PATINA ON PURPOSE: AN INVESTIGATION INTO APPLIED PATINATION ON CONTEMPORARY BRONZE SCULPTURE

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ABSTRACT AND INTRODUCTION

Patination is the process of physical and chemical change that a material undergoes as it ages. The visible age of a work of art can transform degradation into beauty and authority – a testament to how long it has survived as a cohesive material object. Since patina conveys that message of historicity so well, contemporary artists use patination to their advantage, intentionally applying layers of chemical reagents to achieve a similar aesthetic to natural patina and to communicate the desired message of their work. Such pieces resemble historical artifacts and suggest the importance of an object of cultural heritage. Applied patination, while an old idea, has changed in form over time, such that contemporary applied patination is a unique and growing area of study. With the advanced imaging and analytical techniques available today, variables in patination – the manufacture of chemicals; environmental conditions; application methods; and others – can theoretically be analyzed on an individual basis at the point of creation of a work of art. In practice, time and monetary constraints limit the records kept on a work of art. This paper combines an investigation of existing bronze patination research with the author's experience as an intern at The Seward Johnson Atelier (TSJA) to survey the discussion of applied patina on contemporary bronze sculpture. Further field studies of applied patination of metal in a studio setting will guide the future conservation of patinated sculpture.

The concept of contemporary applied patina

Even the niche of applied patination is a broad topic, so some limitations will need to be set for this paper. First, "applied patina" is defined within the scope of this paper as human-induced chemical changes; specifically, the process of introducing salts (for example, copper (II) nitrate, or $Cu(NO_3)_2$) dissolved in water to bronze, which oxidizes the metal. The primary appeal of applied patination is the acceleration of a natural process. Metal oxidation naturally occurs over years or even decades. Meanwhile, applied patina can be accomplished in an afternoon. Besides this, applied patina has a variety of uses – to reflect the aesthetic of natural patina; to create an aesthetically-pleasing pattern and color; and to passivate the metal, or make it unreactive to further, undesired corrosion.

When art is contracted to a studio like The Seward Johnson Atelier, two types of artists make a work of art a reality. The first is labeled a 'designer' in this paper and is the originator of the idea. Usually, the designer will also work in the creative process, for example making preliminary models or doing finishing touches. The designer's vision is what guides the outcome of a work of art. The other type of artist, in this paper labeled a 'technician', enacts the designer's idea with their skill and knowledge in artmaking. Even they follow the designer's designs, they also have executive power over the creation process. For example, the technician can suggest alternatives to ideas outside the designer's budget. Both designer and technician are artists, and they both contribute significantly to the final work of art, even if it is only the designer who is credited.

A designer uses their art to communicate an idea. Each designer's considerations – their message, and the techniques they use to convey it – will be unique to them. But many designers specifically prefer patina in their designs. One of the reasons for this is its flexibility. The temperature at which patina chemicals are applied can change their color. A spray bottle set to gently mist the surface with reagent creates a homogeneous layer of color. A heavier spray can make rings that retain their watery look even when the piece is dry. With a cloth or brush stroke, an artist can draw a linear texture like wood or fur. By varying the tool and methods used, the technician can create different patterns and even regions of light and dark which, when the finished sculpture is regarded from a distance, emphasize its form or texture, creating a contrasting effect called *chiaroscuro* that adds to the piece's dimensionality, as in Figure 1. In these ways, patina can be analogous to paint – capable of broad coverage and smaller detail.

Another motivation for the use of patina is to draw parallels between contemporary creations and antique, or even ancient, objects. Patina is a visual reference to the passage of time, and therefore the length of time the patinated object has existed in the world. Cultural artifacts, among which patinated metals are numerous, are important in part because of their age; over time, they have been venerated as representative of a location, culture, or the beauty of persistence. Therefore, patina has semiotic importance, and patinated objects share that sense of authenticity. An onlooker knows that an ancient Chinese bronze vessel carries high value to human societies because the slow chemical reactions to produce the brilliant blue-green oxide layer happened over two thousand years. Its aged appearance makes it easier to accept this Chinese bronze as cultural heritage; after all, the aesthetic and chemical changes prove it has accompanied two millennia of cultural development (Figure 2).[1]

Figure 1: Matters of the Moment (2008), a cast bronze sculpture by Mike Gyampo. The sculpture exceeds 8 feet and features a cupric nitrate and ferric nitrate patina that accentuates its textures and crevices, making them noticeable from a distance. © Artist or Artist's Estate, photo: Ken Ek.

Patina on new sculptures, therefore, borrows that implication of endurance by copying its aesthetic. Bruce Lindsay, a contemporary artist with two works on permanent display at Grounds for Sculpture, chose a blue-green patina for the bronze portion of his sculpture *Between Essence and Existence* (Figure 3). Here, the patina is not just a color and pattern; it is juxtaposed with the bronze shape's seemingly tenuous position on top of its granite base. A popular concept for contemporary sculpture is contrast – for example, stability and impermanence. Here, the quick application of patina allows for Lindsay to achieve the desired appearance and concept without waiting decades for the natural patina to form.[2]

In a more practical sense, patination develops a protective oxide layer on the metal surface. The metal atoms in pure metal, exposed to oxidizing reagents like oxygen or chlorine, will combine to form more stable compounds at the cost of their identity as separate chemical species. This will occur regardless of human intervention, as oxidizing reagents are common in the environments of public art. Applied patinas are an oxide layer chosen to represent the designer's vision. They occur by a similar, albeit faster, process and thus similarly result in more stable compounds.

Figure 2 (below): An ancient Chinese bronze dui, or serving vessel, held by the Metropolitan Museum of Art (accession number 13.100.7a, b). Some of the red inlay remains in the recesses of the pattern. The subtle green patina could have occurred from a multitude of factors in this object's 2500-year history. Open access image.

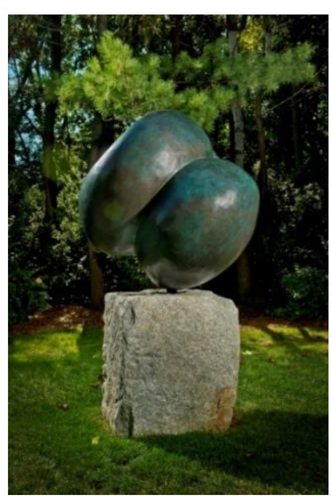

Figure 3: A turquoise-blue patina accentuates the bronze upper portion of Bruce Lindsay's Between Essence and Existence (1992). © Artist or Artist's Estate, photo: Ken Ek.

Administrating art

Patinated sculpture is often placed outside for public or private viewing. Public sculpture can attract residents, tourists, and businesses, making art a topic of discussion or even contention. To uphold art as an expression of culture, not-for-profit organizations arise to create, care for, and publicize public art. The Seward Johnson Atelier is a not-for-profit, 501(c)(3) organization with the mission of promoting the visibility of public artwork, especially through sculpture. It was founded by John Seward Johnson II as a foundry and school in 1974. Johnson also created Grounds for Sculpture, a 42 acre outdoor art gallery and garden, in Hamilton, New Jersey. Since then, it has transformed into a restoration and fabrication facility for Johnson's and many other artists' works, much of which is cast bronze. Bronze is an alloy of various metal elements, with copper being the primary component. Small amounts of additives – usually tin, and in modern alloys silicon or manganese – stabilize pure copper, making it less susceptible to corrosion. Because of this and its classic deep gold color, bronze is a popular choice for metal artists.

Many of Johnson's pieces were created at TSJA's foundry. At the foundry, bronze sculptures are cast using the 'lost wax' technique, also known as *cire perdue*. This method takes advantage of two aspects of wax: the sculpted detail it is capable of holding and the low temperature at which it melts. A sculptor makes a wax mold in the shape of the final sculpture, then makes a sand mold of that. From there, molten bronze is poured into the mold, out of which the wax quickly melts, allowing the bronze to take its place.[3] Johnson's sculptures were often cast in pieces, then welded together to form the complete sculpture. The metal is often 'chased', which is the process of hammering or carving texture on hot metal that may have been lost when casting, creating intricate grooves reminiscent of corduroy, leather, or skin. The casting process is a collaboration of skilled technicians. Casting issues partially determine the result of patination. The heat of the metal can vaporize droplets of water in the mold, which explode and create pinholes in the metal sculpture. Pinholes on an outdoor sculpture collect rainwater, causing conspicuous trails of blue-green oxidation on bronze. These, among other issues, are characteristic problems of outdoor metal sculpture.

TSJA's sculptures typically undergo a cycle of exhibition and repair. A client – for example, a city event planner or arts council – commissions a set of Seward Johnson's works for temporary public display. The pieces are selected and pulled from storage. Then, structural, paint, and patina repairs are completed on the sculptures and their signage, for which the client is billed. The pieces are transported to the location and installed. During the show, the pieces experience harsh conditions – heavy rain, pollutants, abrasions, vandalism – and often return to TSJA in suboptimal condition. Once the pieces are requested for another show, the cycle of repairs repeats. (The Atelier handles art from a multitude of artists; while these sculptures may be part of a private collection and not on show, they still undergo weathering.)

The arts administration perspective is different from that of the designer. Despite the variance in arts organizational structures and missions, a general similarity of all arts organizations is the need for income (or, as not-for-profits call it, funding). This means that an arts organization, like any other business, seeks to maximize gains and minimize losses. The flow of resources – money, time, and employees – limit what artmaking practices are possible. In the structure of The Seward Johnson Atelier, money is made from completing commissions for outside artists and selling Seward Johnson's works, which TSJA owns. As a 501(c)(3), funds gained must go to the organization's mission; therefore, that money is directed to more work on public art, whether that be Johnson's or another artist's pieces.

At an art institution like TSJA, available resources determine the extent of a restoration. If a major issue is discovered on a piece after a budget has been made, and time, money, and workers are not allocated for extensive repairs, that issue may be quickly patched over or left unfixed. This frugality is necessary, if not ideal, and it guides innovations in patination, painting, and passivating. A practice as simple as washing the dust or standing water from a sculpture can prevent unwanted corrosion from forming. But this kind of upkeep is impractical for an arts organization on a tight budget to sustain. Outdoor sculpture parks like Grounds for Sculpture have hundreds of sculptures in their care and too few resources to spare washing them every few weeks. And the more time is spent on the upkeep of artwork, the less time those artworks are in public view. Therefore, arts organizations are more interested in efficient solutions to corrosion mitigation, rather than prohibitively expensive corrosion prevention.

Patination processes

An employee in an art fabrication studio is an artist-technician, responsible for their artistic decisions, as long as they are in service to the artist-designer's vision. Under normal circumstances, applied patination takes place in a studio environment. This often means a well-ventilated, indoor space in which the temperature or humidity may not be controlled. Frequently, however, patination must be done outside. However, the additional complications from weather, insects, and other factors are beyond the scope of this paper.

Modern applied patina is accomplished through the use of chemical reagents that react with the metal surface. Before applied patination takes place, however, the technician must conduct research to ensure they follow the proper protocol. As with any chemical reaction, safety is a high priority. The art institution may have a repository of safety data sheets of patination reagents. These documents give instructions on proper protective equipment, risks of flammability and carcinogenicity, and emergency procedures should someone come in contact with the chemical. The technical data sheets are a similar resource geared toward ensuring the patination reagent is used in the correct way to produce the intended result. Before patination, the technician may glance at or recall this information; and they keep the documents within easy reach should they encounter any problems.

While remembering the precautions of the reagents, the technician gathers the materials they will need. Art institutions buy bulk patination chemicals at high purities from vendors specializing in industrial or artistic reagents.[4] The technician may check the stockroom for these; or they may choose a plastic measuring cup of reagent from a previous project. A label on such a container may describe the composition (chemicals and their proportions), method (hot or cold), or color. However, none of these descriptors are guaranteed (Figure 4). The technician must glean information on the patination of a specific sculpture from its accompanying paper documentation. These are most analogous to a scientific laboratory report, though they differ in format, content, and goals. For example, a studio document may record the supplier but not the concentration of the chemical, as it may be assumed the technical data sheet reference sufficiently explains how to mix the reagent. Further guidance comes from images, written notes, designer input, or, in the case of restoration, from the technician's own observations of previous patination remaining on the sculpture.

Figure 4: An image showing five examples of labeling patination reagents, with various degrees of specificity. From left to right: a) a bucket label describing method (cold) and color (green); b) an unlabeled cup whose contents the technician keeps in their memory or on the project's paper documentation; c) a spray bottle labeled with its chemical composition (ferric [nitrate]); d) a plastic bottle only labeled with its color (black); and e) a plastic bottle of powdered reagent, not yet dissolved, with the supplier's label showing all information. Image taken at The Seward Johnson Atelier by the author.

For the purposes of artmaking , this information is a sufficient start to patination, but adjustments to chemicals and process are inevitable. Here, patination becomes less methodical and more intuitive – a necessity in artmaking, where the creation of an aesthetic supersedes completing a chemical reaction. Putting the patination reagent on the metal may be described in shorthand as "brushed 2:1 cupric/ferric hot patina with chip brush – dark in crevices"; but what isn't written are the multitude of decisions that the technician makes when they decide to move the brush a certain way. While that level of exactitude is impossible and unnecessary, it does mean that every patination and restoration is unique, and further restorations require a high level of perception and skill to match the previous appearance.

Applied patina appears in two primary forms: "hot" and "cold" patina, which differ in some crucial respects. The first of these is temperature. Hot patina involves heating the metal surface with a blowtorch to accelerate the chemical reaction between it and the aqueous reagent. Once the technician determines the metal is hot enough by touching it with a gloved hand, they apply the patina chemical to the surface, which should immediately sizzle and evaporate. (Casting issues, especially variations in thickness of the cast bronze, can cause uneven heating, and therefore an uneven reaction of the patination reagent. Many of the technician's decisions during the patination process involve compensating for these inconsistencies.) The technician wipes away excess chemicals with a wet cloth, and repeats the application process until they achieve the coverage they desire.

In cold patina, patination takes place on room-temperature metal. Small objects are dipped into a bucket or vat of reagent, scrubbed with a stiff brush, and washed with clean water. Again, further dips result in more coverage and a darker color. The technician can build up cold patina slowly to have more control over its intensity while sacrificing the detail and speed of hot patination. At this point in the hot or cold patina process, the desired color has been reached. If the sculpture were to be installed now, though, outdoor conditions would quickly degrade the coating.

Passivation processes

The technician must passivate both hot and cold patinas. Passivation is the process of making the surface of the sculpture passive, or resistant to further undesired chemical reaction. It is a mandatory step in the patination process, since it seals the aesthetic effect from deterioration. It also protects the artist's intended appearance of the piece. Without frequent care, bronze sculpture can severely corrode to the point of structural instability, like in the chloride-induced "bronze disease" discussed later. Indoor sculpture requires passivation as well. Handling and cleaning can introduce unwanted corrosive reactants to the bare patina. Even organic[5] vapors from common conservation tools, like glues, can react with the patina. Formic acids are reactive compounds found in certain wood products that can react with bronze to form copper formates, a type of patina not studied as well as others.[6]

The technician has many choices regarding passivation, all with their own benefits and drawbacks, depending on what they aim to accomplish. TSJA often chooses to passivate its patinated sculptures with wax. For this, the technician buffs microcrystalline wax polish[7] directly onto the patina with a cloth or synthetic brush.[8] Similar to patination, waxing can be done hot or cold; and often, one layer of hot wax is paired with two layers of cold wax. Wax is easy to apply, even to a large sculpture. A thin layer of wax is sufficient to protect the patina surface from the harsh chemicals the sculpture may encounter outdoors. It has the additional advantage of filling pinholes, the casting error that causes conspicuous spots of corrosion. But wax can gather in a sculpture's crevices in pasty white clumps. It also evaporates faster from the surfaces of a sculpture facing the sun and becomes uneven in its coverage within as little as six months. Therefore, wax passivation requires regular re-applications.

Wax is cheaper and less technical than the infrastructure needed for pneumatically-sprayed passivation methods like lacquer.[9] Lacquer, however, has its own advantages. It can be sprayed over patina or wax for a quick protective coat. Lacquer can also be tinted with pigment. In a quick repair on a tight budget, the technician can match the color of the lacquer to the patina and mist, or lightly spray, the surface. While not a permanent solution, lacquer fixes bring a patinated piece to acceptable condition long enough for the duration of a show. A combination of lacquer and wax can negotiate even more time between new coats.

Passivation, no matter the method, is not a permanent process, nor should it be. Even a well-waxed sculpture, if left outside, may require a new coat every six months to retain its appearance. While frequent waxing seems tedious, other solutions have more significant disadvantages. Polyurethane is a case example of undesired side-effects. A priority of conservation, or the processes by which a work of art is maintained, is non-invasive, reversible treatment. A coating of polyurethane can last up to ten years, compared to the 2-5 year lifespan of microcrystalline waxes.[10] But while it is a durable coating, it yellows under ultraviolet light, greatly changing the appearance and character of the artwork. In addition, its removal requires harsh stripping with abrasives. Because of the effort it takes to remove, polyurethane is effectively permanent, and stripping it means re-doing the entire patination process from bare bronze. Lacquer and wax, meanwhile, can easily be removed with solvent liquids like xylene and naphtha, respectively, and a gentle cloth.[11]

An outdoor sculpture may not have received proper upkeep, allowing its color and structural integrity to deteriorate. Or even with sufficient care, erosion or vandalism may necessitate restoration. However, patina restoration need not involve completely removing the previous layer. To avoid wasting materials and exceeding the allotted budget for the project, the technician may choose to conduct a partial patina restoration. Patina restoration is a similar process to new patination. First, the surface is cleaned of old wax and detritus with naphtha and heat. Then, research yields the designer's desires for the piece – images and metal samples are especially useful, as is the remaining patina on the piece. Patina recipes – for example, two parts cupric nitrate to one part ferric nitrate for a particular shade of brown[13] – as recorded in the documentation of the works are helpful to an extent. Studio conditions vary greatly, as do the outcomes of the same proportion of reagents. In addition, the chemicals' age, purity, and concentration can change the hue or shade of the resulting patina. Although it is a scientific process, no patination in a studio environment is carried out as if it were in a lab. The technician usually measures by eye or volume and adjusts the recipe as they need. This does not mean that the technician in the studio is less methodical than the researcher in the laboratory. Each has an inherently different understanding of the materials.

Chemical reactions of patina

The chemical principle that guides patination is electrochemistry. Water that contains dissolved charged particles, or ions, is capable of conducting electricity, so it is called an electrolytic solution. Areas giving or accepting an electric current are called anodes and cathodes, respectively, and it is the anodic position that is corroded. When a metal surface is introduced to water, the anode releases positively-charged ions (cations) into solution. Loose cations form bonds with negatively-charged particles, or anions. Certain combinations of cations and anions form compounds that are not soluble in water. These compounds, or insoluble salts, deposit on the surface, forming a wide variety of microscopic crystalline structures. These structures can be homogeneous, or flat and solid; or hygroscopic, meaning they have a texture that retains moisture. A homogeneous, insoluble deposit on bronze will protect it for years to come. But patina that forms in a sponge-like porosity will keep the electrolytic solution – water – in contact with the bronze surface, encouraging further corrosion.[12] Pinholes also collect water and promote corrosion; and patina can conceal these problem areas without fixing them. They can be removed by polishing the metal surface after casting and before patination, but this process may lead to an undesired aesthetic.

A common source of natural patina on bronze is galvanic corrosion, which requires two metals to occur. Bronze is traditionally an alloy that consists primarily of copper and small amounts of tin. Tin, while not the major component in the bronze alloy, is a crucial contributor to the chemical reactions. Copper is a noble metal, meaning it is less likely to corrode and more likely to act as the cathode. Tin, meanwhile, is considered a base metal, which means it is more likely to corrode and will act as the anode. Therefore, natural galvanic corrosion of outdoor bronze sculpture will likely contain a significant proportion of tin compounds compared to copper compounds. Tin species are less-studied than copper products in a conservation context, but it is known that tin metal passivates over time to form the tin hydroxide $Sn(OH)_4$, and eventually the more stable stannic (tin (IV)) oxide, SnO_2.[14] Hygroscopic structures from other bronze components or dust, or even simply a very humid environment, accelerate this process.

Other types of corrosion occur from more specific environmental factors. Public sculptures share the same space as the public, so they experience the harsh chemical conditions that make modern life feasible. De-icing salt, which is the same compound as table salt (sodium chloride, or NaCl), is spread on road surfaces as a brine.[15] The dissolution of sodium chloride to water releases sodium cations and chloride anions, which lower the melting point of water, making it liquid at lower temperatures. The ice then melts to slush, making its removal easy and wintery morning commutes safer. A side effect of this is the production of chloride ions, which are an aggressive corrosive agent for copper and bronze. Chloride corrosion, or "bronze disease", results in pits in the metal to form, compromising the stability of the sculpture (Figure 5). Chloride ions break apart stable patinas to react with the metal surface beneath.[16] Thus, bronze disease is a self-perpetuating deterioration that can be started by merely some misplaced salt.

$$\text{(a)}\quad Cu_{(s)} \longrightarrow Cu^{+}_{(aq)} + e^{-}$$

$$\text{(b)}\quad Cu^{+}_{(aq)} \longrightarrow Cu^{2+}_{(aq)} + e^{-}$$

$$\text{(c)}\quad Cu^{2+}_{(aq)} + Cu_{(s)} \longrightarrow 2Cu^{+}_{(aq)}$$

$$\text{(d)}\quad Cu^{+}_{(aq)} + Cl^{-}_{(aq)} \longrightarrow CuCl_{(s)}$$

Figure 5: At the anode, solid copper metal is oxidized to the cuprous (copper (I)) ion (a). This is further oxidized to the cupric (copper (II)) ion (b), which attacks the metal again to form more cuprous ion (c). Cuprous chloride, a solid product, forms and deposits on the metal surface.

The relevance of these forms of natural, or at least unintentional, patina to applied patina are that all of these reactions may occur in conjunction, and their products may influence the formation of others. Applied patina may have a passivating effect, but it does not completely prevent additional corrosion. Even wax passivation does not form a perfect barrier between the metal and its environment. But the corrosion that happens on patinated sculpture involves interactions between applied patinas and subsequent natural corrosion. In addition to this, the specific alloy composition, patination reagents, and studio environment greatly impact the result. As modern technologies in art evolve, and new alloys, reagents, and processes are popularized, restorers and conservators must evolve their methods to understand them. The field of applied patination must be understood as distinct from natural patina in terms of the expected chemical reactions and aesthetic longevity.

Cupric nitrate ($Cu(NO_2)$) dissolved in water is one of the more common patination reagents in a studio. By itself, it produces a brilliant blue-green; in combination with other reagents, it creates a blue-leaning tint. Cupric nitrate can be applied hot or cold – the faster hot method usually results in a deeper, richer color. Despite the visual differences, hot and cold patina result in similar chemical structures. Hayez et al. (2006) found that when cupric nitrate patinas are examined under a scanning electron microscope, very similar granulated formations are seen.[17] Raman spectroscopy, which measures the vibrations of individual molecules, shows that the water-soluble cupric nitrate mostly deposits in the form of insoluble rouaite, or $Cu_2(NO_3)(OH)_3$ which is a copper nitrate derivative. Another method of observation, X-ray diffraction, shows that compound to have an monoclinic structure, a consequence of its quick formation.[18] The patina samples in this experiment that were created at high temperatures had a greater degree of crystallization, which in practical terms could mean a more effective passivation layer. Solid cupric nitrate derivatives are relatively inert to further reaction once they form. However, as a rule nitrate compounds are very soluble in water; so for stable solids to form, the metal sculpture must have been in contact with a very strong solution of nitrates. This is a chemical environment that only happens in a studio, not in nature. Therefore, a patina with a majority cupric nitrate derivative composition is most likely applied patina.[19]

Ferric nitrate ($Fe(NO_2)_3$) is a uniquely heat-sensitive reagent. When applied cold, in thin layers it is yellow, and gradually becomes a deep brown with more coverage. When applied hot, the chemical results in a rich red. Like copper nitrate, ferric nitrate can be used in conjunction with other patina chemicals to adjust the color. A solution of ferric nitrate and sodium thiosulfate ($Na_2S_2O_3$) in water forms a green patina that, when combined with another passivation method like wax, forms a protective layer on the bare metal. In a study by Chelaru et al. (2013), this chemical combination was subjected to simulated acid rain conditions and tested by measuring the resistance between the metal electrodes and water, the electrolytic solution. From this data, the rate of corrosion that occurs at anodic positions can be measured. The ferric nitrate and sodium thiosulfate patina with no wax has a 33% increase in protection efficiency compared to bare bronze metal; with wax, this is increased to about 50%.[20] It is because of this stability, along with the range of colors it can produce, that ferric nitrate is a common component in applied patina.

One of the largest gaps in patination research is into other chemicals used in the modern studio. Much of the current scientific research into patinas and metal corrosion in an art context is intended to replicate a historical patination method, appearance, or chemical structure.[21] Instructions, recipes, and safety information can be found for chemicals like ammonium chloride (NH_4Cl), zinc chloride ($ZnCl_2$), potassium bitartrate ($KC_4H_5O_6$, or cream of tartar), and lead acetate ($Pb(C_2H_3O_2)_2$), but few peer-reviewed, detailed studies of these as applied patination reagents exist. Since the products of these reagents do not replicate a historical process of applied patination or represent environmental corrosion, they are not the focus of scientific study. However, these reagents are still commonplace; and whether later or sooner, they and their products on bronze must be studied to preserve and restore sculptures being patinated today.

A new front of patination research that serves the contemporary artist is the creation of new forms of patination. One of the major appeals is the possibility for more colors – oranges, reds, or whites not currently within the reach of known reagents, that must currently be applied with paint. Another possible benefit of novel patinas is increased efficiency. Improving material economy would allow arts organizations to stretch their funds to accomplish more and better pursue their mission. Lastly, safety would come in the form of using less-harmful chemicals (for example, those with lead components). The use of metal complexes, a category of molecules containing a metal atom surrounded by other atoms (ligands) that guide its reactivity, can be a safer and more versatile alternative to traditional methods. Devantier et al. found that if a solution of ammonium chloride (NH_4Cl) is followed by the iron salt $Fe(NO_3)_3$ and then a nitrogen-based ligand, the bronze attains a bright red color. In an environment devoid of oxygen, this color remains; otherwise, the metal surface gradually turns blue. Experimenting with more oxygen conditions can produce an attractive blotched effect.[22]

However, art studios may not be able to afford pricey ligands,[23] nor might they have the infrastructure needed to conduct patination without oxygen.

Conclusion

In applied patination, scientific study of conservation and institutional or individual artistic creation have different goals: the first seeks to replicate historical methods and outcomes for the benefit of conservators, while the second prioritizes ideation, creation, communication, and expression. Science and art, however, are not a dichotomy, and this paper aims to contribute to the development of an understanding of the benefits of these disciplines to each other. Scientific study gains another humanistic goal when it is aimed at improving current human methods of expression and communication. Art is strengthened when the decisions made in its creation and maintenance are informed and cost-efficient.

This can only occur with effective communication. Developing a shared language and process for this partnership benefits artmakers, conservators, and materials scientists alike. Interdisciplinary communication and the amount of published knowledge must both be increased. Further quantitative and qualitative studies of applied patination will improve the longevity of contemporary sculpture. They increase knowledge of the chemical consequences of factors in application, and of how to get to the desired aesthetic within budgetary constraints. They contain ever-greater specificity to contemporary art from cultures and locations often ignored in literature and markets.

To prioritize the development of applied patination knowledge in a useful format, arts administrators can allocate time, money, and staff to recording their practices. They can increase communication with other institutions – artistic or scientific – for mutual transfers of knowledge. They can direct resources to education, particularly for increasing interest in recordkeeping among young professionals. Finding the requisite funds for projects like these is a challenge that government, public, and private support can alleviate. Awareness and money can catalyze improvements to methods of applied patination with sweeping benefits to appreciators of art across the world.

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Notes

1. For a discussion of different attitudes towards conserving and restoring patina on art, see Hilkka Hiiop, "The Possibility of Patina in Contemporary Art or, Does the 'New Art' Have a Right to Get Old?," in Place and Location: Studies in Environmental Aesthetics and Semiotics VI. Tallinn: Eesti Kunstiakadeemia Kirjastus (2008), 153-166.

2. For another example of how patina changes the character of a work of art, see Claudia Silva, Gabriel Vélez, and Henry A. Colorado, "Patina in the construction of the poetic bronze image: science of materials, art, and philosophy," *Heritage Science* 5 no. 36 (2017), 1-11.

3. Terry M. Anderson, "A Studio Manual for Casting Bronze by the Lost-Wax Method" (University of Minnesota, Duluth, dissertation, 1974), 3.

4. Patina chemicals are sold as individual (i.e. powdered ferric nitrate) and pre-mixed (i.e. 'Antique Black'). TSJA also uses automotive polyurethane paints, which are sold as systems – pigments, binders, and reducers come separately, and must be mixed to produce a specific color. Unlike paints, no warranty comes with patina reagents for the outcome.

5. Here, 'organic' is used to refer to a set of carbon-based chemicals that react in similar, predictable ways.

6. David A. Scott, Yoko Taniguchi, and Emi Koseto, "The verisimilitude of verdigris: a review of the copper carboxylates," *Studies in Conservation* 46 sup. 1, no. 2 (2001), 73-74, https://doi.org/10.1179/sic.2001.46.Supplement-1.73.

7. Examples of common wax polish brands include Renaissance Wax, Trewax, Minwax, and SC Johnson. At TSJA, these may be used interchangeably, as the waxes have subtle application differences.

8. Wax can also be sprayed. See Joseph Sembrat, "The use of a thermally applied wax coating on a large-scale outdoor bronze monument," *ICOM Committee for Conservation 12th triennial meeting* (1999), 840-844.

9. Metal-passivating lacquer brands include Incralac, Permalac, and Syncralac. At TSJA, these products are used interchangeably (though not mixed together on one sculpture). Attempts to improve the environmental sustainability of these lacquers have failed to produce a satisfactory result. See Julie Wolfe et al., "Deconstructing Incralac: A formulation study of acrylic coatings for the protection of outdoor bronze sculpture," *ICOM Committee for Conservation 18th triennial meeting* (2017).

10. Luc Robbiola, Christian Fiaud, and Stéphane Pennec, "New model of outdoor bronze corrosion and its implications for conservation," *ICOM Committee for Conservation 10th triennial meeting* (1993), 801.

11. Xylene and naphtha are both flammable, presenting a difficulty when they are used before applying patina by the hot method.

12. Robbiola, Flaud, and Pennec, "New model of outdoor bronze corrosion," 798.

13. Recipes like these are recorded in patination books and websites, but it is presumed the artist will adjust them. See https://www.sciencecompany.com/Patina-Formulas-for-Brass-Bronze-and-Copper.aspx.

14. Stuart Lyon, "Corrosion of Tin and its Alloys," in *Schreir's Corrosion* ed. 4, vol. 3: Corrosion and Degradation of Engineering Materials, editors Tony Richardson et al. (2009).

15. Sodium chloride salt is common and inexpensive, but alternatives with less of an environmental impact are often used in conjunction.

16. A more detailed explanation of the reactions and treatment of bronze disease can be found in Ian MacLeod, "Bronze Disease: An Electrochemical Explanation," *ICCM Bulletin* 7 no. 1 (1981), 16-26.

17. Valerie Hayez, T. Segato, Annick Hubin, and Herman Terryn, “Study of copper nitrate-based patinas,” *Journal of Raman Spectroscopy* 37 (2006), 1213.

18. Hayez, Segato, Hubin, and Terryn, “Study of copper nitrate-based patinas,” 1215.

19. David A. Scott, *Copper and Bronze in Art* (Los Angeles: Getty Conservation Institute, 2002), 250-251.

20. Julieta D. Chelaru, Lucian Barbu-Tudoran, and Liana Maria Mureşan, “Protection of artistic bronzes by artificial patina and wax,” *Studia UBB* Chemia 8 no. 4 (2013), 180.

21. For example, DiCarlo et al. (2017) seek an artificial patina that replicates natural patinas caused by chloride and sulfate pollution. See Giovanni DiCarlo et al. “Artificial patina formation onto copper-based alloys: chloride and sulphate induced corrosion processes,” *Applied Surface Science* 421 (2017), 120-127.

22. Ashley E. Devantier, Susan J. Murch, and W. Stephen McNeil, “Exploration and characterisation of novel bronze patinas derived from simple coordination complexes,” *Dalton Transactions* 40 (2011), 616.

23. A ligand used in this experiment by Devantier et al. (2011), 2,2’-bipyridine, sells for $55 USD per five grams from the chemical supplier Sigma Aldrich. As a comparison, 100 grams of ferric nitrate sells for a comparable price.

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