporadic method of accumulation from the runoff. Samples range from 14.1–80.1 ppm and 40.9–120.6 ppm in the DTPA and microwave digestion tests, respectively. The B–2 experimental sample was collected from underneath the cover of the building away from the influence of the runoff, and therefore shows levels similar to the control samples.

Sample Name	DTPA–Cu* (ppm)	1N HNO3–Cu** (ppm)
A2–3	14.1	40.9
A–3	28.7	70.2
B–2	4.9	14.5
B–3	80.1	120.6
C–2	69.3	102.8
C–3	49.8	84.5
SW–1	4.8	5.7
SW–2	5.1	16.6
SE–3	6.0	21.0

*DTPA Extract Test. **Microwave Digestion Test.

Figure 5. Wood framework (shown upside down) crafted with relief pattern for the ornamental copper panels, which were set inside the framework before concrete slabs were poured. Photo by Joe Price, PTAC 2003.16.122.

Figure 6. Workers setting copper panels inside wood framework before concrete was poured against the inner surface of copper. The outer surface of the copper set against the formwork was then patinated with an acid bath when the formwork was removed. PTAC 2003.16.157.

Figure 7. Image of the copper detailing taken April 30, 2011. Copyright © Mark Hertzberg.

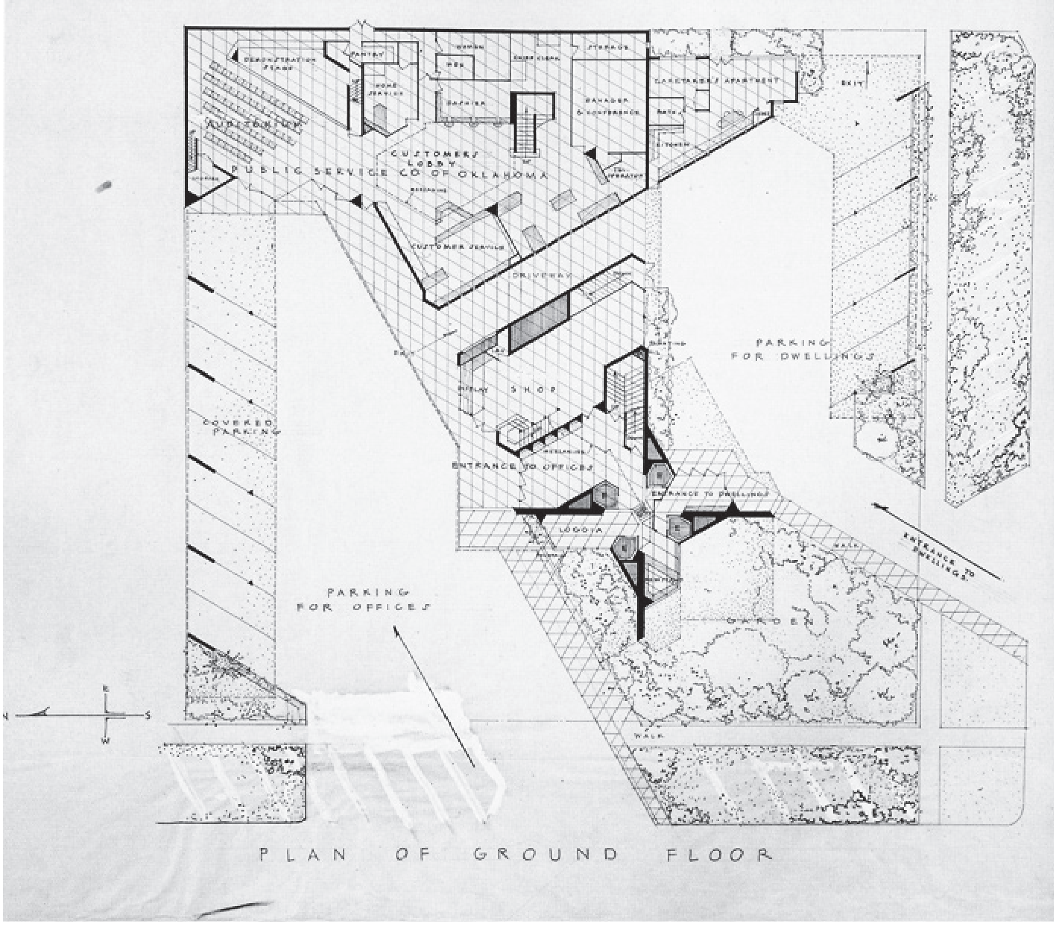
Figure 8. Image of the copper detailing taken January 29, 2011. Copyright © 2011 Amy N. Swift.

Figure 9. Ground floor plan and site plan reflecting final parking changes. Driveway between retail shop and Public Service Co. was subsequently enclosed. Ink on tracing paper, 28x36, FLWF 5215.014. Copyright © 2011 The Frank Lloyd Wright Foundation, Taliesin West, Scottsdale, AZ.

Figure 10. Graphic showing the location of both control and experimental testing sites on the Price Tower property. Amy N. Swift, 2011.

Figure 11. Image of west lawn taken January 29, 2011. Copyright © 2011 Amy N. Swift.

Figure 12. Image of northwest lawn under tower, taken January 29, 2011. Copyright © 2011 Amy N. Swift.


PLAN OF GROUND FLOOR
AUDITORIUM
PUBLIC SERVICE CO. OF OKLAHOMA
CUSTOMERS LOBBY
CUSTOMER SERVICE
DRIVEWAY
SHOP
ENTRANCE TO OFFICES
ENTRANCE TO DWELLINGS
LOGGIA
GARDEN
COVERED PARKING
PARKING FOR OFFICES
PARKING FOR DWELLINGS
CARETAKER'S APARTMENT

9

11

12


SW1
SW2
SW3
A
A2
B
C
2
3
building footprint
hardscape
building overhang
landscape

10

Discussion

The differences between the DTPA and microwave digestion tests are worth noting. While the microwave digestion test comes closest to measuring the actual levels of Cu in the soil, the DTPA values reflect the readily available, or mobile 'free radical,' particles that are considered bioavailable. According to the ecotoxicology of Cu in soil,[19] the bioavailable forms of Cu are what should be considered when assessing risk. Although two of the samples tested using the microwave digestion method show heightened levels of total Cu in the soil over 100 ppm, the bioavailable forms are well within normal limits.

The exterior copper cladding was originally patinated on site using an acid bath, the primary components of which are traditionally copper sulfate, sulfuric acid, and hydrochloric acid.[20] Although no testing of the patina was performed through this study, the components of the acid bath make certain copper compounds more likely than others to develop on the surface. Following this line of reasoning, the main constituents comprising the green patina are likely bronchantite and atacamite. In consideration of Bartlesville historically being a heavy industrial region, antlerite may also make up a portion of the patina product. As these compounds are both sulfur and chloride derivatives, the resultant chemical speciation in the runoff would be copper sulfate and copper chloride compounds, which are readily adsorbed in soil.[21] This would explain why the dilution effects seem to be quite low and Cu contamination is so high in some samples. It also explains the relatively low levels of bioavailable Cu found in the soil. In other words, although the characteristics of the Cu found in the building runoff render it likely to build up to heightened levels in the soil, it is unlikely to migrate into the groundwater or effect living systems in the soil. This is evidenced by the grass that is still able to grow in the areas with elevated copper levels. Since Cu is a bigger hazard to aquatic life than it is in soil, the heightened and acute findings appear inconsequential. However, this points to the necessity of further study of the runoff from the site's gutters and hardscapes.

Conclusion

The case study at Price Tower highlights the importance of understanding the nature of the risks associated with a material when interpreting the results of field testing. In the case of copper, contamination of aquatic systems is the greatest risk. Although the soil contamination tested at high levels in acute locations on site, the relatively stable Cu species present a low level risk of migration into groundwater. It is therefore necessary to consider the chemical speciation, infiltration, and dilution effects when interpreting results. By understanding the types of Cu compounds that have likely developed over the metal, the stability of the Cu in the soil can be assessed and supported by findings in the field. In the case of Price Tower, if the chemical speciation of the patina product had been a more mobile compound, the toxic levels of Cu would have posed a greater risk to migration, and ultimately a greater risk to groundwater contamination.

The copper cladding installed on the façade is not exclusive to the north and west façades that drain into the soil. Runoff from other copper features installed on the building drain to gutters and hardscapes that are then channeled into the stormwater system. With the runoff from the north and west façades having exhibited an acute site impact, it is probable that runoff from other copper features on the building may also contain heightened levels of copper. Since the runoff that drains into stormwater collection effects aquatic systems, it has a much higher associated risk and should be considered for further testing to gauge if on–site mitigation should be implemented.

The historic significance of the Price Tower should be considered while interpreting the results of this case study. As a National Register listed and potential UNESCO World Heritage Site, the historic significance of the building and its copper elements is unwavering. Thus, if deleterious levels of Cu are indeed found through the future testing that this study suggests, mitigation strategies should preclude removal of the significant copper elements and instead focus on alternative strategies, including on–site passive or mechanical strategies.

Lessons for a Future Preservation

The most important conclusion that can be made from the case study at Price Tower is that buildings have a direct impact on their surrounding environment beyond their carbon footprint. The study performed at Price Tower focuses on a material that has been used in building construction for centuries, highlighting the relevance of the issue to the preservation field as a whole. But materials used in modern construction will invariably present a bevy of new and unanticipated problems that have yet to be identified. In recognizing this reality, preservationists must proceed with caution in handling these materials, and should ultimately be asking themselves how this will potentially change the profession in the future. Preservationists are poised to generate a worthwhile and necessary addition to the sustainability dialogue by asking the right questions. What are the risks associated with a given material? What are the appropriate mitigation strategies? How should potential conflicts between authenticity and sustainability concerns be rightfully resolved? By readying preservation to readily adapt both in theory and in practice to these inherent conflicts, the discipline will be better equipped to manage our modern heritage in the name of sustainability.

Notes

1. The Radical Transparency movement focuses on implementing a non-proprietary, open book regulation system of chemical production with regard to new building material production and installation methods. Its reach also extends into consumer products.
2. National Building Technologies website, Chemical and Particulate Pollutants. http://www.natural-building.co.uk/chemical_pollutants.html. Accessed June 2, 2011.
3. Elefante, Carl, "The Greenest Building is... One that is Already Built", *Forum Journal*, Summer, Vol. 21, No. 4, 2007, p. 26-38.
4. National Park Service (1993). Guiding Principles for Sustainable Design. http://www.nps.gov/dsc/d_publications/d_1_gpsd.htm. Accessed February 15, 2011.
5. The Bartlesville area was fundamentally shaped by the financial power of the oil and gas industries from the time that oil was first commercially extracted from local wells in 1897. Harold Price of H.C. Price Co. found success in the 1920s-40s as the industry's technical leader in the coating and laying of pipelines.
6. Wright, Frank Lloyd, *The Disappearing City*, New York, W.F. Payson, 1932.
7. Coles, William A., "Architecture in America: A Battle of Styles", *Skyscraper Casts Its Shadow on the Plains*, Business Week, February 18, 1956. New York: Ardent Media. (364), 1961.
8. Ibid.
9. Alofsin, Anthony, "Pinwheel on the Prairie: An Overview of the Price Tower," *Prairie Skyscraper: Frank Lloyd Wright's Price Tower*, New York, Rizzoli International Publications, Inc., 2005, 22-41.
10. Ibid.
11. Watts, James D., "Frank Lloyd Wright-designed Skyscraper in Running for UNESCO World Heritage Site," *Architectural Record, online journal*. April 10, 2011. Accessed on April 16, 2011. http://archrecord.construction.com/yb/ar/article.aspx?story_id=157864924
12. For more information about the building refer to:
    - *Architectural Record* (1956) vol. 119, a periodical issue dedicated to the Price Tower, cover and pages 153-160.
    - *Prairie Architecture: Frank Lloyd Wright's Price Tower*, published in conjunction with an exhibition by the same name organized by Price Tower Arts Center in cooperation with the Frank Lloyd Wright Foundation in Scottsdale, AZ, which contains a comprehensive history of the building and Wright's tower theories and designs.
13. Richardson, H. Wayne, ed., "Handbook of Copper Compounds and Applications", *Treatment in Copper-Laden Waste Streams*, Peters, Robert W., New York, Marcel Dekker, 1997, 205-209.
14. It was determined in speaking with the site's landscapers that copper-containing fertilizers are not used on the lawn, therefore any copper found in the soil is either naturally occurring or a result of building runoff.
15. The 0-6" depth was a universal standard among multiple sources testing for copper, so this was an important measurement to adhere to. There is however no universally accepted protocol for collecting soil samples. This experiment was interested in finding point-specific values of copper and not average values, so two sources of guidance were used to develop a procedure that fit the purpose of the study.
    - The University of Minnesota's Soil Testing Laboratory, How to Sample, http://soiltest.cfans.umn.edu/howtosam.htm. Accessed December 17, 2010.
    - Allison Turner, "Urban Agriculture and Soil Contamination: An Introduction to Urban Gardening," *Practice Guide* #25, Environmental Finance Center, EPA Region 4. University of Louisville, Center for Environmental Policy and Management, Winter 2009.
16. Soil Testing Laboratory, University of Minnesota, Rm 135 Crops Research Building, 1902 Dudley Ave., St. Paul, MN, 55108; Tel: 612-625-3101; Fax:612-624-3420; email: soiltest@umn.edu; http://soiltest.cfans.umn.edu.
17. The metals are extracted and subsequently separated, thereby producing results that are within a small margin of error from the actual content in the soil.
18. Richardson (207).
19. Toxicology is concerned with the study of chemicals and other hazardous substances, their actions, their detection, and the treatment of adverse effects produced by them in living systems, whether they be human, animal, plant, or microbe. It is an interdisciplinary branch of sciences that integrates the principles and methods of many fields, including chemistry, biology, pharmacology, molecular biology, physiology, and medicine. The sub-discipline of ecotoxicology is the study of contaminants from the biosphere and their effect on other elements of the biosphere. An extensive study of the toxicology of copper can be found in the master's thesis: Amy Swift, *The Toxicology of Copper and Its Implications For Preservation*, Columbia University, 2011.
20. Determination of the Suppressor Additive in Acid Copper Plating Bath (2002) Application Note 145, Dionex Corporation.
21. The difference between adsorption and absorption will be critical to note here. Adsorption is the process by which a copper ion is incorporated, or added, into a chemical compound, thus altering the composition. Absorption refers to copper's ability, regardless of the mineral form it is in, to be incorporated into liquid or gaseous water.

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