Freeze / Thaw: A Menacing Line and Humble Resistance

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DESIGN DECISIONS AND THE WEATHER

The impetus for this investigation comes from rather empirical observations made during 15 years of Midwestern practice and the types of decision making that occurs in the design process. Decisions in practice are always made quite synthetically, with the frequently opposing forces of intention (or "this is what I want it to be") resisted by necessity (or "this is what it can be, based on technology / budget / timeframe / durability / etc."). Not much time is spent on solutions that cannot meet multiple goals at once, and research on new or innovative solutions tends to follow the 10% rule – meaning you can take a 10% risk on a client's project with untested technology, but 90% should be reliable based on experience. This varies both by firm and regionally – technology risks in southern California are low in terms of environmental cladding, but extreme in earthquake resistance. In the Midwest, and in particular the freeze/thaw zone, the weathering of building shells occupies most of our serious concerns for durability and potential failure. Considering the character of the building envelopes in central Iowa, some materials and assemblies that are commonly used in cities directly to the north and south are largely absent around Des Moines. Explanations of cultural differences or colder weather from south to north do not immediately explain the reasons why.

CULTURAL AND TECHNICAL FORCES

It's appropriate to approach the question of technical or climatic determinism of building form with a certain degree of skepticism. Cultural and historical forces play an undeniable role in design decisions at any level. Amos Rapaport argues that anti-climatic responses are common counterpoints to the idea of climatic determinism. "The existence of fairly frequent anticlimactic solutions leads one to question the more extreme climatic determinist views, and suggests that other forces must be at work. Primitive and peasant builders have needs and drives that are "irrational" in terms of climate, these may include ceremonial and beliefs, prestige, status and so on." [1] Cultural Geography, in general, has turned away from environmental determination of form – Lewis Mumford contends that man was a symbol-making animal before he was a tool-making animal[2]. However, This essay is approaching the issue of design from the point of view of practical decision making in terms of utility, because that's how the process often works when determining what buildings are made of and how they're assembled. The view of climate completely determining building form is certainly excessive, although it's understandable to view utility and necessity as primary motivators. Victor Olgyay's diagrams of regional building forms in *Design with Climate* present not only a case for looking at primitive vernacular forms for instruction on how best to passively deal with climate, but also suggests that the forms are a direct and completely logical outgrowth of the climatic forces being applied.

In considering the issue of freeze/thaw we look to the more recent discipline of "Construction History" as an assessment model, taking into account materials, techniques, cost and durability along with cultural factors in discussing how design decisions are made. This provides a means of weighing the impact of climatic decisions against cultural influences and will attempt to separate the common factors that can be applied to choices made because of freeze/thaw concerns.

MAPPING THE ZONE

Developing the map of the freeze/thaw zone required the consideration of a number of factors. The primary concern is the temperature shift, but many places in North America go above and below freezing on a regular basis. Adequate moisture is also required for the mechanism to work, so precipitation amounts need to be studied as well. There is no currently existing nationwide map of this specific phenomenon (as far as I've found, and would be pleased to be mistaken on this point), so the development must determine the criteria that would include or exclude locations. A good starting point is the USDA Hardiness Zones and Average Annual Minimum Temperature Range map.

This map, however, only shows the minimum expected temperatures along the zone lines to assist in determining what plants may effectively grow in certain areas and when planting should occur. It's also notable that the original map was compiled from 1974-1986 temperature data to produce what is currently presented in a 1990 version of the official map. In 2003 the American Horticultural Society revised the map using data from 1986-2002. This new map showed a general warming that shifted the zones northward by an average of half a zone nationwide. The USDA rejected the revised map and they still present the 1990 version as current. Subsequently the National Arbor Day Foundation revised the USDA map in 2006 and it validates the information from the American Horticultural Society that the zones have shifted northward over the past 30 years.[3]

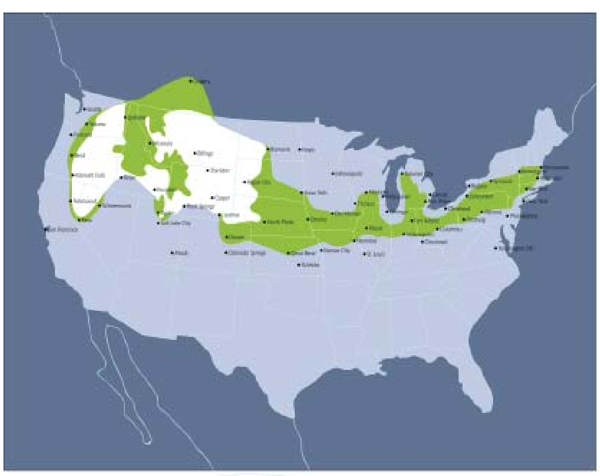

Fig. 1: New Freeze/Thaw Map

In creating this new freeze/thaw zone map (fig. 1) the revised Arbor Day maps and National Oceanographic and Atmospheric Association weather data from the past 20 years were utilized.

Cities that were in planting zone 5 are the most likely candidates to have the maximum numbers of freeze/thaw cycles per season. Studying the weather data for average daily temperatures by month, a somewhat arbitrary decision was made that included cities with 5 months or more of diurnal averages above and below freezing, which is where the zone 5 line primarily centers. This was tested against some initial data on building pathology and the frequency of freeze/thaw related failures along a vertical line from Kansas City (3 months of average daily cycles) and Minneapolis (2 months of average daily cycles). Both Kansas City and Minneapolis have far fewer instances of frost induced failures than Des Moines, which is roughly equal distance between the two cities and has 5 months of average daily cycles. Further refinement of this starting point will likely be necessary, but the process needed to start somewhere to begin evaluation. This approach maps a zone narrow in the Northeast, widening considerably heading west past the Plains States as it bends northward to completion just short of the Pacific Northwest. Next, rain/snowfall amounts were considered, and areas with less than an inch of average monthly precipitation were excluded from the zone. This eliminated cities like Laramie, Wyoming that has almost eight months of the year where average daily temperatures are above and below freezing, but the average monthly precipitation for those months is less than half an inch. While this is not as precise as might be desirable, it offers an area to explore with similar climatic conditions that undoubtedly go through the freeze/thaw cycle frequently under precipitation load.

PATHOLOGY OF FREEZE / THAW AND WATER

In terms of building pathology we normally consider four deterioration mechanisms that destroy buildings. They are structural failures, thermal load failures, hygroscopic infiltration with subsequent damage, and chemically induced damage from internal or external sources. Freeze/thaw acts with two of these mechanisms, thermal and hygroscopic, and can have an impact on the structural damage through their actions. Building deterioration is typically an entropic process that progressively gets worse over time and rarely repairs itself when the destructive actions are removed. In fact with freeze/thaw we consider the repetition of cycles to be an inherent part of the problem. The conditions required to induce the cycle are porous or absorptive materials, surface moisture, material that can be split with the expansive force of freezing, and temperature that declines below freezing. The sequence of freeze/thaw is well explained by Samuel Harris, from his book *Building Pathology*.

> "1. Water runs down the vertical surface of an exposed porous, permeable, absorptive surface,such as concrete, brick, or stone masonry.
>
> 2. The water is absorbed by and into both the crystalline solids and the capillaries, which erupt at the surface of the material.
>
> 3. The water freezes, which results in expansion of the water and subsequently the ice.
>
> 4. The expanding water and ice exert pressure inside the fabric; if the pressure exceeds the modulus of rupture, a crack is initiated.
>
> 5. The water subsequently melts, and the process is repeated, but henceforth, the newly initiated cracks absorb water as well.
>
> 6. Pressure inside the nascent crack extends the crack, and the cycle begins again."[4]

The greater the number of cycles the greater the damage, so frequency has a tremendous impact on the rate of deterioration. Areas of the country that combine freeze/thaw with large seasonal temperature swings have an increased risk, because of the initiation of cracks and joint failures generated through differential thermal movement of non-homogeneous material assemblies. Locations where it gets very hot and then very cold may have steel thermal movement shrinking and expanding a less flexible building envelope, which in turn opens minute cracks – and the rest is an inevitable progressive deterioration of the system. In locations where the temperature hovers closely around the freezing point multiple cycles can occur within a single day. In microclimatic locations on a building (typically the south face) the sun melts snow or ice, then is obscured by clouds or shadows allowing re-freezing, then re-melts with ambient air temperatures rising, and re-freezes at night. The time frame for many of these failures is often twenty years or better, but over time an understanding begins to emerge about what materials and assemblies should simply be avoided in freeze/thaw areas. Cultural impacts on design decisions, a fair amount of ignorance on the part of builders and designers, and often poor construction techniques will often produce solutions ill suited to a climatic condition like freeze/thaw, but over time the collective built environment shows the influence of what works well and what doesn't.

MATERIALS: MASONRY, STUCCO, CONCRETE, WOOD AND METAL

The modification of a material palate or method of assembly may not seem like a significant shift in design decision making, but the difference between choosing a stucco, brick, block, concrete, or metal cladding for a building is certainly noticeable. On a more-subtle note, simply the necessity to add numerous control and flashed expansion joints across the surface of a cement plaster wall, something you might think of as a monolithic planar material, might understandably cause you to look for a different cladding choice. The addition of the control joints would be necessary to control cracking, and the flashing in expansion joints must be extended and provided with adequate drip edges to inhibit water infiltration, but the resulting modification from unbroken plane to gridded panels with protruding sheet metal would not seem to meet the design criteria for the best use of the material (worse yet it might just start to look like EIFS). Water infiltration is the beginning of any damage and 90% of all problems occur at joints and cracks. Moisture also tends to enter a material that has a porosity of as little as 2-3 percent. Brick is typically 6-10 percent porous, granite up to 3 percent, and concrete or stucco can vary considerably, but tends to run above 5 percent. Within the realm of possibilities for enclosure there are certain common categories: Stone, brick (of many types), concrete, concrete masonry, cement plasters (stucco & variations of "exterior insulation and finish systems"), metals, glass, woods, plastic composites, and certain petroleum-based shingle products. The key to avoiding problems with freeze/thaw is finding materials and assemblies that can withstand the forces of freezing or are flexible enough to prevent damage. Water expands (depending on the source information) approximately 9 percent of its total volume when it freezes. While this is frequently cited as a primary mechanism for the origins of life on the planet, it also causes enormous amounts of erosion on both the natural and built environment. The force of expansion is 660 pounds per square inch, which exceeds the surface shear resistance of brick, mortar, most stone, concrete, stucco and concrete masonry units. This force also exceeds the resistance of wood, but the modulus of elasticity of wood allows it to expand and return to its original shape without significant damage. Metals, composites and asphalt shingles resist moisture infiltration adequately to prevent damage to occur.

The relative vulnerability of some materials over others due to freeze/thaw cyclical action is rarely enough to outright prevent the selection of a system, and there are clearly many examples of buildings in the freeze/thaw zone constructed from all of the porous materials. The key to understanding the differences between the freeze/thaw zone and areas above and below is in the frequency of vulnerable material selection and, more importantly, how the form or assembly of the material is designed to shed water quickly and resist infiltration. There are also examples of materials being modified over time and necessitating a different treatment because of their vulnerability to moisture penetration and subsequent freezing. The most notable is brick masonry that has been part of a renovation. It is common throughout the country to see brick that has been at one time painted and later sandblasted to reveal the original color and impart a varied texture. This is often a problem, because it makes the masonry more porous, but in a freeze/thaw cycle it can make a building that has withstood many years of neglect begin to deteriorate much faster because of the sandblasting during renovation. The brick frequently starts spalling and needs to be repainted, aggressively sealed, or clad-over to prevent further damage. This impacts the character of many recently renovated brick infill urban areas in the freeze/thaw zone that either cover their existing brick facades (fig. 2) or need to repaint the buildings, often in colorful patterns – not very satisfying solutions when the original masonry appearance is desired.

What emerges from these considerations are a material palate and assembly shift within the freeze/thaw zone that varies from buildings above

Fig. 2: Multiple layers of façade over brick. Des Moines, Iowa

and below this area. This is difficult to reliably demonstrate in terms of percentages without showing a considerable number of examples, but a selected group of instances can show some of the predominant characteristic changes.

SPECIFIC EXAMPLES

Obviously climatic determinism's pragmatic view and cultural history's social concerns are part of the decision making process that creates the built environment. This makes separating the specific influences of a single aspect of climatic concerns such as freeze/thaw potentially reduced to insignificance or even a spurious argument beyond the actual impact of the phenomenon. Nonetheless, considering the vast amount of time spent in the course of design worrying about building envelope durability, and the number of changes made in material selection and assembly due to freeze/thaw, it seems reasonable to explore the impact of the process. It would appear that similar building styles cross through the freeze/thaw zone with little formal change from areas to the north and south that share similar cultural influences. However, we see freeze/thaw impacting the material choices and methods of assembly used to construct these forms. This seems like common sense, and it surely is just that, but when the same buildings are being predominantly clad in cement plaster, then switch to wood or brick for a 200-mile band, and then back to cement plaster there is quite possibly an influence on the design that can be attributed to factors such as climate. The initial shift away from stucco headed north may simply have been temperature based, but the switch back and forth suggests the influence of another factor. The thesis to be tested here is whether that can be reasonably attributed to the frequency of freeze/thaw cycles.

A vernacular agrarian example of the building form remaining the same but the material changing in part due to durability occurs in midwestern farm buildings based on the German *fachwerk* tradition of wooden infill frames. The heavy timber frame forms a fairly tight grid of structure and bracing around the perimeter walls and the openings are traditionally infilled with a mixture of woven wood latticework covered with clay or plaster, referred to as *wattle and daub*.

This building type was quite common in Europe and traveled to the eastern part of the United States in early farm settlements. In the upper Midwest the plaster infill proved to be particularly susceptible to freeze damage, which stands to reason considering all of the joints moving due to the differential thermal and moisture characteristics of plaster vs. wood. A masonry brick infill with nearly flush mortar joints became more common over time and we see many more surviving examples of this type still in existence, particularly in central Wisconsin German settlements. This would have been a vastly more difficult wall to construct and because it happens in a building type where aesthetic concerns are typically less critical than durability, the influence of freeze/thaw seems likely.

An example of a form being used for aesthetic reasons that went against the logic of durability can be seen in the cornices on Chicago School buildings from the turn of the 20th century. The strong overhanging cornice, an expression of column capitol on the early skyscraper parti, was particularly susceptible to moisture penetration at the extensive horizontal joints. After years of deterioration many of these projecting cornices were removed due to the effects of freeze/thaw cracking, most prominent being Sullivan's Carson Pirie Scott building in the late 1940's and Holabird & Roche's Marquette building in 1950.

Fig. 3: Carson Pirie Scott Building with restored cornice

Both cornices have subsequently been re-created, but after 50 years of absence and with different materials and extensive protection of the horizontal surfaces (fig. 3).

The reasons for continuing this building feature have largely passed, but abstract representations of cornices are more recently often open frameworks of metal that are not subject to freeze/thaw impact, such as Perkins and Will's Skybridge in Chicago and Peter Rose's Centre for Canadian Architecture in Montreal.

Many of the examples of building material shifts occur in residential projects. One of the most common types that are easily able to track are the arts and crafts bungalow homes in the central Midwest. While the styles of the homes vary somewhat, the

Fig. 4: Des Moines Brick/Wood Bungalow

time frames and cultural influences remain fairly consistent across the entire area, so material decisions would have been made primarily for economic, aesthetic and durability concerns. What can be seen in this type of house in the southern Midwest, such as Kansas City, Missouri, is a large percentage of stucco exterior finishes.

Moving into central Iowa, within the freeze/thaw area, finishes become much more commonly wood siding and/or brick (fig. 4).

This might not be seen as particularly uncommon, as southern homes can tend to favor regional styles of the southwest or even California style bungalows, which commonly use stucco finishes – while northern states often look more eastward to the traditions of wood and brick as models of material choices. What is curious in this situation is that moving further northward from Iowa to Minneapolis, Minnesota we find the percentage of cement plaster finishes increasing again, similar to the quantity in Kansas City (fig. 5).

This is a case of frequency, because there are clearly examples of stucco finishes in the freeze/thaw zone and brick or wood in the areas to the north and south, but the numbers drop significantly off in Iowa due to no discernable factor beyond environmental conditions. This is difficult to establish with certainty, but discussions with regional contractors has repeatedly confirmed that exterior stucco is much more problematic in central Iowa than areas to the north and south. Linda Brock notes, "In instances where stucco has fallen

Fig. 5: Minneapolis Stucco/Wood Bungalow

into disfavor, it is usually related to poor construction and detailing rather than the system itself"[5] However, while it is clear that proper installation can prevent many of these problems, when the threshold for perfection of installation is high the result will too often fall short. This appears to be the case even in an area where the installation skill set was typically quite good.

IMPACT

This exploration seemed rather simple at first, with direct knowledge of the design process relative to freeze/thaw and repeatedly having observed significant time and energy spent trying to devise ways around it. None of this, however, was a documented part of the process; these were synthetic decisions made in concert with many others and therefore impossible to point out directly. In observing the built environment around Iowa there is a visible pattern of differences in the buildings from cities to the north and south. This was somewhat indefinable, but it is difficult not to attribute the perceived differences in part to environmental conditions. However, trying to define and demonstrate precisely what the differences are, and how they can be attributed to a single factor, proves problematic. Some progress toward that goal was made in this basic research, but surely much more will need to be done to solidify the case. Without making untenable claims as to the success of the study so far, I can say there are enough examples that appear to support the original thesis of design changes in the freeze/thaw zone to say the differences are real. This is an aspect of construction history that should extend the conversation of building design analysis to particular technical conditions that are a large part of the architectural decision making process.

ENDNOTES

1. Amos Rapaport, *House Form and Culture*, (New Jersey, Prentice Hall, 1969) p. 21.

2. Lewis Mumford, *Technics and Civilization*, (Orlando, Harcourt Brace & Co., 1963) p. 149

3. Tom Christopher, "One Gardener's Almanac." *House and Garden*, (July 2007): 56-58

4. Samuel Harris, *Building Pathology: Deterioration, Diagnostics, and Intervention*, (NY, John Wiley & Sons, 2001) pp.285-6

5. Linda Brock, *Designing the Exterior Wall: An Architectural Guide to the Exterior Envelope.* (NY: John Wiley & Sons, 2005) p. 208

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