XDI
Cross Dependency Initiative

Analysing the Impacts of Extreme Weather and Climate Change on Physical Risks to Infrastructure and Assets: Methodology and Data

STRUCTURAL ANALYSIS: ASSETS AND ARCHETYPE ONLY

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Table of Contents

1 Introduction

Global leaders in physical climate risk analysis since 2007.

XDI is part of The Climate Risk Group – a group of companies committed to quantifying and communicating the costs of climate change.

Backed by a team of specialists across science, engineering and software development, XDI provides best in class expertise in physical climate risk analysis to inform capital allocation, planning and risk management decisions.

XDI analysis is powered by Climate Risk Engines, one of the most flexible, powerful and trusted sources of physical climate risk data in the world.
The Climate Risk Engines use engineering-based methods to assess exposure and vulnerability of asset archetypes to understand the likely damage and failure probability of assets caused by extreme weather and climate change hazards.

Results are expressed in a range of engineering or financial metrics to inform decision-making at all scales.

XDI aims to ensure that the full extreme weather and climate change risk space has been properly explored. Practically this means selecting high emission pathways and testing hazards using the individual regional models which most exacerbate each hazard.

The Climate Risk Engine methodology documentation is broken into a series of documents. The Methodology series of documents includes:

- Climate & Hazard Modelling
- Structural Analysis
- Damage Distribution Analysis
- Impact Functions
- Model Validation
- Specific Product explanations

The purpose of public this Methodology document is to provide an overview of our approach to physical climate risk analysis, specifically the structural analysis methodology.

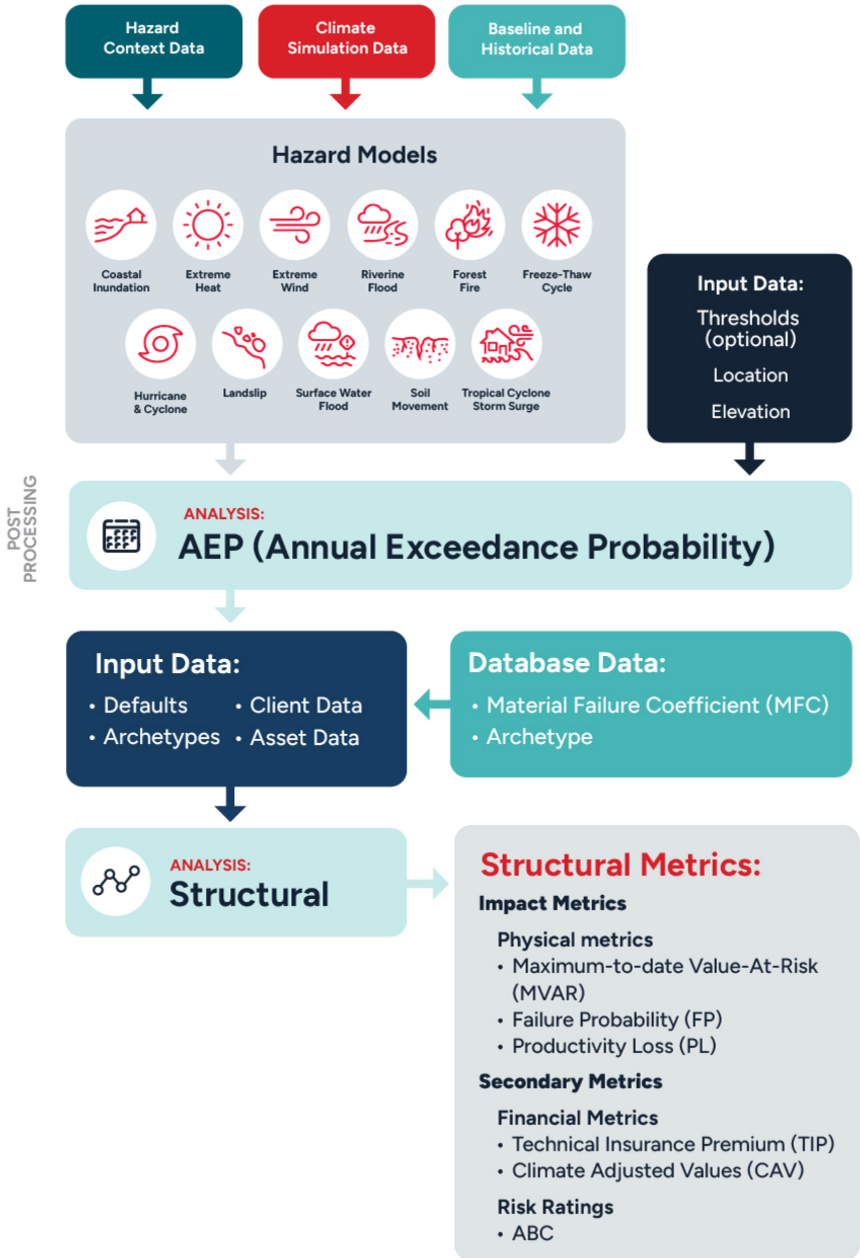

Figure 1: Overview of the Climate Risk Engines Structural Analysis workflow.

For more information visit the XDI website.

2 Structural Analysis

2.1 Summary: What is structural analysis?

Structural analysis forms the core of the Climate Risk Engines analysis suite.

This engineering model calculates risk to individual assets by running analyses on archetypes representing the physical elements that make up each asset, and the dependencies between them.

Structural analysis combines this archetype information with asset-specific information, hazard projections and spatial context data from the asset's location. This goes into a multi-step calculation that determines damage and failure for each element within the asset, and then aggregates up to the asset level to calculate the overall impact for each hazard. After this step, secondary financial and human-impact metrics may be calculated.

There are many other analyses that build on structural analysis. Examples include cross-dependency, large site analyses, and linear asset analysis. Adaptation analysis is performed by stringing together multiple structural analyses over time whilst modifying the structural properties.

The methodology for these products can be found in subsequent methodology documents.

2.2 Structural Analysis

Structural analysis combines an Annual Exceedance Probability (AEP) analysis with an engineering model of an asset. In the structural analysis, an asset is represented by an archetype, which uses a graph of elements to represent real building components (e.g. roof structure, foundations, cladding). The AEPs are combined with per-element exposure and vulnerability coefficients to determine the expected probability of damage or failure for each element of the asset. The element graph is then used to determine the aggregated impact per-hazard, as damage flows up the dependency change. For example, if the foundations are damaged, then the model assumes that the wall structure is also damaged.

Structural analysis uses per-hazard damage thresholds - such as wind speeds based on building codes or floor height - that apply to each element. Not all elements are vulnerable to all factors. For example, walls are affected by wind, and a floor is affected by soil movement that consequently also affects the walls. Elements are made of materials that have differing vulnerability coefficients, which change the damage probability. Concrete, for example, is not affected by flooding, but gyprock is.

Each element's damage probability is calculated individually, and then damage probability cascades up to dependent elements. So, if the walls are damaged, then the roof is also damaged, as well as electrical systems. This is aggregated across elements to a per-hazard damage probability, and then again to an asset-level total damage probability. The same is true for failure probability, such as electrical systems failing due to extreme heat.

For some assets, this total damage probability feeds into financial modelling of the expected costs (related to asset value, mortgage/interest rates and replacement cost). It also cascades into some human-impact metrics. Other human-impact metrics are calculated directly, such as heatwave days and lost-work hours.

2.3 Analysis Input

Structural analysis requires the specification of the scenario and settings to use for the analysis, as well as asset information and associated archetype assumptions.

2.3.1.1 Define the Scenario and Settings

The scenario for analysis consists of the settings which define the datasets to use, as well as the standard inputs to apply. The settings that can changed include:

- **hazards** to include
- **years** to run the analysis for
- which climate simulation datasets to use. These can either be specified as a specific simulation name, or as a broad data collection, such as CORDEX. Different choices can be made for different hazards, if required.
- **data sources** to use for context layers (e.g. which flood data provider to use)
- hazard-specific options, such as wave setup coefficients

- **defence parameter** on or off to restrict the inundation saturation
- **asset lifting** on or off to restrict flooding over exposure
- **truncation parameter** restricts the return frequency or the wind speed threshold to limit the scope of exposure

2.3.1.2 Define the Asset

An asset can be defined as a static, physical building or other piece of infrastructure with a defined location, cost, material and other attributes used for analysis. An asset can be as small as a single power pole, road section or pipe or as large and complex as something like an airport, power station or manufacturing facility.

In the finance sector, the asset-analysis focus may be on residential property such as houses and apartments and commercial assets like offices, factories and shops. These types of assets are defined by construction materials, design standards and unique specifications.

Once it is determined which types of assets need to be included, each asset type is assigned an archetype to allow the Climate Risk Engines to assess vulnerability.

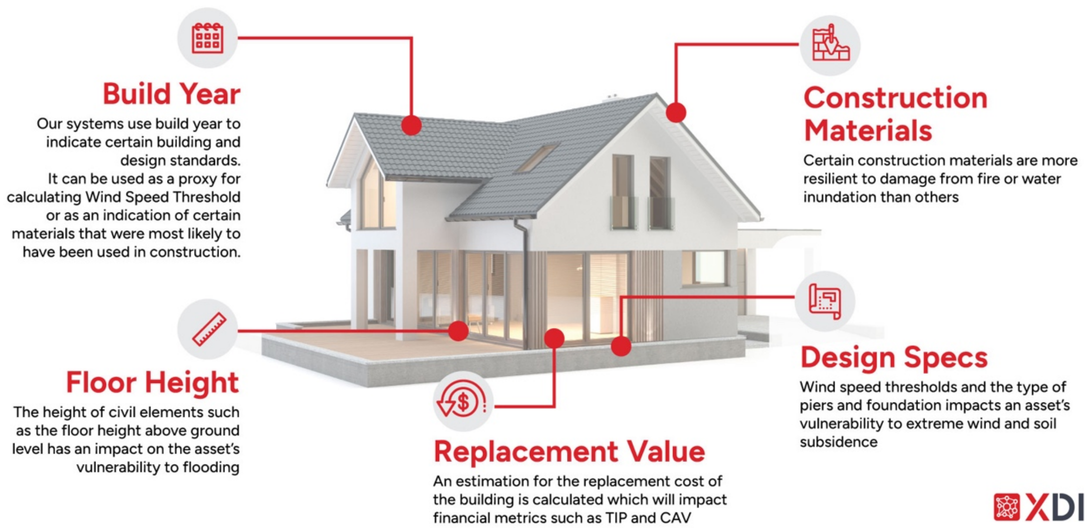

Figure 2: A 'residential dwelling' archetype in the Climate Risk Engines considers specifications around floor height, build year, construction materials, design specifications and replacement value to assess its vulnerability to extreme weather and climate change.

The asset inputs for structural analysis include the following parameters:

- asset ID
- name and address
- **location (latitude, longitude)**: used to determine the asset's location. This represents the asset centroid, or for large site assets a grid of centroids.
- **elevation**: used in the coastal inundation hazard
- **height above ground**: used in flood and inundation hazards
- **market value** and **replacement costs**: used in financial metric calculations
- **age** or **build year**: used in estimating building regulations at the time of build; affects extreme wind hazard only
- **design thresholds** used for extreme heat, extreme wind and tropical cyclone/hurricane
- **element material** overrides the archetype default material
- **number of residents**: used for human impact metrics
- **number of customers**: used for customer impacts

Except for the location and elevation, most fields can be left blank, and the structural analysis will assume default values.

2.3.1.3 Define the Archetype

In structural analysis, different archetypes are defined by different elements, different exposures, and different element materials.

An archetype can be defined by any set of elements, depending on what is present and relevant for climate-related risk analysis. The archetype database has over 130 archetypes, representing everything from street trees, drains and houses to port infrastructure, power stations and airports. New archetypes can be added to the system, however in most cases this requires substantial research.

See Assets and Archetypes below for more details.

Elements

The elements of an archetype are the major physical or conceptual components that make up the archetype. For some assets, such as houses and other buildings, these usually represent real physical components, such as walls, roofs and windows, and these may be broken down into sub-components. For infrastructure assets, elements are often more abstract, representing the major conceptual components, such as civil engineered structures, electrical systems, and chemical and biological components.

Each element contains information about its exposures to each hazard, as well as its contribution to asset failure and damage risk and its inter dependency with other elements within the archetype.

3 Assets and Archetypes

3.1 Defining an Archetype

An archetype is a standardised type of structure or infrastructure asset based on nominal industry design specifications and construction materials used in major elements such as electrical, civil, mechanical and engineering components. The archetype is used to classify asset types based on their make-up to determine how climate change and extreme weather may cause damage or failure.

The Climate Risk Engines use a 'representative asset' or archetype based on nominal industry archetypes. This archetype represents the real asset, such as a house, road or telecommunications tower, but can also represent an entirely hypothetical asset to inform resilience planning processes.

An archetype is a generic analogue used to represent the characteristics of a subclass of assets, which can then be applied across multiple assets of the same kind. Archetypes allow the use of general, repeatable information across an asset class, obviating the need to uniquely specify each individual asset's characteristics.

3.2 Structural Analysis Archetype

The Climate Risk Engines use as-constructed engineering diagrams and other industry information sources to define the following key archetype characteristics:

1. **Elements present** – e.g. access, civil, electrical, electronic, information, mechanical.
2. **Height of above ground** – e.g. 0.2 m for the civil element.
3. Main **construction material** for each element – e.g. steel or concrete (the archetype allows only one material to be assigned to each element).
4. The **interdependencies between elements** – e.g. if the wall structure is damaged, it is assumed that the roof is also damaged.

Each archetype in the Climate Risk Engines contains the following specifications:

1. **Base information** – the name and family of the archetype as well as other archetype-specific metadata.
2. **Element specifications** – listing the elements within the archetype, the proportion of the asset replacement cost represented by each element (expressed as a percentage), and whether the element can cause the whole asset to fail if it isn't operating (yes/no).
3. **Element exposure** – listing the hazard(s) each element is exposed to, as not all elements are exposed to all hazards (e.g. an underground element is not exposed to extreme wind).
4. **Element dependency** – establishing the internal 'failure relationship' between the elements, e.g. the asset's electronics would fail it the electrical element fails.

5. **Design overrides** – detailing any specifications that operate at a whole of asset-level, rather than at the element or material level, e.g. wind speed tolerance.

3.3 Archetype Elements

To determine asset vulnerability, the asset is divided into its component elements as defined by the archetype, with each element's material characteristics and exposure levels informing the damage thresholds and failure points defined within the archetype.

These element properties are:

- **name:** the element's name
- **exposure coefficients:** definition of whether each element is exposed to each hazard.
- **dependencies:** list of all other elements that will be damaged if this element is damaged.
- **failure**: coefficient that represents whether this element can cause the asset to fail.
- **proportion**: fraction of total asset value that is assigned to this element.

3.4 Element Exposure and Dependencies

Archetype element exposures define which elements are present and the exposure of these elements to each hazard.

Figure 3 presents an example of a simple house archetype the elements it might contain, and the dependencies between them.

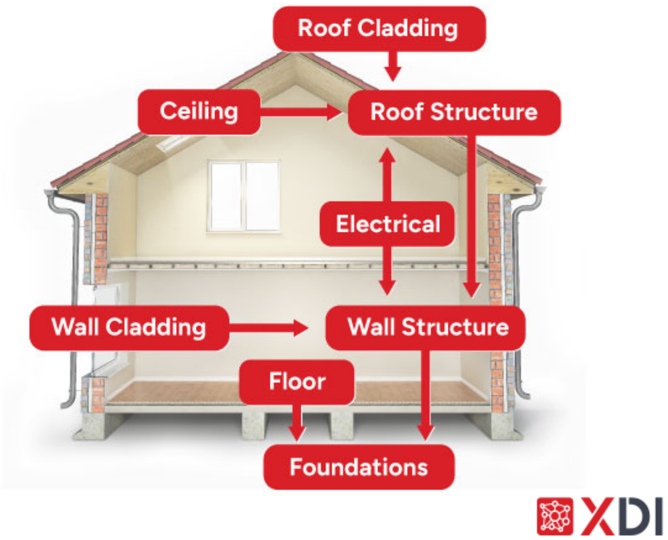

Figure 3: The elements that a simple house archetype might contain, and the dependencies between them.

3.5 Material Performance Specifications

When an asset fails, it can be because a hazard has exceeded its materials' tolerances. The Climate Risk Engines separate an asset into elemental parts and assigns to each of these a defining material.

The material performance specifications are each referred to as a Material Failure Coefficient (MFC). For a given material and hazard the MFC is the probability that the element using this material will be damaged when exposed to a specified hazard event.

To establish the damage and failure of an element, within the asset a material failure coefficient is calculated based on a material threshold; that is, ability to withstand a specific hazard. This is done for each hazard.

3.6 Asset Design Specifications

In some cases, a failure threshold may be associated with design specification rather than a material. For example, the failure threshold could be whether the water level breaches the height above ground design specification of the civil structure.

A design specification is important as it is used to identify the probability of such a threshold being exceeded. Thus, once a failure threshold is known for a given material/element, analysis uses hazard map data and climate change projection algorithms to calculate the Annual Exceedance Probability (AEP) of such an event occurring for each year being analysed.

Table 1: Hazards and design specifications.

Hazard	Design Specification	Example
Coastal Inundation	Salt water breaching the entry height	0.5 metres elevation above mean sea level
Extreme heat	Temperatures exceeding the design envelope	Mechatronic: 30℃ ambient temperature, or Heating, ventilation, air conditioning: 49℃ ambient temperature
Extreme Wind	Wind gusts exceeding design threshold	1-in-100-year gust
Riverine Flooding	Flood water breaching the entry height	1 metre height above ground
Surface Water Flooding	Flood water breaching the entry height	1 metre height above ground
Tropical Cyclone	Wind speed exceeding design threshold	60m/s

Tropical Cyclone Storm Surge	Flood water breaching the entry height	1 metre height above ground

4 Calculate Damage and Failure Metrics

4.1 Calculate Hazard Annual Exceedance Probabilities

Structural analysis calculates a single AEP series for each hazard using physical or return-frequency thresholds, such as floor height for flood, and return period for wind, based on the archetype and asset information. This process uses data from climate simulations, historical observational climate data, and spatial context layers, depending on the hazard and scenario specifications. Each hazard AEP series is calculated once per asset location, and then applied to each element.

The thresholds used for each hazard are:

- **Coastal Inundation**: elevation above sea level *plus* asset height above ground in metres.
- **Extreme Heat**: provided directly as either a temperature (°C) or return period.
- **Extreme Wind**: can be provided as a return period or a fixed wind speed in m/s.
- **Flooding (Riverine and Surface Water)**: asset height above ground in metres.
- **Forest Fire**: fixed global HDW threshold
- **Freeze-Thaw**: NA
- **Landslip**: NA
- **Soil Movement**: fixed global return period for drought.
- **Tropical Cyclone/Hurricane**: a fixed wind speed in m/s.
- **Tropical Cyclone Storm Surge**: elevation above sea level *plus* asset height above ground in metres.

4.2 Calculate Per-Element Impacts

Each element has exposure factors that mitigate the impacts of the hazard AEPs to that element. For example, roof cladding is exposed to wind, but foundations are not. These are combined with the material failure coefficients (MFC) for each element. Timber, for example, is somewhat susceptible to water-related hazards, while gyprock is very susceptible to water damage.

4.3 Aggregation Over Hazards

Aggregation is performed over the hazard to generate asset level metrics.

The outcome of these aggregations is **VAR% (Value At Risk)**, which represents total damage probability, and **total FP% (Failure Probability)**.

Aggregation of structural results is used for many secondary analyses. Mostly, it consists of extracting metrics (such as VAR, or Failure Probability) from all structural analyses in a project, grouping the results (e.g. by postcode or suburb), and then running some statistics over them (average, bin-and-count, etc). Aggregated results may be attached to spatial polygons to allow mapping. They may also be aggregated themselves, as for example, lists of the top-10 highest risk suburbs under a particular metric.

5 Structural Metrics

Structural metrics are the range of output values that the structural analysis model produces. These metrics are grouped into:

1. Impact metrics
   a. **Physical metrics**: The base probabilistic metrics in any given year for any given hazard.
2. Secondary metrics
   a. **Ratings**: Use the physical metrics to group the results into categories that indicate level of concern.
   b. **Financial metrics**: Use the physical metrics to infer financial impacts.

5.1 Impact Metric – Physical Metrics

5.1.1.1 Value at Risk (VAR)

See also Post Processing Maximum-to-Date Value at Risk (MVAR).

Value at Risk in each analysed year is expressed per hazard per asset and as an asset's overall potential damage caused by climate-related hazards, as a proportional of the total asset value.

5.1.1.2 Failure (FP)

Failure Probability is the annual probability of a climate hazard causing the asset to stop working with or without damage. This is reliant on the vulnerability of an archetype's element to a particular hazard.

5.1.1.3 Productivity Loss (PL)

Productivity loss considers the effects of different types of disruption, including periods of closure associated with different hazard events. PL% are based on Failure Probability, which includes both the annual average probabilities of event occurrence and the vulnerability of the asset and its components.

5.2 Secondary Metric – Risk Rating

Risk Ratings are expressed in as High, Medium and Low Risk Properties and as ABC Risk Bands. Risk Ratings are a simple classification of the MVAR% risk in a given year for an individual asset or a portfolio of assets, that express the severity of the risk.

FEMA Standard Thresholds

FEMA sets out two points of concern in providing government insurance: 1-in-500-year flood return frequency and a 1-in-100-year flood return frequency.

It is possible to take a 1-in-100-year flood as a high-risk threshold for insurability. This can be improved upon by determining how deep the 1-in-100-year flood is at a given location and the consequent damage. An improved measure at the 1-in-100-year threshold would therefore accommodate severity, vulnerability and resilience. One way to do this is to examine the threshold at which damage occurs for the property (and thus account for vulnerability) and establish if this is above or below the 1% probability. Another equivalent approach is to test if the Average Damage Ratio is greater than 1% for the property. Both approaches take the concept of a 1-in-100-year insurability threshold but increase its effectiveness as a measure of risk by accounting for severity and vulnerability.

5.2.1.1 High Medium and Low

High Risk Property Count (HRP#): The total count of properties in the year specified that are 'high risk' i.e. equal to or over 1% VAR.
Consistent with US Federal Emergency Management Agency (FEMA) definitions.

Moderate Risk Property Count (MRP#): The total count of properties in the year specified that are 'moderate risk' i.e. equal to 0.2% and up to 1% VAR.

Low Risk Property Count (LRP#): The total count of properties in the year specified that are 'low risk' i.e. less than 0.2% VAR.

5.2.1.2 ABC and ABCDE

ABC Risk Bands – Risk Rating classification using MVAR for a given year for an individual asset. Where:

- **A** – Low MVAR <0.2%, or 0.002
- **B** – Moderate MVAR 0.2% - 0.99%, or 0.002 to 0.0099
- **C** – High MVAR >=1%, or 0.01

ABCDE Risk Bands:

- **A** – Low MVAR <0.2%
- **B** – Medium MVAR 0.2%-0.99%
- **C** – High MVAR 1%-1.99%
- **D** – Very High MVAR 2%-4.99%
- **E** – Extreme MVAR >=5%

5.3 Secondary Metric - Financial Metrics

The key financial metrics that are calculated mostly relate to real estate value and are based on the market value and replacement cost of the asset. These are:

- **Technical Insurance Premium (TIP):** the expected financial costs of damage to the asset.
- **Total Technical Insurance Premium (TTIP)**: the sum of the TIP in a given year.
- **Climate Adjusted Value (CAV):** the new expected market value, per year, taking accounting for deprecation due to increased insurance costs and accounting for mortgage expenses changes into account, in today's currency.

5.3.1.1 Technical Insurance Premium (TIP)

The TIP is the cost of damage to a property. Using the replacement cost, expressed in current day currency with no discounting or adjustments for other transaction costs, combined with the MVAR per asset for all hazard impacts.

5.3.1.2 Total Technical Insurance Premium (TTIP)

The Total Technical Insurance Premium is the sum of all TIPs for all assets or properties in a portfolio. Different aggregation levels can be specified for decision making purposes e.g. geographic area or asset sub-type. The TTIP is useful in drawing attention to the likely financial risk associated with climate change hazards.

5.3.1.3 Climate Adjusted Value (CAV)

Climate Adjusted Value is the percentage reduction in value for the property, relative to an equivalent property unaffected by climate change.

Climate Adjusted Value (CAV) assumes that borrowed funds are finite and that money spent on insurance or self-insurance against extreme weather and climate related hazards must redirect financial resources away from servicing a mortgage or loan on that asset. Using a default interest rate, this diversion of funds is calculated as an equivalent reduction in the principal value of the loan that may be borrowed.

As the value of a property may fluctuate with the market, the reduction in the lending capacity is expressed as a percentage reduction in market value rather than an absolute value. The Climate Adjusted Value is therefore the percentage reduction in value for the asset or property, relative to an equivalent property unaffected by extreme weather and climate change.

6 Post processing

6.1 Maximum-to-date VAR%

Climate change models, like the weather, can be subject to lots of variability. Therefore, picking results from individual years for reporting risks delivering erratic results. There can also be long term trends which change – for example wetting for two decades followed by drying, which means it can be hard to say if the risk is going up or down.

Often the climate models do not increase consistently throughout time, due to factors such decreasing trends for part or all of a time series. The Climate Risk Engines are intended to build resilience to the worst possible conditions. This means that the *Worst Risk* through time should be held when moving past that point. As such the Climate Risk Engines performs **maximum-to-date adjustments** in post-processing, where results are run through a cumulative maximum, such that no year has a lower risk than the year before.

7 Deriving Material Failure Coefficients

The Material Failure Coefficient (MFC) for a given material and hazard is the probability that the element using this material will fail when exposed to a specified hazard event.

The Material Performance Database is a catalogue of the MFCs that are used to test element materials against the hazards to which they are exposed.

The MFCs used are derived using many different methods that included:

- Empirical data from historical experience was used to establish a mathematical relationship.
- Probability distribution of hazards and material relationships.
- Extrapolation of known relationship for equivalent materials.
- Standard engineering parameters for materials that can be used to predict a materials performance to different hazards
- The use of design proxies that build on the design specifications of an asset to infer the failure thresholds of the materials.

For example, where structural failure is concerned, ultimate strength clearly quantifies material strength.

8 Archetypes Applied

8.1 Structural Analysis Archetypes

As a default, Table 2 shows an example definition of two archetypes for structural analysis. These are sometimes varied by geography, if sufficient information is provided that would suggest the defaults are not suitable. It is also possible to change all of these settings for each individual asset.

Table 2: Example archetype default properties.

Archetype	Archetype A	Archetype B
Build Year	Wind Speed Threshold of 1:500	Wind Speed Threshold of 1:200
Heat Threshold	42 degrees Celsius	35 degrees Celsius
Floor Height	0.1 m	0.5 m
Foundation Design	Rigid Foundation	Pier or Pylon Design
Roof Construction	Steel construction with galvanised steel fastenings and steel cladding	Timber construction with galvanised steel fastenings and steel cladding
Wall Construction	Concrete	Brick
Floor Construction	Timber	Concrete

9 Structural Model Hazards

9.1 Coastal Inundation

Flooding caused by sea water is referred to as coastal inundation. It can be caused by high tides, in combination with elevated sea level driven by wind and low air pressure, the size and frequency of waves and the dynamics at the sea-land interface. Coastal inundation events are exacerbated by rising sea levels.

9.1.1.1 Structural Asset Data

The vulnerability of an asset to flooding is based on the elements present in each archetype, the relative elevation above sea level of each exposed element and the behaviour of the materials used in that element when exposed to water.

Most critical is the elevation above sea level, as empirical data shows a sharp increase in damage once water breaches the asset entry point.

For coastal inundation, the flood levels are referenced relative to the national height datum taken from a range of international digital elevations.

9.2 Extreme Heat

The maximum daily near-surface air temperature is referred to as Extreme Heat. Extreme Heat does not typically cause damage to physical assets. There are some materials and archetypes that may be affected, such as asphalt and roads, however the temperatures needed are very high and are not normally a trigger for damage to commercial or residential property.

Extreme temperatures can cause various systems to fail. For example, a smartphone exposed to direct sunlight may overheat and shut down. However, once it cools it should operate normally. The same process can affect commercial, industrial and utility assets, especially through the failure of control electronics. Air conditioners can stop working above 45 °C, leading to closure of shopping centres or factories.

Hence, heat extremes are assumed to be associated with asset failure and disruption rather than damage.

9.2.1.1 Structural Asset Data

Failure probability from extreme heat is an important indicator especially for productive assets such as business premises or critical infrastructure where there may be significant lost income or customer disruptions when the asset stops working. Failure of air conditioning, power, water or communications in homes may put lives at risk.

9.3 Extreme Wind

The Climate Risk Engines extreme wind model draw from two types of extreme wind; (1) synoptic wind and, (2) convective wind. Both are modelled under extreme wind, though they have different drivers for baseline hazard data and climate projection data. Tropical Cyclone wind damage is modelled and reported as a separate hazard.

Synoptic

Synoptic winds are driven by pressure gradients between large-scale atmospheric pressure systems (on the order of hundreds of kilometres, e.g. low pressure systems) that are the result of temperature differences across the Earth.

Convective

Convection, the processes that produce thunderstorms, poses numerous threats to individuals and property including damaging straight-line winds, large hail, heavy rainfall, lightning and tornadoes.

Convective Available Potential Energy (CAPE) and wind shear (bulk wind difference) between the Surface and 6 km (S06) are considered the most influential environmental attributes for the formation and development of severe convection that is capable of producing damage

9.3.1.1 Structural Asset Data

The wind speed design threshold for each asset is assumed to follow national building codes for the year of build or rebuild. Increased design resilience may be applied for dwellings that have been built beyond code to specific wind speed thresholds / return frequencies. Reduced resilience may be applied based on empirical wind performance data. Empirical wind speed survival data is drawn from various research agencies.

9.4 Forest Fire

The forest fire model takes into account fire weather (with a climate change signal), maximum wind speed and vapour pressure deficit (VPD), the difference between the absolute humidity and the water vapour saturation point for a given temperature, ground fuel mapping, and ground fuel attenuation.

Forest fires can destroy buildings and infrastructure through direct flame or intense radiant heat. Assets considered to be at risk are those under or surrounded by trees, or close enough to trees to be affected by intense thermal radiation should the forest catch on fire. Grass fires are also a potential risk but are not covered by this analysis.

9.4.1.1 Structural Asset Data

In structural analysis, the exposure of the elements (e.g. roof, walls, floor) of an asset to a forest fire is defined within each asset archetype.

9.5 Freeze-Thaw

Freeze-thaw is the process by which porous materials such as concrete, brick and stone are damaged when liquid water freezes and expands inside them. Non-porous materials such as steel will not be affected.

Typical studies on material failure due to freeze-thaw look at the number of freeze-thaw cycles until the material fails. The Climate Risk Engines consider a freeze-thaw cycle as any day where there is a Tmin less than 0 °C and a Tmax greater than or equal to 0 °C.

9.5.1.1 Structural Asset Data

Initially, the model considers if the asset's archetype would be exposed to freeze-thaw. Then the properties of the materials, including porosity, must be considered.

9.6 Landslip

Landslips are natural disasters where the ground moves downhill because of gravity, taking soil, rocks, or anything that comes along the way. Landslips are very destructive, causing loss of life and destruction of infrastructure resulting in significant financial damage amounting to billions of dollars each year. Landslips can happen for various reasons, including geological factors (like the type of soil or rocks), geomorphology (how the land is shaped), physical factors (such as tectonic activities), and even human activities (such as land clearing). However, all landslips have one thing in common: they need a trigger to happen.

The trigger is an external event or force that sets off the landslips. Some common triggers include heavy rainfall, which is responsible for about 90% of landslips. When it rains heavily for a period of time, the soil becomes soaked with water, making it unstable and more likely to collapse.

Because of climate change, heavy rain events are expected to increase in frequency.

9.6.1.1 Structural Asset Data

The damage and failure of the asset to landslip is based on the likely exposure of the asset from the location input parameters. In the case of landslip exposure, complete damage and failure is assumed.

9.7 Riverine Flooding (Fluvial) and Surface Water Flooding (Pluvial)

Fluvial flooding from fresh water (as opposed to sea water) is referred to as riverine flooding. Pluvial flooding can also cover situations of surface flows, flash floods or storm water.

9.7.1.1 Structural Asset Data

The vulnerability of an asset to flooding is based on the elements present in each archetype, the relative heights of each exposed element, and the behaviour of the materials used in that element when exposed to water.

Most critical is the height above ground of the civil element (e.g. floor heights), as empirical data shows a sharp increase in loss once water breaches the normal flood level.

Height above ground can also be varied for individual assets (to override that of the archetype) or applied for sensitivity testing.

9.8 Soil Movement

The lack of soil moisture within reactive clay soils is the trigger for major soil movement and cracking. Lower-level suction can lead to clay soils drawing moisture away from the surface soils during drought. Some vegetation can also play a role in removing soil moisture. Soil shrinking and swelling can lead to extensive damage of assets if the foundations also move. Buildings on light strip footings or unstiffened slabs are vulnerable to soil movement.

9.8.1.1 Structural Asset Data

Assets are initially checked to test for the types of soil they're located on, and thereby the level of exposure to soil movement.

The vulnerability of assets to severe soil movement is associated with the design of foundations (less so the type of materials used). Foundations can be designed to cope with soil movements and such designs are captured at the archetype level. For foundations that are vulnerable to soil movement, an empirical or assumed probability of damage is assigned to the civil elements.

9.9 Tropical Cyclone / Hurricane

Tropical cyclones, also known as hurricanes and typhoons, cause significant destruction through high winds, storm surge and rainfall. Numerous studies link Sea Surface Temperature (SST) to tropical cyclone development and strengthening of cyclone genesis that bring strong winds.

While the frequency of tropical cyclones is projected to remain constant with increased atmospheric temperatures, studies suggest significant increases in the proportion of Category 4 and 5 (the most severe) cyclones across all ocean basins.

9.9.1.1 Structural Asset Data

The wind speed design threshold for each asset is assumed to follow national building codes for the year of build or rebuild. Increased design resilience may be applied for dwellings that have been built beyond code to specific wind speed thresholds / return frequencies.

9.10 Tropical Cyclone Storm Surge

Tropical cyclone storm surge is a change in the water level compared to the standard water level, induced by tropical cyclones/hurricanes/typhoons. Tropical cyclone storm surge is perhaps the most damaging aspect of Tropical cyclones, especially in regions where buildings are designed to withstand tropical cyclone wind speeds. Additionally, storm surges can cause significant loss of life.

9.10.1.1 Structural Asset Data

The vulnerability of an asset to flooding is based on the elements present in each archetype, the relative elevation above sea level of each exposed element and the behaviour of the materials used in that element when exposed to water.

Most critical is the elevation above sea level of the civil element, as empirical data shows a sharp increase in damage once water breaches the normal flood level.

10 Climate Risk Engines Model Caveats and Limitations

10.1 Business Purpose

The Climate Risk Engines analysis results are intended to provide quantified analysis of climate change physical risk to the built environment. It can therefore be applied by companies, government and non-government asset owners and stakeholders.

The system is tuned for adaptation cost benefit analysis.

10.2 Model Development

The Climate Risk Engines have been under constant development by Climate Risk Pty Ltd since 2012. They have been used for analysis of utilities, local and state government assets, large/global commercial estates and residential assets.

The infrastructure assessed includes water, wastewater, roads, power, telecommunications, education, health facilities, rail, emergency, transition assets, renewable based assets, and a wide range of residential, commercial and industrial properties.

10.3 Model Methods: Assumptions and Limitations

10.3.1.1 Asset/Input Data

Assumption

This relates to who provides default specification the Climate Risk Engines. Asset locations are provided by the client directly, or through the Climate Risk Engines with relevant default specifications and details included.

The Climate Risk Engines will always choose models that exacerbate assets risk.

Limitation

The use of default (not client-provided) asset data may result in skewed results. Data provided by clients may not always be complete or satisfactory and may lead to skewed results.

10.3.1.2 Results

Assumption

The Climate Risk Engines provide a forecast, prediction or projection not based on any real or planned asset.

Limitation

The model's analysis does not purport to 'cover the field' of all potential risks associated with climate change nor to address coincidence or correlation between such risks.

The Climate Risk Engines do not necessarily cover the impact of any actual built infrastructure, modifications, adaptations or resilience-building measures (public or private) that have been, or may be, applied and result in reduced (or exacerbated) hazard levels.

No representation is made in relation to the availability or coverage of insurance to a real or planned asset.

10.3.1.3 Application of results

The Climate Risk Engines have been realised through their ground-up build, employing:

- bespoke code, running on specially configured banks of high-speed servers
- engineering methods focused on the physical mechanisms that undermine the ability of an asset, system or person to function
- statistical and probabilistic methods to compute how extreme weather and climate change will cause damage into the future.

The capabilities resulted in clients and subsidiary bodies undertaking:

- cost benefit analysis and adaptation planning across large numbers of highly engineered assets
- processing of an ever-expanding range of fixed and linear water, wastewater, power, road, rail and telecom assets
- benchmarking of sectors against one another using the same scenarios, which provides the ability to analyse cross dependent risks, as well as the identification of cost-sharing and collaborative adaptation opportunities
- extensive physical risk analysis on asset portfolios presented in line with leading practice on TCFD reporting, in keeping with EBRD, IIGCC and more.
- high level, aggregated climate risk analysis on a portfolio of residential mortgages.

10.3.1.4 Not to be Taken as Financial Advice

Assumption

The information presented in products and services has been generated using an expert selection of the scientific methods and computational modelling techniques available at the time of creation.

However, at any time, these calculations are subject to physical, political, regulatory, technological and stakeholder-related variables and uncertainties that could cause results to differ materially.

10.4 Conditions of Use

10.4.1.1 Analysing Data

The model is designed specifically for:

- Fixed infrastructure from a range of utility types, including but not limited to:
    - building, water, power, telecommunication, transport, government, emergency.
    - linear assets, such as:
        - pipes, roads, rail tracks.
    - large sites, such as:
        - industrial estates, shopping centres, land use planning sites.

It is not appropriate to use the model on:

- Agricultural systems
- Ecosystems
- Non-fixed assets such as:
    - Vehicle fleets
    - Watercraft

11 Archetypes List

The Archetype database is made up of over 130 archetypes.

Dwelling archetypes are residential type archetypes. They are differentiated by the types of elements present.

Dwelling archetypes include:

- Emergency services
- Commercial buildings
- Residential buildings

Infrastructure archetypes include:

- Council infrastructure
- Transport infrastructure
- Water and Sewage Infrastructure
- Energy infrastructure including network
- Telecommunications infrastructure
- Port and Supporting Infrastructure

Full list available to clients.

12 MFC Database

Material Failure Coefficients (MFC) lists the materials in the database and the failure coefficient per hazard.

Table 3: MFC Database stored in the archetype database.

MFC Database available to clients

XDI
Cross Dependency Initiative

www.xdi.systems