ARUP

A Universal Taxonomy for Natural Hazard and Climate Risk and Resilience Assessments

Buildings Edition

May 2024

Version 1.0

Wildfire smoke in San Francisco, 2020

This framework provides stakeholders a universal language for risk and resilience assessments so that they can better communicate and align their needs for specific applications. We hope that it will bring much needed consistency and transparency to the growing demand for natural hazard and climate risk assessments around the world and lead to more resilient outcomes. This version is focused on buildings and the organizations and people who use them.

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Foreword

Rashmin Gunasekera | Senior Disaster Risk Management Specialist

Global Facility for Disaster Risk Reduction at the World Bank

It is a pleasure to write the foreword for this publication of a Universal Taxonomy for Natural Hazard and Climate Risk and Resilience Assessments. This risk framework is commendable for focusing on the impacts of natural hazards, and bringing together the technical synthesis of the different types, styles, and applications of risk assessments. I foresee this publication becoming a key guide for technical risk practitioners and various stakeholders across the academic, public, and private sectors, as it provides practical advice and support in scoping and evaluating quantitative disaster risk assessments.

In the last few years, we have seen a significant increase in demand for global, national, local, and asset level quantitative risk assessments – even more so when considering climate related risk assessments.

However, guidance and a taxonomy that helps both producers and consumers of this risk information has been scarce.

It is clear that more is needed to better define risk assessments on scoping, different applications of the results, the range of outputs, the implications of results, the associated costs, and importantly, the associated uncertainty. This risk taxonomy now goes a fair way towards addressing the knowledge gap.

From an end user perspective, in my experience of having worked in academia, public, and private sectors for more than 20 years, we have lacked the framing of disaster risk assessments as shown in this publication, particularly that with a focus on some higher level, key technical information. In the public sector, for example, at the World Bank and the Global Facility for Disaster Reduction Recovery (GFDRR) where I currently work, the topic of disaster risk assessment is of critical importance. For those of us working at the cutting edge, we need to focus not only developing innovative analytics and tools but also on supporting Disaster Risk Reduction (DRR) policy formulation, increasingly extending the work to quantifying physical vulnerabilities, which makes this publication even more relevant for us. Therefore, I support and commend the objective to advance this knowledge for evaluating natural hazard impacts, not only on buildings but also on people and communities.

Looking ahead, I see signs for future further development and expansion of this taxonomy in relation to different asset classes and infrastructure sectors and different climate change scenarios. One key angle would be to expand the taxonomy to non-technical audiences as well. I look forward to the next steps and uptake of the risk taxonomy in our projects in the years to come.

Applications and uses

Introduction

There is an increasing need to take action on climate adaptation in the built environment. Various stakeholders, from property professionals to financiers, have been tasked with leading the way. Yet risk and resilience are highly technical topics and there are limited resources to help non-technical stakeholders navigate the path forward. We often find that we are not talking the same language, causing mis-alignment and unmet expectations between the consumers and providers of risk and resilience information and strategies. Ultimately, this inhibits the speed and quality of enacting resilience and adaptation measures at the scale needed.

There is currently no universal regulatory framework that differentiates between levels or types of risk assessment for natural hazards and climate change, and no criteria governing what should be considered adequate or appropriate for each situation in which a risk assessment might be required.

The Risk Class Taxonomy and Resilience Class Taxonomy were developed to fill this gap. They provide a framework for establishing what levels of risk assessment should be undertaken, at a minimum, to make resilience-related decisions or take actions with sufficient confidence to increase resilience.

The Simplified Risk Class Taxonomy provides a high-level summary for reference and communication purposes. The Risk Class Taxonomy explicitly outlines the risk assessment approaches, data needs, data quality, and typical outputs to achieve a given Risk Class and also includes sub-taxonomies for seismic, flood, wind, and heat hazards as well as a taxonomy for how to include climate change effects in risk assessments. The Resilience Class Taxonomy outlines the types of resilience solutions and maturity level needed to achieve a given Resilience Class.

The section on User Personas outlines how to use the taxonomies for specific use cases by stakeholders in specific roles within an organization.

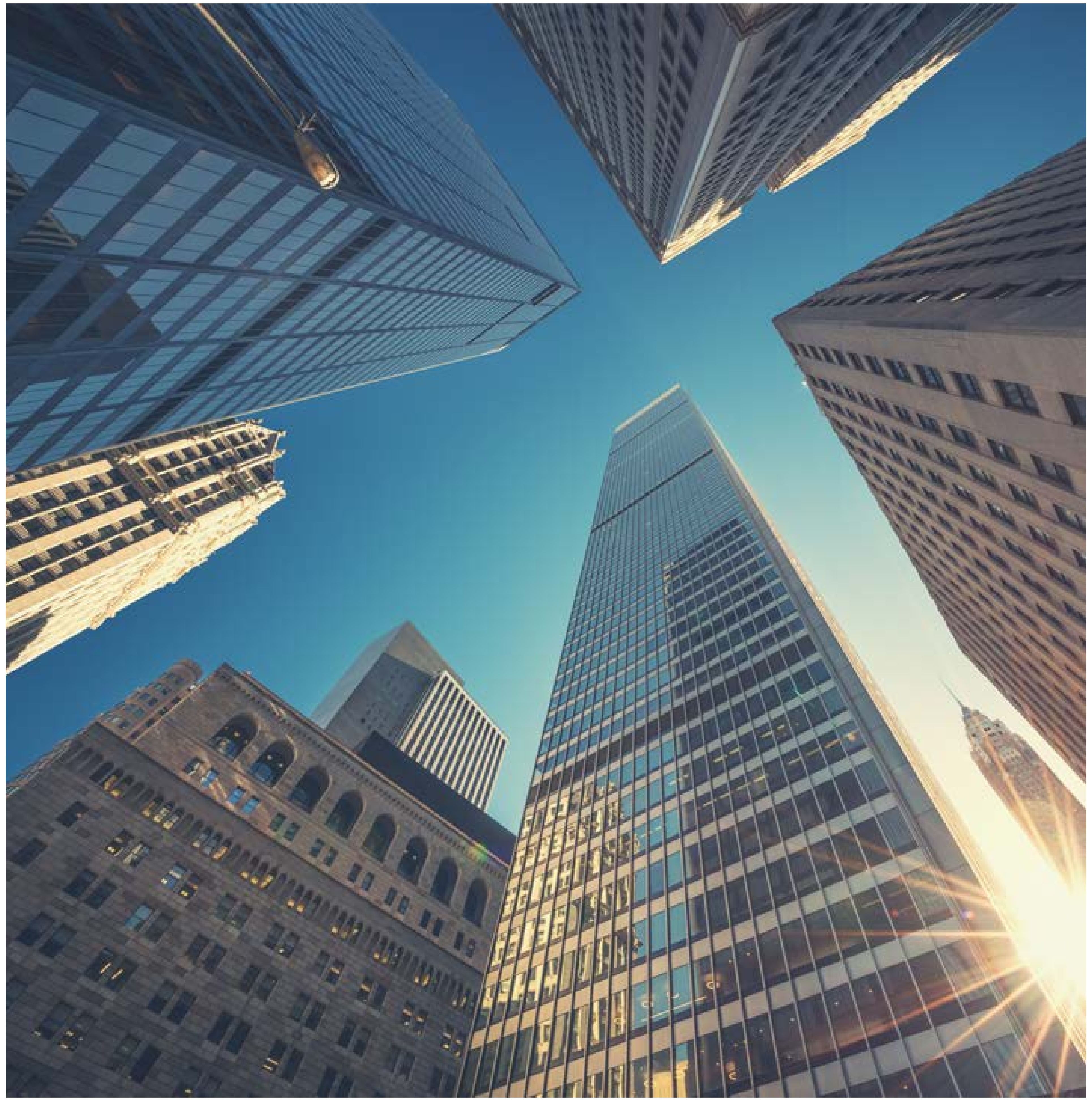
Simplified Risk Class Taxonomy

	Basic Hazard Screening Class 0	Basic Risk Screening Class 1	Enhanced Risk Assessment Class 2	Advanced Risk Modeling Class 3
Application	Pre-screening and awareness	Preliminary risk assessment for screening and low-stakes decisions	Risk assessment for material decisions, preliminary resilience actions, and budgets	Advanced risk assessment to inform high-stakes decisions, resilience-based design, implementable resilience actions, and costs
Assessment approach and resolution	Hazard and exposure assessment	Archetype-specific risk assessment	Building-specific risk assessment	Building-specific component-level probabilistic risk modeling
Accuracy and confidence level	Lowest	Low	Medium	High
Level of effort	Lowest	Low to Medium	Medium to High	Highest
Typical risk outputs	Qualitative hazard ratings or scores	Qualitative risk ratings	Quantitative risk metrics (best estimate)	Quantitative risk metrics (fully probabilistic)

Scope

The Risk Class Taxonomy is applicable to natural hazard impacts on buildings, building occupants, and the organizations that they support. The Resilience Class Taxonomy supports integration of resilience solutions at the building asset level. The taxonomies can be leveraged for supporting assessments of buildings at any scale, from individual buildings to regional or national levels.

Future editions of the taxonomy may include various types of infrastructure, including utility and transit systems. In the meantime, the current Risk Class Taxonomy provides notional guidance on what constitutes a similar Risk Class level for infrastructure systems.



When to use the taxonomy

For clients including private organizations, public entities, or multi-lateral development banks, the taxonomies provide a:

- Reference for where to include risk assessments in internal project development processes or project cycles
- Reference for what to include in the technical specifications in Request for Proposals (RFP) or Terms of Reference (TOR)
- Framework for comparing bids/proposals from vendors/consultants who may be offering different levels of risk assessment or resilience solutions for the same RFP

For practitioners, consultants, and vendors, the taxonomies provide a:

- Framework to describe, price, and differentiate their service offerings
- Tool for setting scope of work expectations with project developers, funders, or other stakeholders

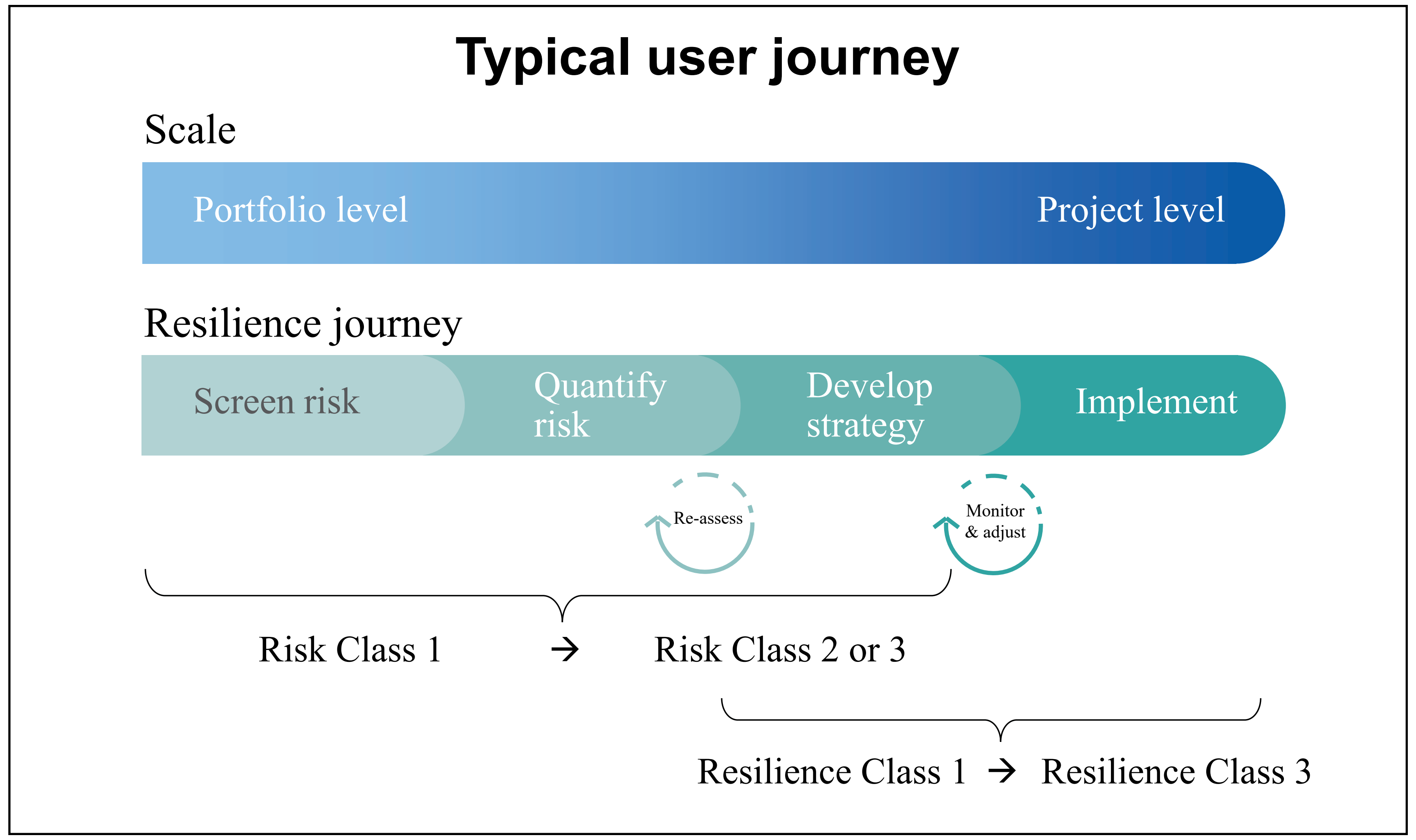
Application

The Risk Class Taxonomy identifies a number of common applications, including decisions or actions, that may be supported by each Risk Class and resulting in plans or projects that align with a given Resilience Class.

This journey can be mapped to the specific organizational workflows and needs of different users to reflect multiple use cases (see User Personas for further details).

Lower Risk Classes are generally intended for awareness, reporting, risk screening, or low-stakes resilience decisions while higher Risk Classes are intended to unlock higher-stakes resilience and adaptation decisions, which may be costly, invasive, or disruptive.

The Risk Class Taxonomy outlines various levels of risk assessment to increase confidence in making progressively more costly or complex decisions as users embark or advance in their journey to resilience.

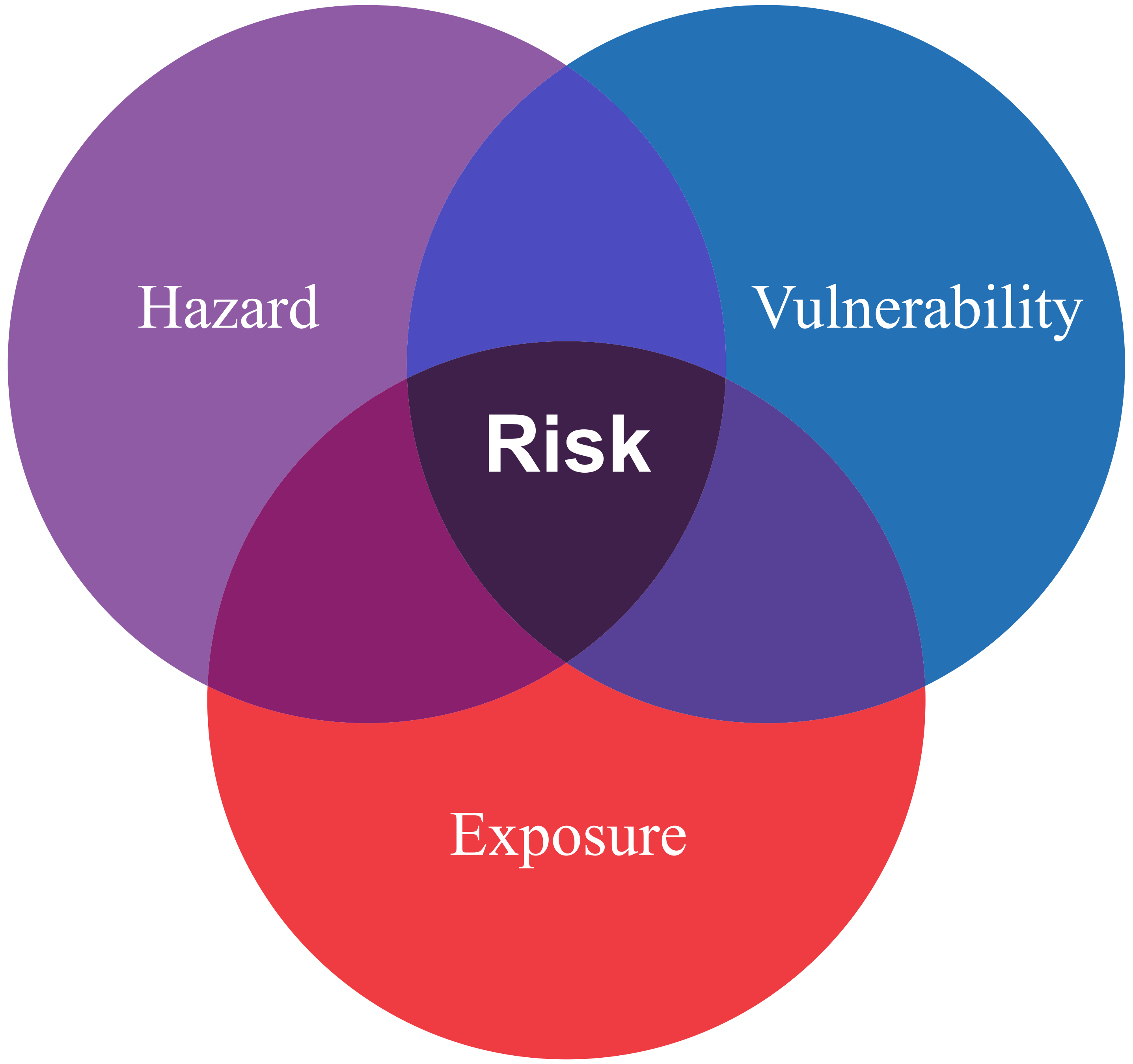


What is risk?

Defining risk

Risk is the probability of incurring a given consequence. A risk assessment must integrate the following elements:

How likely is a hazard event to occur, and what is the intensity?



How damageable are the exposed assets and how susceptible are building occupants?

What are the characteristics, functions, and replacement values of exposed assets or the number of building occupants?

How do you assess risk for individual buildings?

The various methods are outlined in the Risk Class Taxonomy. The approach illustrated here represents Risk Class 3.

1

Exposure
The location, type, values, and capacities of structural, architectural, and mechanical components and the building functions they support as well as the number and sensitivity of building occupants.

2

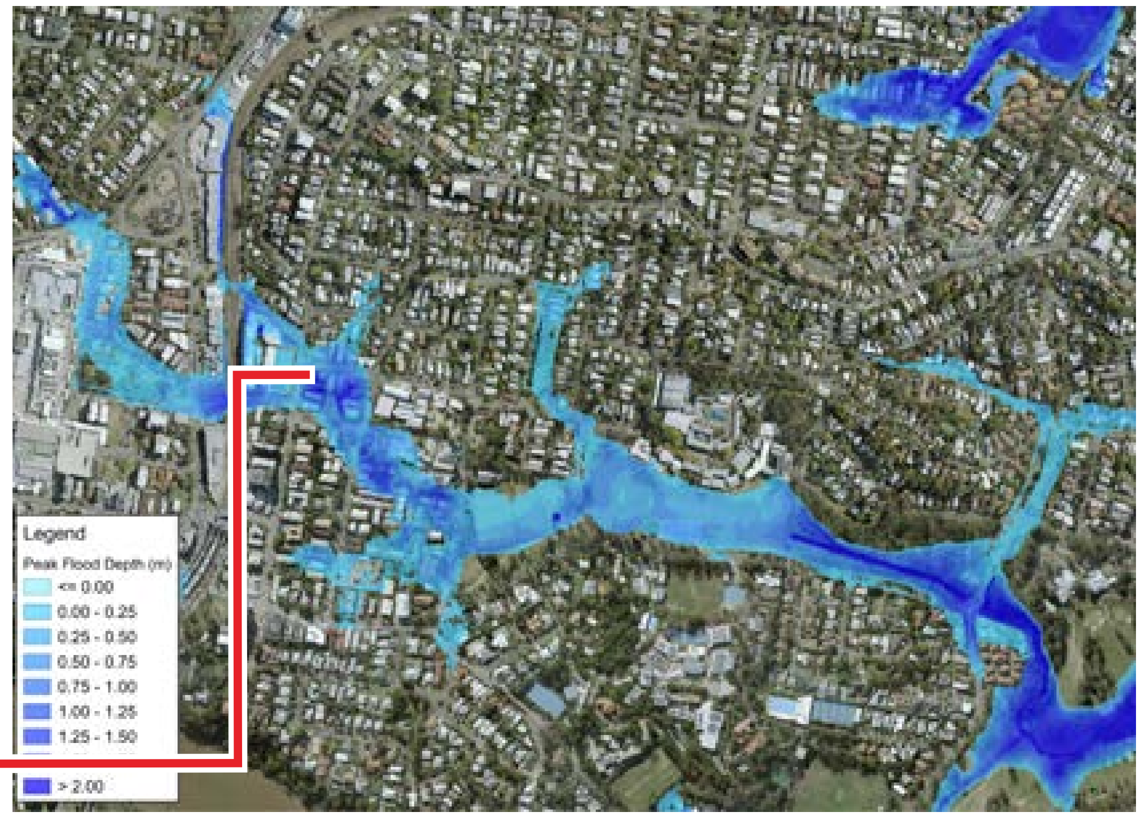
Vulnerability
The probability that building components are damaged to a certain severity given the hazard intensity.

For building occupants, impacts could be directly from hazards (e.g., heat) or indirect (e.g., falling debris from earthquakes)

Representation of a Class 3 risk model

3

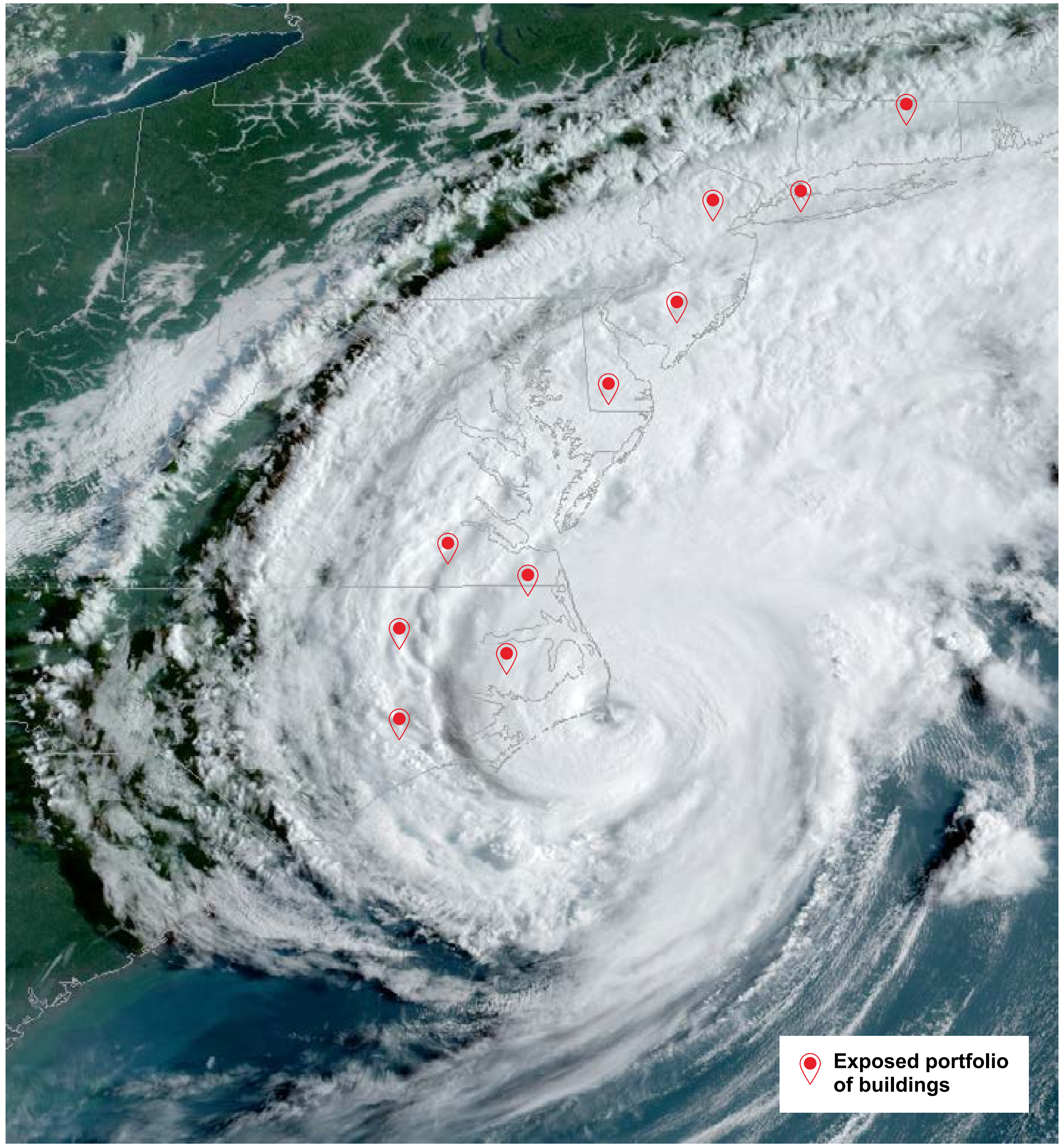
Hazard
The probabilistic likelihood and corresponding intensity of the hazard (e.g., flood depth) experienced by the exposed building elements or populations over a given future time period. For hyperlocal hazards like flood and wildfire, the spatial resolution must be high enough to accurately capture the hazard severity at the building footprint.



How do you assess risk for a portfolio of buildings?

For regional portfolios of buildings, an event-based simulation, which accounts for the geographic spatial correlation of a given scenario event, may be warranted if realistic "shared fate" risks need to be quantified. This is applicable to buildings that could experience the same event but with different levels of intensity depending on their location in relation to the event (i.e. storm track of a large hurricane, or epicenter of an earthquake).

Shared fate risks could include the joint probability of simultaneous downtime at two or more buildings, estimates of functional space recovery for campuses, or total financial losses across a region. Without an event-based assessment, the aggregated risks across multiple individual buildings is likely to be overestimated.



Defining risk
How do you assess risk for individual buildings?
How do you assess risk for a portfolio of buildings?
Consequence types and communication of risk

Consequence types and communication of risk

When risks are communicated to stakeholders, they should be intuitive for all audiences and be tied to specific consequence types. Qualitative risk ratings or scores, if used for communication purposes, should be underpinned by quantitative definitions of likelihood and consequences, by consequence type, and per hazard. If risk scores are difficult to interpret, they hold little value for decision makers. In general, the level of confidence desired for these metrics should align with the quantification methods outlined in the corresponding Risk Classes.

Downtime is perhaps the best indicator of "resilience." This can be measured in terms of functional recovery, which is the time it takes for the building to regain its functions, or re-occupancy, which is the time it takes to allow tenants to safely occupy a structure even if power and water are unavailable.

Typical consequence types

Organizational impacts

- Downtime
- Repair costs and inventory loss
- Lost revenues or property value

Human impacts

- Health and wellness
- Injuries and fatalities
- Population displacement

Resilience and adaptation

What is resilience?

Resilience and adaptation

For buildings, a Resilience Class Taxonomy has also been defined to help stakeholders understand the level of resilience solutions development appropriate for their specific needs, with progressively higher Resilience Classes representing more confidence in the feasibility, complexity, and cost to implement the solutions in existing buildings or new construction.

The Resilience Class Taxonomy is aligned with the Risk Class Taxonomy since resilience and adaptation solutions are largely informed by identification of the factors driving risk. Implementation of the most costly or complex resilience solutions requires deep insights into the vulnerable building components driving the risk so that physical retrofits can be developed and targeted.

The Resilience Class Taxonomy is focused on physical interventions and operational measures, aimed at managing and reducing risk, increasing adaptive capacity and/or creating redundancy, at the asset level for buildings. Broader resilience considerations at the system, organizational or community level, including social cohesiveness of the populations and system dependencies are not included herein.

Resilience is the ability to withstand or rapidly recover from the effects of a hazard. Building resilience refers to the role that a building plays in supporting an organization to deliver it's core services or mission, or in ensuring safe and livable conditions for building occupants.

Incorporating climate change effects

Climate change effects

Incorporating climate change effects

It is most important to properly quantify climate-related hazards for the baseline or present-day climate conditions. Once established, baseline climate-related hazards should also account for climate change effects where attribution science indicates it could be adjusted, but this may depend on stakeholder needs and is not required to satisfy a given Risk Class. However, the Climate Change Effects Taxonomy provides further guidance if climate change effects are to be included in the risk assessment. In this case, the requirements outlined in the Climate Change Effects Taxonomy can be integrated with the hazards development guidance contained in either the Risk Class Taxonomy or the hazard-specific sub-taxonomies, with alignment necessary to achieve the same Risk Class.

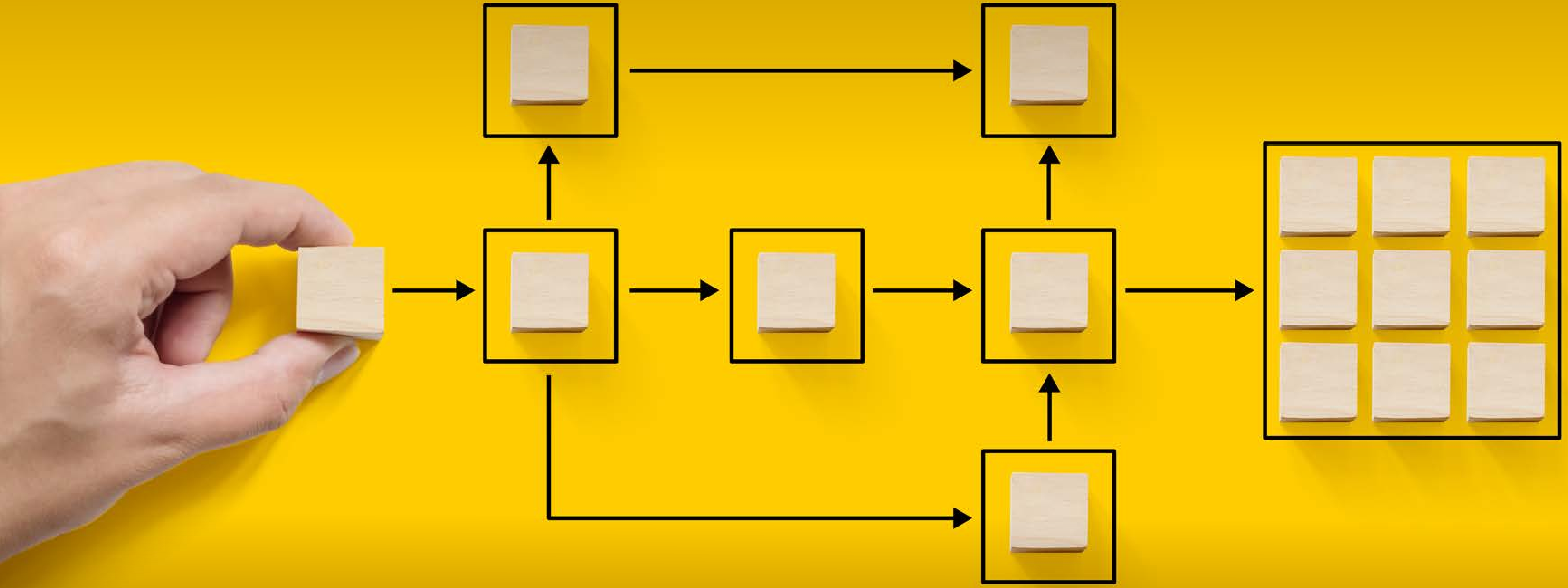
Incorporating climate change effects in hazard assessment is typically undertaken using data from Global Circulation Models (GCMs) for discrete emissions or shared socioeconomic scenarios (RCP or SSP), and time horizons (e.g. 2070). Hazard data for building risk assessments cannot be extracted directly from the GCMs. For example, heat variables such as dry bulb temperature must be post-processed from the available time series and extreme value analysis must be undertaken to quantify the return period related to a given temperature. Precipitation data must be used to develop shifted intensity-duration-frequency used as input to hydrological models in order to determine flood hazard at a site.

The choice of climate scenarios is at the discretion of the decision-makers and depend on their risk appetite (e.g., risk averse organizations may choose more pessimistic emissions scenarios) and the life-cycle of their organizational mission (e.g., cities, universities, and other institutions may target longer time horizons than corporations).

The spatial resolution of climate models and their modeled hindcast or future projections data is typically much coarser than the resolution of hazard data needed for risk assessment of individual buildings, as such, it is important to make sure both the climate change and hazard analysis approaches are aligned and allow for a reasonable tolerance of differing resolutions.

Taxonomy charts

Taxonomies



	Basic Hazard Screening Class 0	Basic Risk Screening Class 1	Enhanced Risk Assessment Class 2	Advanced Risk Modeling Class 3[a]
Application (individual buildings)	• Pre-screening for higher classes of risk assessment • Awareness	• Site selection • Preliminary risk assessment	• Indication of vulnerable components • Technical due diligence for acquisition • Preliminary adaptation measures, costs, and cost-benefit analysis	• Identification of vulnerable components • Component-specific risk mitigation and shovel-ready adaptations • Final cost estimates and cost-benefit analysis • Resilience-based design of new buildings
Application (portfolio of buildings)		• Screening for more advanced risk assessment • Regulatory disclosures	• Risk-informed resilience strategy • Preliminary budgets • Preliminary insurance optimization	• Final capital plans • Insurance optimization
Typical scale	Up to national scale	Up to large-size portfolios	Up to medium-size portfolios and campuses	Individual buildings up to 10's of buildings and campuses
Assessment approach	Hazard and exposure assessment (vulnerability not meaningfully considered)	Building-level loss functions (semi-quantitative) or engineering-based desktop study w/ minimal calculations	Building-level loss functions (semi-quantitative) w/ engineer validation or engineering-based enhanced desktop study (requiring calculations)	Component-based probabilistic risk modeling w/ Monte Carlo simulations
Accuracy and confidence level	Lowest	Low	Medium	High
Hazard[b]	• Deterministic or single return period • Coarse to moderate resolution • Qualitative indicators/descriptions	• Probabilistic • Moderate spatial resolution • Quantitative intensity metrics (i.e. flood depth) vs likelihood for at least one return period	• Probabilistic • Moderate to high spatial resolution • Quantitative intensity metrics (e.g. flood depth) vs likelihood at multiple return periods (i.e. hazard curves) • Validation of hazard data by engineer and basic site-specific adjustments as needed	• Probabilistic and multiple return periods • Highest resolution site-specific hazard modeling with quantifiable uncertainty
Exposure (all require geo-location)	Geo-location only	Assumed building characteristics based on known occupancy type & height category (e.g. low rise)	Basic building information based on archetype supplemented with known important building features pertaining to each hazard (e.g. finish floor elevation for flood risk) and design information to quantify resisting capacity (e.g. strength of wind-resisting system)[c]	Building-specific component information[c]
Vulnerability	None (or generic building archetype as a proxy)	Occupancy-specific building archetypes based on empirical loss models or component-based risk models (i.e. Class 3) OR engineering study	Occupancy-specific archetypes w/ building-specific modifiers based on empirical loss models or component-based risk models (i.e. Class 3) OR engineering calculations	Component-level damage models assigned to each component or thermal models of the building for heat, capturing conditions including age
Source data for exposure and vulnerability	Geo-locations typically provided by stakeholders or exposure mapping from publicly available maps or satellites	Occupancy types and heights typically provided by stakeholders or publicly available property data	Publicly available street views and maps to determine surrounding environment and topography and property condition assessments or due diligence reports	Building construction documents, including structural, mechanical, civil, and architectural drawings as needed for hazards being studied
Consequence	Exposure to hazards	Repair costs and downtime	Geo-specific repair costs in absolute terms or proportion of asset replacement value Downtime models include realistic repair sequences and impeding factors	
Risk metrics	Qualitative hazard ratings	Qualitative risk ratings underpinned by quantitative likelihood vs consequence bins	Quantitative metrics (median or best estimate) likelihood vs consequence	Fully-probabilistic quantitative metrics with explicit uncertainty defined

The Risk Class Taxonomy outlines minimum criteria to satisfy the given Risk Class. The minimum criteria for a given Risk Class must be satisfied for all categories. It is possible to exceed the minimum criteria in a given category, but this would not constitute assignment of a higher Risk Class. For example, one could use higher resolution flood hazard data than the minimum requirements outlined for Risk Class 0 assessment but if vulnerability is not considered, it remains a Risk Class 0. However, higher resolution hazard data would certainly increase the confidence of the Class 0 assessment and the user can determine how to communicate that to interested stakeholders.

[a] It is possible to exceed these requirements for some hazards that impose dynamic loads on buildings, such as earthquakes or wind (see hazard-specific taxonomies for more detail).

[b] Stochastic event sets are recommended to be used for risk assessments of portfolios of buildings if realistic aggregate risk metrics are required.

[c] If unattached building contents are important for functionality (i.e. servers in data center) or represent a significant value, either monetary or mission-critical, these must be included.

	Conceptual Class 0	Schematic Class 2	Implementable Class 3
Resilience/adaptation solution maturity	Scoping and awareness only	Feasibility and preliminary budgeting only	Implementable and final cost estimates defined
Typical actions and detail	**Physical interventions:** High-level concepts for strengthening, upgrading, or relocating building components and contents **Operational measures:** High-level ideation of possible operational solutions such as creating redundant systems, development of business continuity plans, protection of data, mitigation of impeding factors that delay initiation of repair, training or capacity-building programs, or relocating functions or people	**Physical interventions:** Schematic level designs for strengthening, upgrading or relocating building components supported by engineering calculations **Operational measures:** Detailed scoping of operational solutions, including required level of effort and costing, and preliminary development of governance structure, supported by stakeholder engagement	**Physical interventions:** Construction documents including drawings and specifications supported by detailed engineering calculations and/or models **Operational measures**: Governance is defined, and specific champions are identified and assigned to fully develop and implement or complete the operational resilience action or activity
Applicability to building or organization	Generic solutions, may not be applicable or feasible for specific building being designed or retrofitted or may not be applicable to organization	Solution specific to building archetype, may be applicable and feasible for specific building being design or retrofitted and may be applicable to organization	Solution developed specifically for building being designed or retrofitted and organization that owns or operates it
Confidence level[a]	Low	Medium	High
Cost Estimate Class[b]	Class 5	Class 3 to 4	Class 1 to 2
Underlying Risk Class[c]	Class 1	Class 2 or 3	Class 2, 3 or 4
Typical cost-benefit analysis approach[d]	Proxy method considering mitigation impact and costs independently	Probabilistic quantification of losses at multiple return periods to calculate avoided losses, consideration of asset life extension and discount rate Avoided losses are direct costs (to repair damage) at a minimum but lost revenues and human impacts (e.g. casualties) are recommended to be considered	Probabilistic quantification of losses at multiple return periods to calculate annualized avoided losses, consideration of asset life extension and discount rate Avoided losses are direct costs (to repair damage), lost revenues, and human impacts (e.g. casualties) Sensitivity analysis on costs, discount rates, monetized values assigned to revenue loss and casualty assumptions, and asset life extension
Typical cost-benefit metrics[d]	Qualitative ratings for mitigation effectiveness and costs	• Benefit-cost ratios at end of asset life • Net present value of the cumulative discounted benefits over the asset life minus the initial cost/investment in mitigation • Resilience payback period (i.e. time for investment to break even)	

[a] The confidence level is associated with the applicability of the resilience solution to the specific building that is being designed or retrofitted, the uncertainty in the cost, and the feasibility of implementing it.

[b] Per AACE 56R-08 Cost Estimate Classification System.

[c] Risk assessment must be performed for baseline case (no adaptation) and for each resilience strategy considered to quantify the benefits (i.e. avoided loss). For new construction, the baseline case may be designed to building code standards with additional strategies considering enhanced design.

[d] Not required to achieve a Resilience Class but cost-benefit analysis would support the business case for implementing a solution. Deterministic cost-benefit analysis, (i.e. assumes likelihood of consequence occurrence is certain) would overestimate the benefit to cost ratio and are not recommended. For broader consideration of investment prioritization, financial cost-benefit data can be included in multi-criteria decision frameworks that also weigh more qualitative factors such as co-benefits of resilience actions towards sustainability, equity, or policy goals.

		Basic Hazard Screening Class 0	Basic Risk Screening Class 1	Enhanced Risk Assessment Class 2	Advanced Risk Modeling Class 3
Hazard	Modeling approach[a]	Probabilistic or deterministic seismic hazard analysis	Probabilistic seismic hazard analysis		Site-specific probabilistic seismic hazard analysis
Hazard	Spatial resolution	10km	8 km	2km	Exact location
Hazard	Intensity metrics	MMI or PGA	PGA or Peak Spectral Acceleration at fundamental building period		Spectral accelerations at multiple period ordinates (e.g. PGA, 0.2s, 1s) relevant to period range of anticipated building behavior OR Ground motion time histories linearly or spectrally matched to response spectrum target
Hazard	Likelihood method	Single deterministic or intensity-based scenario (based on single return period)	At least one return period	Multiple return periods	Multiple return periods and risk realizations that capture uncertainty about the median intensity-based hazard values
Hazard	Hazard-specific requirements	Assumption of rock or soft soil conditions	Soil site class augments hazard values or else assume soft soil	Soil site class augments hazard values	Site-specific Vs30 augments hazard values, if time history analysis is used visual inspection of spectrally matched time histories, inclusion of velocity pulses and appropriate significant duration depending on earthquake source
Exposure	Known building/site characteristics	Geolocation	Occupancy type, building height, and primary construction material	Lateral system type (e.g. brace), construction era/year for ductility and building strength capacity, and soil classification	Fundamental period of the building, story heights, story stiffnesses All damageable building components, their locations, orientation, and force/deformation capacities
Vulnerability	Hazard-specific requirements	n/a	None		Component fragilities from the literature (e.g. FEMA P-58), or derived from physical testing, virtual simulation, empirical observation, or engineering calculations
Vulnerability	Structural analysis method[b]	n/a	Simple engineering calculations to estimate global building movements (e.g. roof drift) or not required if empirical loss model is employed	Closed form engineering equations to estimate global building movements or not required if empirical loss model is employed	Nonlinear response history analysis of multi-degree-of-freedom representation of building to obtain story drifts and peak floor accelerations

[a] Seismic hazard data can be obtained from building codes, commercial vendors, or developed by qualified geoseismic experts, and their models must meet the requirements herein.

[b] In seismic risk analysis, an additional step is often required to determine the building movements, which are used as inputs to the vulnerability assessment. For Risk Class 3, an Multi Degree of Freedom "stick" model is acceptable. For more detailed assessment to obtain the highest level of confidence, a nonlinear response history analysis of a 3-dimensional model of the building is recommended to quantify building movements and structural damage and collapse more explicitly.

		Basic Hazard Screening Class 0	Basic Risk Screening Class 1	Enhanced Risk Assessment Class 2	Advanced Risk Modeling Class 3
Hazard	**Modeling approach**	Deterministic or probabilistic analysis	Probabilistic and statistical modeling		Advanced site-specific modeling including dynamic hydrology and unsteady flow hydraulics and compound flood modeling as necessary.
Hazard	**Spatial resolution[a]**	100m and above	30 to 90m [or 100m and above for city-level or larger assessment]	10 to 30m	1 to 3m
Hazard	**Intensity metrics**	Inundation classification (in or out of flood zone)	Inundation depth or proxy depths	Inundation depth	Inundation depth, velocity (if near river), duration (for downtime)
Hazard	**Likelihood method**	Single deterministic or intensity-based scenario (based on single return period)	At least one return period	Multiple return periods	Multiple return periods and risk realizations that capture uncertainty about the median intensity-based hazard values
Hazard	**Hazard-specific requirements**	None	Moderate-resolution topography information and easily accessible rainfall intensity data	Moderate-resolution topography data, easily accessible rainfall data from local meteorological stations, nearby stream gauge data, and basic information about relevant flood defense infrastructure If included in model, verify adequacy of community-level flood defenses	High-resolution (e.g., LiDAR) topographic data, detailed and use/cover data, detailed stormwater infrastructure information such as storm drain networks and culverts, rainfall data from local meteorological stations, nearby stream gauge data, and nearby tide gauge data (if coastal). All should represent the "current" conditions reasonably. Verify site-specific stormwater conveyance capacity (e.g. size, location, inverts) for inclusion in hazard model
Exposure	**Known building/site characteristics**	Geolocation (point location)	Geolocation (building footprint), occupancy type, building height category (e.g. low rise)	Finish floor elevation, presence of basement, location of equipment and critical building components, building construction type	All damageable building components, their locations, and elevations above floor
Vulnerability	**Hazard-specific requirements**	n/a	None		Component fragilities from the literature or derived from physical testing, empirical observation, or engineering calculations

[a] Interpolation between pixels/grid cells is not allowed to achieve spatial resolution requirement

		Basic Hazard Screening Class 0	Basic Risk Screening Class 1	Enhanced Risk Assessment Class 2	Advanced Risk Modeling Class 3
Hazard	Modeling approach[a]	**Non-cyclonic:** statistical evaluation **Cyclonic:** deterministic		**Non-cyclonic:** statistical evaluation **Cyclonic:** stochastic simulation	
	Spatial resolution	<10km	<2km		<1km
	Intensity metrics	Wind speed (typically 3 sec gust but 10 min or mean hourly also possible)	3 sec gust wind speed	3 sec gust wind speed, adjusted for terrain	
	Likelihood method	Single deterministic (e.g. hurricane category) or intensity-based scenario (based on single return period)	At least one return period	Multiple return periods	Multiple return periods and risk realizations that capture uncertainty about the median intensity-based hazard values
	Hazard-specific requirements	Open terrain unless actual terrain known	Open terrain unless actual terrain known	Terrain adjusted based on actual conditions at site	Terrain adjusted based on actual conditions at site, directionality considered, for cyclonic winds precipitation should be considered in damage models[b]
Exposure	Known building/site characteristics	Geolocation	Occupancy type, building height category (e.g. low rise)	Roof construction type, surrounding missile environment, wind capacity based on design wind speed	All damageable building components, primarily the building envelope, exposed equipment, and structural members and their locations and wind resistance capacities. For hurricanes, interior building components including finishes that could be impacted from rain intrusion through damaged building envelope (e.g. facade breakage)
Vulnerability	Hazard-specific requirements	n/a	None		Component fragilities from the literature or derived from physical testing, virtual simulation, empirical observation, or engineering calculations

[a] Wind hazard data can be obtained from building codes, commercial vendors, or developed by qualified wind engineers, and their models must meet the requirements herein

[b] For tall buildings or buildings with irregular shapes, wind tunnel testing or CFD simulation is recommended to better determine the pressure load on envelope components but not required for Class 3 assessments.

		Basic Hazard Screening Class 0	Basic Risk Screening Class 1	Enhanced Risk Assessment Class 2	Advanced Risk Modeling Class 3
Hazard	**Modeling approach[a]**	Average historical values	Time series analysis of daily observed data (or hourly if typical yearly exceedance values are needed) and extreme value analysis to generate independent hazard curves for each discrete temperature variable [i.e., Dry Bulb Temperature (DBT), Wet Bulb Temperature (WBT) or Heat Index.]	Time series analysis of daily observed data (or hourly if typical yearly exceedance values are needed) and extreme value analysis to generate independent hazard curves and/or joint probability hazard curves for coincident variables (i.e. DBT & WBT, DBT & humidity, Heat Index).	
Hazard	**Spatial resolution**	Regional (20km to 50km for nearest airport or weather station, or using existing mapped regional temperature data)	City wide (10km to 20km, from nearest airports and weather stations)	Intra-city (2km to 10km, from nearest airports and weather stations)	Site-specific (< 2km), needs to be able to capture micro-climates
Hazard	**Intensity metrics**	*External* annual maximum temperature (DBT or WBT)	*Internal* maximum temperature (DBT or WBT)	*Internal* maximum heat index for unconditioned buildings (for populations) *Internal* maximum temperature (DBT, WBT, and/or coincident) (for equipment)	
Hazard	**Likelihood method**	Single deterministic or intensity-based scenario (i.e., single return period)	At least one return period	Multiple return periods	
Hazard	**Hazard-specific requirements**	n/a	None	Need for coincident DBT and relative humidity, specific humidity or WBT, in order to obtain Heat Index (a way to measure heat stress on people) or other coincident values to assess equipment de-rating or failure.	Consider duration of extreme heat events or heatwaves. Consider urban heat island effects. Consider climate re-analysis gridded data from satellite to address data scarcity and increase resolution of observed data.
Exposure	**Known building/site characteristics**	Geolocation	Occupancy type	Presence of cooling systems, presence of operable windows, presence of other types of equipment than can cause heat re-entrainment (e.g. generators or chillers).	Type of contents and equipment, type of cooling strategies (passive or active) or systems and their capacities, type and capacity of insulation, reliance of cooling systems on power network and energy backup systems
Vulnerability	**Susceptibility / vulnerability / fragility parameters[b]**	n/a	For equipment/contents supporting critical building functions, basic engineering calculations or results form thermodynamic modeling of occupancy-specific archetypes to estimate temperature change from external to internal spaces For populations in unconditioned buildings, general estimate of Heat Index change from external to internal spaces	Thermodynamic modeling of occupancy-specific archetype with building-specific modifiers including cooling system types: • For equipment/contents supporting critical building functions, to estimate temperature change from external to internal spaces, accounting for heat re-entrainment effects. • For populations in unconditioned buildings, general estimate of Heat Index change from external to internal spaces.	Thermodynamic modeling of specific building, equipment and cooling system characteristics and capacities: • For equipment/contents supporting critical building functions, to estimate temperature change from external to internal spaces, including model heat re-entrainment effects from specific equipment • For populations in unconditioned buildings, to estimate Heat Index change from external to internal spaces, and assess heat stress on people with distinction of vulnerable groups

[a] All data from historical observations, not from GCMs, except for climate re-analysis data which supplements historical observation.

[b] Assumption that exposed populations are inside building. The translation of external to internal heat hazard is dependent on the building characteristics and cooling system. If heat risk of exposed populations is external, then no building information or thermodynamic modeling is required.

	Basic Hazard Screening Class 0	Basic Risk Screening Class 1	Enhanced Risk Assessment Class 2	Advanced Risk Modeling Class 3
Typical spatial scale	50km to 100km	25km to 50km	10km to 25km or point analysis (at weather station points)	<10km or point analysis (at weather station points)
Typical temporal scale	Annual, seasonal high-level change factors/indicators	Annual / seasonal / monthly data or daily data	Daily data	Daily or hourly data
Climate change analysis	Long-term trends on mean annual / seasonal / monthly changes.	Deterministic analysis of modeled hindcast and future projected data to obtain a single change factor for climate variables from an ensemble of GCMs[a].	Probabilistic analysis of modeled hindcast and future projected daily time series to conduct Extreme Value Analysis on climate variables from an ensemble of GCMs[b] and obtain a set of change factors or absolute values for multiple return periods[c].	Probabilistic analysis of modeled hindcast and future projected daily or hourly time series to conduct Extreme Value Analysis, data resampling or weather generation on climate variables from an ensemble of GCMs[c] and obtain a set of change factors or absolute values for multiple return periods[d].
Climate change downscaling method	No downscaling	Bias correction or simplified statistical downscaling. Delta Change or Morphing approach with a single change factor.	Statistical downscaling and bias correction: Probabilistic Delta Change or Morphing approach with multiple change factors (one for each return period).	Non-parametric statistical downscaling: resampling or simple weather generators with daily data. Parametric statistical downscaling model or weather generators with daily or hourly data. Advanced dynamical downscaling model with daily or hourly data[e].
Accuracy/confidence in the analysis[f]	Lowest	Low	Medium	Medium-High
Typical climate variables	Variables such as: • Temperature • Precipitation • Wind speed • Sea water level	Variables such as: • Temperature (minimum, mean and maximum) • Precipitation • Wind speed • Humidity (relative humidity) • Sea water level	Variables such as: • Temperature (minimum, mean and maximum) • Precipitation (daily precipitation) • Wind speed (sustained windspeed) • Humidity (relative humidity) • Sea water level • Snowfall	Variables such as: • Temperature (minimum, mean and maximum) • Precipitation (Hourly or daily precipitation) • Wind speed (wind gusts, sustained windspeed, wind direction) • Humidity (relative or specific humidity) • Sea water level • Snowfall • Solar radiation
Methodology to integrate climate change into climate hazards	Trends for climate variables may be used as a proxy for hazard trends as long as the inherent assumptions made are recognized and caveated.	A deterministic analysis of the climate variables can be used to calculate a single change factor on the inputs for a probabilistic hazard analysis for hazards that are not directly quantified by the climate variables (e.g. flood, wildfire, and sea level rise, drought) OR a single change factor can be applied to the baseline hazard curve in post-processing for hazards that are directly quantifiable by the climate variables (e.g. temperature).	A simplified probabilistic modeling of the climate variables should be done to align with the simplified probabilistic modeling of the hydrometeorological hazards, so that climate-adjusted climate variable curves are directly used as inputs to the standard hazard analyses (i.e., climate-adjusted rain exceedance curves are input into hydrological and hydraulic models to obtain climate-adjusted flood results).	A fully probabilistic modeling of the climate variables should be done to align with the fully probabilistic modeling of the hydrometeorological hazards, so that climate-adjusted variable time series or climate-adjusted climate variable curves are directly used as inputs to the standard hazard models (e.g. rain time series or rain exceedance curves are input into hydrological and hydraulic models where a probabilistic analysis is conducted to obtain probabilistic climate-adjusted flood results).
Typical climate-adjusted hazard outputs	Trend or narrative of increase or decrease	Hazard intensity metric with and without climate change (e.g. flood depth)		

[a] Sources may include: published IPCC / International or national GCM aggregated results to obtain single change factors or projected values. Directly use GCM/RCM aggregated data (annual, seasonal, monthly) to obtain single change factors or change values.

[b] A sub-set of GCMs may be selected to discard any outlier or erroneous GCMs for the location of interest.

[c] Sources may include: published international or national downscaled results for multiple change factors or projected values for different return periods. Use of published international or national downscaled daily time series data to calculate multiple change factors or projected values for different return periods.

[d] Sources may include: published national or sub-national downscaled daily or hourly time series data to calculate multiple change factors or projected values for different return periods or exceedance probabilities to get complete hazard curves.

[e] Advanced dynamical downscaling using models such as WRF is optional.

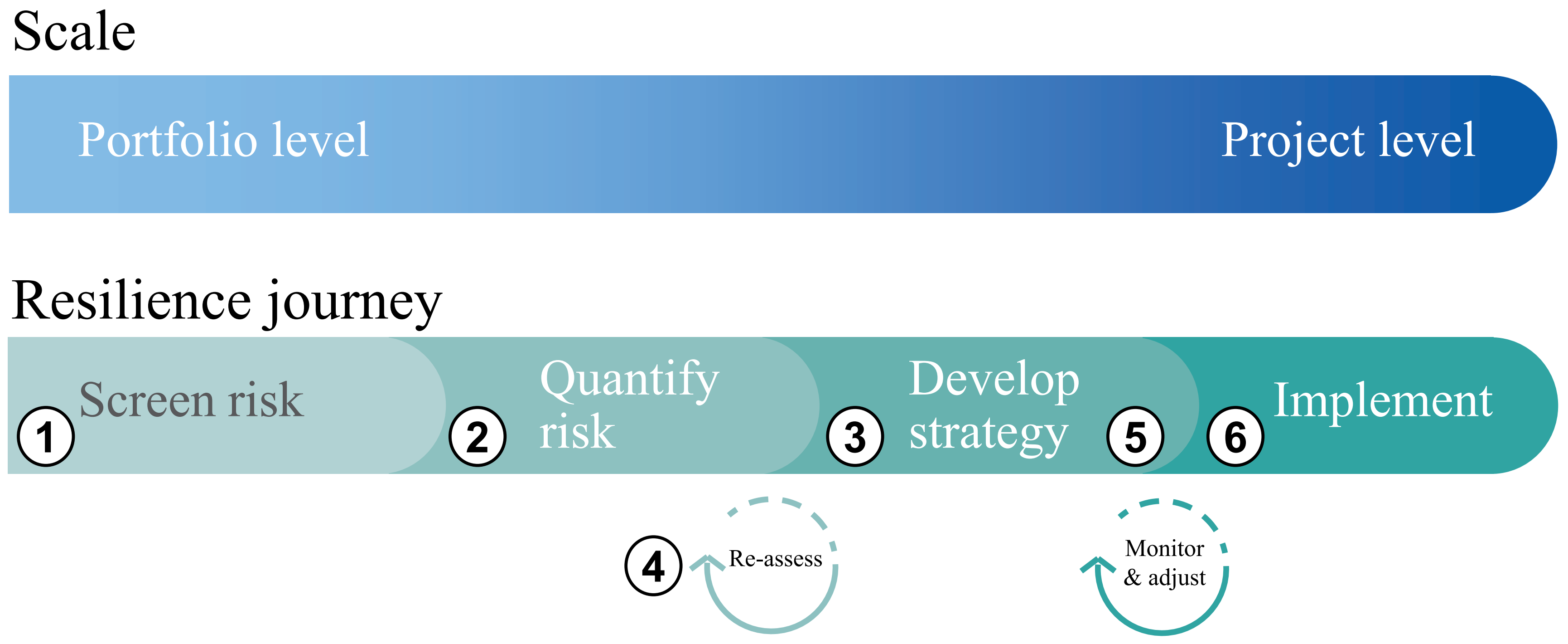
[f] The confidence in the analysis is not representative of the confidence in the climate projection data. There is high uncertainty in this data, and this should be conveyed and addressed across all Classes.

User personas

Introduction

User personas are semi-fictional representations of the intended users of this framework. They represent specific roles and responsibilities within an organization that are most likely to find the taxonomies helpful to address their specific needs around risk and resilience topics.

The purpose of this section is to allow readers to align themselves with selected user personas that demonstrate how the taxonomy can support their needs along a typical resilience journey specific to their role.



Corporate resilience lead

Organization type
Enterprise / corporate

Typical titles
Head of Resilience,
Chief Sustainability Officer

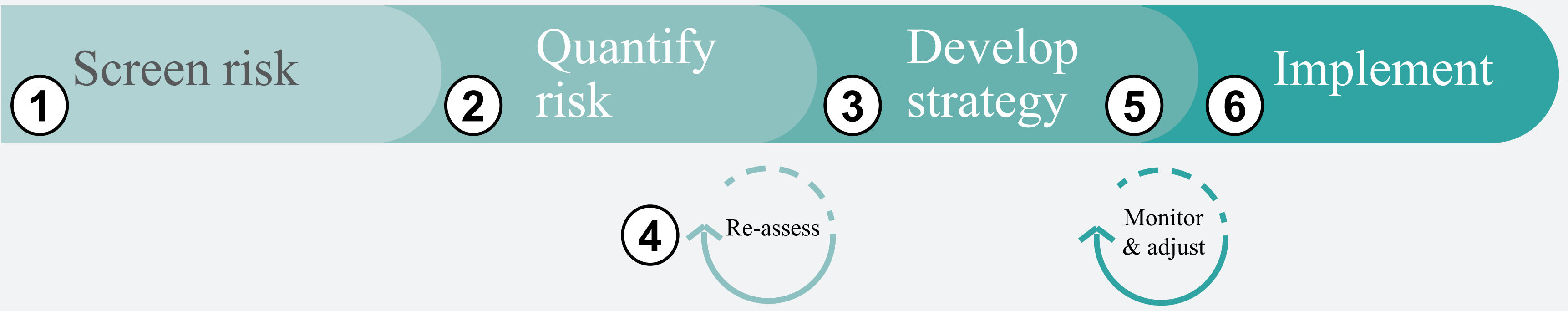
Use case
Portfolio (existing assets) risk assessment & development of resilience strategy

"As a consumer of risk information with subject matter expertise, I want to assess business and safety risks for my organization's people and portfolio of assets, so that I can:

1. Communicate risk to leadership
2. Report / disclose
3. Create the business case to invest in resilience and adaptation measures programmatically

Scale

Resilience journey



User journey

1 Undertake or procure a **Class 1** Risk Assessment of all assets for all hazards that could have a material impact as a basic screening (skip to Step 2 if top hazards are already known). To satisfy minimum reporting requirements, skip to Step 3.

2 Procure a Class 2 Risk Assessment for prioritized hazards and/or assets identified in Step 1 and/or the need for a more detailed **Class 3** Risk Assessment.

3 To satisfy minimum reporting requirements, identify resilience measures per **Resilience Class 1** and skip to Step 6. Otherwise, identify resilience measures and budgets, per **Resilience Class 2**.

4 Re-assess risk for each candidate resilience strategy (i.e. compilation of measures) to determine risk reduction effectiveness employing a **Class 2** or **Class 3** Risk Assessment.

5 Finalize resilience strategy based on cost-benefit or multi-criteria decision analysis of each strategy. Develop candidate resilience measures per **Resilience Class 3**.

6 For reporting only, submit disclosures. Otherwise, carry out physical protection or correction interventions, retrofit of buildings and/or non-structural soft or operational measures to increase adaptive capacity.

Corporate property lead

Organization type

Enterprise / corporate

Typical titles

Real Estate Lead,
Site Development Manager

Use case

Project (new or existing assets) risk assessment & development of resilience strategy

"As a layperson consumer of risk information, I want to assess risk for a specific asset in my pipeline, so that I can:

1. Inform site selection
2. Inform due diligence
3. Inform resilient design or retrofit

User journey

1 Undertake or procure a **Class 1** Risk Assessment of the individual site or asset for all hazards that could have a material impact. For site selection, skip to Step 3.

2 For due diligence, procure a **Class 2** Risk Assessment for prioritized hazards identified in Step 1.

3 For site selection, identify resilience measures per **Resilience Class 1**, skip to Step 5. For due diligence, identify resilience measures and budgets, per **Resilience Class 2**.

4 For due diligence, re-assess risk for each candidate resilience strategy to determine risk reduction effectiveness employing a **Class 2** Risk Assessment.

5 Use results to make a site selection, acquisition, or divestment decision.

6 Hand off to design consultants or in-house design teams to develop resilience-based design requirements for new construction or retrofit of existing construction to a **Resilience Class 3** level.

Disaster & climate risk specialist

Organization type

Multi-lateral Development Bank (MDB)

Typical titles

Disaster and Climate Risk, Management Sector Lead

Use case

Multi-sector risk assessment for development strategy creation

"As a consumer of risk information with subject matter expertise, I want to assess risk at the country or regional (multi-country level), so that I can:

1. Inform baseline diagnostics to start strategic dialogues with the Borrowers to set priorities
2. Develop Country and/or Sector Development Strategies

Scale

Resilience journey

User journey

1 Undertake or procure a **Class 1** Risk Assessment for all assets that comprise a given sector of interest at a country or regional level for all hazards that could have a material impact. The hazard assessment should include stochastic generation of events and the outputs should consist of quantitative risk metrics aggregated at the geographic and sector level.

2 Identify resilience needs and recommendations at geographic and sector level per **Resilience Class 1** to make financing, investment or technical cooperation decisions, and to inform the development of a pipeline of programs or projects.

3 Hand off specific activities or projects to project leads for implementation, which may include more detailed **Class 2** or **3** Risk Assessment.

Introduction
Corporate resilience lead
Corporate property lead
Disaster & climate risk specialist
Sector specialist
Government resilience lead
Government planning lead
Financial & insurance specialist
Risk and resilience practitioner

Sector specialist

Organization type

Multi-lateral Development Bank (MDB)

Typical titles

Sector Project Team Leader (urban, health, education, infrastructure)

Use case

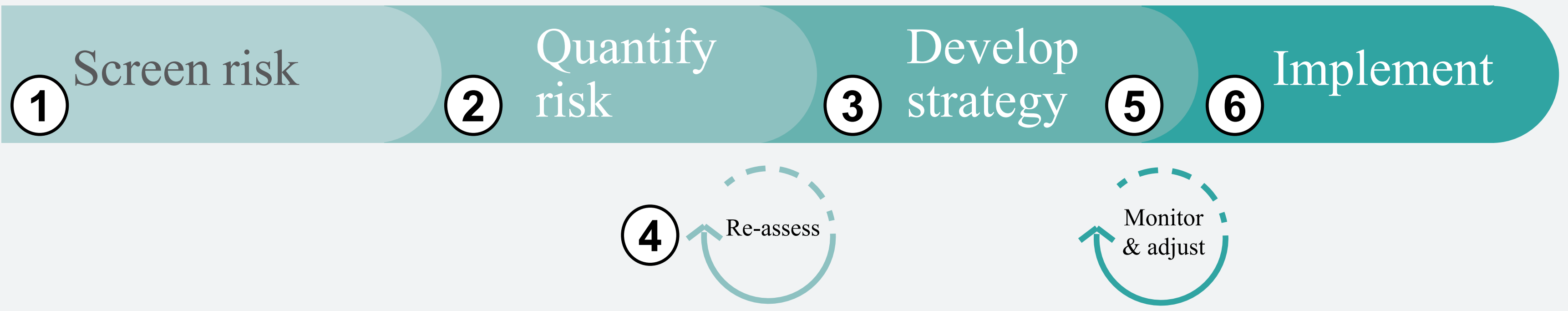
Project (new or existing assets) risk assessment & development of resilience strategy

"As a layperson consumer of risk information, I want to assess risk for a school/hospital/government building in my pipeline, so that I can:

1. Align with Bank policies and commitments to unlock project funding
2. Inform due diligence
3. Inform resilient design or retrofit

Scale

Resilience journey



User journey

1 Undertake or procure a **Class 1** Risk Assessment of the individual site or asset for all hazards that could have a material impact on the building aligned with internal Bank procedures.

2 Procure a **Class 2** Risk Assessment for prioritized hazards identified in Step 1.

3 For due diligence and operation preparation, identify resilience measures and budgets, per **Resilience Class 2**.

4 Re-assess risk for each candidate resilience strategy to determine risk reduction effectiveness employing a **Class 2 Risk** Assessment.

5 Use results to make a site selection, alternative design or retrofit decision.

6 Hand off to design consultants to develop resilience-based design requirements for new construction or retrofit of existing construction to a **Resilience Class 3** level.

ARUP

Government resilience lead

Organization type
Government or public entity

Typical titles
Chief Resilience Officer,
Hazard Mitigation Manager

Use case
Multi-sector risk assessment for development strategy creation

"As a consumer of risk information with subject matter expertise, I want to assess risk for the highest level of aggregation for a geographical region (country, state, city), so that I can:

1. Inform baseline diagnostics to identify institutional capacities and needs
2. Inform public policy development

Scale

Resilience journey

User journey

1 Undertake or procure a **Class 1** Risk Assessment for all assets that comprise a given sector of interest at a national, subnational or local level for all hazards that could have a material impact. The hazard assessment should include stochastic generation of events and the outputs should consist of quantitative risk metrics aggregated at the geographic and sector level.

2 Identify resilience needs and recommendations at geographic and sector level per **Resilience Class 1** to make planning, financing, investment or technical cooperation decisions, and to inform the development of a pipeline of programs or projects.

3 Hand off specific activities or projects to project leads for implementation, which may include more detailed **Class 2** or **3** Risk Assessment.

Government planning lead

Organization type

Government or public entity

Typical titles

Sector Officer (government buildings, community housing, education)

Use case

Project (new or existing assets) risk assessment & development of resilience strategy

"As a layperson consumer of risk information, I want to assess risk for a specific program, project or asset in my pipeline, so that I can:

1. Align with national or local policies to unlock project funding
2. Inform due diligence
3. Inform resilient design or retrofit

User journey

1. Undertake or procure a **Class 1** Risk Assessment of the individual site or asset for all hazards that could have a material impact on the building aligned with national or local procedures.
2. Procure a **Class 2** Risk Assessment for prioritized hazards identified in Step 1.
3. Identify resilience measures and budgets, per **Resilience Class 2**.
4. Re-assess risk for each candidate resilience strategy to determine risk reduction effectiveness employing a **Class 2** Risk Assessment.
5. Use results to make a site selection, alternative design or retrofit decision.
6. Hand off to design consultants to develop resilience-based design requirements for new construction or retrofit of existing construction to a **Resilience Class 3** level.

Financial & insurance specialist

Organization type

Enterprise / Corporate

Typical titles

Chief Resilience Officer,
Hazard Mitigation Manager

Use case

Portfolio (existing assets) risk assessment & development of financial protection strategy

“As an experienced consumer of risk information, I want to assess business and safety risks for my organization’s portfolio of assets, so that I can:

1. Report / disclose
2. Procure optimal financial protection through insurance or other instruments

Scale

Resilience journey

User journey

1 Undertake or procure a **Class 1** Risk Assessment of all assets for all hazards that could have a material impact across selected sectors as a basic screening.

2 Procure a **Class 2** Risk Assessment for prioritized hazards identified in Step 1. Quantify the financial losses for the existing conditions.

3 Identify financial risk management, protection and transfer recommendations. Identify residual financial risk for each strategy.

4 Finalize optimized financial risk management strategy based on risk layering, cost-benefit and financial feasibility analysis of options.

5 Use results to make financing, investment and/or insurance decisions, and to inform the development or update of risk management and transfer instruments and offerings.

Risk and resilience practitioner

Organization type
Consultant

Typical titles
Risk Analyst,
Resilience Consultant

Use case
Project (new or existing assets) risk assessment & development of resilience strategy

"As a producer of risk information with subject matter expertise, I want to assess business, safety and disaster risk for a specific client's asset, so that I can:

1. Screen out negligible risks
2. Evaluate higher risks to identify risk drivers and opportunities
3. Develop a set of resilience measures

User journey

1 Undertake a **Class 1** Risk Assessment of the individual site or asset for all hazards that could have a material impact as a basic screening (Skip to Step 2 if top hazards are already known).

2 Undertake a **Class 2** Risk Assessment for prioritized hazards and/or assets identified in Step 1 and/or the need for a more detailed **Class 3** Risk Assessment.

3 Identify resilience measures and budgets, per **Resilience Class 2**.

4 Re-assess risk for each candidate resilience strategy (i.e. compilation of measures) to determine risk reduction effectiveness employing a **Class 2** or **Class 3** Risk Assessment.

5 Finalize resilience strategy based on cost-benefit or multi-criteria analysis of each strategy. Develop candidate resilience measures per **Resilience Class 3**.

6 Use results to inform the development or update of the asset's design requirements and to directly influence the design process, and/or to carry out physical protection or correction interventions, retrofit of buildings and/or non-structural soft or operational measures to increase adaptive capacity.

Glossary of terms

Adaptation

Measures taken as part of an overarching risk management process (see Risk management) to lessen the impacts of primarily climate-related hazards.

Building archetypes

Used in Class 1 and 2 risk assessments, archetypes are intended to represent a general category of buildings that have similar occupancy types and physical characteristics (e.g., building height).

Climate risk

The likelihood and severity of impacts to people, buildings, infrastructure, organizations, or communities, resulting from the physical effects of climate-related events, such as hurricanes, heatwaves, and wildfires, measured in social and economic terms, and exacerbated by climate change effects.

Climate scenarios

A combination of an emission / concentration / radiative forcing scenario and a selected future time frame. Could also be used to describe current or present day baseline conditions.

Consequence types

Risks are expressed in relation to a certain consequence type. For buildings, these could include repair costs, downtime, lost revenue, and inventory losses. For building occupants these could include fatalities and/or injuries, and health and wellness impacts.

Downtime

The time required to achieve a defined recovery state (e.g. re-occupancy or functional recovery) of a building's functions after a hazard event has occurred.

Exposure

Any physical element(s) that coincides in time and space with a natural hazard. For buildings, exposure is characterized by its location, function, physical properties, contents, replacement value, and number of building occupants that might be at risk.

Fragility functions

Fragility functions relate hazard intensity metrics (e.g. 3 sec gust wind speed) to the probability that specific building components or contents of a building may incur discrete damage states of increasing severity and/or extent. Component-based fragility functions are utilized in Class 3 risk assessments.

Functional recovery

A recovery state at which a building can be used for its primary function. In most cases, this means that the building must be safe, any damage hindering re-occupancy or functionality must be repaired, and power, water, and heating must be available. See REDi (2023) for more details.

Hazard

The potential intensity of a particular natural physical event that can cause physical impacts to buildings or occupants. The hazard intensity is measured at the building location and can be deterministic (i.e. for a single defined event such as a M7 earthquake) or preferably probabilistic such that each intensity magnitude corresponds to a likelihood or probability of occurrence. The latter is typically expressed as return periods or probability of exceedance in a given year or over a specified multi-year or decade time horizon. Hazard data is typically derived from historical observations and extrapolated to estimate future rare events (that may not have previously occurred in the documented history) using extreme value analysis or stochastic event sets. Climate change effects can be incorporated to augment the hazard for a specified emissions scenario and time period (e.g. RCP 8.5, 2070). Average or mean values are not typically used for risk assessment unless they are intrinsically predictive of damage to physical components (e.g. peak 3 sec gust wind speed) or harm to building occupants (e.g. internal heat index).

Monte Carlo simulations

A widely used method for quantifying uncertainty in risk analysis utilizing probabilistic sampling techniques to capture randomness associated with uncertainty in each variable of the risk assessment.

Resilience

The ability to withstand or rapidly recover from the effects of a hazard. To the extent that buildings support the capacity of individuals, communities, institutions, businesses and systems to fulfill their basic needs, delivery of core services, or mission, they perform a crucial role in resilience. The most analogous risk metric for measuring building resilience is therefore the time it takes to recover functions (see Downtime and Functional recovery).

Glossary of terms

Resilience-based design

An approach that integrates enhanced building design, contingency planning, and risk verification (to a Class 3 level of assessment) to ensure that owners can resume operations and/or provide livable conditions quickly following a hazardous event. This definition was specifically developed for the REDi resilience-based design guidelines (www.redi.arup.com).

Resilience Class

Defines the level of detail and maturity for resilience and adaptation solutions recommended for planning, budgeting, costing, and implementation purposes.

Risk

Describes the likelihood of incurring a certain magnitude of loss or consequence. It is derived by integrating hazard, exposure, and vulnerability. It should be underpinned by quantitative analysis and risk metrics but can be expressed in descriptive terms (e.g. high, medium, or low) or as scores for communication purposes. See Risk metrics below.

Risk Class

Defines the level of detail in a risk assessment recommended to support certain decisions with sufficient confidence in consideration of their cost or complexity, primarily around resilience actions.

Risk management

A process that includes risk identification, quantification, prevention, risk mitigation, and risk transfer for known risks and adaptative capacity to manage both known and unknown risks.

Risk metrics

Quantitative risk metrics can be expressed in annualized terms, the probability of exceeding a certain loss threshold (e.g. number of days of downtime) over a given time horizon, or losses corresponding to a given hazard intensity level (with a defined likelihood or return period) or scenario event.

Risk mitigation

Mitigation has largely been adopted by climate change professionals to describe actions to reduce greenhouse gas emissions. In the context of risk and resilience assessment, mitigation is any action to reduce the physical or operational impacts that hazardous events pose on buildings and the organizations or building occupants they support.

Shared fate risks

The risks determined from impacts of a single hazard event (e.g. Hurricane Sandy) on multiple buildings simultaneously, either geo-spatially distributed or generally centralized on a campus or neighborhood.

Stochastic event sets

Typically used in the context of hazard modeling, the development of stochastic event sets using Monte Carlo techniques (or other sampling techniques) to “simulate” hypothetical future hazard events like hurricane/cyclone tracks and corresponding windspeed fields. The results can be used to quantify the hazard at a single site or provide realistic scenarios for assessing shared fate risk (see above).

Vulnerability

The susceptibility of a building to be damaged or impaired by a hazard event. Often quantified through mathematical functions relating hazard or demand parameters to the extent and severity of damage to buildings or building components and contents (see Fragility functions and Vulnerability curves).

Vulnerability curves

Relates hazard intensity metrics to the expected loss in terms of the consequence type, often derived from empirical models or physics-based models of building archetypes for Class 1 and 2 purposes.

References

R.1 IPCC, 2021: *Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* [Masson-Delmotte, V., P. Zhai, A. Pirani, S.L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M.I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T.K. Maycock, T. Waterfield, O. Yelekçi, R. Yu, and B. Zhou (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 2391 pp. doi:10.1017/9781009157896.

R.2 IPCC, 2022: *Climate Change 2022: Impacts, Adaptation, and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* [H.-O. Pörtner, D.C. Roberts, M. Tignor, E.S. Poloczanska, K. Mintenbeck, A. Alegría, M. Craig, S. Langsdorf, S. Löschke, V. Möller, A. Okem, B. Rama (eds.)]. Cambridge University Press. Cambridge University Press, Cambridge, UK and New York, NY, USA, 3056 pp., doi:10.1017/9781009325844.

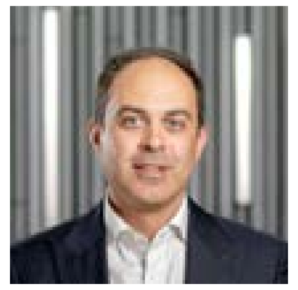
R.3 REDi, 2023. Hogan, J., Almufti, I., and Ackerson, M., *REDi: Resilience-based Design Guidelines for Floods*. Arup. www.redi.arup.com

R.4 United Nations, 2015. *Sendai Framework for Disaster Risk Reduction 2015-2030*. https://www.undrr.org/media/16176/download?startDownload=20240523

R.5 UNDRR, 2023. *The Report of the Midterm Review of the Implementation of the Sendai Framework for Disaster Risk Reduction 2015–2030*. UNDRR: Geneva, Switzerland.

Acknowledgements

Lead Authors



Ibbi Almufti
Multi-hazard

Daniela Zuloaga
Multi-hazard and climate change

Main Contributors

Meg Ackerson
Flood

Kenny Buyco
Multi-hazard

Jack Hogan
Flood and sea level rise

Karen Barns
Multi-hazard

Alexej Goehring
Heat and climate change

Ben Shao
Seismic and wind

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Graphic design
Alicia O'Connor

Editing
Chloe Ginnegar
Jackie Wei Green

Technical contributions and editing
Ilana Judah

Juliet Mian

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Rashmin Gunasekera
James Daniell
Harriette Stone
Antonios Pomonis