State-of-practice, research gaps, and plan for safety and serviceability performance evaluation of residential building balconies in a changing climate

Bélec, Gilbert; Almansour, Husham

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Author(s): Gilbert Bélec and Husham Almansour

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Authors

Gilbert Bélec, M.A.Sc., Husham Almansour, Ph.D., P.Eng.

Project Manager

Belec, Gilbert

Digitally signed by Belec, Gilbert
DN: C=CA, O=GC, OU=NRC-CNRC, CN="Belec, Gilbert"
Reason: I authored this document.
Location: Ottawa, Canada
Date: 2024.11.18 17:19:16-05'00'
Foxit PDF Editor Version: 13.1.4

Gilbert Bélec, M.A.Sc., Research Associate
NRC Construction Research Centre

Approved

Marzieh Riahinezhad, Ph.D. P.Eng., Lead
Resilient Residential Retrofit Theme
Climate Resilient Built Environment Initiative
NRC Construction Research Centre

Approved

Armstrong, Marianne

Digitally signed by Armstrong, Marianne
DN: cn=Armstrong, Marianne, c=CA, o=GC, ou=NRC-CNRC, email=marianne.armstrong@cnrc-nrc.gc.ca
Date: 2024.11.20 08:53:41 -05'00'

Marianne Armstrong, M.A.Sc., P.Eng., Director
Climate Resilient Built Environment Initiative
NRC Construction Research Centre

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Executive Summary

A scoping study on the state-of-the-art of performance evaluation of existing balconies for residential buildings under climate change was conducted. The team has found that there are no distinct or specific methodologies to evaluate the performance of existing balconies, and, in general, there is very little available literature specifically studying or reporting on the performance evaluation and retrofit techniques for residential balconies of all types. The existing practice relies on general building evaluation methodologies and could underestimate the severity of the effects of climate change on residential balconies.

Balconies occupy a unique position within buildings. As balconies protrude outside the building envelope, they are exposed to environmental elements, which makes them susceptible to various climate stressors while being required to support considerable loads, including but not limited to dead loads (notably from concrete slabs), live loads attributed to occupancy, wind loads and resultant vibrations, and snow loads.

Through an examination of media articles and literature publications, it can be seen that incidents of balcony failures, ranging from partial occupancy restrictions to catastrophic collapses, are common occurrences and have often resulted in tragic human casualties. Construction errors are the primary cause of these failures, compounded by inadequate maintenance practices and irregular inspections. Moreover, the environmental exposure significantly exacerbates the risks associated with balconies. Elevated levels of humidity and temperatures can drastically shorten the lifespan of wooden balconies. In contrast, heightened atmospheric CO_2 levels accelerate the carbonation process of concrete, hastening the corrosion of reinforcement bars and steel elements.

The impacts of climate change can be challenging to generalize. Indeed, the effects can vary significantly from one region to another; while some areas may experience heightened precipitation levels, others may encounter a decrease. Similarly, the risks posed by extreme events, such as hurricanes or heatwaves, and their frequency, along with phenomena like increased wind speeds shifting vibration frequencies and elevated precipitation and humidity, do not uniformly affect every balcony structure. Increased heat exchange from balcony slabs into buildings can lead to discomfort and higher energy consumption for cooling. Additionally, higher temperatures may reduce the durability of composite materials, especially when exposed to sunlight, and accelerate steel corrosion when paired with humidity. Rising temperatures also contribute to more frequent freeze-thaw cycles. Concrete is particularly vulnerable to freeze-thaw damage, and over time, freeze-thaw cycles reduce concrete strength and increase the risk of chloride ingress, ultimately raising the likelihood of reinforcement corrosion. While uncertainty persists regarding the overall change in mean wind speeds due to climate change, there is a strong consensus that wind speeds are accelerating in certain regions while decreasing in others. This variability has significant implications, especially for balconies in high-rise buildings where wind speeds are already substantial. Alterations in wind velocity can

influence the frequency excitation of balconies, potentially causing vibrations that may discomfort occupants. The likelihood of more intense and frequent precipitation events is on the rise. When coupled with increased humidity and temperatures, it heightens the risk of corrosion for steel components and creates conditions conducive to wood rot, a prominent cause of balcony failures. Additionally, heavy rainfall can pose a threat to poorly constructed balconies, exerting enough pressure to cause substantial damage. Finally, extreme weather events, such as tornadoes and cyclones, have become more frequent in recent decades, with shifts observed in the regions where they occur. These events impose increased loads on residential buildings and balconies, requiring updates to risk maps to reflect changing realities. An increase in wildfires and their intensity could also lead to structural damage to residential balconies.

The examination of major North American standards (ASTM, ASCE, CSA, IBC, and NBCC) and European standards revealed a notable absence of a dedicated methodology tailored explicitly for evaluating the performance of existing balconies. While these standards offer guidelines for general structural elements, they lack provisions for assessing accelerated deterioration, particularly for components directly exposed to weathering effects. Conversely, several methods exist for evaluating the effectiveness of thermal breaks and gauging the thermal efficiency of specific elements. In the private sector, various approaches, including cover meters, hammer tests, and sampling and coring techniques, are employed. However, there needs to be clearer guidance on how to interpret and utilize the results obtained from these assessments. This gap underscores the need for standardized protocols and more transparent, more explicit directives within the industry to ensure comprehensive and practical evaluation of balcony performance.

Likewise, the investigation uncovered a lack of standards explicitly addressing the rehabilitation process for balconies to address damage in the context of a changing climate. Existing methodologies predominantly rely on traditional load estimations and fail to propose strategies to extend the service life of balconies in the context of accelerating impacts of climate change. A lack of research on extreme wind loads was identified. While thermal break solutions are increasingly common in new balcony construction, implementing them in existing balconies presents financial and logistical challenges. New techniques typically involve physically isolating the structural link between the external balcony and the building's beam or diaphragm, which is financially impractical or technically unfeasible for existing structures. However, alternatives exist for thermally insulating certain existing balconies by applying an insulating shell to exposed surfaces. Although this method is less effective and more costly than thermal breaks used in new construction, it offers a feasible option for improving thermal insulation in some existing balcony structures.

During the scoping study, the team engaged with the CSA A500 technical committee – Building Guards. Although this scoping study primarily centred on balconies as a structural element, guards play a crucial role in ensuring occupant safety. They can have deteriorating effects on the outer perimeter of balcony slabs due to wearing and deterioration. The team identified common gaps in assessing the performance of balconies and guards amidst changing climate conditions. Subsequent discussions with the committee led to the development of a proposed collaboration roadmap. As a first step, the NRC would undertake a parametric study on standard balcony types and structural materials. This study will establish a foundation for assessing balcony performance and devising rehabilitation strategies. Existing research on guards would also be incorporated to capture a global picture of balconies. Upon completion of this step, the next phase will involve integrating these findings into an updated edition of the CSA A500 standard. This collaborative effort holds the potential to significantly enhance the availability of resilient methodologies for assessing performance and retrofitting residential constructions. By integrating insights from both balcony and building guards research, the updated standard would offer comprehensive guidelines to address the challenges posed by climate change and offer guidance to improve the resiliency, safety and longevity of residential structures.

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1 Introduction

1.1 Background

Although no definitive evidence remains, a brief history of balconies may take us back 5,000 years ago, circa 3000BC, in Mesopotamia, where overhanging parapets or narrow balconies were built to provide shade in the streets of early cities. They would later, by 1400BC, be used as a means of increasing light exposure and aeration of buildings in Ancient Greece (Shepperson, 2009, 2017). Balconies went through many iterations through the ages, from *maenianum* in the Roman Empire to *mashrabiya* in the Abbasid Caliphate or the *hourd* in medieval times (Britannica, 2023; Viollet-le-Duc, 1875). These elevated outdoor spaces have served many functional purposes but have also been used for aesthetic reasons and have engrained themselves in the collective culture. William Shakespeare's Romeo and Juliet, with its famous "balcony scene", is another example of what balconies represent to society. Commonly known as an iconic symbol of romance (even though, as it turns out, nowhere is there any mention of a balcony in the work and Shakespeare himself may not even have known what a balcony was (Leveen, 2014; Percec & Punga, 2022)), the play even gave its namesake to the Juliet balcony type.

In modern-day life, balconies offer many advantages to homes. They expand living space, which can be quite beneficial in an urban area with limited space availability. They provide access to fresh air, a way to connect to nature and are often used to grow potted plants or even small gardens. In some places, balconies offer breathtaking views over cities or landmarks that would not otherwise be as splendid through windows or from the ground. Balconies may also serve as social gathering areas, where guests may rest or freshen up. They may also serve as an aesthetically pleasing feature and can even increase property value as home buyers may be on the lookout for these small nooks. The COVID-19 outbreak further emphasized humanity's appreciation of balconies for a more sustainable lifestyle, where many socially distanced gatherings and events took place, and many sought them out as refuges for personal healing and emotional support (Bayazit Solak & Kisakurek, 2023; Park & Shin, 2022).

Climate change raises many challenges to building balconies' safety, serviceability, service life, and leads to increased heat transfer through the building envelope. The National Building Code of Canada defines serviceability limit states as those restricting the intended use and occupancy of buildings and include deflection, vibration, permanent deformation and local structural damage such as cracking (NRC, 2020). Given the observed increase in wind-gusting speeds and frequencies, increased recurrence and duration of extreme heat waves, increase in rain leading to wet service conditions, increase in freeze-thaw cycles, and accelerated deterioration due to elevated levels of carbonation in crowded urban zones, there is a high risk of damage and failure of residential buildings' balconies. A preliminary literature review showed no comprehensive Canadian or international guidelines or standards for evaluating the safety, stability, serviceability, and heat transfer potential of balconies subjected to accelerated deterioration, extreme wind loads, or heat waves. A brief review of mass media in recent years reveals several balcony failures have occurred, leading to injuries and even loss of life. There are reports that approximately one deck, balcony or porch failure every week during “deck season” (Carradine et al., 2008). There is an urgent need to develop comprehensive design and evaluation procedures based on climate adaptation for existing balconies regarding climatic loads, simplified analysis and design procedures, testing, and quantitative performance evaluation. Balcony slabs in Canada are subject to large temperature gradients in winter and extreme heat waves in the summer. For instance, in winter, their outside part is subject to extreme cold, as low as -40 °C, while the inside/floor part is subject to mild room temperatures of about +20 °C. On the other hand, in the summer, the outside part could be subject to extreme heat as high as +50 °C (under direct solar radiation), while the inside/floor part is still subject to room temperatures of about +20 °C. The temperature gradient between the cold and warm parts of balconies can be as much as 60 °C. As a result, adequate thermal insulation between the indoors and the outside is highly sought. Given all the climate stresses mentioned earlier, proper attention should be placed on the heat transfer potential of balconies while safety, stability, and serviceability requirements should be developed to provide adequate guidelines for evaluating existing balconies.

1.2 Objectives

The objective is to summarize the state-of-practice on current methods used to address the risks and impact of climate change on the loss of safety, serviceability, increased potential for heat transfer, and increased repair requirements for balconies.

1.3 Definitions

1.3.1 Types of platforms

A look at the word balcony itself, from the Italian *balcone* (scaffold, possibly from the Old Saxon *balko* or from another Germanic source), suggests it is a platform projecting from the sides of a building (Charitonidou, 2021; Harper, 2017). A significant number of structural platforms serve a similar purpose to balconies but exist in a definable and distinct manner. For this work, the focus will be exclusively on residential balconies as they are defined within the following sentences as outdoor structures that are subjected to the elements and may be more susceptible to the effects of climate change.

1.3.1.1 Balcony

A residential balcony is an accessible exterior platform intended for occupancy that can be considered an elevated structure, acting as an exterior projection of an upper floor (Britannica, 2023; NRC, 2020; Ross, 2023). They usually feature a private entrance but may also offer means of egress, often used as a second point-of-access as required by law. Balconies are traditionally smaller than decks and are required to have some form of guard fence to help prevent the risk of falls.

1.3.1.2 Deck

Although it shares many common attributes with balconies, a residential deck is a ground-level or slightly elevated platform usually located next to a home's back door. In some cases, decks may reach the second floor of a residential building, for instance, when it sits on sloped terrain where the ground level is only accessible from within or from the rear. California Senate Bill No. 721 (see §2.3), known as the Balcony Inspection Law, considers "exterior elevated elements" as those being at least 6' (1829 mm) above ground level. This distinction is used as a determining factor to qualify which type of exterior platform may be subject to the Bill itself.

1.3.1.3 Others

Platform structures used around residential homes that serve similar yet distinguishable purposes due to their emplacement. A porch is very similar to a deck but is usually located in front of residential buildings. A veranda (or the lanai in Hawaii) is similar to a porch, but the term usually implies a roofed platform that may wrap around the sides or the entire building. A patio is essentially a ground-level deck; however, it is structurally independent and not attached to the residential structure. Other platforms such as terraces, a flat surface often seen on roofs, or loggia, a roofed and often walled balcony, may also be associated with residential buildings.

1.3.2 Balcony structures

1.3.2.1 Categories

The main types of balconies found on residential buildings are presented here (Balconette, 2023; Coleongco, 2022). Mezzanines and other interior balconies will not be covered.

Cantilever	Cantilevered balconies are strikingly similar to floating shelves. They protrude from the structure and are connected exclusively to the wall(s) on the floor system.
Hung/Suspended	A hung balcony is very similar to a cantilever, except that it is also connected to the exterior wall using cables, rigid bars, or other equivalent systems under tension.
Stacked	Stacked balconies share many aspects with cantilever ones. They include a direct connection to the ground through vertical pillars that serve as load-bearing supports. These balconies are generally repeated on several storeys with the same layout, giving them a stacked appearance.

Juliet, False/Faux	Although minor differences may be found between Juliet and False balconies according to various sources, both balcony types serve essentially the same purpose of providing the advantages of balconies (e.g., additional daylight) without the requirements of structural elements. They are typically not meant for load-bearing and may be as simple as guard rails next to upper-storey windows.
Loggia	Loggias are roofed balconies that can be fully closed and temperature controlled, reducing environmental exposure. However, the exterior façade and soffit of the decking remain exposed to the elements.

1.3.2.2 Configurations

Balcony configuration is an essential element of thermal insulation and refers to a balcony's relative position relative to the building. Balconies can generally be split into two configurations: external or internal. External balconies project beyond the exterior face of a building and are connected to only one surface of the structure. In contrast, internal balconies may be connected to more than one perimeter wall. These two configurations can be seen in Figure 1, where an external balcony is represented on the leftmost subfigure, and internal balconies are in the two other subfigures.

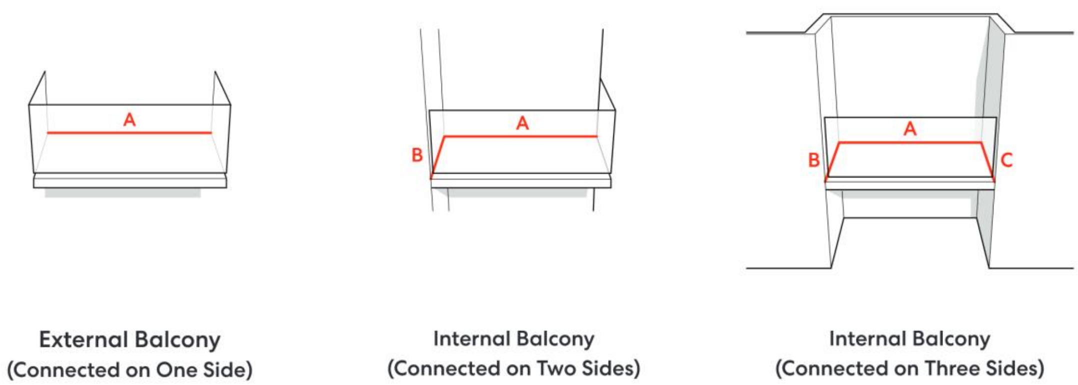

Figure 1: Balcony configurations

(Häberli & Collins, 2022)

1.3.2.3 Components

Without going into the specific components of balconies, as these may vary significantly based on the structural arrangement and the material used, the general components found on every balcony are detailed next. For instance, a stacked balcony features pillars, whereas a cantilever balcony does not.

Decking	This represents the flooring system of the balcony, such as a concrete slab or the wood balcony's beam/joist framing system.
Guard rail	A safety measure that keeps the balcony’s occupants within the confines of its perimeter where no walls are present. Sometimes called balustrades.
Wall	Walls are typically part of the structure into which the balcony is integrated; however, they can also be part of a loggia.

1.3.2.4 Materials

There are four main categories of structural materials used to construct residential building balconies: wood, concrete, composites, and metal (aluminum, wrought/cast iron, steel), as well as combinations of these materials. Glass can also be used for balconies, but it is more commonly used for guard railings in residential buildings. Stone is also used at times, but only sometimes in North America.

1.3.2.5 Connection details

As the majority of the balcony structure is exposed to the environment, heat exchange can be enabled due to the decking connection between the balcony and the interior floor of the structure. A thermal break, or barrier, is a non-conductive system designed to interrupt a heat flow path (Morrison Hershfield Ltd., 2021). For instance, wool insulation used in housing aims to provide a thermal break to the heat transfer between the interior and exterior of the structure. Several connection details are used for residential balcony structures that also help mitigate this exchange of energy, as shown next (Häberli & Collins, 2022).

Continuous slab

The continuous slab extends directly into the building's central flooring system, provides no thermal barrier, and leads to high thermal exchange. Figure 1 details this connection.

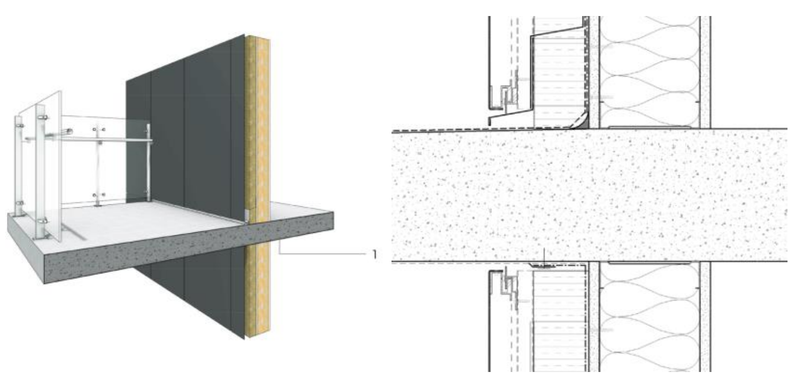

Figure 1: continuous concrete slab (1)

(Häberli & Collins, 2022)

Continuous slab with intermittent concrete

A continuous slab partially extends into the building's main flooring system at selected locations, leading to intermittent interruptions of the direct connection. Voids in between these locations can then be filled with insulating material. This provides a partial barrier to heat exchange, but its efficacity remains limited as a significant portion of the slab remains continuously connected for structural reasons. A detail of this connection can be seen in Figure 2.

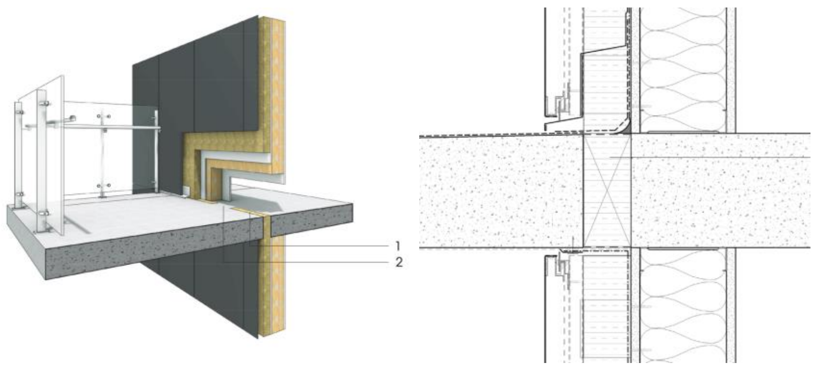

Figure 2: continuous concrete slab (2) with intermittent thermal insulation in voids (1)

(Häberli & Collins, 2022)

Continuous slab with structural thermal break

A thermal break can be provided along the entire surface of contact between the exterior portion of the decking and the interior slab. Thermal insulation can be provided with steek, rigid polystyrene, or proprietary materials. Structural connections extend from the balcony to be secured within the adjacent structure. This connection type provides more effective thermal insulation of the structure. A detail of this connection can be seen in Figure 3.

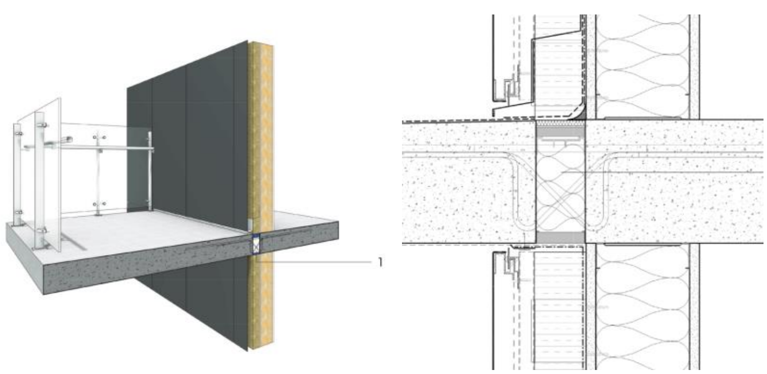

Figure 3: continuous concrete slab with structural thermal break (1)

(Häberli & Collins, 2022)

Continuous slab with wrapped insulation

This balcony connection encapsulates the entire balcony within the insulation, effectively wrapping the structural system within the thermal barrier. It generally provides poor thermal insulation as the exposed surface remains quite large, leading to significant heat exchanges with the balcony. However, the plane of heat transfer with the structure's interior remains the point of contact at the wall. A detail of this connection can be seen in Figure 4.

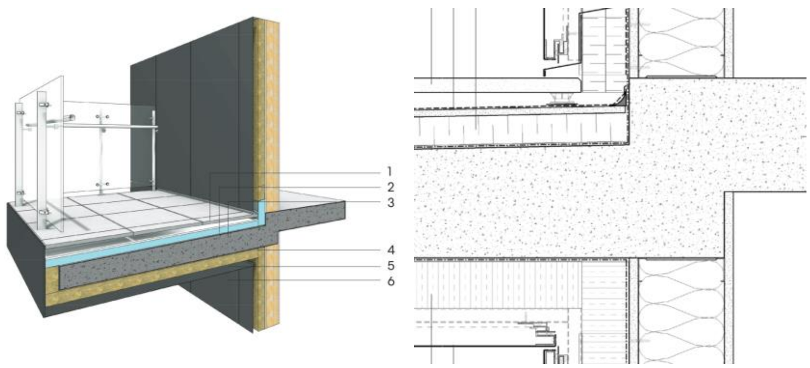

Figure 4: continuous concrete slab (4) with wrapping insulation (3, 5) and protective finishing (1, 2, 6)

(Häberli & Collins, 2022)

Discrete moment or knife plate connection

Discrete moment connection balconies are typically used with pre-built balconies. This can allow reduced surface contact for the thermal barrier due to smaller slab sections, which are enabled by higher quality control from offsite construction. Fasteners are installed on the building slab with intermittent steel supports, which serve as connections to transfer load from the balcony to the primary structural system. A detail of this connection can be seen in Figure 5.

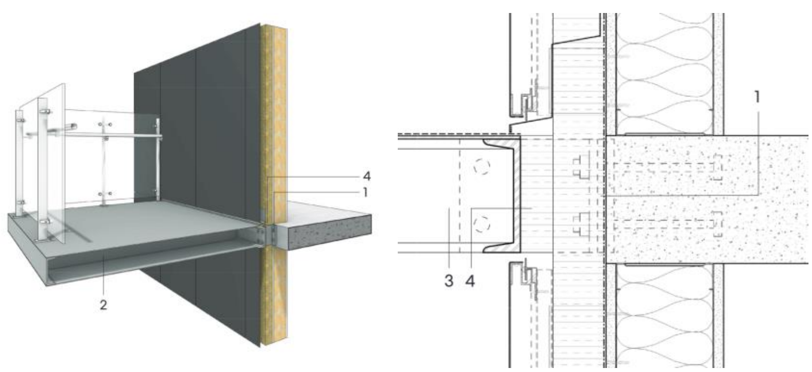

Figure 5: steel balcony (2,3) with thermal insulation (4) and discrete connections (1)

(Häberli & Collins, 2022)

Discrete connection with suspension/compression

This connection type follows from the knife plate connection; however, a tension (from above) or compression (from below) member is added to help transfer the load to the exterior edge of the building envelope. Since part of the load is transferred elsewhere, the contact surface at the decking level can be reduced, lowering heat transfer. A detail of this connection can be seen in Figure 6.

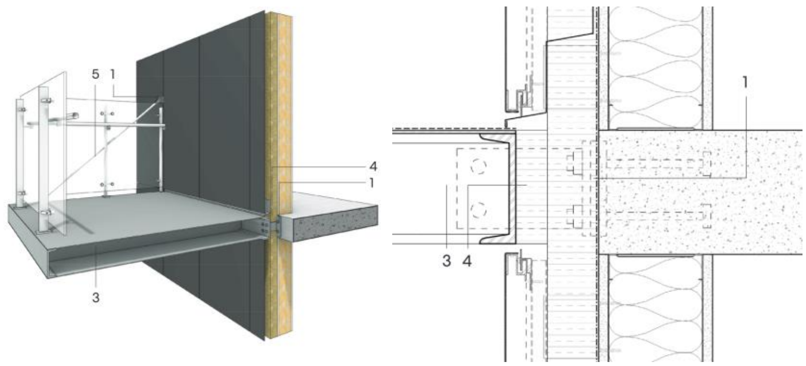

Figure 6: steel balcony (3) with thermal insulation (4), discrete connections (1) and structural tension rod (5)

(Häberli & Collins, 2022)

Simply supported

Simply supported connections utilizes the same load transfer concept as discrete connections with compression. However, the load is transferred to the ground with a post, distinct from being tagged onto the structural system of the building. A detail of this unique connection can be seen in Figure 7.

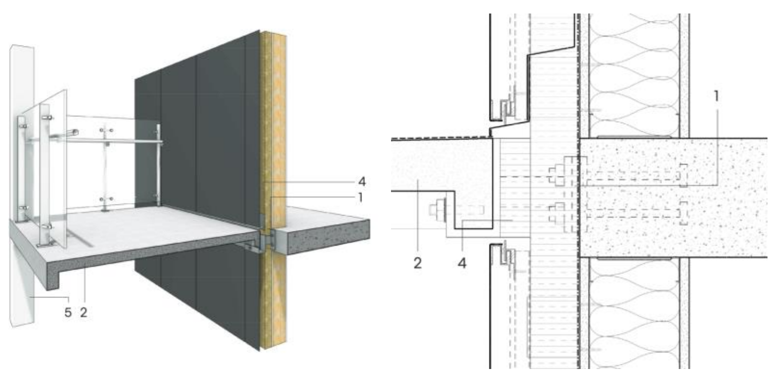

Figure 7: concrete slab (2) with thermal insulation (4), discrete connections (1) and structural support column (5)

(Häberli & Collins, 2022)

Self-supported

Freestanding balconies can be erected next to the building they serve using their own structural system. Minimal connections between the balconies and the structure, as long as sufficient lateral restraints can be provided, result in a remarkably efficient thermal break. However, it's important to note that the cost of such systems is typically higher than the alternative options. A detail of this connection can be seen in Figure 8.

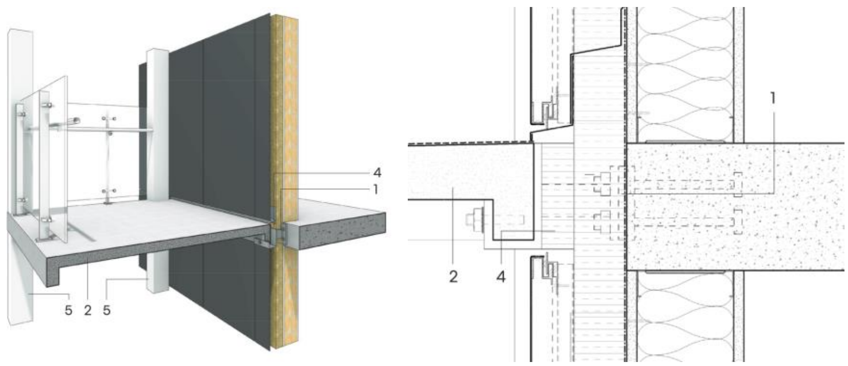

Figure 8: continuous concrete slab (2) with intermittent insulation in voids (1)

(Häberli & Collins, 2022)

1.3.3 Residential buildings

Residential buildings are typically divided into low-rise, mid-rise and high-rise buildings. Statistical classification for residential buildings sometimes only considers low-rise buildings (fewer than five storeys) and high-rise buildings (five or more storeys) (Statistics Canada, 2019). The Statistics Canada classification will be followed to combine mid- and high-rise residential buildings, considering the safety and serviceability of residential building balconies and combine mid- and high-rise residential buildings. Taking this a step further, one can describe low-rise residential building balconies as having primary structural elements constructed from wood. Conversely, mid- and high-rise residential building balconies have structural systems with concrete, steel, or composite materials. This can be asserted without much loss of generality, as the National Building Code of Canada only allowed timber construction up to 6 storeys until its 2020 edition (OPBC, 2019) at which point the code allowed mass timber buildings up to 12 storeys; it is unlikely that a high-rise concrete building would feature timber balconies, although some certainly exist.

1.3.4 Glossary

The following terms are used throughout the report and will be considered in the context of climate change. Unless stated otherwise, these terms were defined by the National Oceanic and Atmospheric Administration (NOAA, 2023).

Climate stressor	A condition, event, or trend related to climate variability and change that can exacerbate hazards.
Hazard	An event or condition that may cause injury, illness, or death to people or damage to assets.
Impacts	Hazards have effects on natural and human systems. Evaluating potential impacts is a critical step in assessing vulnerability.
Resilience	The capacity of a community, business, or natural environment to prevent, withstand, respond to, and recover from a disruption.
Risk	There is a potential for negative consequences where something of value is at stake. In the context of the assessment of climate impacts, the term *risk* is often used to refer to the potential for adverse consequences of a climate-related hazard. Risk can be assessed by multiplying the probability of a hazard by the magnitude of the negative consequence or loss.
Vulnerability	The propensity or predisposition of assets to be adversely affected by hazards. Vulnerability encompasses exposure, sensitivity, potential impacts, and adaptive capacity.

1.4 Report structure

The report is divided into 5 chapters. Rather than splitting it between low-rise and mid-/high-rise buildings, the findings were presented by topic.

Chapter 1	Introduction to balconies and context matter.
Chapter 2	Review of state-of-practice of residential balconies.
Chapter 3	Proposed collaboration work plans for a second phase of the study.
Chapter 4	A summary of the findings.

This is followed by a list of references consulted to complete the report, as well as appendices containing supplementary material.

2 State-of-practice of existing residential balconies

2.1 Reported issues with balconies

There have been a number of unfortunate incidents related to failures of balconies in recent decades in North America. The following is a summary of some of the more critical events, as well as an overview of the aftermath resulting from these disasters.

2003, Chicago IL

13 deaths, 57 injured

A three-storey housing complex with “double-decker” timber balconies was hosting an evening party. The third-floor deck, pictured below, was filled with as many as 50 guests when it suddenly collapsed, taking the second-floor deck down with it and sending as many as 100 guests total tumbling down into a basement pit. Witnesses reported that the balcony “looked sturdy” yet beams tore away from the wall with little warning. After the collapse, the rest of the structure was brought to the ground as it was deemed a safety hazard. Initially, blame was laid at the feet of the guests as some witnesses reported “jumping” and considered the balconies overcrowded. City inspectors would later reveal that the porch extended too far away from the building, was larger than allowed by city code, did not have proper supports, had insufficient wood flooring, and was secured to the wall with screws lacking adequate capacity.

Figure 9: Chicago balcony collapse (AP)

In the aftermath of the tragedy, the building owner was sued and settled for US $16.6 million. The city of Chicago proceeded to conduct additional inspections, finding 6670 violations in 2006. Harsher building code restrictions were imposed, including Municipal Code Section 13-196-570 which governs maintenance of stairways and porches (BBC, 2003; CBS Chicago, 2023, p. 20; CBS News, 2003; USATODAY.com, 2011).

2010, St-Laurent (Montréal) QC

1 injured

A five-storey building's occupant was sitting on her fourth-floor balcony when it suddenly collapsed, leaving her stranded, one floor below as shown in Figure 10. The balcony was constructed with concrete and structural steel and showed considerable corrosion of steel beams. The victim's neighbour, who shared the same balcony, claims water would seep inside the building at the balcony level during each rainstorm. This was the second such incident at this location, as another balcony had collapsed in the same building seven years prior.

Figure 10: 2010 St-Laurent balcony collapse (Radio-Canada)

After this second incident, the Régie du bâtiment du Québec inspectors closed access to all remaining balconies and required structural assessment before access was restored. The *Régie* put out a press release to remind building owners that ensuring the safety and serviceability of balconies was their responsibility. It also informed citizens that a toll-free direct line had been set up where they could signal potential building safety hazards to the province. The police were said to consider a criminal investigation into the incident, but no further information could be located (Meunier, 2010; Radio-Canada, 2010; RBQ, 2010).

2015, Berkley CA

6 deaths and seven injured

Thirteen international students fell from a fourth-floor balcony in Berkley CA which suddenly collapsed. The balcony's deck consisted of concrete, supported by cantilevered wood beams. An analysis of the load-bearing capacity of the balcony suggested that the load from the 13 occupants was within the design capacity of the balcony. The failure mechanism occurred due to dry rot which began on the top side of the cantilever beams, as seen in Figure 11, which caused the beams to fail beneath the design capacity. Despite the building being less than 10 years old, dry rot was accelerated due to the long-term presence of high moisture saturation in the sheathing layers which were in contact with the support joists. The deck material thickness was not explicitly stated on the drawing (referring to another section) leading to the contractor selecting a section only a third of the required thickness, and a sacrificial membrane was not provided by the contractor, which resulted in water infiltration that ultimately led to the incident (CSLB, 2017; Global News, 2015; McGreevy, 2017; Slowey, 2017; Taggart, 2015). Following the incident, the State of California passed bill SB-465 to legislate balcony inspections.

Figure 11: 2015 Berkley balcony collapse (CSLB)

There have been many more such incidents, however, follow-up information is often not divulgated to the public, or often only at a much later date once investigations and pending litigation are over or even after trials are concluded. Incidents resulting in loss of life seem to result in fast-laned investigations and often lead to new legislation. The team found many similar issues reported in the media, but often with no apparent follow-ups. There is no common cause for collapses other than the negligence of one of the involved parties, be it in the design, construction, maintenance or operation phases.

In 2009, two people in Calgary, AB, were hurt when the railing of a second-storey balcony fell to the ground. Upon inspection, signs of rot were apparent on the wood railings, resulting in condemnation of the building's other balconies (CBC, 2009). In 2013, seven people were flung from the second floor of a balcony which suddenly collapsed in St-Laurent (Montréal) QC. Firefighters on the scene indicated that the balcony may have been overcrowded, but no definite cause was identified at the time (CBC, 2013; Gagné, 2013; TVA, 2013). In 2017, a worker refinishing floors leaned on a wrought-iron Juliet balcony rail on the third floor and fell to his death at a Harrisburg, PA, apartment building when the balcony suddenly collapsed. The building was inspected in 2015; however, the inspector did not evaluate the load-carrying capacity of the balcony as it was thought to be decorative. The collapse was later found to have been caused by severe corrosion of lag screws which had been exposed to rainwater infiltration after years of loading (Haughton, 2021). Still in 2017, three occupants were injured in Calgary following a 9-meter fall when a railing failure occurred on the second storey of a Calgary three-plex (Global News, 2017). An illegally built balcony in the township of Langley, BC, led to injuries of almost 40 wedding goers in 2019, when it collapsed. Many construction flaws, such as only two supporting columns or wall connections secured with nails and screws, were cited in a lawsuit launched by the victims (Abbotsford News, 2019). Five people were injured in 2019 when a balcony fell from the fourth floor of a multi-residential building in Grand Forks, ND. A lawsuit was launched by the victims, claiming that the balcony suffered from water infiltration resulting from inadequate siding and flashing and, ultimately, structural damage caused by the rot of the wood (Shirley, 2020). The city of Ottawa, ON, saw three balconies detach and collapse from a 10-year-old residential condominium building in 2019. Fortunately, no one was injured in the events. Occupants of the building reported significant sagging to management who performed some repairs, described by one resident as "drilled some holes into the ceiling" on the faulty balconies (CBC, 2019; CTV News, 2019). Still in 2019, three people were injured when the flooring of a Cowansville QC balcony fell to the ground, leaving the guard railing still secured to the building. Police are reported to have said that "pressure from the three individuals caused the balcony's floor to collapse" (Global News, 2019; TVA, 2019). In 2021, seven people were injured, including four seriously, when an Ottawa ON balcony collapsed from the second floor. The city of Ottawa revealed that the building owner had been ordered to perform several maintenance repairs which had not yet been done (CBC, 2021). A Malibu house saw its balcony collapse during a birthday party in 2021, resulting in injuries to seven people, including two seriously. Video of the incident shows that the balcony was very crowded, potentially exceeding the design load capacity of the structure (Globalnews.ca, 2021). In 2022, a 13-month-old child was injured along with three other occupants when a Laval QC balcony collapsed. The police on site did not offer any immediate explanation for the collapse (CTV News, 2022). In 2022, a man was hospitalized and two more injured after falling two storeys when a North Okanagan BC balcony collapsed from a home they were renting. The victims were reportedly in conversation on the balcony when it went down. No causes were yet identified for the collapse (Global News, 2022). In 2023, eight people fell and suffered minor injuries when a stairwell with steel balcony collapsed from a home near Québec City, QC. The stairwell detached itself from the wall of the building, taking the balcony and its occupants down with it. The cause for the collapse is not yet known (Radio-Canada, 2023).

2.2 Balconies in a Changing Climate

Climate change is impacting the global climate, leading to widespread alterations of observed atmospheric tendencies. Climate trends, once thought to be relatively stable within a given region, are now showing indications of transiency. GHG (greenhouse gas) concentration levels are increasing, likely leading to increases in average global temperature. Many weather and climate extremes have been observed to change as a result, with heatwaves, heavy precipitations, droughts and cyclones becoming more frequent. Heatwaves have intensified since the 1950s while cold waves have become less frequent (IPCC, 2021).

Some of the climate events identified by the IPCC (Intergovernmental Panel on Climate Change) are already adversely affecting the long-term safety and serviceability of residential balconies, increased potential for heat transfer, and accelerating their deterioration (Almås et al., 2011; Campione & Cannella, 2020; Lahdensivu, 2012; Lisø, 2006; Lisø et al., 2006; Pakkala, 2020; Wittocx et al., 2022). Table 1 summarizes some of the climate stressors identified by the IPCC as well as the risks they pose to residential balconies of all types. Increased imposed loads, premature performance losses as well as shortened life expectancy, and increased maintenance requirements are likely to occur as a result.

Table 1: Climate stressors and risks to residential balconies

Climate variable	Potential residential balconies impact
Extreme heat	Higher temperatures will lead to higher heat exchange from balcony slabs to the interior of buildings, causing more discomfort to occupants as well as increased energy use to cool down their residences. Extreme heat events such as heat waves and heat domes are also becoming more prevalent. Higher temperatures may also negatively impact the durability of composite materials, especially when paired with exposure to sunlight. Increased temperature (combined with humidity) also results in accelerated rates of steel corrosion (Y. Zhang et al., 2022).
Freeze-thaw cycles	Although uncertainties remain as to the relative frequency of freeze-thaw cycles, increasing temperatures lead to colder regions being subjugated to more frequent freeze-thaw cycles. The freeze-thaw attack is particularly harsh on the durability of concrete, a common material for balconies. As internal water freezes in the concrete, it expands by approximately 9%, causing internal stress that

	leads to surface cracking. Long-term impacts of freeze-thaw damage lead to a reduction in strength, and loss of adhesion and facilitate chloride ingress, resulting in higher risks of reinforcement corrosion (Pakkala, 2020).
Wind speeds and frequency	While there remains uncertainty about mean wind speed changes due to climate change, there is high confidence that wind speeds in some regions are accelerating while others are seeing the opposite (Zeng et al., 2019). Increased wind speeds are particularly impactful for high-rise building balconies, where wind speeds are already considerable. Changes in wind velocity also affect the frequency excitation of balconies, possibly resulting in vibration that could make occupants uncomfortable.
Precipitations and humidity	The intensity and frequency of precipitations are likely increasing. These increases in precipitations and humidity (together with temperature increases) lead to higher risks of corrosion for steel members. It also promotes conditions where wood may be susceptible to developing rot (wet and dry), which is one of the leading causes of balcony failures (Carradine et al., 2008). The intensity of rainfalls has also been cited as a source of damage to some balconies with questionable construction quality, where heavy rain can exert sufficient pressure to cause significant damage (Souza & Araújo, 2011).
CO_2 concentration levels	Higher carbon dioxide (CO_2) concentration levels accelerate the carbonation reaction, leading to reduced alkalinity concentrations in concrete. This in turn results in a lowered chloride threshold of reinforced concrete and a higher risk of corrosion of internal rebars (Shirkhani et al., 2020; J. Zhang et al., 2018).
Extreme events	The occurrence of extreme events (e.g., tornadoes, cyclones, etc.) has increased in recent decades. It is also very highly likely that the areas where these events take place are changing. For instance, tropical cyclones move further north, and their peak intensity also reaches further north. Hurricanes have also reached further north, with some even hitting landfall on Canadian soil in recent years (Pelot, 2019). These extreme events amplify loads imposed on residential buildings and balconies, and a shift in the location where they occur means that risk maps may need to be updated to reflect the new reality. Although not explicitly targeted at balconies, the Climate Resilient Home Guide also indicates heightened risks due to wildfires and

	recommends taking appropriate measures to limit the inflammability near houses (CRH, 2022).

2.3 Existing legislation

Municipal councils are usually the ones in charge of enforcing balcony maintenance through inspection. Their legislation is generally derived from provincial, state, or federal building codes or refers to it, leaving the balance of the work to the inspectors or evaluating engineers. As mentioned previously, some of the more stringent inspection requirements are direct results of catastrophic collapses that resulted in the loss of life of balcony occupants. The city of Chicago enforced more regular inspections and made its municipal code requirements more strict regarding minimum requirements for existing buildings (CCDB, 2011). Among these requirements, the council stated that every balcony should be kept in a safe condition and sound repair, with additional requirements requiring that the floor be sound and devoid of rotting or deteriorating supports. The relevant portions of the city's guidelines for evaluation are presented in Appendix A for reference. This inspection guide provides a simplified method for evaluating the repair requirements of the various balcony elements. It works by assigning an importance weight to each element and multiplying it by the ratio of deficient elements over the total elements of the type that an inspector has identified. The overall score indicates the level of repairs required based on the balcony's size and elevation from grade.

Another important legislation is California's Senate Bill SB-721 and SB-326, sometimes referred to as the E3 program (Elevated Exterior Elements). These bills were passed following the Berkeley tragedy (§2.1) and the ensuing investigation, to ensure the safety of existing decks and balconies. Together, the bills require extensive inspections (15% of each element type) for elevated platforms that are at least 6 feet above the ground in a statistically meaningful way (95% random samples). The inspections must ultimately be carried out by licensed architects or engineers every 9 years to assess the current state of the structural elements and estimate their projected life span. However, the legislation only targets specific buildings: multi-residential structures with at least 3 units and only considers elevated platforms made from wood (Cronk, 2022). Therefore, any balcony whose structural elements consist of steel or concrete is not targeted by the bill. Nonetheless, a number of recommendations stemmed from the investigation, both for the California Building Code (ICC, 2016a) and the California Existing Building Code (ICC, 2016b), both later issued by the International Code Council to the national level (ICC, 2018a, 2018b). The changes mainly target appropriate moisture protection and clarity of plan details as indicated in Table 2.

Table 2: Balcony code changes

Item	Description
107.2.5	“Where balcony or other elevated walking surfaces are exposed to water from direct or blowing rain, snow, or irrigation, and an impervious moisture barrier protects the structural framing, the construction documents shall include details for all elements of the impervious moisture barrier system. The construction documents shall include manufacturer's installation instructions."
2304.12.2.6	“Enclosed framing in exterior balconies and elevated walking surfaces that are exposed to rain, snow, or drainage from irrigation shall be provided with openings that provide a net free cross ventilation area not less than 1/150 of the area of each separate space."
Table 1607.1	“Minimum live loads for balconies and decks are increased from being the same as the occupancy served to 1.5 times the load for the occupancy served, but need not exceed 100 psf."

2.4 Methodologies for the performance evaluation of balconies

2.4.1 Load-carrying capacity

The team consulted the major North American design codes (ICC, 2024a, 2024b; NRC, 2020) as well as material-specific manuals and could not find any proposed evaluation method to calculate the load-carrying capacity specifically targeting existing balconies. These design codes do provide the minimum level of loading that can be expected on structures, adapted from several other sources such as ASCE/SEI 7-22, although in this case climatic loads are still being developed and will be introduced in the next updated version.

The evaluation of existing balconies is therefore performed as with any other standard structure, referring the users to local city construction guidelines, typically based on national standards such as ACI 562 or ACI 214.4 for existing concrete structures, see Table 3 for additional references. Note that several of these standards refer the reader to further specifications for requirements of some tests (e.g., ASTM C1583 to evaluate bond capacity). Most of these standards offer load and resistance factor design evaluation and standardized tests to evaluate the strength of existing material, to be performed by material specialists. While some non-destructive testing options are used by inspectors, the quantitative evaluation methods are destructive and require extraction of samples (wood, steel, concrete), or other techniques such as removal of concrete cover to inspect corrosion of reinforcement rebar (EGBC, 2020). The British Guide to the design of balconies and terraces (BS 8579, 2020) similarly does not offer any means to evaluate the load-carrying capacity of existing balconies.

Table 3: North American standards for evaluation of existing structural elements

Material	Standard	Description
Concrete	ACI 214.4	Provides testing procedures for evaluating the strength of concrete in existing structures.
	ACI 562	Requirements for assessment, repair and rehabilitation, including material properties and design of structural repairs.
	CSA A23	Guidance for material testing to determine strength. Provides deflection limits and strength evaluation procedures, including load tests.
Steel	AISC 360	Provides design guidelines for capacity and serviceability, including consideration of fatigue, vibration, deflections and thermal expansion / contraction. Details for fastener design.
	CSA S16	Provides design guidelines and analysis methods of structures, including aging effects such as fatigue. Evaluation of unknown existing steel is estimated with a conservative value. Details for fastener design. Inspection guidance for new structures, but not existing ones.
Wood	CSA O86	Provides deflection limits and strength evaluation procedures. Design and capacity of fasteners. Design for fire safety.
	AWC 2024	Provides deflection limits and strength evaluation procedures. Design and capacity of fasteners. Design for fire safety.

	TFEC 3	Provides methods of evaluating material strength, fire damage and perform condition assessment (e.g., sounding tests, identify typical damage types). Suggests various load testing procedures. Refers to AWC 2024 for structural evaluation.

2.4.2 Conductivity and thermal bridges

Balconies act as linear thermal bridge elements and are affected by several factors such as geometry, material properties, ambient temperature variation, and convective/radiative heat transfer coefficients at the surfaces (Ghobadi et al., 2021).

The most detailed methodology that could be found for evaluating the potential of thermal insulation is the British guide on Thermal bridges in building construction (BS 10211, 2017). The relevant section of the standard is based on ISO 10211 and suggests creating simplified 2D or 3D models and proposes calculations based on the thermal conductivity, dimensions of exposition, air cavities, material thickness, surface resistance, and other similar parameters to evaluate the thermal linear transmittance of a given element. The proposed methodology is sufficiently detailed and its applicability to balconies is not an issue. Other standards that offer hand calculation methods include ASHRAE Fundamental and the National Energy Code of Canada for Buildings. In situ testing can be found in ASTM 1363 (Guarded Hot Box testing) and ASTM 1155 (Standard Test Method for Determining Floor Flatness and Floor Levelness Numbers).

More advanced evaluation of thermal transmittance can be performed with finite element thermal modelling. This is often performed to evaluate retrofitting techniques or for the development of thermal breaks of new balconies (Aghasizadeh et al., 2022; Finch et al., 2014; Ge et al., 2013; RDH, 2013).

2.4.3 Permeability

There are many available permeability test methods for concrete, however, widespread acceptance for the use of a single one has yet to be achieved (Milla et al., 2021). Milla performed a literature review of these existing methods, a summary table is provided in Appendix B. Many of these tests are difficult to conduct, expensive and not suitable for regular inspections. The authors found that these tests exhibit a number of issues and proposed recommendations to fix the identified gaps. Establishing a model that predicts moisture ingress based on resistivity could aid in assessing risks related to chloride ingress, freeze-thaw damage, and the formation of calcium oxychlorides. Considering that sulphate attack and alkali-aggregate reactivity are influenced by moisture migration, correlating resistivity measurements with moisture availability could offer secondary insights into concrete's susceptibility to these distress mechanisms.

Steel is not inherently permeable to liquids, although the presence of water can facilitate its corrosion.

2.4.4 Durability, preservation, and risks of accelerated corrosion

The state of decay for wood can be assessed through various predictive models. (Brischke & Thelandersson, 2014) conducted a summary review of existing approaches for predicting the outdoor performance of wood products. Models were developed to map hazards, predict decay based on field tests and laboratory tests, and predict service life. The most comprehensive guideline for the preservation of timber structure durability is the series published by CSIRO Sustainable Ecosystems (MacKenzie et al., 2012), volumes 1 to 12 which cover climate data for service life prediction modelling, reliability, decay at and above ground level, atmospheric corrosion of fasteners, and insect attacks along with design guides for service life.

The weathering of wood is also caused by light, water and heat. This causes raised grains, loose grains, and results in reduced fastener contact, affecting safety performance. Otherwise, weathering has little impact on mechanical properties. Fungal decay is also an important factor in untreated wood, although it can become problematic under exposure to water even when treated. The main issue with fungal decay is that as soon as it becomes visible, it means that the decay is already in an advanced stage. This makes it very challenging to detect the problem early on and address it before the need for replacement. It is possible to use acoustic tests and electrical methods to identify degradation in lumber. Other risks that can affect wood durability include chemical decay, bacteria, and insects (beetles, termites, borers, carpenter ants and bees) (Anderson, 2002).

There are also wood decay index risk maps, using the Scheffer Index, initially developed by (Scheffer, 1971) as shown in Figure 12. A high Scheffer Index indicates a high correlation between environmental conditions and an associated risk. Such maps are critical to help designers determine the level of protection that should be sought to enable resiliency of wood structures, including balconies (Wang & Morris, 2008). A similar research was conducted by (Setliff, 1986) to develop a decay index map for Canada. Given that these maps were developed 40-50 years ago, (Lebow & Carll, 2010) set out to investigate the shift in decay hazard over the last 40 years and found that the variation in index values was greater than the variation in weather parameters, meaning that the accelerating climate change stressors lead to more critical regions, and also increased the risk of zones already at high risk due to compounded effects. (Wang & Morris, 2008) also performed this study in Canada and the USA a few years earlier and noticed an increase in the Scheffer Index across almost every location investigated. (Morris & Wang, 2011) argued for the Scheffer index as a preferred method to assess decay risk zones in Canada.

A similar assessment of steel structures was performed by (Ozkan et al., 2023). The research polled the status of steel samples in 8 cities across Canada to monitor the progression of steel loss based on time exposure to environmental effects. A comparison of loss against time for some Canadian cities can be seen in **Error! Reference source not found.**. The developed methodology was also used to predict the corrosion rates up to 2100, based on predictive climate models. Over the next 80 years, it is expected that an increase in corrosion during the first year of exposure will lie between 7-20% for most locations investigated. Preservation of steel can be achieved by ensuring proper drainage so that it does not sit in a pool of water. There will nonetheless be risks of corrosion due to atmospheric humidity which can be mitigated by specialized coatings (as often done on steel bridges), however, this may be expensive for small-scale applications such as fixtures, leading building owners to typically wait until replacement of the steel is required.

No similar research could be found for concrete structures. The durability of concrete against carbonation attacks can be mitigated by increasing the cover thickness. This makes it so that concrete rebars are deeper within the concrete and will require additional exposure before the onset of corrosion becomes possible. Reducing exposure to humidity (adequate impermeability of the system) can also help slow down the carbonation risks. (Lisø, 2006) developed a method to assess the relative potential of frost damage for concrete. Frost damage is a risk triggered through freeze-thaw cycles. While this may not be a universal risk, some regions with a predicted increase in temperatures may experience several dozen freeze-thaw cycles in a single winter. When combined with increased humidity, this risk can be even more compounded.

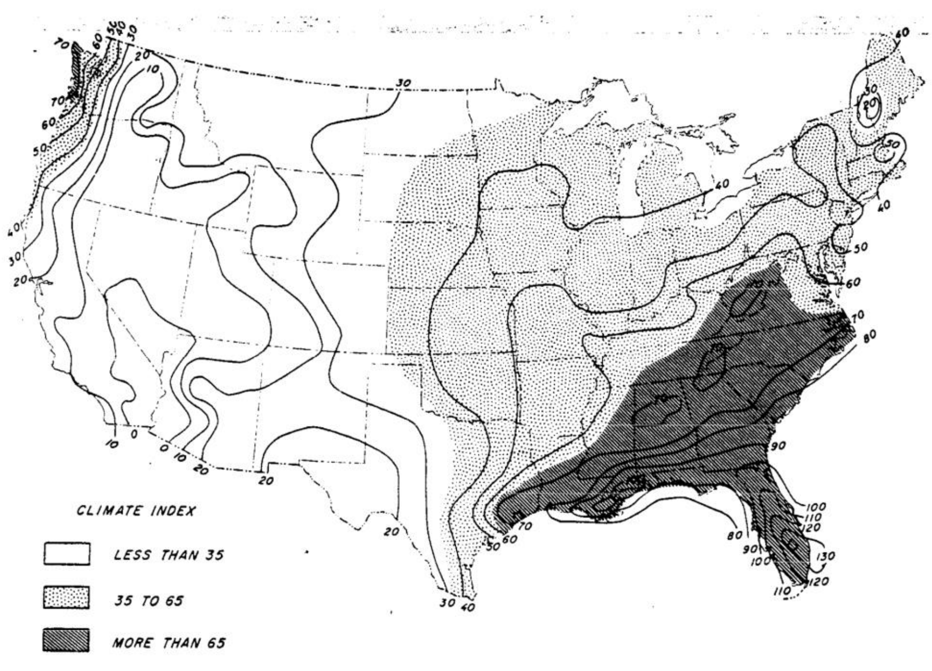

Figure 12: Climate index map for wood decay. Higher values increase the rate of decay.

(Scheffer, 1971)

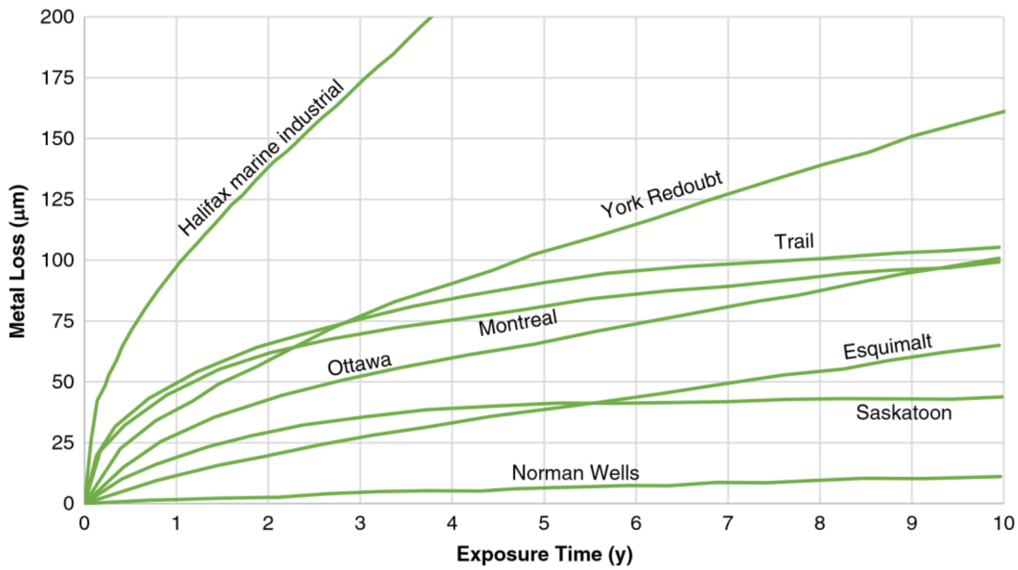

Figure 13: Corrosion mass loss as a function of time for steel in Canada

(Ozkan et al., 2023)

2.4.5 Impact of extreme weather events

(Grudzińska, 2021) conducted a long-term monitoring of summer temperatures in apartments with glazed balconies of various constructions. These apartments were situated in prefabricated multi-family buildings located in the southeastern region of Poland subjected to a warm-summer humid continental climate zone. The monitoring process allowed for an assessment of overheating based on the concept of adaptive comfort, while also examining the influence of sunspace construction and inhabitants' behavior. Measurements were carried out with temperature loggers and did not involve any measuring of the direct heat transferred by the balconies. The research confirmed the significant variation in temperatures during the summer due to the transfer of heat through thermal breaks and suggested adding shading of balconies if possible as a mitigation measure. Although no extreme heatwave was discussed in the study, it can be expected that the increased temperature within residences would be increased even further.

Wind storms, be they tornado, hurricane or other, can generate winds in the hundreds of km/h. With great surprise, the team could not find any published literature investigating these effects specifically on balconies. Design guidelines specifying wind loads and required fasteners are available for timber elements, such as the International Building Code. The effects of vibration are, however, investigated (Zheng et al., 2020).

2.5 Retrofitting techniques for rehabilitation of balconies

For retrofitting of general structures, the reader is referred to the standards identified in Table 3. In this section, the focus is specifically for retrofitting techniques that have been known to be applied to balcony structures.

2.5.1 Load-carrying capacity

Guidelines for the design of new wood decks and balconies are available (BC Housing, 2018, 2022) but no research or guidelines could be found to suggest repairs for wooden balconies. The standard practice is to replace damaged members.

For concrete balconies damaged with corroded reinforcement, there are five common repair techniques to address load-carrying capacity or to delay further damage: patch repair, conventional repair, galvanic cathodic protection, impressed current cathodic protection or total replacement (Wittocx et al., 2022).

Patch repair aims to replace delaminated concrete with a repair mortar, this slows down the corrosion process but does not stop it. This technique has limited structural benefits and may only be effective for a short period of time, around 5 to 7 years (Krishnan et al., 2021). Conventional repair also replaces delaminated concrete but goes further to protect the reinforcement by cleaning existing rust and providing a solution to stop or slow down further corrosion. It is also recommended to replace all reinforcement around the edges of the slab as they are typically more exposed. It is a considerably more invasive repair method but can extend the life of balconies by up to 20 years (Wittocx et al., 2022).

When it has been identified that damage is too important, balconies are typically demolished and built anew. This allows engineers to fix any structural issues in the existing design and/or modify the balcony's structural system and can be more economically advantageous as well as provide a greater level of serviceability (Souza & Araújo, 2011).

Retrofitting of steel balconies depends largely on the nature of the issue. If the corrosion level is fairly low, grinding the existing rust and providing a protective coating can be sufficient to maintain adequate performance. However, more severe corrosion requires new steel to be added or replacement of existing steel.

2.5.2 Thermal insulation

Thermal insulation of balconies is highly dependent on their connection type. For new constructions, insulation can be achieved by providing thermal breaks between the building envelope and the balcony with various materials, such as composites used in the private sector by FABREEKA[1]. However, this is not an economically viable solution for retrofitting existing balconies as it would entail a very costly procedure to detach the platform from the building to install the thermal break. The only rehabilitation method, without reinstallation or reconstruction, to provide thermal insulation of balconies comes in the form of covering the existing structure within a wrapping material less likely to be conducting heat as shown earlier in Figure 4.

2.5.3 Permeability

Pretreatment of materials, while a viable solution to increase permeability, such as steaming, ponding, or solvent exchange drying is not a viable technique to retrofit water-damaged lumber (Hansmann et al., 2002). Replacement of damaged wood is the most economical and feasible solution.

Polyurethane (PU) can be used as waterproofing on the top of slabs. However, this material is susceptible to wear and tear and can cause water leakage after some years of use (Wittocx et al., 2022). In the industry, this type of solution is often offered for waterproofing concrete slabs, such as by Soprema[2]. The company claims that this coating can provide up to 50 years of waterproofing protection to enhance concrete's durability over time and help prevent corrosion. For wood and steel elements, a coating can be applied to temporarily protect the material. This protection will need to be maintained and replaced (by first grinding the elements to remove the existing coating) every few years depending on the environmental conditions.

When water damage is more extensive due to years of leaking, a thorough renovation and redesign are required. (French, 2018) showcased the extent of the repairs necessary for the balconies of 4 buildings from 2 different cities in Texas. In many cases, extensive replacement of the existing balconies was required. Unfortunately, water damage in wood and concrete elements is difficult to repair, which leads to such decisions. The paper describes the best practices as mitigation: select adequate materials for waterproofing, provide adequate drainage to promote water flow at the membrane level as well as drainage, and add non-permanent wearing surfaces with some waterproofing properties that can be easily replaced over time. The key for the author is to minimize exposure to water.

2.6 Research gaps

This section identifies the primary research gaps that need to be addressed to enhance the performance and safety of residential balconies.

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[1] https://www.fabreeka.com/products/fabreeka-tim-structural-thermal-break/
[2] https://soprema.us/solutions/waterproofing/

- There are no specific methodologies for evaluating the performance of existing balconies, and the literature on this topic is sparse. Current practices rely on general building evaluation methods, which may underestimate the impact of climate change on residential balconies.
- The major North American and European standards do not provide a dedicated methodology for evaluating the performance of existing balconies; evaluation is performed following standard requirements but the standards lack provisions for assessing accelerated deterioration for components directly exposed to weathering effects.
- Existing standards specific to balconies only offer design advice for new constructions. City inspection guidelines are simplified and rely on the experience of the inspector.
- There are no standards specifically addressing the rehabilitation process for balconies to address damage and they do not provide strategies to extend the service life of balconies in the context of accelerating impacts of climate change.
- Climatic loads are still under development and not currently specified for evaluation purposes.
- Non-destructive tests are not standardized or commonly used, and quantitative evaluation methods are destructive by nature. There is a lack of clear guidance on how to interpret and utilize the results obtained from these assessments.
- Thermal break solutions are increasingly common in new constructions, however, their implementation for new balconies remains challenging and not as efficient as the physical break inserted between the balcony slab and the building’s outer beam or diaphragm.
- There are many available permeability test methods for concrete, however, widespread acceptance for the use of a single one has yet to be achieved.
- No work could be identified on wind-load effects of aging balconies, be it from the structural point-of-view or due to vibration.

2.7 Summary of state-of-practice

Considering the levels of risk associated with failing balconies, it is noteworthy that existing legislation is somewhat lax regarding their inspections and maintenance. Even the most advanced regulations that could be found only apply to certain balcony types and multi-residential buildings. Although methodologies for testing existing structural elements exist, it was found that these techniques do not specifically target balconies and their combinations of important service loads while being exposed to environmental effects. This is especially true when it comes to load-carrying capacity for serviceability.

On the other hand, there are several standardized existing methods to calculate the thermal conductivity of existing structures, and balconies are not subjected to any specific conditions that would render them invalid. It is the project team's opinion that no gaps currently exist to assess the thermal conductivity of existing residential balconies. Retrofit for thermal insulation is a complex procedure and might not be very cost-effective.

The permeability of balconies is a mixed-bag issue. Steel is not susceptible to water infiltration, while wood has a long history of research to explain its permeability although no good solution to retrofit balconies against this type of damage. For concrete, many tests exist to determine its permeability but they are complex and not easily performed for a balcony inspection. There is no clear indicator of how to evaluate the level of water damage in concrete.

Performance evaluation for balconies is an ongoing research area. A good amount of research was performed on determining the risks of deterioration of various materials/elements in the given environment, based on their location to account for variations in local climate. Risk assessments for timber structures are well developed, with proposed guidelines to estimate service life and monitor the state of embedded corrosion for fasteners. However, the team could not find any assessments for balconies subjected to high wind levels, other than the effects of vibration.

The main gap identified consists of the lack of details regarding the issues facing balconies specifically when it comes to the evaluation of their load-carrying capacity and their serviceability in terms of deformation and vibration under service loads. The existing standards and guidelines provide methods that are applicable to every type of structural element for wood, steel or concrete but do not offer consideration for the damage types due to environmental exposure. There is limited research and data in this research area, and the industry offering solutions does not publish its findings when conducting retrofit of balconies exposed to deterioration.

> *"Most of the time when I see decks that are inspected, they are nailed only. The requirements are they should have lag bolts every two feet staggered, two inch lag bolts and they should have ledger flashing to prevent water from getting in behind," Stelmashuk said. "They should have galvanized nails, actual hanger nails not screws or common nails that could rust. These will fail over time."*
>
> (Global News, 2017)

This estimate exemplifies, perhaps, the primary source of damages to residential balconies. Construction errors, or even negligence, result in a weakened structure which is susceptible to loads that should have been within the serviceable limits, had the structure been built accordingly. It is of high concern that the effects of climate change on accelerating deterioration will compound with poor construction practices and lacking balcony inspection to further accelerate deterioration and potential failures of existing balconies. In summary, this chapter presented what can be done to assess the performance of balconies in terms of durability, reviewed the risks of accelerated deterioration, the risks associated with wet services and loss of permeability, and reviewed the risks attached to extreme weather events.

3 Future Work

This chapter summarizes discussions with potential collaborators for a second phase of the project. Based on the review of standards and literature, a work plan is proposed to address the identified research gaps and develop guidelines that will enhance the resiliency of existing balconies.

3.1 Potential collaboration

The project team was introduced to the CSA A500, Building Guards, technical committee through Marzieh Riahinezhad from the NRC and Andrew Crees from the CSA Group. Considerable common interests were found and a desire to work together seemed natural. New climatic loads are an issue for building guards, and the standard requires a new edition to develop the new requirements. Guard rails are integral to the safety of occupants on balconies and can have detrimental effects, especially on the edges of balconies where they are secured. Guards can also cause issues with the permeability protection of balconies should they become loose and be able to move around, potentially damaging an impermeable membrane. A roadmap for potential collaboration was discussed, which would integrate the findings of a second phase of this project within the standard.

A partnership with a university is also recommended to accelerate the proposed work. Collaborating with a university, particularly with at least 1 Master's graduate student, could facilitate parallel research efforts on key tasks. This collaboration would not only help accelerate the project but also ensure alignment with the timeframe of the R^3 initiative. It would also enhance the efficiency and effectiveness of the efforts to achieve the stated goal.

3.2 Tasks required to address existing gaps

The goal of the second phase of this project would be to develop guidelines that will help practicing engineers and building owners determine the best course of action when faced with deteriorating residential balconies. Two potential ways forward are being proposed. In the first part, a cost-effective work plan represents the minimum required tasks to achieve that goal. Due to its limited scope, its potential impact may be more limited. In the second part, an extensive work plan is proposed. This alternative encompasses the tasks of the cost-effective work plan but also includes additional steps strongly recommended through discussions with the CSA A500 technical committee to achieve a higher level of impact. While these additional steps would not all be necessary to achieve the stated goal of the potential second phase, it was strongly hinted that an experimental portion of the study would be highly beneficial. The required tasks to achieve this goal can be split into two sections: a research study, followed by the development of guidelines.

In the research study, the types of balconies to investigate should be defined, along with parameters to be studied within an acceptable range. This would be followed by detailed finite element analysis and experimental testing of test balcony samples. Subsequently, a parametric study on accelerated damage can be conducted to determine the performance of new and existing balconies. Finally, an investigation into the effectiveness of retrofit methodologies can be carried out to propose solutions to observed deterioration.

The development of guidelines would require the creation of an advisory committee consisting of experts in the field. The developed guidelines could be used to see the development of a new edition of CSA A500 which would incorporate climatic loads and information to assess the impact of these loads on existing and new balconies and guards. Capacity-building tools could be developed to help users work with the new requirements of inspection of existing or design of new infrastructure.

4 Summary

The scoping study investigated the performance evaluation of existing balconies in residential buildings under the influence of climate change. It revealed a lack of specific methodologies for assessing balcony performance, with existing practices relying on general building evaluation techniques. Balconies face unique challenges due to their exposure to environmental stressors and the need to support significant loads. Incidents of balcony failures are common, often attributed to construction errors and exacerbated by environmental factors like humidity, temperature, and extreme weather events. Despite these risks, very little published research on performance evaluation and retrofit of existing residential balconies was found.

The major climate change risks to balconies were reviewed, such as changes in temperature and precipitation which pose challenges for balcony durability, with concrete particularly vulnerable to freeze-thaw damage. Wind speeds can impact balcony vibrations and structural integrity. Additionally, increased precipitation heightens corrosion risks for steel components and promotes wood rot. Increased CO_2 concentration levels also negatively impact concrete, wood and steel structures, accelerating their deterioration. Despite the absence of specific standards for balcony performance evaluation and rehabilitation, there are methods for assessing thermal efficiency and structural integrity. However, implementing thermal break solutions in existing balconies is financially and technically challenging. Some alternatives for thermal insulation exist, albeit they are less effective and more expensive.

Among the research gaps identified, there are no specific methodologies or standards for evaluating the performance of existing balconies, and the available literature on this topic is sparse. Current practices rely on general building evaluation methods, which may underestimate the impacts of climate change and accelerated deterioration, and there is no clear guidance for non-destructive testing, rehabilitation processes, or assessing wind-load effects on aging balconies.

Two alternatives for future work, including a collaboration with the CSA A500 technical committee are proposed. Discussion with the committee highlighted common gaps in assessing balcony and building guard performance under changing climates. The proposed collaboration roadmap involves initial work by the NRC to establish a methodology for assessing balcony performance and proposing retrofit solutions. This work would ultimately be integrated into an updated CSA A500 standard. The collaborative work would enhance resilient methodologies for assessing performance and retrofitting residential constructions, ensuring the safety and longevity of residential structures amidst changing climates. The many challenges and gaps identified make it crucial to develop an assessment framework tailored to the distinct characteristics and vulnerabilities of residential balconies.

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Appendix A

Reproduced from the City of Chicago's Porch Design & Construction Guidelines (City of Chicago, 2011).

CITY OF CHICAGO **DEPARTMENT OF BUILDINGS** SECTION **H** **PORCH EVALUATION**

This section utilizes the information within these Porch Design & Construction Guidelines to establish a consistent understanding of what is required when addressing violations, making repairs or construction of a new porch. This section evaluates the level of compliance required for existing porches based on the percent of work needed. The following steps detail the Porch Evaluation Process:

1 General Requirements For All Repairs	2 Compliance Statement	3 Understanding Compliance Requirements	4 Determine Repair / Replacement Level of Compliance	5 Review Building Code Summary
Review the requirements of the Chicago Building Code for porches.	Verify that the information in this section is as complete and accurate as possible based on your knowledge of the porch project	Understand the calculations used to derive the level of compliance in Step 4.	Calculate the percent of required repairs based upon the observed deficiencies and any deficiencies listed in building code violations. The percent of required repairs will determine the level of compliance.	Review the Building Code Summary Table based on the level of compliance determined from the calculation in Step 4.

BUILDING INFORMATION	
BUILDING ADDRESS:	

STEP 1: GENERAL REQUIREMENTS FOR ALL REPAIRS

COMPLIANCE OF THE FOLLOWING IS REQUIRED FOR ALL EXISTING COMPONENTS OF DECKS AND PORCHES:

CHAPTER 13-196 EXISTING BUILDINGS MINIMUM REQUIREMENTS: 34(13-196-570) Stairways and Porches – Maintenance

(A) Every flight of stairs and every porch floor shall be free of holes, grooves, and cracks, which are large enough to constitute possible accidents hazards.

(B) Every stairwell and every flight of stairs, which is more than two risers high, shall have rails not less than two and one-half feet high, measured vertically from the nose of the tread to the top of the rail; and every porch which is more than two risers high shall have rails not less than three and one-half feet above the floor of the porch.

(C) Every rail and balustrade is firmly fastened and is maintained in good condition.

(D) No flight of stairs shall have settled more than one inch out of its intended position or have pulled away from supporting or adjacent structures.

(E) No flight of stairs shall have rotting, loose or deteriorating supports.

(F) The riser height and the tread width of each flight of stairs shall be uniform.

(G) Every stair tread shall be sound and be securely fastened in a substantially level position.

(H) Every stair tread shall be strong enough to bear a concentrated load of at least 400 pounds without danger of breaking.

(I) Every porch shall have a sound floor

(J) No porch shall have rotting, loose or deteriorating supports.

STEP 2: COMPLIANCE STATEMENT

As Homeowner, Licensed Architect or Engineer of Record, I certify that to the best of my knowledge and belief the repairs for this project listed above fully comply with the requirements of Chicago Building Code and the Porch Design & Construction Guidelines.

PRINT:		DATE:	
SIGNED:		LICENSE NO.:	
EMAIL:		PHONE:	

STEP 3: DETERMINE COMPLIANCE REQUIREMENTS			
COMPLIANCE IS BASED ON THE RATIO OF WORK REQUIRED FOR EACH COMPONENT DETERMINED BY THE FOLLOWING AND MULTIPLIED BY THE MULTIPLIER PROVIDED IN THE TABLE OF STEP 4.			
COLUMNS:			Number of Columns Requiring Replacement Divided by the Total Number of Columns x No. of Porch Levels, Including Column Splices and Base Connections.
BEAMS:			Lineal Feet (LF) of Beams Requiring Replacement Divided by the Total Lineal Feet of Beams in the Porch Decks and Stair Landings.
BEAM-COLUMN CONNECTIONS:			The Number of Beam-Column Connections Requiring Replacement Divided by the Total Number of Beam-Column Connections Including Stair Landings.
JOISTS:			Lineal Feet (LF) of Joists Requiring Replacement Divided by the Total Lineal Feet of Joists in the Porch Decks and Stair Landings, Including Joist Hangers or Connections.
DECKING:			Square Feet (SQ FT) of Deck Area Requiring Replacement Divided by the Total Deck Area Including Stair Landings.
FOOTINGS:			Number of Footings Requiring Replacement Divided by the Total Number of Footings.
STAIR STRINGERS:			Number of Stringers Requiring Replacement Divided by the Total Number of Stair Stringers, Including Connections.
STAIR TREADS AND RISERS:			Number of Stair Treads Requiring Replacement Divided by the Total Number of Stair Treads.
GUARDS & STAIR GUARDS:			Lineal Feet (LF) of Guards and Stair Guards Requiring Replacement Divided by Total Lineal Feet of Guards and Stair Guards.
LEDGER & LEDGER CONNECTIONS:			Lineal Feet (LF) of Ledger Beam, Including Bolts, Requiring Replacement Divided by the Total Lineal Feet of Ledger Beams.
LATERAL BRACING:			Lateral Bracing System Provided (“1” yes or “0” no) Divided by the Lateral Bracing System Required (“1 yes” or “0” no). (The need for a lateral bracing system during inspection is determined by whether the structure is out-of-plumb or observed lateral displacement, vibration and/or shaking occurs during use.)
THE LEVEL OF COMPLIANCE FOR THE ENTIRE PORCH IS DETERMINED BY THE SUM OF THE PERCENTAGE OF WORK FOR EVERY COMPONENT REQUIRING REPAIR.			
LESS THAN 25%	=	**LEVEL 1:**	Repair and/or replace individual components as required
50% OR LESS	=	**LEVEL 2:**	Repair and/or replace individual components as required and upgrade all handrails, stairs and exit paths to current building code requirements.
MORE THAN 50%	=	**LEVEL 3:**	Repair and/or replace all components to meet current building code requirements.

STEP 4: DETERMINE REPAIR / REPLACEMENT LEVEL OF COMPLIANCE

CALCULATE THE RATIO OF REPAIR REQUIRED FOR EACH COMPONENT AND MULTIPLY THAT VALUE BY THE MULTIPLIER LISTED IN THE TABLE. THE LEVEL OF COMPLIANCE FOR THE ENTIRE PORCH IS DETERMINED BY THE SUM OF THE PERCENTAGE OF WORK FOR EVERY COMPONENT REQUIRING REPAIR.

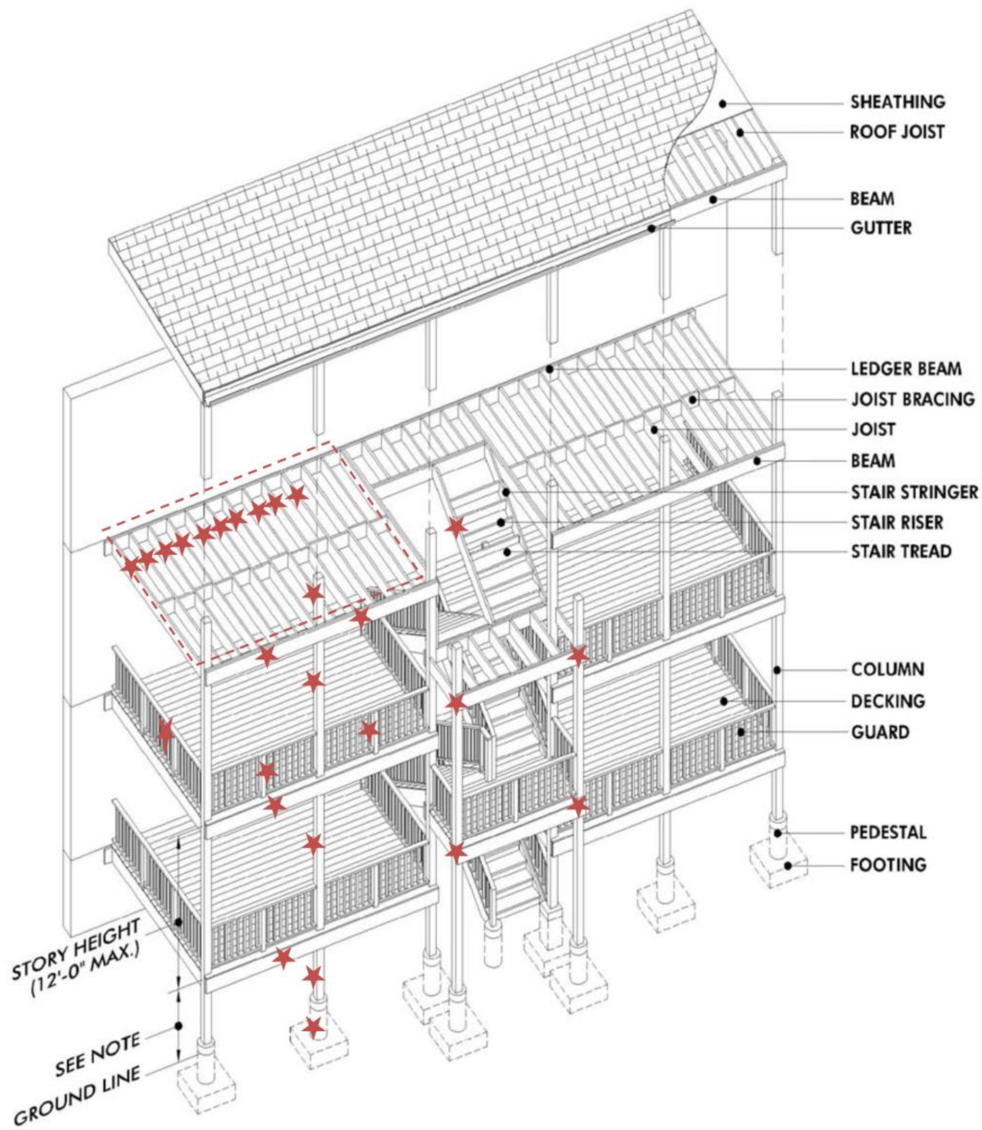
Member / Component	No. of Unit(s) To be Repaired			No. of Unit(s) For Entire Deck / Porch					WEIGHTED PERCENTAGE OF REPAIR WORK
	No.	UNIT		No.	UNIT	MULTIPLIER			
Columns		QTY	/		QTY	X	12	=	
Beams		LF	/		LF	X	12	=	
Beam-Column Connections		QTY	/		QTY	X	12	=	
Joists		LF	/		LF	X	10	=	
Decking		SQ FT	/		SQ FT	X	9	=	
Footings		QTY	/		QTY	X	12	=	
Stair Stringers		Stringer(s)	/		Stringer(s)	X	9	=	
Stair Treads & Risers		Treads	/		Treads	X	5	=	
Guards & Stair Guards		LF	/		LF	X	12	=	
Ledger & Ledger Connection		LF	/		LF	X	5	=	
Lateral Bracing		QTY	/		QTY	X	2	=	
Sum of all Components (% of Total Porch Structure Requiring Repair Work)								=	
% of Total: Less Than 25%								=	LEVEL 1
% of Total: Less Than or Equal to 50%								=	LEVEL 2
% of Total: More Than 50%								=	LEVEL 3

STEP 5: REVIEW BUILDING CODE SUMMARY				
CODE REQUIREMENTS PER LEVEL OF COMPLIANCE:	**LEVEL 1**	**LEVEL 2**	**LEVEL 3**	**NEW CONST'R**
BALCONIES, DESIGN LOAD: 100 LBS / SQ FT Live Load – 16(13-52-090)			X	X
DECKS, DESIGN LOAD: 100 LBS / SQ FT Live Load – 16(13-52-090)			X	X
DECKS, DESIGN LOADS: Existing Residential - Built Prior to 2003 – Area Other than Exit Path, 40 LBS / SQ FT LIVE LOAD	X	X		
GUARDS / STAIR GUARDS, DESIGN LOAD: Built After 2003 - 200 LBS Concentrated Load Anywhere Along Top Rail – 16(13-52-100)			X	X
GUARDS / STAIR GUARDS, DESIGN LOAD: 50 LBS / LF Uniform Live Load On Top Rail – 16(13-52-100)	X	X	X	X
PORCHES, DESIGN LOADS: 100 LBS / SQ FT LIVE LOAD – 16(13-52-090)			X	X
PORCHES, DESIGN LOADS: Existing Residential - Built Prior to 2003 – Area Other than Exit Path, 40 LBS / SQFT LIVE LOAD	X	X		
EXIT / STAIRS, DESIGN LOAD: 100 LBS / SQ FT LIVE LOAD – 16(13-52-090)	X	X	X	X
STAIRS, DESIGN LOAD: 400 LBS / PER TREAD LIVE LOAD – 34(13-196-570)	X	X	X	X
DECKS, REQUIREMENTS: Less than Five (5) Feet Under Supports, Lattice or Wire Mesh Skirting – 7(15-8-321)	X	X	X	X
DECKS, REQUIREMENTS: Not Less Than Six (6) Feet From Lot Line, Six (6) Feet From Another Structure & No Maximum Area – 7(15-8-321)				X
DECKS, REQUIREMENTS: Not Less Than Three (3) Feet From Lot Line, Six (6) Feet From Another Structure & 400 SQ FT Maximum – 7(15-8-321)				X
DECKS, REQUIREMENTS: Deck Setback At Exterior Wall, When There Is A Two (2) Hour Noncombustible Parapet Wall At Least Three (3) Feet High And The Deck Covers Less Than 33% of Roof Area – 7(15-8-321)		X	X	X
DECKS, REQUIREMENTS: Zero (0) Feet Setback When Laid Directly on Ground with No Air Spaces – 7(15-8-321)				X
PORCHES, REQUIREMENTS: Combustible Wood, Not Less Than Six (6) Feet From Property Line – 7(15-8-320)			X	X
PORCHES, REQUIREMENTS: Enclosure, No Rating, Greater Than Six (6) Feet From Interior Lot Line – 34(13-200-260)		X	X	X
PORCHES, REQUIREMENTS: Enclosure, One (1) Hour, Greater Than Three (3) Feet From Interior Lot Line – 34(13-200-260)		X	X	X
PORCHES, REQUIREMENTS: Enclosure, Two (2) Hours, Less Than Three (3) Feet From Interior Lot Line – 6(13-60-100)		X	X	X
PORCHES, REQUIREMENTS: Existing, Not Exceeding Three (3) Stories, May Extend to Roof Regardless of Setbacks – 7(15-300-260)		X	X	X

STEP 5: REVIEW BUILDING CODE SUMMARY				
CODE REQUIREMENTS PER LEVEL OF COMPLIANCE:	**LEVEL 1**	**LEVEL 2**	**LEVEL 3**	**NEW CONST'R**
PORCHES, REQUIREMENTS: Existing, Not to Exceed Four (4) Stories in Height When Rebuilding – 7(15-8-320)				X
PORCHES, REQUIREMENTS: One-Hour Rated Side Walls, Not Less Than Three (3) Feet From Property Line – 7(15-8-320)				X
PORCHES, REQUIREMENTS: Not Less Than One (1) Foot From Lot Line, Six (6) Feet From Another Structure & 50 SQ FT Maximum - 7(15-8-323)	X	X	X	X
PORCHES, REQUIREMENTS: Not to Exceed Three (3) Stories in Height – 7(15-8-320)				X
PORCHES, REQUIREMENTS: Shall Not Project More Than Ten (10) Feet from Building Or Exceed 150 SQ FT Per Dwelling Unit – 7(15-8-320)				X
PORCHES, REQUIREMENTS: When Fronts Entirely on Street, 200 (SQ FT) Square Feet Maximum – 7(15-8-320)	X	X	X	X
GUARDS, REQUIREMENTS: Built After 2003 - Openings, Shall Not Let (8) Inch Diameter Sphere Pass between Balustrades at 34 Inches to 42 Inches High – 33(13-124-335)		X	X	X
GUARDS, REQUIREMENTS: Built After 2003 - Openings, Shall Not Let Four (4) Inch Diameter Sphere Pass between Balustrades at Less than 34 Inches High – 33(13-124-335)		X	X	X
STAIR GUARDS, REQUIREMENTS: Built After 2003 - Openings, Shall Not Let Six (6) Inch Sphere Pass Through Triangular Opening Between Riser and Tread and Bottom Rail, Shall Not Let Four (4) Inch Diameter Sphere Pass between Balustrades – 33(13-124-335)		X	X	X
GUARDS, REQUIREMENTS: 42 Inches Minimum Height – 34(13-196-570) & 33(13-124-330)		X	X	X
GUARDS & STAIR GUARDS, REQUIREMENTS: Guards or Handrails Shall Not Have Ladder Effect – 33(13-124-335)	X	X	X	X
STAIR GUARDS, REQUIREMENTS: Stair Guards or Handrails Shall Not Be Less Than 34 Inches or Greater Than 38 Inches, Measured Vertically From Stair Noising – 10(13-160-320)	X	X	X	X
GUARDS, WHEN REQUIRED: Elevations Greater than Two (2) Feet Above Grade – 33(13-124-320)	X	X	X	X
GUARDS, WHEN REQUIRED: Open Areaways Exceeding Three (3) Feet in Depth – 33(13-24-320)		X	X	X
EXTERIOR STAIRS, REQUIREMENTS: Shall be Adequately Lighted by Electricity – 10(13-160-660)	X	X	X	X
EXTERIOR STAIRS, REQUIREMENTS: Shall Not Exceed 50% of the Required Vertical Exits – 10(13-160-040)	X	X	X	X
EXTERIOR STAIRS, REQUIREMENTS: Shall Not Exceed Thirty (30) Feet in Vertical Distance to the Highest Floor Served – 10(13-160-040)				X

STEP 5: REVIEW BUILDING CODE SUMMARY				
CODE REQUIREMENTS PER LEVEL OF COMPLIANCE:	**LEVEL 1**	**LEVEL 2**	**LEVEL 3**	**NEW CONST'R**
EXTERIOR STAIRS, REQUIREMENTS: Solid Risers Are Not Required, Except that a Four (4) Inch Diameter Sphere Shall Not Pass Between the Treads – 10(13-160-590) & 33(13-124-335)	X	X	X	X
EXTERIOR STAIRS, REQUIREMENTS: Treads & Landings Shall Be Solid, Except for Openings for Drainage - 10(13-160-590)		X	X	X
STAIRS, REQUIREMENTS: 44 Inches Wide, 36 Inches Wide for Occupancies Other than Institutional Less than 50 Persons – 10(13-160-220)				X
STAIRS, REQUIREMENTS: 44 Inches Wide, 36 Inches Wide in Residential Occupancies When Serving Only One Dwelling Unit. – 10(13-160-220)				X
STAIRS, REQUIREMENTS: 9 Inches Minimum Tread Depth Exclusive of Nosing or 10 Inches Tread Depth Including Nosing – 10(13-160-300)		X	X	X
STAIRS, REQUIREMENTS: Doors Swinging Into Exit Landing Shall Maintain 75% of Required Exit Width Beyond Door Edge When Open – 10(13-160-200)		X	X	X
STAIRS, REQUIREMENTS: Eight (8) Inches Maximum Riser Height – 10(13-160-300)		X	X	X
STAIRS, REQUIREMENTS: Handrails May Project Four (4) Inches on Each Side into Stair Width		X	X	X
STAIRS, REQUIREMENTS: Height of Two (2) Risers Plus One (1) Tread Shall Be Greater Than 24 Inches or Less Than 27 Inches – 10(13-160-300)		X	X	X
STAIRS, REQUIREMENTS: Landings, Equal to Width of Stairs or Four (4') Feet Wide Maximum – 10(13-160-310)		X	X	X
STAIRS, REQUIREMENTS: No Flight Shall Have Less Than Two (2) Risers – 10(13-160-310)		X	X	X
STAIRS, REQUIREMENTS: Seven (7) Feet Minimum Headroom, Residential Occupancies		X	X	X
STAIRS, REQUIREMENTS: Six (6) Feet Eight (8) Inches Minimum Headroom, Residential Occupancies		X	X	X
STAIRS, REQUIREMENTS: Winders Permitted in Residential Occupancies with Two (2) Dwelling Units or Less – 10(13-160-300)				X
STAIRS, REQUIREMENTS: Winders, Treads Shall be Nine (9) Inches Wide or Greater at 18 Inches From Inside Railing - 10(13-160-300)		X	X	X

PORCH EVALUATION EXAMPLE



THE ILLUSTRATED PORCH HAS BEEN EXAMINED FOR THE ADEQUACY OF MEMBER SIZES AND DETERIORATION AND FOUND TO HAVE A NUMBER OF DEFICIENT MEMBERS. THE DEFICIENT MEMBERS ARE MARKED WITH A STAR. IN PLAN, THE PORCH EXTENDS 8'-0" FROM THE BUILDING WALL AND THE COLUMNS ARE SPACED AT 7'-6" o.c. THE INTERMEDIATE STAIR LANDING IS 7'-6" x 3'-6". EVAULATE THE PORCH USING THE TABLE IN STEP 4. DISREGARD THE ROOF STRUCTURE.

STEP 4: DETERMINE REPAIR / REPLACEMENT LEVEL OF COMPLIANCE									
CALCULATE THE RATIO OF REPAIR REQUIRED FOR EACH COMPONENT AND MULTIPLY THAT VALUE BY THE MULTIPLIER LISTED IN THE TABLE. THE LEVEL OF COMPLIANCE FOR THE ENTIRE PORCH IS DETERMINED BY THE SUM OF THE PERCENTAGE OF WORK FOR EVERY COMPONENT REQUIRING REPAIR.									
Member / Component	**No. of Unit(s) To be Repaired**			**No. of Unit(s) For Entire Deck / Porch**					**WEIGHTED PERCENTAGE OF REPAIR WORK**
	No.	**UNIT**		**No.**	**UNIT**	**MULTIPLIER**			
Columns	4	QTY	/	24 + 4 = 28	QTY	X	12	=	0.143 x 12 = 1.71
Beams	4 x 7.5 ft. = lin. 30 ft.	LF	/	19 x 7.5 ft. + 6 x 8 ft. = 190.5 lin. ft.	LF	X	12	=	0.157 x 12 = 1.88
Beam-Column Connections	4	QTY	/	26	QTY	X	12	=	0.154 x 12 = 1.85
Joists	10 x 8 ft. = 80 ft.	LF	/	6 x 12 x 8 ft. + 3 x 5 x 3.5 ft. + 2 x 7 x 3.5 ft. = 677.5 lin. ft	LF	X	10	=	0.118 x 10 = 1.18
Decking	8 ft. x 15 ft. = 120 sq. ft.	SQ FT	/	6 x 8 ft. x 15 ft. + 5 x 3.5 ft. x 7.5 ft. = 851.25 sq. ft.	SQ FT	X	9	=	0.141 x 9 = 1.13
Footings	1	QTY	/	8	QTY	X	12	=	0.125 x 12 = 1.5
Stair Stringers	1	Stringer(s)	/	10	Stringer(s)	X	9	=	0.1 x 9 = 0.9
Stair Treads & Risers	9	Treads	/	9 x 5 = 45	Treads	X	5	=	0.2 x 5 = 1
Guards & Stair Guards	8 ft. + 15 ft. = 23 lin. ft.	LF	/	6 x 8 ft. + 10 x 4.5 ft + 14 x 7.5 ft. + 4 x 3.5 ft. + 6 x 4.5 ft. = 239 lin. ft.	LF	X	12	=	0.096 x 12 = 1.15
Ledger & Ledger Connection	0	LF	/	3 x 5 x 7.5 ft. = 112.5 lin. ft.	LF	X	5	=	0
Lateral Bracing	1	QTY	/	1	QTY	X	2	=	1 x 2 = 2
Sum of all Components (% of Total Porch Structure Requiring Repair Work)								=	14.3
% of Total: Less Than 25%								=	LEVEL 1
% of Total: Less Than or Equal to 50%								=	LEVEL 2
% of Total: More Than 50%								=	LEVEL 3

Whether a building owner has to build a new porch or make repairs to an existing wood porch, exterior stairway, balcony or deck, the following steps should be taken:

1	PORCH EVALUATION	2	SELECT A DESIGN PROFESSIONAL (IF APPLICABLE)	3	APPLY FOR A PERMIT	4	SELECT A CONTRACTOR	5	REQUEST INSPECTIONS & PROJECT CLOSEOUT

STEP 1: PORCH EVALUATION

PORCH EVALUATION

For existing porches, use the Porch Evaluation Section and the Porch Checklist Section to assess the current condition of the porch and establish what repairs are required. After the condition of the porch has been assessed and the required work is determined, the appropriate DOB building permit program can be determined. Regardless of whether an existing porch is being repaired or a new porch is being constructed, the Porch Checklist Section can be used to assess whether the construction work meets the Chicago Building Code and DOB requirements. Meeting these requirements will ensure that the project will pass the DOB inspections. In general, this Section provides guidance for a successful porch project.

STEP 2: SELECT A DESIGN PROFESSIONAL / PREPARE BLUEPRINTS

SELECT A DESIGN PROFESSIONAL:

The design professional that is selected must to be licensed in the State of Illinois. They must either be a licensed Architect or Structural Engineer to create drawings for a project in the City of Chicago.

To find a suitable design professional, one of the following professional associations can be contacted for recommendations. In addition, the Internet or the telephone directory can be used.

- Association of Licensed Architects (ALA) (847) 382-0630
- American Institute of Architects Chicago (AIA Chicago) (312) 670-7770
- Structural Engineers Association of Illinois (SEAOI) (312) 372-4198

After finding several likely candidates, interview the design professionals. During the interviews with potential design professionals, obtain information regarding other similar projects that they have done. In addition, obtain references that can be contacted to confirm the adequacy of the services provided on these other projects. In addition, if possible, view these projects.

To obtain costs for the design of the porch, request that each architect or structural engineer submit a proposal for their services. Their proposals should be detailed and include their fees for each phase or aspect of their work. In general, experienced design professionals should be able to provide a flat or fixed fee for all of their services. If, however, they are being requested to investigate the condition of the porch for repair, their services may be provided on an hourly basis. If the agreement is to be based upon an hourly fee, a not-to-exceed value should be provided. Their proposals should also include a time of completion for their services.

The owner's agreement or contract with the design professional should also include a payment schedule or some provision regarding when payment will be made. The owner may want to provide a single payment when the building permit is issued, but the design professional may also want to be assured that they will be paid for their services and be paid in a timely manner.

Additional drawings or information may be required by the DOB during the permit review process. The agreement with the design professional should define whether there will be an additional fee for complying with the DOB request, or whether the design professional will do the additional work at no additional cost to his client.

In essence, the owner may want to request that the design professional agree that the drawings and calculations prepared by them are adequate to comply with the requirements of the CBC and the DOB and that no additional fees will be charged to comply with any DOB request for more information. On the other hand, the design professional cannot be expected to anticipate every request from the Building or Zoning Departments.

PREPARE DRAWINGS (AND CALCULATIONS):

The instruments of service of the architect or structural engineer are drawings and, in some instances, calculations. The drawings are to include framing plans, details, material specifications, design loads, and notes that are sufficient to describe what the repair or new work is to consist of. The details on the drawings must be cross referenced to framing plans. The description of the work must be sufficient to obtain a building permit and provide the contractor with a clear understanding of what work needs to be completed. Depending upon the condition of the porch, calculations may also be necessary to determine the structural capacity of the structure. The submittal of drawings must be accompanied by photographs of the existing porch conditions.

If the project includes porch repairs, the drawings need to show how to correct the existing defects in detail. Some of those defects may be listed in a violation notice from the Department of Buildings. The violation notice may not, however, include all of the defects or deficiencies that exist on the porch structure. Therefore, the design professional must examine and analyze the entire porch structure for its compliance with the CBC. They must show all of the work required to repair the porch or create compliance with the CBC on the drawings submitted for permit.

Illustrations of the graphic information that should be shown on the drawings are included in SECTION D: DRAWINGS and SECTION F: EXAMPLE DESIGN.

Three (3) sets of drawings should be printed for submission to the City of Chicago Department of Buildings. Sets should be distributed in the following manner, one (1) set each:

- Contractor's record and working plans to be kept at the job site
- Record copy for the Department of Buildings
- Building owners records

REQUIRED INFORMATION: PER PORCH TYPE & PERMIT PROGRAM			PERMIT PROCESS EPP NO PLANS	EPP DETAILS	SPR LICENSED STAMPED PLANS	SPR HOMEOWNERS ASSISTANCE
LEVEL 1 & 2: REPAIRS:	**1 or 2 STORY PORCH:** ANY NUMBER DUs Less than six (6) feet from grade to first floor **1 STORY FRONT PORCH: 200 SQ FT OR LESS** Less than six (6) feet from grade to first floor **1 STORY DECK: 450 SQ FT OR LESS** Less than six (6) feet from grade to first floor	LEVEL 1: Repairs	X			
		LEVEL 2: Repairs		X		
	ENTRY PORCH / DECK: 50 SQ FT OR LESS Less than six (6) feet from grade to first floor	LEVEL 1 & 2: Repairs	X			
	1 or 2 STORY PORCH: ANY NUMBER DUs Greater than six (6) feet from grade to first floor **3 STORY PORCH:** ANY NUMBER DUs Regardless of Distance from grade to first floor **ROOF / GARAGE ROOF DECK:** ANY NUMBER DUs	LEVEL 1: Repairs	X			
		LEVEL 2: Repairs			X	
LEVEL 3: REPAIRS / REPLACEMENT & NEW CONSTRUCTION:	**1 STORY FRONT PORCH:** 200 SQ FT OR LESS Less than six (6) feet from grade to first floor **1 STORY DECK:** 450 SQ FT OR LESS Less than six (6) feet from grade to first floor **ENTRY PORCH / DECK:** 50 SQ FT OR LESS Less than six (6) feet from grade to first floor	LEVEL 3: Repairs Replacement & New Construction		X	X	
	1 or 2 STORY PORCH: 2 DUs OR LESS Less than six (6) feet from grade to first floor	LEVEL 3: Repairs Replacement & New Construction			X	X
	1 or 2 STORY PORCH: MORE THAN 2 DUs Regardless of Distance from grade to first floor **3 STORY PORCH:** ANY NUMBER DUs Regardless of Distance from grade to first floor **ROOF / GARAGE ROOF DECK:** ANY NUMBER DUs	LEVEL 3: Repairs Replacement & New Construction			X	

Easy Permit Process, No Plans: The Easy Permit Process, with no plans (or drawings), allows homeowners and licensed contractors to obtain a porch or deck permit to make repairs to existing porches, without drawings although photographs of existing conditions are required. Through this program an applicant is able to obtain a permit the same day if all of the required documentation is submitted upon application for the permit.

Easy Permit Process, Details: The Easy Permit Process, using the details included in these Guidelines, allows homeowners, buildings owners, and licensed contractors to obtain a porch or deck permit by providing a site plan/framing plan generated by the applicant in conjunction with the details & sections provided in SECTION D: DRAWINGS. This permit process is intended for repairs, replacement or new construction for a limited number of porch types. To obtain a permit, prepare or complete the documents listed herein and then schedule an appointment with a DOB Project Manager (PM). Upon submittal of the documents and photographs of existing conditions, the PM will review the information to assess compliance with the program. Through this program an applicant can receive a permit the same day for most applications. If further review is required, the DOB Project Manager will make that review within 1-2 weeks and the applicant will be contacted when the permit is ready for pick-up.

Standard Plan Review, Licensed Stamped Plans: The Standard Plan Review Process, with plans stamped by a licensed design professional, allows a qualified owner's representative to apply for a porch or deck permit. After drawings are prepared by a structural engineer or architect, they are submitted with photographs of existing conditions, as a part of the permit application. A meeting is scheduled with a project manager and the permit application is submitted. The application and related documents are reviewed by the project manager as a "desk review." If necessary, "corrections" will be issued and the documents must then be modified by the design professional. After the "corrections" are addressed, the design professional must schedule a second review meeting with the project manager. If the "corrections" have been correctly addressed, the project manager will process the permit within 1 to 2 weeks. The applicant will then be contacted to pick-up the permit.

Standard Plan Review, Homeowner Assistance: This Standard Plan Review process includes the use of the Homeowner Assistance program to obtain porch or deck permits. To obtain a permit, a site plan/framing plan must be created by the applicant and used in conjunction with the details & sections provided in SECTION D: DRAWINGS. Using this process, permits can be obtained for repairs, replacement or new construction for a limited number of porch types. To initiate the process, an appointment must be made with a project manager. At that appointment, the application and related documents, including photographs of existing conditions, are submitted to and reviewed by the project manager. If the project manager determines that additional information is required or that changes must be made, written "corrections" will be issued. The homeowner will then be responsible for addressing the "corrections" and scheduling another meeting with the project manager. When the "corrections" have been completely addressed, the DOB project manager will process the permit within 1 to 2 weeks and the homeowner will be contacted when the permit is ready for pick-up.

REQUIRED INFORMATION: PER PORCH TYPE & PERMIT PROGRAM	PERMIT PROCESS			
	EPP	EPP	SPR	SPR
	NO PLANS	DETAILS	LICENSED STAMPED PLANS	HOMEOWNERS ASSISTANCE
DOCUMENTS: Plat of Survey	X	X	X	X
DOCUMENTS: Easy Permit Application	X	X	N/A	N/A
DOCUMENTS: Homeowner Site Plan / Framing Plan	N/A	N/A	N/A	X
DOCUMENTS: Building Permit Application	N/A	N/A	X	X
DOCUMENTS: Electrical Permit Application (If Applicable)	☐	☐	☐	☐
DOCUMENTS: Excavation Certificate, Insurance & Notifications to Adjacent Owners	N/A	N/A	☐	☐
DOCUMENTS: Certificate of Primary Residence	☐	☐	☐	X
DOCUMENTS: Certificate of Responsibility	☐	☐	☐	X
PICTURES: Existing Conditions - Overall Area	X	X	X	X
PICTURES: Areas to be Repaired - Close-Ups	X	X	X	X
PLANS: Site Plan	N/A	X	X	X
PLANS: Framing Plans	N/A	N/A	X	X
PLANS: Project Specific – Sections & Details	N/A	N/A	X	N/A
PLANS: Porch Design & Construction Guidelines – Sections & Details	N/A	X	N/A	X
CONTRACTORS: General Contractor, Licensed	☐	☐	☐	☐
CONTRACTORS: General Contractor, Owner	☐	☐	☐	☐
CONTRACTORS: Mason (Concrete), Owner	☐	☐	☐	☐
CONTRACTORS: Mason (Concrete), Licensed	☐	☐	☐	☐
CONTRACTORS: Electrical, Licensed (If Applicable)	☐	☐	☐	☐

ALWAYS REQUIRED: BASED ON PERMIT PROGRAM	X
MAY BE REQUIRED: BASED ON PERMIT PROGRAM	☐
NOT APPLICABLE: BASED ON PERMIT PROGRAM	N/A

STEP 3: APPLY FOR A PERMIT

1 Permit Process & Office Locations

STEP 1
Permit Process

- ❑ Easy Permit Process:
  - •No Plans
  - •w / Details
- ❑ Standard Plan Review
  - •Homeowners Assistance
  - •Licensed Stamped Plans

OFFICE LOCATIONS

Department of Buildings
121 N. La Salle - Rm. 900
Monday through Friday
8:30am to 4:30pm
All Programs

North / Addison Office
2550 W. Addison Street
312.742.2560
Tuesday & Wednesday
8:30am to 4:30pm
Prescriptive Porch &
Homeowner Assistance Only

Southwest / Kedzie Office
4770 S. Kedzie Ave.
312.745.4240
Tuesday & Wednesday
8:30am to 4:30pm
Prescriptive Porch &
Homeowner Assistance Only

Central / 95th Street Office
2006 E. 95th Street
312.745.0995
Tuesday & Wednesday
8:30am to 4:30pm
Prescriptive Porch &
Homeowner Assistance Only

2 Permit Intake Review Meeting

STEP 2A
Schedule Intake Meeting

- ❑ Applicant schedules intake appointment online at www.cityofchicago.org/buildings
- ❑ Architect / expeditor creates building permit application online at DOB website.

STEP 2B
Intake Appointment Meeting

- ❑ Zoning Review
- ❑ Identify code violations & stop work orders
- ❑ Review photographs of existing conditions and plans for completeness & process application in computer.

3 Other Department Reviews

STEP 3A
Landmarks Commission Review (As Required)
(Before DOB Reviews, If Applicable @ 33 N. La Salle - 16th Floor)

- ❑ Landmark Buildings & Landmark Districts

STEP 3B
Department of Planning & Development (As Required)
(Before DOB Reviews, If Applicable @ 121 N. La Salle 7th Floor)

- ❑ Lakefront Protection District
- ❑ Plan Developments: -Short Form Review

4 Technical Reviews

STEP 4
EASY PERMIT PROCESS
(No Plans)

- ❑ Same Day Permit Issued w/o Plans and all required documents submitted in proper form.

EASY PERMIT PROCESS
(Details)

- ❑ Same day permit issued with applicant generated site plan, framing plan, and details from Porch Design & Construction Guidelines with all required documents submitted in proper form.

STANDARD PLAN REVIEW
(Homeowner Assistance)

- ❑ Same day permit issued with owner generated site plan, framing plan, and details from Porch Design & Construction Guidelines with all required documents submitted in proper form. Assistance provided to homeowner by DOB Project Manager at intake appointment

STANDARD PLAN REVIEW
(Licensed Stamped Plans)

- ❑ Same day desk reviews by DOB Project Manager at intake appointment
  - •Architecture
  - •Electrical
  - •Structural Review

5 Technical Reviews & Plan Compliance

STEP 5A
Plan Review Corrections

- ❑ Corrections issued in writing by DOB Project Manager
- ❑ Corrections shall be made by Architect, Engineer of Record or Homeowner

STEP 5B
Code Variance *(If Applicable)*

- ❑ Building Board of Appeals
- ❑ Administrative Relief Request
- ❑ Standards & Tests

STEP 5C
2nd Appointment

- ❑ Applicant schedules appointment online at www.cityofchicago.org/buildings

6 Final Review

STEP 6A
Department of Zoning Approval
(Must be obtained by applicant in-order to proceed)

- ❑ Stamps & signature on plans and application

STEP 6B
2nd Appointment Final Review by Project Manager

- ❑ Permit documents & plans submitted to PM
- ❑ Review documents for approvals & completeness
- ❑ Comply corrections identified at intake meeting
- ❑ Tabulates fees
- ❑ Verify final corrections & plan compliance
- ❑ Stamp approved drawings

7 Permit Issuance

STEP 7A
Permit Issuance

- ❑ Pay for permit at Revenue window
- ❑ Provide Proof-of-Payment to Pick-up plans & Permit from Project Manager

STEP 7B
Field Inspections

- ❑ Request Inspection as required online at www.cityofchicago.org/buildings

STEP 4: SELECT A CONTRACTOR

SELECT A CONTRACTOR:

The contractor must complete the project in a timely manner and in conformance with the design prepared by the architect or structural engineer. The contractor must start the project when agreed and pursue it to completion without interruption. The contractor must not "redesign" the porch in the course of completing the work.

To initially find a contractor, search using the Internet, telephone director or industry resources. Interview several perspective contractors and determine their experience with similar projects. Request a list of similar projects and owners and then contact those owners and examine their projects. Ask the perspective contractors to provide bids based upon the drawings that have been prepared by the architect or structural engineer. Given a complete set of drawings, the contractors should be able to provide fixed prices for the entire project. There should be no need for a time and material agreement with a contractor.

Your agreement with the contractor should define the method and schedule of payment. Payment for the project should occur as the work is being completed. A large initial payment should not be necessary and is not desirable. As the owner, you do not want payments to exceed the value of the work in place. On the other hand, the contractor wants to ensure that he will be paid and be paid in a timely manner. Therefore, payment at certain milestones in the project is most desirable. Final payment should occur when the project passes final inspection and the permit is signed by the building inspector.

STEP 5: REQUEST INSPECTIONS & PROJECT CLOSEOUT

REQUEST INSPECTIONS:

An owner or a contractor can request that a porch inspection be scheduled.

Where work on a porch is required to address violations, call the Department of Building at (312) 743-7200 to find out which district supervisor in the Conservation Bureau is responsible for the area where the building is located. Obtain the name and phone number of the supervisor for future correspondence. At each of the following milestones, call the supervisor to request an inspection:

- Foundation Inspection: Before placing concrete
- Intermediate Inspection: Review of work in progress
- Final Inspection: After all the work is completed.

For new construction of porches only, the DOB will accept photographic evidence of the adequacy of the foundation(s). Each photograph must include a placard indicating at what address and where on the site the foundation was constructed. **The photographs must show a sufficiently large portion of the site to prove that it is at the correct address. The photographs must show sufficient detail to prove that the reinforcement steel and dimensions are correct.**

For new construction of porches, the request for Intermediate and Final Inspections should be made online at www.cityofchicago.org/buildings.

It is recommended that the building owner be present during all inspections and that they take part in meetings between the building inspectors and contractor. This involvement in the project will provide the owner with first-hand knowledge of the progress of the work and any issues regarding the project.

PROJECT CLOSEOUT:

It is very important to have the building permit signed (on the back side) during the intermediate inspections. This provides a record of the approval of the various project phases.

After the project passes the final inspection and the permit is signed, the building owner should keep the original permit as a written record and proof that:

- The design and execution of the work has followed agreed upon and accepted procedures.
- The project has been inspected by the Department of Buildings.
- The work on the building (or porch) has been reviewed by the Department of Buildings.

Appendix B

Summary of existing water permeability test methods for concrete, from (Milla et al., 2021).

Sample Number	Test Name	In Situ	Test Duration	Mechanism/ Concept	Merits	Limitations	Test Instrument Commercially Available?
1	Initial Surface Absorption Test (BS 1881-208:1996)	No	150 min	Water absorption	Relatively quick (~150 min) and simple NDT	Difficulty to ensure water tightness, measured property is greatly affected by the moisture condition of the concrete, cannot be applied to underside of the concrete, does not measure bulk permeability	Yes
2	Autoclam Permeability Method	Yes	60 min	Water pressure (absorption)	Total duration of each test <30 min including instrument setup time, portable setup, easy to use, NDT, good relationship with other durability test results has been seen	Not a standardized test. Measurements are only applicable to concretes with less than 80 % internal humidity	Yes
3	Standpipe Absorptivity Test	Yes	Varies	Water absorption	Very simple to carry out on site	Lacks sensitivity that ISAT and Autoclam sorptivity tests possess. Not a standardized test	No
4	Figg Poroscope Method	Yes	40 min	Water pressure (absorption)	Simple and easy test	Relatively poor repeatability and drilling the hole might change microstructure of concrete. Not a standardized test	Yes
5	Covercrete Absorption Test (CAT)	Yes	1 h	Water absorption	Believed to avoid localized effects because of phenomena such as carbonation on the concrete absorption properties	Provide insufficient information regarding modeling of long-term capillary transport properties and are limited to describing the surface effects on capillary absorption. Not a standardized test	No
6	Water Absorption (RILEM CPC 11.2)	No	3 days	Water absorption through surface	None noted in literature	Destructive, time-consuming, and laborious; needs field cores to be drilled for tests	No
7	Water Sorptivity (ASTM C1585)	No	8 days (Overall, 4 weeks including specimen conditioning)	Water absorption by capillary suction	Standardized preconditioning, test conditions more representative of field concrete, results can be used for modeling	Destructive, time-consuming, and laborious test; results very sensitive to specimen conditioning; needs field cores to be drilled for tests	No
8	South African Water Sorptivity	No	1 day	Water absorption by capillary suction	Sensitive to microstructural properties near concrete's surface	Destructive, needs field cores to be drilled for tests	No
9	Water Absorption by Vacuum Saturation	No	2 days	Bulk water absorption under vacuum	Provides consistent pore volume results, better porosity results compared to ASTM C642	Destructive, needs field cores to be drilled for tests. Not a standardized test	No
10	Water Absorption by Boil Test (ASTM C642)	No	2 days	Bulk water absorption	Easy and quick method	Test underestimates total porosity. Does not directly measure permeability	No
11	Australian Water Absorption Test (AS 1012.21)	No	2 days	Bulk water absorption	Very easy test, improvements over ASTM C642, superior repeatability and reproducibility, very sensitive to even small changes in concrete, very good relationship with chloride intrusion	Destructive, needs field cores to be drilled for tests	No
12	Germann Water Permeability Test	Yes	40 min	Water pressure (absorption)	Tests can be performed on horizontal and vertical surfaces	Problems with obtaining constant water pressure on nonhorizontal concrete elements. Not a standardized test	Yes
13	Depth of Water Penetration Under Pressure (EN 12390-8 & DIN 1048-5)	No	3 days	Pressurized water (permeation)	Penetration depth measured, represents field concrete condition subjected to hydraulic pressures, good correlation of water penetration with surface resistivity has been observed	Destructive test	Yes
14	Field Permeability Test- FPT (Florida Test)	Yes	40 min	Pressurized water	Rapid test method	Slightly destructive because of drilling the hole	No

Summary of chloride ion permeability test methods for concrete, from (Milla et al., 2021).

Sample Number	Test Name	In Situ	Test Duration	Mechanism/ Concept	Merits	Limitations	Test Instrument Commercially Available?
1	Salt ponding test (AASHTO T 259)	No	90–180 days	Diffusion	Calculates chloride diffusion coefficient. Can be used to model service life	Overestimates sorption. Extremely time-consuming. Destructive test. Not valid for samples containing steel reinforcing	No
2	Bulk diffusion test (ASTM C1556)	No	35–90 days	Diffusion	Calculates chloride diffusion coefficient. Can be used to model service life	Very time-consuming. Destructive test. Not valid for samples containing steel reinforcing	No
3	Accelerated Chloride Penetration (NT Build 443)	No	35–90 days	Diffusion	Calculates chloride diffusion coefficient. Can be used to model service life	Very time-consuming. Destructive test. Not valid for samples containing steel reinforcing	No
4	RCP (ASTM C1202)	No	6 h	Migration, non-steady state	Rapid indication of chloride ion penetrability	Overestimates benefits of SCMs. Prone to sample heating errors and high variability. Not valid for samples containing steel reinforcing. No migration coefficient calculated. Destructive test	Yes
5	Steady-State Migration Cell Experiment (NT Build 355)	No	7 days (or longer, until steady-state conditions are achieved)	Migration, steady-state	Migration coefficient can be used to model service life	Time-consuming. Requires specialized equipment and skills. Destructive test. Not valid for samples containing steel reinforcing.	No
6	Non-Steady State Migration Cell Experiment (NT Build 492)	No	6–96 h (depending on voltage selected)	Migration, non-steady state	Measures actual chloride penetration depth. Migration coefficient can be used to model service life	High variability. Requires specialized equipment and skills. Destructive test. Not valid for samples containing steel reinforcing	Yes
7	Effective Diffusion Coefficient by Migration (JSCE-G571)	No	7 days (or longer, until steady-state conditions are achieved)	Migration, steady-state	Migration coefficient can be used to model service life	Time-consuming. Requires specialized equipment and skills. Destructive test. Not valid for samples containing steel reinforcing	No
8	Surface Resistivity (AASHTO T 358)	Yes	5 min	Electrical resistivity	Extremely fast, easy to use, nondestructive test	Overestimates benefits of SCMs. Not valid for samples containing steel reinforcing	Yes
9	Bulk Conductivity (ASTM C1760)	Yes	5 min	Electrical resistivity	Extremely fast, easy to use, nondestructive test	Overestimates benefits of SCMs. Not valid for samples containing steel reinforcing	Yes
10	Formation Factor (AASHTO PP 84)	No	5 min–91 days (Depending on which method is used to obtain pore solution chemistry)	Electrical resistivity	Normalizes resistivity results by considering pore solution chemistry. Nondestructive test	Measuring the pore solution resistivity directly can require special equipment and skills. Modeled estimates of pore solution resistivity are not reliable in binary and ternary mixtures. If bucket test is used, specimen may have to be monitored for a substantial period (up to 91 days). Not valid for samples containing steel reinforcing	Yes

Summary of correlations between surface resistivity and other concrete permeability test methods, from (Milla et al., 2021).

Comparison	R^2	Trendline	w/cm	Mix Components	Number of Mixtures	Reference
BR versus SR	0.9986	Linear	0.34, 0.35, 0.37, 0.39, 0.40, 0.41	Portland cement, fly ash, silica fume, metakaolin, slag	12	Spragg et al.[92]
	0.78	Linear	0.44	Type II-V cement, grade 100 slag, grade 120 slag	16	Ghosh and Tran[99]
	0.58	Linear	0.44	Type II-V cement, silica fume	10	Ghosh and Tran[99]
	0.99	Linear	0.44	Type II-V cement, metakaolin	10	Ghosh and Tran[99]
	0.86	Linear	0.44	Type II-V cement, class C and class F fly ash	22	Ghosh and Tran[99]
	0.99	Linear	0.37	Type I/II cement, class C fly ash, class F fly ash, slag, metakaolin, sugarcane bagasse ash, ground glass	19	Tibbetts et al.[112]
	0.9781	Linear	0.37, 0.42, 0.47	Type I/II cement, class F fly ash, portland limestone cement	24	Cavalline et al.[113]
	0.98	Linear	0.37, 0.38, 0.40, 0.42, 0.43, 0.45	Portland cement (type not specified), fly ash, slag	9	Gudimettla and Crawford[114]
log BR versus log D_{RCM}	0.87	Linear (Logarithmic)	0.40, 0.45, 0.47, 0.55	Slag-cement based concrete (CEM III/B 42,5 N)	47	van Noort, Hunger, and Spiesz[83]
RCP versus BR	0.95	Power	0.37	Type I/II cement, class C fly ash, class F fly ash, slag, metakaolin, sugarcane bagasse ash, ground glass	19	Tibbetts et al.[112]
SP versus SR	0.9488	Power	0.35, 0.40, 0.50	Type I cement, metakaolin	12	Ramezanianpour and Jovein[115]

Comparison	R^2	Trendline	w/cm	Mix Components	Number of Mixtures	Reference
SR versus RCP	0.8922	Power	0.35, 0.50, 0.65	Type I/II cement, class C fly ash, class F fly ash, grade 100 slag, grade 120 slag, silica fume	21	Rupnow and Icenogle[89]
	0.8656	Power	Not disclosed	Not disclosed	343	Jenkins[91]
	0.98	Power	0.37	Type I/II cement, class C fly ash, class F fly ash, slag, metakaolin, sugarcane bagasse ash, ground glass	19	Tibbetts et al.[112]
	0.7741	Power	0.35, 0.37, 0.42, 0.47, 0.48	Type I/II cement, class F fly ash, portland limestone cement	47	Cavalline et al.[113]
	0.89	Power	0.37, 0.38, 0.40, 0.41, 0.42, 0.43, 0.44, 0.45	Portland cement (type not specified), fly ash, slag	11	Gudimettla and Crawford[114]
	0.9219	Power	0.35, 0.40, 0.50	Type I cement, metakaolin	12	Ramezanianpour and Jovein[115]
	0.8977	Power	0.40, 0.45, 0.50, 0.55, 0.60	Type I cement, RHA, tuff, pumice, silica fume, metakaolin	57	Ramezanianpour et al.[116]
	0.7933	Power	0.48	Type I cement, class F fly ash, portland limestone cement	18	Medlin[117]
	0.9219	Power	0.48	Type I cement, class F fly ash	9	Medlin[117]
	0.92	Power	0.37, 0.4, 0.42, 0.43 0.45, 0.46, 0.47, 0.48, 0.50	Type I/II cement, class C fly ash, class F fly ash, fine limestone powder	25	Tanesi and Ardani[118]
	0.9481	Power	Not disclosed	Portland cement (type not specified), fly ash, slag, silica fume	134	Chini, Muszynski, and Hicks[119]
SR versus BT	0.3767	Power	Not disclosed	Not disclosed	101	Jenkins[91]
WP versus SR	0.8268	Power	0.4, 0.45, 0.5, 0.55, 0.6	Type I cement, rice husk ash, tuff, pumice, silica fume, metakaolin	57	Ramezanianpour et al.[116]

Note: BR = bulk resistivity (ASTM C1760); BT = boil test (ASTM C642); D_{RCM} = migration diffusion coefficient (NT Build 492); RCP = rapid chloride permeability test (ASTM C1202); SP = salt ponding (ASTM C1543); SR = surface resistivity (AASHTO T 358); and WP = water penetration (EN 12390-8). [a] Author did not specify the composition of the concrete mixtures tested. Rather, the study mentioned the number of mixtures evaluated by the state DOT.