EU-LEVEL TECHNICAL GUIDANCE ON ADAPTING BUILDINGS TO CLIMATE CHANGE

EUROPEAN COMMISSION, DG CLIMATE ACTION

European Commission

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Abbreviations and acronyms

Abbreviation/Acronym	Name
AR5	Fifth Assessment Report
AR6	Sixth Assessment Report
BREEAM	Building Research Establishment Environmental Assessment Method
CEN/CENELEC	European Committee for Standardization
CPR	Construction Products Directive
CVRAs	Climate Vulnerability and Risk Assessments
DGNB	German Sustainable Building Council
DNSH	Do no significant harm
EED	Energy Efficiency Directive
EIA	Environmental Impact Assessment
EPBD	Energy Performance of Buildings Directive
EU	European Union
GFDRR	Global Facility for Disaster Reduction and Recovery
GHG	greenhouse gas
ICC	International Code Council
IEMA	Institute of Environmental Management and Assessment
IFC	International Finance Corporation
IPCC	Intergovernmental Panel on Climate Change
ISO	International Organization for Standardization
JRC	Joint Research Centre
LEED	Leadership in Energy and Environmental Design
NBCC	National Building Code of Canada
NDPs	Nationally Determined Parameters
NFRD	Non-Financial Reporting Directive
OID	Observatoire de l'immobilier durable
PBWD	performance-based wind design
RCPs	representative concentration pathways

Abbreviation/Acronym	Name
REDi	Resilience-based Engineering Design Initiative
SFDR	Sustainable Finance Disclosure Regulation
TCFD	Task Force on Climate-related Financial Disclosures
UKCP	UK Climate Projections
WG1	Working Group 1 Report (IPCC)

EXECUTIVE SUMMARY

This report constitutes the *EU-level technical guidance on adapting buildings to climate change*. The guidance collects and synthesises existing methods, specifications, best practices and guidance for climate-resilient buildings into a document that can provide practical advice for professionals and be referenced or used in different EU policy documents. In particular, the first four chapters of the guidance presented here provide 1) an overview of existing EU-level policies and standards relating to adaptation in buildings, 2) a summary of the current state of structural design building standards at a European and national level, relating to climate resilience in buildings, 3) an overview of the main elements of climate vulnerability and risk assessment for buildings, as well as 4) the main building blocks of existing approaches used to rate resilience of buildings. A separate report, the *Best practice guidance on adapting buildings to climate change*, provides guidance on how to enhance the resilience of buildings, including by presenting practical solutions and case studies.

EU policy and standardisation environment for resilient buildings

The legislative framework of the European Union (EU) reflects the important role of buildings for climate change through a number of relevant policies. The first priority of the framework lies in reducing energy consumption and thereby greenhouse gas (GHG) emissions from energy consumed in buildings, i.e. on climate mitigation and energy efficiency, with instruments such as the Energy Performance of Buildings Directive (EPBD) and the Energy Efficiency Directive, or the Ecodesign Directive. Climate adaptation in buildings has been in the background of climate mitigation. However, more general advances sparked by the EU adaptation strategy have developed the understanding of the extent of climate change and the pressure for adaptation. The EU Green Deal initiated a series of strategies, action plans and legislative initiatives that address the sustainability challenges in a comprehensive manner, including further steps on climate adaptation in buildings, such as Commission proposals for the revisions of the EPBD and of the Construction Products Directive (CPR), the Renovation Wave, the Circular Economy Action Plan and the New European Bauhaus. Thus, while in the past EU policy instruments have often focused on reducing GHGs, the need for climate change adaptation in buildings is increasingly reflected in the EU policy landscape. This report summarises the current state of relevant policy and standardisation instruments for climate change adaptation in buildings as initiated by the EU. It is intended to give an overview and general understanding of the policy landscape to stakeholders from the building industry and interested members of the public.

Climate resilience in structural design

Normative guidance provided by the Eurocodes and national regulations (such as building codes) adopted in each European country incorporate climate actions in the structural design. Conventionally, these respond to past weather events and are not updated frequently to changing conditions. Other industry and academic guidance provide additional support, voluntarily implemented in projects. This chapter of the report focuses on the application to structural design, covering only the primary structure. It summarises the current state of structural design building standards at a European and national level. It is primarily intended to give an overview and general understanding of the current and upcoming updates to standards and regulations (including the levels framework) for the implantation of climate resilience. Best practices relating to the primary structure, in connection with a number of key priority hazards, are covered in the separate report entitled *Best practice guidance*.

Climate vulnerability and risk assessment for buildings

Climate vulnerability and risk assessments (CVRAs) are commonly used to evaluate the potential effects of climate change on a system. They are an effective tool to identify where there is a need to adapt to future climate change and therefore to inform the prioritisation and implementation of risk mitigation measures. CVRAs are frequently conducted on both a mandatory and voluntary basis in different contexts, and an abundance of methodologies have been developed across sectors. Although the approach to CVRA for infrastructure is fairly well-defined, there is no widely used methodology for performing CVRAs in buildings in Europe to date, despite the fact that the Sixth Assessment Report (AR6) of the Intergovernmental Panel on Climate Change (IPCC) states that 'information on climate risks needs to be embedded into the architectural design, delivery and retrofitting of housing'. This report identifies core elements of a CVRA methodology applicable to buildings, and suggests a practical, phased approach to implementing it. These include: 1) an assessment of exposure, covering the physical hazards that a building is likely to be exposed to within its expected life span, along with any environmental factors that may have an influence; 2) an assessment of the vulnerability of a building to any identified hazards, comprising an analysis of sensitivity / susceptibility and adaptive capacity; and 3) an overview of the potential impacts, along with an assessment of the likelihood and magnitude of these in order to assess climate-related risks to the building.

Climate resilience rating approaches for buildings

Resilience to climate change is defined as the capacity of interconnected social, economic and ecological systems to cope with a hazardous event, trend or disturbance, responding or reorganising in ways that maintain their essential function, identity and structure. In the building sector, the term 'resilience' can have multiple meanings. In general, resilient buildings should be planned, designed, built and operated in a way that anticipates, prepares for, and adapts to changing climate conditions. They should also be able to withstand, respond to, and recover rapidly from disruptions caused by these climate conditions. These buildings should contribute substantially to reducing or preventing the adverse impact of the current or expected future climate, or the risks of such adverse impact, whether on that building itself or on the people that inhabit them, or the nature that surrounds them, and the assets they are composed of. Approaches to rating the resilience of buildings and other assets are being developed by different types of stakeholders, and for different purposes. This chapter of the report provides a synthetic review of these existing approaches, as well as a set of recommendations for the future development of such approaches. In particular, it also outlines the main elements of an approach that could be used to rate the resilience of buildings, which could be used by small-scale developers, asset managers or owners.

INTRODUCTION

This report constitutes the *EU-level technical guidance on adapting buildings to climate change*. The guidance collects and synthesises existing methods, specifications, best practices and guidance for climate-resilient buildings into a document that can provide practical advice for professionals and be referenced or used in different EU policy documents.

The guidance is structured around the following chapters:

- Chapter 1: European Policy and Standardisation Environment Adaptation Review
- Chapter 2: Climate Resilience in Structural Design Review
- Chapter 3: Climate vulnerability & Risk Assessment Methodology overview
- Chapter 4: Climate Resilience Rating Approach Review

1. EUROPEAN POLICY AND STANDARDISATION ENVIRONMENT ADAPTATION REVIEW

1.1 Introduction

This report summarises the current state of relevant policy and standardisation instruments for climate change adaptation in buildings as initiated by the EU. It is intended to give an overview and general understanding of the policy landscape to stakeholders from the building industry and interested members of the public.

1.2 General policy approach to adaptation

The overall EU policy approach to climate adaptation is outlined in the **EU climate adaptation strategy**[1] **and the Climate Law**[2].

A first adaptation strategy was published in 2013 and a revised version in 2021.

The 2013 strategy contained three objectives, namely to (1) promote action by the Member States, (2) promote better-informed decision-making, and (3) promote adaptation in key vulnerable sectors, such as agriculture and fisheries. Buildings and construction were also mentioned in this document with the ambition to establish standards for climate-resilient infrastructure. In response to these objectives, all Member States enacted their national climate adaptation strategies and many plans or sectoral strategies to provide further details at the national level. An information platform exists in Climate-ADAPT[3], where knowledge, examples and documents are centrally accessible. Furthermore, adaptation is increasingly considered in EU funding programmes like LIFE and included in policy instruments. The policy approach has therefore been decentralised, both from a governance and legal perspective, which reflects the context-dependent nature of climate adaptation. However, this also means that policy measures are mostly high-level, voluntary and often not specific to sectors, including the building sector.

The EU climate adaptation strategy has been found, overall, to be successful in an evaluation[4], and the high level and indirect nature of measures undertaken were considered to be appropriate and useful; however, it was also found that areas of social vulnerability and concrete implementation needed to be strengthened. Different stakeholders had also called for more concrete actions and targets at both EU and national levels[5].

Assessments of location-based risks are a critical prerequisite to adapting buildings in a targeted manner. Therefore, the new EU adaptation strategy adopted in 2021 continues this path and puts a stronger emphasis on the need for data on future climate conditions at the local level and mainstreaming of adaptation in all levels and sectors. This includes the building sector where the Renovation Wave[6] sets adaptation among the principles for renovating the existing building stock. Through the principle of *high health and environmental standards*, the Renovation Wave aims for the protection and adaptation of buildings to climate hazards such as high temperatures, floods, storms and many more. A series of other key principles guide the renovation efforts, including affordability, decarbonisation and integration of renewables, life-cycle thinking and circularity, as well as the respect for aesthetics and cultural value.

[1] https://climate-adapt.eea.europa.eu/eu-adaptation-policy/strategy

[2] https://ec.europa.eu/clima/eu-action/european-green-deal/european-climate-law_en

[3] https://climate-adapt.eea.europa.eu/

[4] EU Commission, 2018. Evaluation of the EU strategy on adaptation to climate change. Available at: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52018SC0461

[5] See for example statements from Eurocities, Council of European Municipalities and Regions, or European Environment Bureau.

[6] https://energy.ec.europa.eu/topics/energy-efficiency/energy-efficient-buildings/renovation-wave_en

The durability of buildings and their materials are also of primary importance in the circular economy action plan[7], which seeks to reduce the resource intensity of the EU economy including the construction industry. For buildings, Section 3.6 of the action plan foresees 'promoting measures to improve the durability and adaptability of built assets in line with the circular economy principles for buildings design and developing digital logbooks for buildings'. Longer lifetimes of buildings and their components mean that climate change will affect them with increasing impact. To address this challenge, adaptability is a key supporting feature for existing and new buildings[8].

At the national level, EU Member States have adopted adaptation strategies and plans as provisioned by the EU adaptation strategy. The strategies and plans vary in age, detail and scope. The key objective of the plans is the monitoring of climate risks and the collection of data for forecasting future changes in climatic conditions to raise awareness of adaptation needs. In relation to buildings, measures are primarily foreseen at the urban planning and zoning level (e.g. in the strategies of Belgium, Croatia, Germany and Sweden) or public procurement of national ministries (e.g. in the strategy of France). National information websites and brochures with specific information for buildings are also available in several countries. These are often targeted at the key risks (e.g. sea-level rise in the Netherlands and Denmark, floods in Austria and Finland). Thus, guidance and support measures are in place that can be used or adapted to a construction project or existing building.

Policies setting adaptation requirements for specific measures for new construction or renovation of existing buildings are currently not in place at national level. This also reflects the context-dependency of adaptation measures even within the Member States. The planning for appropriate adaptation solutions is delegated to the local level, where specific climate risks can be accounted for. The situation may change if the proposal from the Commission on the revision of the EPBD is accepted in the Council and European Parliament, as it would require Member States to address the climate resilience of both new and existing buildings.

Finally, the Climate Law adopted in 2021 introduces a mandatory objective for both the Member States and the EU level for continuous progress towards more adaptation (reducing vulnerabilities and increasing adaptive capacity). This creates significant additional incentives to act on adaptation in all sectors, including that of construction.

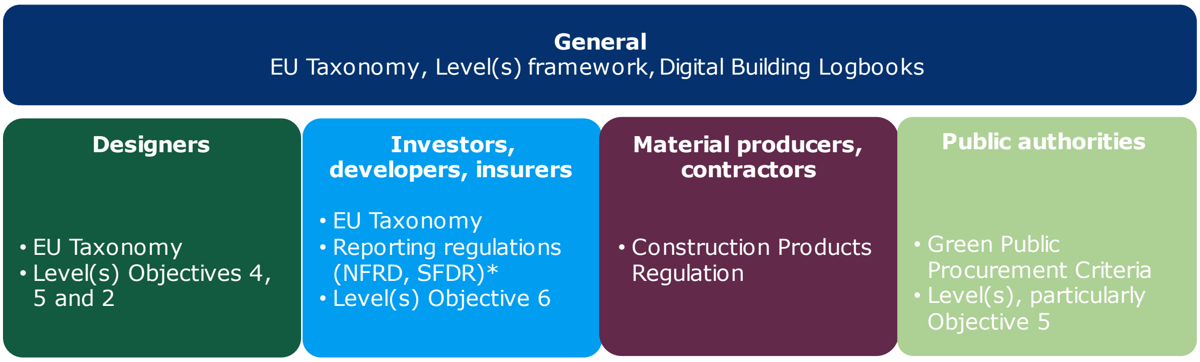
1.3 Policies to support climate change adaptation in the building sector

Mainstreaming adaptation in the building sector is supported by several instruments that help different stakeholders in adapting to climate hazards. Figure 1.1 illustrates the different instruments that are in place at a general level and by the specific actors in the sector to which they are addressed. General instruments create a framework in which transparency and common methodologies for assessing and implementing climate adaptation in buildings are established next to other sustainability topics. Requirements or guidelines for the different actor groups are defined in further, specific instruments. These are summarised in the following chapters. EU funding instruments provide for investment in buildings to support the efforts of climate-proofing the EU's infrastructure. Notably, the InvestEU programme and funds for cohesion and regional development offer grants and loans for such projects.

[7] https://ec.europa.eu/environment/strategy/circular-economy-action-plan_de

[8] See also the mentioned circular economy principles for building design: https://ec.europa.eu/docsroom/documents/39984

Figure 1.1 Overview of EU policy instruments for climate adaptation



* NFRD: Non-Financial Reporting Directive; SFDR: Sustainable Finance Disclosure Regulation

1.3.1 Policies for general transparency and guidance

The **EU Taxonomy** for sustainable economic activities provides a general framework of criteria for sustainability. Progressively, companies and financial institutions are required to map their activities and report on the share of sustainable ones. This aims at increasing transparency through a framework for standardised and comparable reporting based primarily on the extensive work of a technical expert group and the platform that is now providing expert advice. To be considered sustainable, an economic activity has to deliver a substantial contribution to one of six sustainability areas, one of which is climate adaptation.

Thus, criteria for construction and renovation projects have been established. Essentially, the following steps are required to provide substantial contributions to climate adaptation in buildings:

1. Screening to identify climate risks that may affect the performance of the building in the future over its expected lifetime. Climate risks are indicated in a table as an Annex to the detailed criteria. Table 1.1 shows the climate hazards for which the risk screening needs to be conducted.
2. Where the screening shows a risk for climate hazards, a climate risk and vulnerability assessment (CRVA) is conducted.
3. Assess the adaptation solutions (both physical and non-physical) to reduce the identified risk.
4. Adaptation solutions that substantially reduce the most important risks are finally implemented.

Further details on the requirements are included, specifying the proportionality of the CVRA depending on the lifespan of the building, or the use of climate projections based on best practices. The implementation of adaptation solutions also has specific requirements to avoid adverse effects on other aspects. These include people, nature, culture or economic assets, favouring nature-based solutions, and being consistent with local adaptation strategies, among others. An easily navigable description of the criteria is provided in the EU Taxonomy Compass[9]. Example cases can be found in the final report of the technical expert group[10].

[9] https://ec.europa.eu/sustainable-finance-taxonomy/tool/index_en.htm

[10] EU Commission, 2020. Taxonomy: Final report of the Technical Expert Group on Sustainable Finance. Available at: https://ec.europa.eu/info/sites/default/files/business_economy_euro/banking_and_finance/documents/200309-sustainable-finance-teg-final-report-taxonomy_en.pdf

Table 1.1 List of climate hazards as presented in Annex A to the EU Taxonomy

	Temperature-related	Wind-related	Water-related	Solid mass-related
Chronic	Changing temperature (air, freshwater, marine water)	Changing wind patterns	Changing precipitation patterns and types (rain, hail, snow/ice)	Coastal erosion
	Heat stress		Precipitation or hydrological variability	Soil degradation
	Temperature variability		Ocean acidification	Soil erosion
	Permafrost thawing		Saline intrusion	Solifluction
			Sea-level rise	
			Water stress	
Acute	Heat wave	Cyclone, hurricane, typhoon	Drought	Avalanche
	Cold wave	Storm (including blizzards, dust and sandstorms)	Heavy precipitation	Landslide
	Wildfire	Tornado	Flood (coastal, fluvial, pluvial, groundwater)	Subsidence
			Glacial outburst	

The criteria for climate adaptation specify a process for local and project-specific decisions on climate adaptation. The sustainability classification of economic activities concerning buildings based on a substantial contribution to climate mitigation also has to consider adaptation, though. The EU Taxonomy defines minimum criteria for all areas called Do no significant harm (DNSH). For climate adaptation, these criteria require a process that is the same as the one described above as part of the substantial contribution. Screening the risks from the list of hazards and conducting CRVAs, as well as assessing and implementing adaptation solutions to reduce the risks, are also all required as DNSH for climate mitigation, with slightly looser requirements.

However, in media coverage of the EU Taxonomy and industry publications, adaptation receives relatively little attention compared to climate mitigation. A large number of industry documents discuss the climate mitigation criteria, while only very few provide detailed assessments of the ones for adaptation. As reducing GHG emissions has been the focus of attention with EU policies, this is also where the industry tries to comply first. One of the existing reports shows that, for current buildings, the documentation for a climate-adapted status is challenging[11]. Therefore, fulfilling the criteria for substantial contribution or DNSH may be challenging for buildings, even recently constructed ones.

In summary, the EU Taxonomy defines a process to be followed for construction and renovation projects, as well as real-estate investments to be considered a sustainable economic activity. An assessment of the risks as well as of the adaptation solutions and their implementation in design is needed for an increasing number of projects. The reports for this project support the different steps with a compilation of best practice adaptation solutions and information on CRVA and structural assessments.

[11] DGNB, DK-GBC, GBCe, ÖGNI (2021). EU Taxonomy Study – Evaluating the market-readiness of the EU taxonomy criteria for buildings. Available at: https://gbce.es/wp-content/uploads/2021/03/GBCs_EU_Taxonomy_Market_Readyness_Study.pdf

Standardisation can provide further harmonisation of processes, products and materials. In Europe, EN and ISO standards as developed (or adopted, as in the case of ISO) primarily by CEN/CENELEC set such harmonised and controllable definitions. In this context, the standard EN *ISO 14090:2019 Adaptation to climate change — Principles, requirements and guidelines* has been developed.

It specifies the integration of adaptation within or across organisations, understanding impacts and uncertainties and how these can be used to inform decisions. The additional EN ISO 14091 further addresses vulnerability, impacts and risk assessment for organisations in the context of climate change[12]. Based on these foundations, the development of more detailed standards for infrastructure objects and the update of existing ones will take place in the coming years.

Many more standards have been developed for the energy performance of buildings, which also interact with climate adaptation, in particular to temperature hazards. In this area, specific standards, for example for historic buildings, also exist.

Between 2014 and 2022, CEN/CENELEC revised certain building standards to take into account future climate, steered by their Adaptation to Climate Change Coordination Group, who acted on a 2014 mandate received from the European Commission.[13]

The EU is also working on creating an EU model for **Digital building logbooks** for new and existing buildings. These logbooks can help harmonise information on individual buildings, including the steps undertaken to adapt to climate risks. Buyers, contractors and other relevant actors will then have easily accessible information available. More information can be found in the scoping studies[14] on this instrument.

1.3.2 Designers

Many steps of the **EU Taxonomy** process need to be carried out during the planning and design process of a building or its renovation activities. As most adaptation solutions require planning decisions for orientation, external and internal space use as well as materials, the risk screening, CVRA and solution assessment have to be completed before finalising the building design plan. This creates additional requirements for building designers.

The EU has developed the **level(s)** framework (see Box 1.1) to support designers with a voluntary structure for assessing and reporting on building sustainability features. Levels is designed to be used in three levels depending on the design phase of the building. This includes several indicators relevant to climate adaptation that can be used to measure the performance of a building. Most importantly, level(s) includes criteria for maximising thermal comfort under present conditions in indicator 4.2 and including adaptation to future climate conditions in macro-objective 5. Additionally, criteria under indicator 3.1 for reducing water consumption minimise the risks of the building and its users in relation to droughts. The general purposes of each level and indicator are shown in Table 1.2.

Box 1.1 Summary of level(s) framework

The level(s) common framework is an initiative by the European Commission and developed by the Joint Research Centre (JRC). Published in 2021, it is based on six macro-objectives that address key sustainability aspects over the building life cycle. The sustainability indicators within each macro-objective describe how the building performance can be aligned with the strategic EU policy objectives in areas such as energy, material use and waste, water, indoor air

[12] CEN/CENELEC (2020). Standards for the Environment. Available at: https://www.cencenelec.eu/media/CEN-CENELEC/Areas%20of%20Work/CENELEC%20sectors/Accumulators,%20Primary%20cells%20and%20Primary%20Batteries/Documents/standardsfortheenvironment.pdf

[13] https://ec.europa.eu/growth/tools-databases/mandates/index.cfm?fuseaction=search.detail&id=546

[14] https://op.europa.eu/en/publication-detail/-/publication/40f40235-509e-11eb-b59f-01aa75ed71a1/language-en/format-PDF/source-search

quality and resilience to climate change. The macro-objectives are:

1. **greenhouse gas emissions along a building's life cycle;**
2. **resource-efficient and circular material life cycle;**
3. **efficient use of water resources;**
4. **healthy and comfortable spaces;**
5. **adaptation and resilience to climate change;**
6. **optimised life-cycle cost and value.**

In a detailed checklist and an online tool, level(s) supports with clarifications, possible data sources and general design options. This is available for thermal comfort in indicator 4.2 and 5.1, for sustainable drainage in 5.3, and more generally for extreme weather events in 5.2. The steps provide useful inspiration for adaptation considerations and the reporting structure creates clear documentation for building owners, users and designers over the lifetime of the building.

Table 1.2 Level(s) indicators and criteria for macro-objective 5: Adaptation and resilience to climate change

Indicator	Level(s) criteria Level 1	Level 2	Level 3
3.1 Use stage water consumption	• Be aware of five highly relevant aspects for reducing and optimising use stage water consumption. • Describe how these aspects were considered (or not) during discussions and decision-making at the concept design stage.	• Estimate the water consumption per person in the building as a function of the water consuming devices, appliances and irrigated areas via an Excel-based calculator. • Minimise potable water consumption by the specification of more efficient devices and appliances and by rainwater harvesting and/or grey-water reuse.	• Take measures of actual water consumption over the course of 1 year. • Estimate occupation rates of the building. • Compare estimates with measures.
4.2 Time outside of thermal comfort	• Assess the risks of occupier thermal discomfort during the heating and cooling seasons for the building type being assessed. • Understand measures that can be taken to create a comfortable thermal environment in the building types being assessed.	• Assess the energy requirements of a building. • Make a quantitative assessment of the indoor thermal conditions according to the Category II temperature ranges stipulated in EN 16978-1 (or national equivalent). • Make an overheating assessment of a building for the purpose of obtaining a building permit.	• Collect monitoring data on the thermal conditions in a building to compare the performance with design simulations, and/or • Carry out a post-occupancy survey of occupants to determine the level of dissatisfaction with the thermal comfort conditions and compare the results with the design estimates.
5.1 Protection of occupier health and thermal comfort	• Assess the risks of occupier thermal discomfort during the cooling seasons for the building type being assessed. • Understand and identify measures that can be taken to future-proof a building's thermal environment and/or incorporate adaptation measures	• Specify overheating assessment as part of building permit • Consider different aspects of thermal comfort, including localised discomfort effects	• Measure EPB assessment subtypes: climate corrected, use corrected or standard. • Commission functional performance testing. • Compare estimated satisfaction levels with those obtained from occupier surveys.
5.2 Increased risk of extreme weather	• Be aware of steps to take during the conceptual design stage (and even earlier) to ensure that the awareness of extreme weather events at the building location is	Not yet developed	Not yet developed

Indicator	Level(s) criteria Level 1	Level 2	Level 3
	maximised. • Optimise the design of the building and any surrounding plot area for adaptation to extreme weather events.		
5.3 Sustainable drainage	• Set out the steps to take during the conceptual design stage in order to embrace sustainable drainage options as much as possible. • Be aware of both the risk of flooding at the building and the possible effect of the building itself on flood risk in surrounding and downstream areas.	Not yet developed	Not yet developed

In addition to these indicators on future climate conditions, the guidelines for assessing and reporting the suitability of design for adaptability and renovation are highly relevant for designers, too. Adaptability to changing user needs also ensures that risks from future climate conditions can be prevented as well as becoming possible in the process.

As the instrument is very new and voluntary for building designers, the experiences with level(s) are still limited. However, the tool has strong potential to bring adaptation to similar levels of attention as energy efficiency and other objectives. The criteria and guidance level(s) offers are useful references for designers. Still, the use for the adaptation to different climate hazards, in particular to safeguarding thermal comfort in a building, will need to be proven in-depth in the future to make a full assessment.

1.3.3 Owners, investors, developers and insurers

The **EU Taxonomy** targets the economic activities of large companies and financial institutions. These will have to progressively assess their activities against the Taxonomy criteria and report on the alignment with these criteria.

Additional legal instruments for non-financial companies (**Non-Financial Reporting Directive**, NFRD) and financial institutions like banks and insurance companies (**Sustainable Finance Disclosure Regulation**, SFDR) make the reporting on sustainability and the EU Taxonomy criteria mandatory. However, the SFDR also includes its own definition of environmentally sustainable, which focuses on climate mitigation and waste reduction. Therefore, whether climate adaptation takes a prominent role is still uncertain. Criteria such as climate mitigation receive higher attention and are more easily measurable. Still, even with the DNSH requirements, investors and insurers as well as other non-financial companies will have obligations to report on the risk screening and adaptation solutions implemented in the buildings of their portfolios and supported by the latest climate research.

From the **level(s)** framework, two indicators create a link between climate adaptation and financial implications for investors, developers and insurers. This tool offers guidance on life-cycle costing of the building and encourages them to consider the relationship between upfront costs and use-stage costs. If future climate risks and energy consumption in response to higher temperatures are included, this exercise reveals the financial implications of design choices at present and in the future. The framework offers qualitative and quantitative guidance for this.

1.3.4 Material producers and contractors

NB: Instruments in this section are currently in a revision process. Text will need to be updated when agreements are reached, and new legislation is adopted.

Some adaptation solutions require specific materials. Additionally, all building materials need to be able to resist climate hazards such as droughts, floods and strong winds. Therefore, material producers play an integral role in ensuring that buildings are adapted to future climates.

The **Construction Product Regulation** (CPR)[15] is a central policy instrument for construction materials and buildings. Currently, the version in force since 2011 is being revised. A proposal for a new CPR was published by the EU Commission in March 2022. The annex to this new proposal includes a requirement that the likely impacts of climate change on the life span should be taken into account in standardisation requests and harmonised technical specifications covering materials (referred to as construction products) for integration into buildings (called construction works).

This means that anticipating climate risks would be legally required in all standards and technical specifications for construction products under the revised CPR, when it enters into force. This would point to the high relevance of product standards for building materials, which have so far been missing.

1.3.5 Public authorities

Public authorities influence the climate adaptation and resilience of buildings as well. Besides competencies for spatial planning and zoning of urban development, public authorities also act as owners and developers of buildings. While considering the differences in role, scope and competencies, some instruments for climate adaptation apply to all levels, from local to national governments, international organisations and, more widely, public institutions. Several building-related policy instruments are in development for public authorities.

In 2016, the EU has developed a guidance on criteria to be used in the **sustainable public procurement** of office buildings[16]. A process to update these criteria for buildings is currently ongoing[17] and will expand the criteria for climate adaptation through three elements. The guidance on green public procurement (GPP) remains voluntary for authorities to use when procuring buildings. The proposed guidance on climate adaptation relates to ensuring future thermal comfort, resilience to flooding, sustainable drainage, and resilience to main energy and water failures. For each of these hazards, guidance on building design, a process of establishing the adequate level of adaptation, and verification processes are currently developed. Once the final GPP criteria are published, they will provide inspiration and structure to public authorities, but they could also be used beyond this audience for other building developments.

The objectives and indicators of the **level(s)** framework can also provide guidance to policy development. In particular, the above-mentioned macro-objective 5 on adaptation and resilience to climate change may offer relevant insights into policy strategy for adaptation in buildings.

In addition, the proposed revision of the **EPBD** contains provisions requiring national governments to address climate adaptation in new and existing buildings. Therefore, further national measures for climate adaptation can be expected in the future, even if the pace and scope of these measures will likely vary between Member States.

[15] https://ec.europa.eu/growth/sectors/construction/construction-products-regulation-cpr_de

[16] JRC, 2016. Green Public Procurement Criteria for Office Building Design, Construction and Management. Available at: https://susproc.jrc.ec.europa.eu/product-bureau//sites/default/files/contentype/product_group_documents/1581681021/jrc100010_gpp_office_buildings_technical_report_final.pdf

[17] JRC, 2022. EU Green Public Procurement (GPP) criteria for the design, construction, renovation, demolition and management of buildings. Draft technical report. https://susproc.jrc.ec.europa.eu/product-bureau//sites/default/files/2022-03/GPP_Buildings_TR_v1.0.pdf

1.4 Realised and expected impacts, trade-offs and co-benefits

As the previous sections show, the ground for adaptation in buildings has been laid in different EU policies and initiatives. In this section, their achieved merits and the expected ones for the future are discussed, as well as the relationship of climate adaptation to the principles of the Renovation Wave.

The impacts that EU policies have realised so far are difficult to determine as most instruments are very recent and voluntary. Efforts to monitor and anticipate climate change to map risk zones and raise awareness represent relevant progress for climate adaptation in all sectors. Platforms such as Climate-ADAPT that contain links to policies, studies and best practice reports facilitate the access to resources.

Both the EU Taxonomy and the level(s) framework have been introduced recently and still need to show their impacts. According to the experts consulted from all across the EU, the methodologies for defining compliance with the EU Taxonomy's climate adaptation criterion are still under development in national initiatives. The legal status of the Taxonomy and the reporting requirements for large companies and financial institutions means that the impact on new buildings will likely increase in the coming years.

Level(s), on the other hand, has the potential to support the creation of a common language on sustainability and climate adaptation in buildings. However, the landscape of sustainability reporting or certification schemes for buildings is already very diverse with initiatives such as Building Research Establishment Environmental Assessment Method (BREEAM), Leadership in Energy and Environmental Design (LEED) or German Sustainable Building Council (DGNB). Level(s) offers a less complex and less demanding alternative. However, its use in systems at the operational level still needs to take place and will determine its contribution.

The expected impacts of the instruments that have been proposed are still more uncertain as they depend on the final formulation of the legal text. Several challenges remain for the building industry. The first meeting of the Resilience Cluster Group of the High-Level Construction Forum concluded that further harmonisation of national adaptation policies and methodologies will need to be overcome to jointly achieve a more resilient building stock[18].

All these points highlight the strengths and weaknesses of the decentralised policy approach to climate adaptation. On one hand, the instruments provide process guidance and requirements for different actors in the value chain to determine and implement the relevant adaptation solutions. On the other hand, the use of adaptation solutions remains largely unclear and cannot be checked systematically.

The push for climate adaptation in EU policy furthermore interacts with several other key principles of the Renovation Wave. Climate change adaptation offers **co-benefits** to the following:

- The decarbonisation of the building sector is addressed in most EU policy instruments and takes priority over climate adaptation in the public debate, as well as in the requirements set because many adaptation solutions to heat and cold overlap with energy efficiency measures, such as insulation and passive heating and cooling.
- The affordability of buildings represents an essential human need. Well-designed climate adaptation supports the long-term affordability of housing by reducing energy bills and repair costs in the future.
- Adaptation further contributes to life-cycle thinking in the building sector by increasing the lifetime of buildings and their re-usability in response to climate hazards. Several instruments such as the CPR and level(s) actively combine adaptation and life-cycle thinking.

[18] High Level Construction Forum, 2021. Meeting Report. Reporting from the 1st meeting of the Resilience Cluster Group. Available at: https://ec.europa.eu/growth/system/files/2021-11/HLCF_1st_ResilienceClusterGroup_MeetingReport.20.pdf

At the same time, adaptation measures present some potential **trade-offs** with the same principles:

- Higher material use for resistance to storm, subsidence or flooding could potentially increase the embodied carbon emissions of a building. This leads to higher GHG emissions unless changes are made to the production of these materials.
- Due to special requirements, higher material needs and more complex planning, the initial costs for risk assessment, design and construction are also higher and can reduce the affordability of new buildings.

As a result of these benefits and trade-offs, all stakeholders have to reflect on current practices to enable a stronger inclusion of considerations on climate change adaptation in the building sector. Designers and developers can systematically integrate life-cycle assessment and life-cycle costing methods in new construction and renovation projects. The level(s) framework includes guidance on each of these elements. Material producers can provide more low-carbon construction materials to reduce embodied carbon levels; also, public authorities should revise codes on urban planning and building requirements to mitigate local climate change effects.

1.5 Conclusions and recommendations

The EU policy framework has started to require and support more action for adapting buildings to climate change. These actions are largely still taking shape, and some are voluntary. However, climate adaptation is starting to step out of the shadow of climate mitigation. Assessing climate risks for buildings and reporting on the decision to implement certain adaptation solutions will have to be expanded to comply with the EU Taxonomy. Supporting instruments exist in knowledge-sharing platforms, the level(s) reporting framework and guidance on criteria for sustainable public procurement.

This means that adaptation action has been made more accessible and easier. This guidance further contributes by highlighting priorities and solutions for buildings across Europe.

Further assessments of the EU policy instruments and the framework, in general, will be needed in the future after adoption and practical implementation. In particular, evaluation of the impacts they will have had on climate adaptation will need to be assessed in retrospect after some time has passed, or – if applicable – before, as in the case of cultural heritage.

2. CLIMATE RESILIENCE IN STRUCTURAL DESIGN REVIEW

2.1 Introduction

This section summarises the current state of structural design standards at a European and national level. It is primarily intended to give an overview and general understanding of the current and upcoming updates to standards and regulations for the implementation of climate resilience.

The findings outlined in this chapter are relevant to the following stakeholders:

- European standardisation organisations;
- National standardisation bodies and national authorities dealing with construction standards and regulations;
- Design and renovation teams (engineering).

2.2 Findings

2.2.1 Eurocodes

The EN Eurocodes are a series of 10 European Standards, EN 1990 to EN 1999, providing a common approach for the structural and geotechnical design of buildings and other civil engineering works and construction products. Each Eurocode consists of several parts that cover technical aspects[19].

Climatic actions are considered in building structures primarily through EN 1991: snow loads, wind actions, thermal actions (due to temperature variations) and atmospheric icing – the latter is to be included in the second generation of the Eurocodes. Each Eurocode has a National Annex for each country which contains the values of nationally determined parameters (NDPs). In the current version of Eurocodes, regional allowances for climatic loads are made through climatic data or maps in each country's National Annex[20]. The standard design is based on the probability of occurrence, with design requirements based on the potential severity of the event, location or importance of the building[21].

Characteristic values are fixed on a statistical basis, corresponding to a prescribed probability of not being exceeded on the unfavourable side during a 'reference period', considering the design, working life of the structure and the duration of the design situation. The characteristic value of climatic actions is based upon the probability of 0.02 of its time-varying part being exceeded for a reference period of 1 year. This is equivalent to a mean return period of 50 years for the time-varying part. However, in some cases, the character of the action and/or the selected design situation makes another fractal and/or return period more appropriate[22].

Eurocode EN 1991-1-3 includes a clause of design for exceptional snowfalls and drifts resulting from a snow deposition pattern that has an exceptionally infrequent likelihood of occurring. The National Annexes decide whether to treat these as accidental actions, in locations where they are unlikely to occur, or as transient/persistent actions.

[19] https://eurocodes.jrc.ec.europa.eu

[20] JRC Report: Dimova, S., Fuchs, M., Pinto, A., Nikolova, B., Sousa, L. and Iannaccone S. (2015). State of implementation of the Eurocodes in the European Union, EUR 27511, doi:10.2788/854939, http://publications.jrc.ec.europa.eu/repository/handle/JRC97893

[21] JRC Report: Formichi, P., Danciu, L., Akkar, S., Kale, O., Malakatas, N., Croce, P., Nikolov, D., Gocheva, A., Luechinger, P., Fardis, M., Yakut, A., Apostolska, R., Sousa, M.L., Dimova, S. and Pinto, A. Eurocodes: background and applications. Elaboration of maps for climatic and seismic actions for structural design with the Eurocodes, EUR 28217, doi:10.2788/534912, JRC103917, https://publications.jrc.ec. europa.eu/repository/handle/JRC103917

[22] BS EN 1990:2002

2.2.2 Future of Eurocodes

Eurocodes have typically assumed that future climate conditions will be similar to historic conditions. The 2013 EU adaptation strategy identified standards as potentially important to guarantee the resilience to climate change. Technical material is being developed as part of the standardisation work programme for the second generation of Eurocodes. This analyses and provides guidance for potential amendments to the Eurocodes addressing relevant impacts of future climate change, both general and material-specific[23].

Updates are currently being considered by the Technical Committee CEN/TC 250 'Structural Eurocodes' in their response to Mandates M/466 and M/515 'Towards a second generation of EN Eurocodes'[23]:

- M/466 EN programming mandate addressed to CEN in the field of the structural Eurocodes;
- M/515 EN mandate for amending existing Eurocodes and extending the scope of structural Eurocodes.

The second generation of Eurocodes is planned to include the following[24]:

- Assessment, re-use and retrofitting of existing structures and their strengthening;
- Incorporation of ISO Standards in the Eurocodes family, such as atmospheric icing of structures and actions from waves and currents on coastal structures;
- Developing information on the determination of material and resistance factors improving the fire safety engineering approach;
- Potential amendments for Eurocodes with regard to structural design addressing relevant impacts of future climate change (general and material specific);
- Recent results relevant to innovation, e.g. performance-based design, sustainability concepts.

The work stream incorporating climate change proposes the introduction of a 'scaling factor' (FC) for climate actions. This scaling factor will be included in four climatic actions: snow, wind, thermal actions and atmospheric icing. These are expected to be addressed as a revision of the NDPs of EN 1991-1-3, EN 1991-1-4, EN 1991-1-5 and EN 1991-1-9. Their incorporation is relatively straightforward for snow, thermal and atmospheric icing actions. However, for wind actions, scaling factors are more challenging, as wind speed statistics used in Eurocodes are based on synoptic storms. Actions from different storm types are not directly comparable (different wind profiles and characteristics) and there is less established research on other types, such as thunderstorms[25].

These are still at the draft stage, with the committee reviewing and voting for their incorporation. Further implementation of the NDPs into revisions of the National Annexes will consequently not be in place for a few years. However, the main challenge lies in the uncertainties associated with climate projections and the constant improvement and update in modelling, which will keep progressing alongside the development of guidance. Key changes in the second-generation suite of the Eurocodes are presented at *https://eurocodes.jrc.ec.europa.eu/2nd-generation/second-generation-eurocodes-what-new*

The Joint Research Centre (JRC) of the European Commission provides scientific and technical support to the mandates. The JRC produces background documents published to integrate the latest scientific and technological knowledge developments. These include some background documents concerning the adaptation of structures to future climates.

1. Thermal design of structures and the changing climate (2020)[26]

This report concludes:

[23] https://eurocodes.jrc.ec.europa.eu/2nd-generation/second-generation-eurocodes-what-new

[24] https://eurocodes.jrc.ec.europa.eu/2nd-generation-evolution/standardisation-works-2g-eurocodes

[25] Meeting with Francesco Ricciardelli, leader of project team SC1.T6, M/515 Phase 4.

[26] https://publications.jrc.ec.europa.eu/repository/handle/JRC121351

- Models for extreme value calculations of thermal action will need to be updated based on new knowledge on variation of climate parameters, both with respect to traditional input data as well as model data and analysing tools.
- The trends on temperature show increasing values over all Europe.
- Estimates of characteristic values of climatic actions should be updated with intervals no longer than 10 years.

2. Expected implications of climate change on the corrosion of structures (2020)[27]

This paper includes various findings from different studies relating the effect of climate change on concrete and steel structures. An increase in temperature and relative humidity will increase the corrosion and deterioration of a concrete structure by:

- cover-cracking initiation and propagation;
- an increase in the carbonation depth;
- an increase in chloride concentration at the rebar level.

The risks can be assessed with solutions to include:

- an increase in concrete cover and durability of concrete structures;
- the use of higher-grade concrete or reinforcement such as low carbon steel, stainless steel, galvanised or other methods of cathodic protection or glass-fibre reinforced polymer rebar;
- a recommendation to use protective acrylic-based surface coatings for the existing buildings;
- the use of certain types of blended and alkali-activated (AA) cement.

The effects of climate change, including temperature change, accelerate corrosion in steel structures[28]. This results in cross-section thickness loss, thus affecting the structural performance in terms of strength, stiffness and ductility. Appropriate protection dependent on exposure should be considered to avoid this.

These background documents intend to present and provide research data. They provide frameworks to account for climate change and, in general, expected variations. This technical data could then influence and provide the framework for the development and implementation of climate change into Eurocodes. However, from the point of production of the background documents to their consideration and implementation in Eurocodes, a long and thorough process must be followed and agreed upon with many stakeholders.

The project team set up as part of Mandate M/526, Adaptation to Climate Change Coordination Group in CEN-CENELEC, is producing a draft background document on updates to Eurocodes to incorporate climate change, which is expected to be published soon. This mandate has already produced recent background documents.

2.3 National regulations and other initiatives

This section summarises the findings of other initiatives in European Member States. The findings incorporated here are non-exhaustive, and a full country-by-country review would have to be carried out to incorporate the recommendations of each country's National Annexes under Eurocodes, building codes and additional policies.

[27] https://publications.jrc.ec.europa.eu/repository/handle/JRC121312

[28] Expected implications of climate change on the corrosion of structures (JRC, 2020).

Germany intends to replace its postal code-based maps with geo-coordinate-based climate risk zones, particularly in wind loads[29], and the approach for estimating impacts of heavy rain events. In the Netherlands, flooding is regulated by the Dutch Water Act rather than through building regulations, considering climate change related to water management[32]. In Norway, performance-based building code addresses flooding, storm surge and landslides / avalanches, but these are based on historical data. The precipitation intensity is updated annually[29].

In Austria, climate change-effect for snow loads (EN1991-1-3) is described in informative Annex A, describing a method to derive a multiplying factor. These establish a transparent and scientifically based method to derive the characteristic snow loads. However, changes in standard methods of calculation may cause significant deviations in the values, therefore multiplying factors should be relevant to the method used.

Ireland includes significant consideration concerning hurricanes (e.g. roof strapping) in the building regulations. Further updating of Irish Standards and codes of practice are currently in progress (incorporating driving rain index, freeze/thaw, frost heave, snow loading and design weather files up to 2080).

However, homogenisation of the datasets to assess climate actions is still a major challenge to develop future climate datasets. This is being investigated through the JRC studies using the Eurocodes Nationally Determined Parameters Database (NDPs Database)[30].

2.3.1 National Adaptation Plans

Other initiatives are implemented through National Adaptation Plans of European countries, building certification schemes such as BREEAM, or local authorities/planning policy requirements. Some examples of National Adaptation Plans with initiatives on buildings include:

- Norway: klima2050.no/
- Sweden: Klimatanpassning.se/
- Austria: klimawandelanpassung.at, Adaptation strategy for Austria (bmk.gv.at)
- Belgium: klimaat.be, Burgemeestersconvenant.be
- Germany: DIBt - German Institute of Civil Engineering
- Denmark: klimatilpasning.dk, Climate Ready Housing
- Greece, Cyprus, Italy: urbanproof.eu/, LIFE Urbanproof project
- Poland: klimada2.ios.gov.pl/
- France: adaptation-changement-climatique.gouv.fr/thematiques/batiment

EU resources are in use in most countries, including the *Guide to Cost-Benefit Analysis of Investment Projects*[31], *Climate Change and Major Projects* and *Guidelines for Project Managers*[32]. All of these have a positive and progressive impact on adapting buildings to climate change. However, in most situations they provide a holistic approach to building/urban design, where the primary structure in most cases is not affected or does not provide the most relevant contribution to adaptation.

2.3.2 Other countries

A brief commentary is provided on considerations taken and progress by other countries to incorporate climate change actions into their building codes, based on the findings of the Global Resiliency Dialogue (2021) report[29].

[29] The use of climate data and assessment of extreme weather event risks in building codes around the world (Global Resiliency Dialogue, 2021).

[30] https://data.jrc.ec.europa.eu/dataset/jrc-eurocodes-ndps

[31] European Comission (2014). Guide to Cost-Benefit Analysis of Investment Projects.

[32] European Commission (2016). Guidelines for Project Managers: Making vulnerable investments climate resilient.

2.3.2.1 *Canada and the USA*

In the 2025 National Building Code of Canada (NBCC), new climate change provisions will be considered, incorporating future climate scenarios linked to degrees of global warming.

The American National Standard, International Code Council (ICC), have produced several standards for various climatic events, aligning with ASCE 7. These include the 'ICC Standard 600: Standard for Residential Construction in High-Wind regions' and the International Wildland-Urban Interface Code, focusing on areas with higher risks for wildfires.

2.3.2.2 *Australia and New Zealand*

In Australia, there is no current plan for full incorporation of climate change into the National Construction Code (NCC); however, they have set up research on future climate scenarios to improve building resilience. Bushfire provisions in the NCC are adopted by individual local jurisdictions based on their relative risk level. Additionally, a 5 % climate change multiplier to the regional wind speeds in cyclonic wind regions is proposed for the national wind code in 2022.

Similarly, in New Zealand, there is no current incorporation of climate change. However, there is research on how future climate change data can be incorporated into the building code by the Ministry of Business, Innovation and Employment, through the building for climate change programme[29].

2.4 General findings and recommendations

Currently, climatic actions are based on historic data instead of predictive data and no countries have fully implemented future climate risks. However, as seen with the Eurocodes and other building codes, there are aspirations to improve the resilience of buildings to extreme weather events. Updating building codes with accurate data would have the most significant effect on the design of structures, directly linked to being designed for resilience considering future climate scenarios. To ensure comparability and traceability, updating and aligning databases to standards (e.g. World Meteorological Organisation normal standards) is required if the use of historic data is preferred. Eurocodes should establish a common method to determine characteristic climatic loads, as there is currently a discrepancy between countries and application methods. Therefore, the application of a factor could be a simplification to address future climate scenarios.

There is an understanding that some European countries have incorporated some regulations to address future climate events. However, it is understood that it is challenging to address certain events as part of the building codes, such as hailstorms and storm surges impacting coastal regions. Some countries consider representative concentration pathways (RCPs) scenarios linked to degrees of global warming, whilst others consider a dynamic adaptive pathway[29].

Eurocodes should encourage the use of performance-based wind design (PBWD) in addition to code design. Project-specific design could combine recorded meteorological data with reanalysis data, which would provide a more accurate approach to the design of wind loads, until building codes provide more specific information. Other measures can include limiting peak story drift for operational performance to mean recurrence intervals.

There was no evidence on findings of any consideration of adaptation of exposure or durability factors as part of the codes. The material Eurocodes (EN 1992 to EN 1996) should progress to ensure structural durability is proportional to the exposure to climatic actions and possibly extend the design life of the structure beyond the minimum building life. The JRC reports[26,27] correlate the effects of climate change with the durability and expected building life. However, no tangible outcomes directly reflect what exposure classes or factors should be considered depending on the exposure to different climatic hazards.

EN 1990 defines design life as the period for which the structure shall be used with anticipated maintenance but without major repair. Most buildings are usually retained beyond this. Buildings should be able to withstand climatic actions, but longer building retention could be compromised in future climate conditions. Therefore this would link the lifetime of the building with expected climatic loads, and thus future climate scenarios. Factors of safety and redundancy are accounted for in the building design for climate loading, and most existing buildings have inherent redundancy. However, if future climate scenarios are not considered at design or at the time of adaptation of existing buildings, and these exceed the factored safety, the expected building design life could reduce or be unsafe after significant exposure to extreme conditions.

It is therefore important to provide increased resiliency of long-life structures to climate change consequences, with cost-effective benefits to avoid later retrofitting existing structures. The design life should consider a long-term view, beyond the original life cycle of the building and consider durability, longevity and adaptation to climate change. Generally, by applying durability, disassembly, adaptability and circularity principles, the properties of structural elements can be enhanced to enable their reuse in future life cycles.

Retention of existing and historic structures through adaptation and strengthening can provide a solution with less environmental impact than having to replace them with a new build. Additionally, this will contribute to maintaining and enhancing built heritage and the importance of retaining existing structures. Even though Eurocodes fail to address this currently, the second generation of Eurocodes should be able to support and provide further guidance on the repair and reuse of existing buildings. This, however, cannot fully be addressed by Eurocodes, and guidance such as CEN TC 346 Conservation of Cultural Heritage, supported by local guidance, heritage and planning requirements should be considered to support the adaptation of existing buildings to climate change.

2.5 Gap analysis and additional suggested further research

It is identified that the main gaps in the research arise from the ongoing implementation of future climatic scenarios in various building codes. More clarity in the field of structural design will arise from updates and publications, which seek a common approach in the application of building structural design. Additionally, the review of all national policies and adaptation plans is beyond the scope of this research, as the identification of structural-related implementation is not immediately addressed individually by each strategy, but instead relies on the application of Eurocodes. While some countries may provide additional specific guidance, as highlighted in Section 2.3, this is very fragmented. As a result, there is no holistic solution to implement adaptation of the structure to climate change. The incorporation of guidance on the adaptation of existing structures is also crucial to ensure future climatic scenarios do not affect existing structures.

At a national level, other institutions, research centres and government advisory bodies could be reached to provide additional feedback on current progress and outlook, such as Global ABC, with leading documentation on building resilience. Negligible findings on specific structural best practice examples were available, again relating to the lack of understanding of the effects of future climatic scenarios.

2.6 Conclusions and recommendations

Overall, current progress to incorporate climate change adaptation into structural design codes and standards has been poor. This is due to:

- the extensive process required to update building codes and regulation documents;
- the projections of future climatic scenarios in various geographies and locations across Europe, with multiple possible scenarios;
- the inappropriate characterisation of the potential impacts of climate change on weather patterns and their adverse effects on the primary structure.

Significant research and initiatives are being led in this area by the European Commission, particularly with the publication of the JRC background documents. Until this documentation is implemented into the codes, it would be recommended to promote guidance and implementation on a project-specific basis as best practice.

Typically, building codes and guidance currently avoid focusing in detail on structural design measures for adaptation. This document makes assumptions about the current development of the Eurocodes. This document should therefore be revised after the publication of these, which would fully clarify the approach taken to incorporate climate change adaptation in structural design standards.

In a project-specific situation, scaling factors can be incorporated to climatic effects to ensure sufficient allowance is included in the design to account for a specific climate hazard (e.g. increased wind load, snow load, flooding loads on the substructure). Structural design following building codes already allows for some redundancy by using safety factors. Safety factors incorporate the consideration for loads being more onerous or conservative material capacities, creating an inherent redundancy against any unfavourable climatic actions. Homogenisation of data and a common approach to future climatic scenarios should be supported through Eurocodes to complement scaling factors proposed to account for future climate adaptation. This will have to rely on combined work with local authorities and guidance.

Further understanding between the building life and the impact of natural hazard risks becoming more severe and frequent is required. Resiliency should aim to address structures to fully recover after an event. Codes should progress to ensure that structural durability is proportional to the exposure to climatic actions and possibly extend the design life of the structure beyond the minimum building life.

However, another essential consideration in adaptation to climate change is not to over-design and over-specify materials to account for any possible increase in climate hazards. Instead, the right balance between structural resilience and embodied carbon emissions of structural materials should be considered. Where possible, optimisation of the design to avoid climate change impacts that do not contribute to additional structure emissions should be pursued, weighing between reduced emissions and increased longevity.

3. CLIMATE VULNERABILITY & RISK ASSESSMENT METHODOLOGY OVERVIEW

3.1 Introduction

This chapter reviews and synthesises existing climate vulnerability & risk assessment (CVRA) methodologies, to inform the development of a methodology specifically adjusted for buildings and blocks of buildings. To do so, existing literature has been assessed against criteria to identify best-practice examples.

This chapter provides:

- an overview of existing CVRA methodologies and approaches;
- an assessment of the best identified CVRA methodologies and approaches;
- recommendations for a CVRA approach specific to buildings.

This chapter is relevant for:

- authorities – to aid the development of climate-related strategies for buildings;
- investors, insurers, developers – to increase their understanding of climate-related risks, improve cooperation between stakeholders and ensure investment is directed to resilient buildings;
- engineers, architects, builders – to improve awareness of climate-related risks and ensure that climate resiliency is built in to designs from an early stage.

3.1.1 Key concepts and definitions

A **hazard** is 'the potential occurrence of a natural or human-induced physical event or trend that may cause loss of life, injury, or other health impacts, as well as damage and loss to property, infrastructure, livelihoods, service provision, ecosystems and environmental resources'[33]

Exposure is 'the presence of people; livelihoods; species or ecosystems; environmental functions, services, and resources; infrastructure; or economic, social, or cultural assets in places and settings that could be adversely affected'."[33]

Sensitivity is 'the degree to which a system or species is affected, either adversely or beneficially, by climate variability or change'. The term 'sensitivity' is sometimes replaced with 'susceptibility' in the literature, although there is a subtle difference between the two.

Adaptive capacity is the ability of systems, institutions, humans and other organisms to adjust to potential damage, to take advantage of opportunities, or to respond to consequences.[34]

Vulnerability is the propensity or predisposition to be adversely affected and is defined by the IPCC as a combination of susceptibility and adaptive capacity.[35] In more practical methodologies, vulnerability is generally considered to be the product of both the exposure and sensitivity analyses[36] [37]

[33] IPCC (2021). Sixth Assessment Report. Impacts, Adaptation, and Vulnerability. Available at: https://www.ipcc.ch/report/sixth-assessment-report-working-group-ii/

[34] MA (2005). Appendix D: Glossary. In: Ecosystems and Human Well–being: Current States and Trends. Findings of the Condition and Trends Working Group [Hassan, R., Scholes, R. and Ash N. (eds.)]. Millennium Ecosystem Assessment (MA). Island Press, Washington DC, USA, pp. 893-900.

[35] IPCC (2014) Fifth Assessment Report. Impacts, Adaptation, and Vulnerability. Available at: https://www.ipcc.ch/report/ar5/wg2/

[36] European Commission (2021). Technical guidance on climate-proofing of infrastructure projects for the period 2021-2027. Available at: https://op.europa.eu/en/publication-detail/-/publication/23a24b21-16d0-11ec-b4fe-01aa75ed71a1/language-en

Risk results from the interaction of vulnerability (of the affected system), its exposure over time (to the hazard), as well as the (climate-related) hazard and the likelihood of its occurrence.

The interaction between these components is explored in Section 3.3.

3.1.2 Climate vulnerability and risk assessments

CVRAs are commonly used to evaluate the potential effects of climate change on a system. They are an effective tool to identify where there is a need to adapt to future climate change and therefore to inform the prioritisation and implementation of design and mitigation measures.

CVRAs are frequently conducted on both a mandatory and voluntary basis. As discussed in Chapter 1, the EU policy framework has started to require and support more action for adapting assets to climate change. Even when not required, CVRAs are often used voluntarily by stakeholders to understand the risks facing an asset and improve resilience. Some specific requirements and recommendations include:

- the EU Taxonomy Regulation, which requires companies to carry out an adequate CVRA for reporting on their contribution to the goals of climate change adaptation and mitigation;
- the CVRA, which can also be conducted to inform a financial disclosure, as recommended by the Task Force on Climate-related Financial Disclosures (TCFD);
- the potential for impacts of climate change to be incorporated within Eurocodes in the future, although structural design standards such as Eurocodes generally only consider current climate conditions (see Section 2.2);[38]
- the Environmental Impact Assessment (EIA) Directive states that it is important to assess the vulnerability of projects to climate change;
- the use of CVRA by the insurance sector is discussed within Section 3.3 below.

There are also variations in the approaches used to undertake a CVRA, with different emphasis put on vulnerability and risk, depending on the context. The most widely accepted definitions of the different components of a CVRA come from the Intergovernmental Panel on Climate Change (IPCC). The climate risk definition in the Fifth Assessment Report (AR5)[39] of the IPCC is widely used and considers both external climatic factors (hazards and spatial exposure) and internal vulnerabilities to those changes (vulnerability) when attempting to predict impacts. Thus, risk is a function of vulnerability, exposure and hazard, as defined in AR5 and maintained in AR6[40]. The interaction between these components varies within the literature, as discussed in the following sections, depending on the aim of the approach.

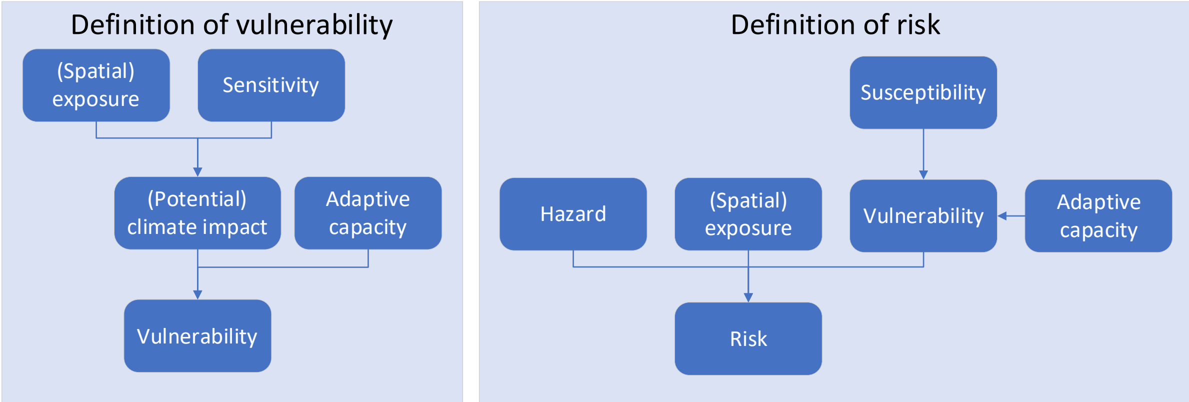
[37] Umweltbundesamt (2017). Guidelines for Climate Impact and Vulnerability Assessments. Available at: https://www.umweltbundesamt.de/sites/default/files/medien/376/publikationen/guidelines_for_climate_impact_and_vulnerability_assessments.pdf

[38] Commission of the European Communities (2009). White Paper. Adapting to climate change: Toward a European framework for action. Available at: https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52009DC0147&from=EN

[39] IPCC (2014). Fifth Assessment Report. Impacts, Adaptation, and Vulnerability. Available at: https://www.ipcc.ch/report/ar5/wg2/

[40] IPCC (2021) Sixth Assessment Report. Impacts, Adaptation, and Vulnerability. Available at: https://www.ipcc.ch/report/sixth-assessment-report-working-group-ii/

Figure 3.1 Vulnerability as per IPCC 2007 and risk as per IPCC 2014[41]



3.1.3 CVRAs for buildings

The impacts of climate change are already being felt globally, with some organisations, regions and sectors more likely to be adversely affected than others. The built environment is one sector particularly at risk from climate change, with considerable potential damages and losses to real estate[42]. The IPCC AR6 states that 'information on climate risks needs to be embedded into the architectural design, delivery and retrofitting of housing'.[43] Although the approach to CVRA for infrastructure is fairly well defined, a more specific, widely applicable methodology for buildings would allow for more appropriate and targeted adaptation measures to be identified and implemented in order to improve resilience to climate change. In particular, a methodology for CVRA in buildings is needed, which is practical and understandable to the wide range of user groups that may conduct a CVRA, such as:

- building users, facility managers and owners;
- design teams (engineering and architecture) and consultants; and
- investors, developers and insurers (as detailed in Section 3.3 below).

For new buildings and renovation projects, the assessment would ideally be done at an early design stage to allow the incorporation of suitable adaptation measures. Given the uncertainty of climate projections and the potential for unforeseen impact development, it is advisable to carry out a CVRA at regular intervals within the lifespan of a building.

Importance of building typology

When conducting a CVRA, the building typology is a key consideration. For instance, sensitivity factors differ if the building being considered is a single-family house, an office building, a school or a hospital. Similarly, the resources available to carry out a CVRA are different if the owner of the building is an individual rather than a public authority or a large private developer. Table 3.1 below presents an overview of the main typologies of buildings and how they can impact the way a CVRA is performed. Where relevant, specific recommendations relating to different types of buildings are included within the sections below.

[41] Umweltbundesamt (2017). Guidelines for Climate Impact and Vulnerability Assessments. Available at: https://www.umweltbundesamt.de/sites/default/files/medien/376/publikationen/guidelines_for_climate_impact_and_vulnerability_assessments.pdf

[42] UNEP (2021). Practical guide to climate-resilient buildings and communities. Available at: https://www.unep.org/resources/practical-guide-climate-resilient-buildings#:~:text=This%20UNEP%20publication%20demonstrates%20how,structures%20are%20largely%20self%2Dbuilt

[43] The IPCC AR6 is currently at the final draft stage and as such is subject to final edits.

Table 3.1 Overview of building typologies and related implications for a CVRA

Characteristics	Building typology	Implications for a CVRA
Type of user/function	Residential, commercial, education, industrial, logistics, high rise, science, data centres, healthcare, leisure/sport, hotels, culture/tourism, government, public use, urban regeneration	• Different sensitivity factors • Different adaptive capacity
Ownership	Privately-owned/public building	• Difference in the amount of resources or rationale for performing a CVRA • Varying ability and resources to implement adaptation solutions
Scale and form	Single-family house / multi-family house / large building	• Different sensitivity factors • Varying levels of exposure to climate hazards

3.2 Identified CVRA methodologies applicable to the built environment

A literature review identified approximately 20 documents that were relevant to the topic of a CVRA for buildings (see Appendix 1). Literature was identified both through desk research and through consultation with stakeholders.

Table 3.2 presents the short list of 12 methodologies and approaches most applicable to buildings and CVRAs according to the criteria listed below. A longer version of the table, with additional details, is presented in Appendix 2.

- Directly applicable to buildings, or can be easily adapted to apply to buildings;
- Provide a sufficient level of detail and a transparent methodology;
- Applicable to countries in the European Union;
- Broadly consistent with accepted definitions of vulnerability and risk as defined by the IPCC AR5 and AR6.

Table 3.2 Overview of identified CVRA methodologies and relevant approaches

Name	Strengths	Limitations
European Commission (2021). Climate proofing of infrastructure	• Clear, detailed methodology for use in practice	• Not specific to buildings • Vulnerability definition does not factor in building inhabitants or the use of different buildings
Institute of Environmental Management and Assessment (2020). Environmental Impact Assessment Climate Change Resilience	• Detailed methodology for use in practice • Widely used (in the UK)	• UK-orientated (link to EIA Directive) • Not specific to buildings
Umweltbundesamt (2017). Guidelines for climate and vulnerability assessments	• Builds on IPCC definitions of a CVRA • Provides a description of the steps to implementing a CVRA	• Not specific to buildings but contains an example of an impact chain for buildings
ISO 14091 (2021). Adaptation to climate change	• Provides a description of the steps to implementing a CVRA • Includes examples of indicators for a CVRA	• Not specific to buildings
Green Ribbon Commission (2019). Climate Resilience Template for Buildings	• Specific to buildings • Describes a comprehensive resilience planning process for buildings, incl. steps for a CVRA	• Focused on Boston (USA)
United Nations Environment Programme (2021). Practical guide to climate-resilient buildings and communities	• Specific to buildings • Useful detail on vulnerability determinants and wider impacts / social factors • Provides details on adaptation measures	• Does not describe steps of a specific methodology
United Kingdom Green Buildings Council (2022). A Framework for Measuring and Reporting of Climate-related Physical Risks to Built Assets	• Clear methodology and accompanying framework • Practical guidance with a focus on buildings • Aligned with TCFD recommendations	• Reporting framework rather than CVRA methodology
Observatoire de l'immobilier durable (2022). Guide des actions adaptatives au changement climatique	• Aligned with IPCC 2014 risk definition • Specific to buildings • Accompanying guidance notes on the impacts of key hazards on buildings	• Does not describe steps of a specific methodology
Umweltbundesamt (2022). How to perform a robust climate risk and vulnerability assessment for EU taxonomy reporting? Recommendations for companies – Draft	• EU Taxonomy – aligned • Step-by-step methodology	• Not specific to buildings
The Geneva Association (2021). Climate Change Risk Assessment for the Insurance Industry	• Draws attention to the need to assess climate risks for businesses/assets, and in particular suggests quantitative/qualitative scenario analysis[44]	• Not specific to buildings • Does not describe steps of a specific methodology
PSI-TCFD (2021). Insuring the climate transition: enhancing the insurance industry's assessment of	• Clear definition of steps and concepts for scenario	• Not specific to buildings

[44] Scenario analysis is a method for predicting the possible occurrence of an object or the consequences of a situation, assuming that a phenomenon or a trend will be continued in the future.

Name	Strengths	Limitations
climate change futures	analysis	• Does not describe steps of a specific methodology • Based on modelling
Zurich (2019). Managing the impacts of climate change: risk management responses – second edition	• Draws attention to the need to assess climate risks for businesses/assets • Defines CVRA-related concepts from the point of view of the industry	• Not specific to buildings • Does not describe steps of a specific methodology • Involves modelling
Coalition for Climate Resilient Investment (2021). Physical Climate Risk Assessment Methodology	• Defines steps for the quantification of climate impacts on assets	• Not specific to buildings • No details on how CVRA is specifically carried out
European Bank for Reconstruction and Development (2018). Advancing TCFD Guidance on Physical Climate Risks and Opportunities	• Provides recommendations for scenario analysis disclosures in relation to physical risk (concrete steps)	• Not specific to buildings • Does not describe steps of a specific methodology
Cambridge Institute for Sustainability Leadership (2019). Physical risk framework: Understanding the impacts of climate change on real estate lending and investment portfolios	• Describes steps to applying catastrophe modelling to understand physical risks and impacts on investors/lenders' portfolios	• Does not describe steps of a specific methodology • Involves modelling

3.3 Assessment of identified CVRA methodologies

Methodology types

Most of the reviewed documents describe a process-based methodology for CVRAs. Other documents (e.g. Practical guide to climate-resilient buildings and communities) describe concepts or issues that are relevant to CVRAs in buildings, but do not describe the actual methodologies. These have been included in the review as they provide relevant insights into how CVRAs can be conducted in this context.

The process-based methodologies comprise a varied number of steps or phases that users need to go through to assess vulnerability and risks. Some methodologies include steps such as 'identify relevant climate hazards', 'assess exposure', 'assess vulnerability', while others consider 'data collection', 'develop impact chains' as relevant steps for the CVRA process and describe the components of risk as a conceptual framework.

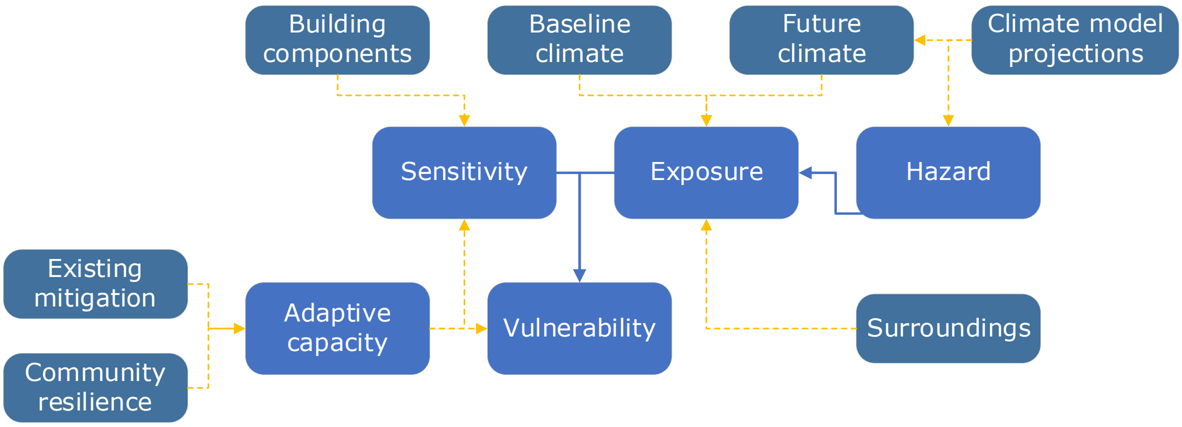
Components and definitions

The figure below illustrates different components of a CVRA identified in the methodologies reviewed. Some methodologies include a larger number of components (e.g. IEMA), while others are rather simple, including a reduced number of basic components (e.g. OID).

Overview of CVRA components

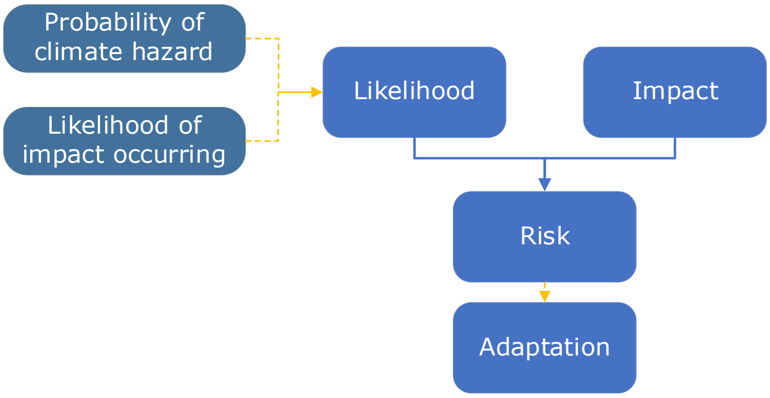
Phase 1 (Screening)

Figure 3.2 Overview of CVRA components – Phase 1 (Screening)



Phase 2 (Subject to outcome of Phase 1)

Figure 3.3 Overview of CVRA components – Phase 2 (subject to outcome of Phase 1)



Source: Own illustration.

Most methodologies provide a definition of the different components, which are in general in line with the IPCC AR5 definitions. When it comes to the actual assessments of the components, the level of detail is quite varied, with some methodologies specifying how to assess them in detail, even against specific indicators (e.g. *Technical Guidance on Climate Proofing of infrastructure*, ISO)[45,46], and other methodologies not going into detail (e.g. OID).

Applicability to buildings

Although a range of CVRA methodologies were identified, very few of them relate specifically to buildings. Many approaches focus on assessing climate vulnerability at larger scales such as regional or local/urban scales, rather than at the level of an individual building or block of buildings. However, several approaches cover infrastructure or assets more generally and could be adapted to focus more specifically on buildings (as per the recommendations in the next chapter).

Climate hazards and regions included

Only some of the methodologies assessed indicate the specific hazards they are applicable to (e.g. IEMA, Green Ribbon Commission), while most of the others indicate that the relevant climate hazards for a specific location need to be identified as part of the hazard assessment.

Impact, ease of use and limitations

It has not been possible to assess to what extent the different methodologies are implemented in practice at the level of buildings, and therefore it is not possible to assess impact of the methodologies. It is also challenging to assess ease of use, as most of the methodologies do not go into details on how the actual assessments of the different components of CVRA will be performed. It is expected that challenges in the implementation of the methodologies relate to the availability of data at the building level (in particular local climate data, for example). Depending on the use and level of detail needed for the CVRA, resources to perform the assessment can also be a limitation.

In general, the biggest limitation of the methodologies assessed is regarding their direct applicability to buildings, as well as the lack of detail concerning the procedures to actually perform the analysis of each of the components of a CVRA. The next chapter provides insights on how to deal with these limitations.

CVRA in the insurance sector

The literature review and stakeholder consultation have highlighted that the insurance sector considers the assessment of climate-related physical risk from a slightly different perspective to other stakeholders.

While property owners, engineers, architects (and other) stakeholders undertake CVRAs to get a better understanding of what the risks faced by a building are and how to tackle them, i.e. to identify the most appropriate climate adaptation measures, the insurance sector (and investors) aim to understand physical risk under a financial perspective. Specifically, they:

- assess physical risk for underwriting purposes, i.e. to understand whether it makes sense to insure a specific asset, and at what price. This is also important for disaster and climate risk management following an event;
- assess physical risk to guide strategic and portfolio-level decisions, i.e. to understand where it makes sense to invest; and/or

[45] The Technical Guidance for Climate Proofing of infrastructure provides an overview of a scoring system to assess sensitivity, exposure and vulnerability, where a grading from high to low is attributed to each element of the analysis.

[46] For instance, ISO contains examples of indicators for risk assessments for each of the 'risk components' of a CVRA. For example, 'Location of habitats in areas affected by sea level rise' is an indicator of exposure of ecosystems, or 'Resourced climate change adaptation plan of action' is an indicator of adaptive (organisational) capacity.

- assess physical risk to comply with reporting and disclosure requirements, e.g. under the Task Force on Climate-related Financial Disclosures (TCFD).

In all cases, a financial analysis follows the assessment of risks.

These activities can be undertaken both prior to the construction of a new building or on existing buildings. Notably, when it comes to underwriting, gaining an early understanding of physical risk can stimulate the implementation of adaptation measures, which can in turn favour insurability.

Currently, there is no uniform or coherent approach to taking physical risk into account in the insurance sector. While a number of guidance documents were developed or are in the process of being developed in relation to the TCFD recommendations (as included in Table 3.2 above), there are still a variety of implementation approaches within the sector.

Specifically, the sector:

- integrates climate projections in natural catastrophe models[47] (with a number of limitations);
- implements alternative CVRA approaches, e.g. scenario analysis[48]; or
- does not take physical climate risk into account as such, i.e. these considerations are not yet taken into account when it comes to underwriting or during portfolio-level strategic decisions.

Notably, one or more of these approaches can be adopted at the same time by a company. A scenario analysis can also be relevant for investors and lenders.

3.4 Recommendations for CVRA methodology applicable to buildings

The proposed methodology demonstrates how to conduct a CVRA for buildings and was developed based on the reviewed literature. In particular, the methodology builds on the *Climate proofing of infrastructure*, which is considered to be one of the most practical and relevant for a variety of audiences. Recommendations are provided to adjust this methodology and make it fully applicable to a building rather than infrastructure in general.

Notably, the applicability of the proposed methodology can vary depending on the context in which this is conducted. In particular, factors such as available budget and the expertise to conduct a CVRA, availability of climate projections and the end user (and use) of the CVRA can play a role when it comes to how this methodology can be implemented in practice. For example, if the perceived importance and hence time and budget allocated are low, some steps might be skipped, or if no detailed climate projections are available, the end result of the CVRA can differ in terms of level of detail and usability.

With this in mind, it is understood that, as a minimum, a CVRA methodology for buildings should consist of:

- an assessment of **exposure**, covering the physical hazards that a building is likely to be exposed to within its expected life span, along with any environmental factors that may have an influence;
- an assessment of the **vulnerability** of a building to any identified hazards, comprising an analysis of **sensitivity/susceptibility** and **adaptive capacity**; and
- an overview of the potential **impacts**, along with an assessment of the **likelihood** and **magnitude** of these in order to assess climate-related risks to the building.

These core components of the recommended approach to CVRA for buildings are illustrated in

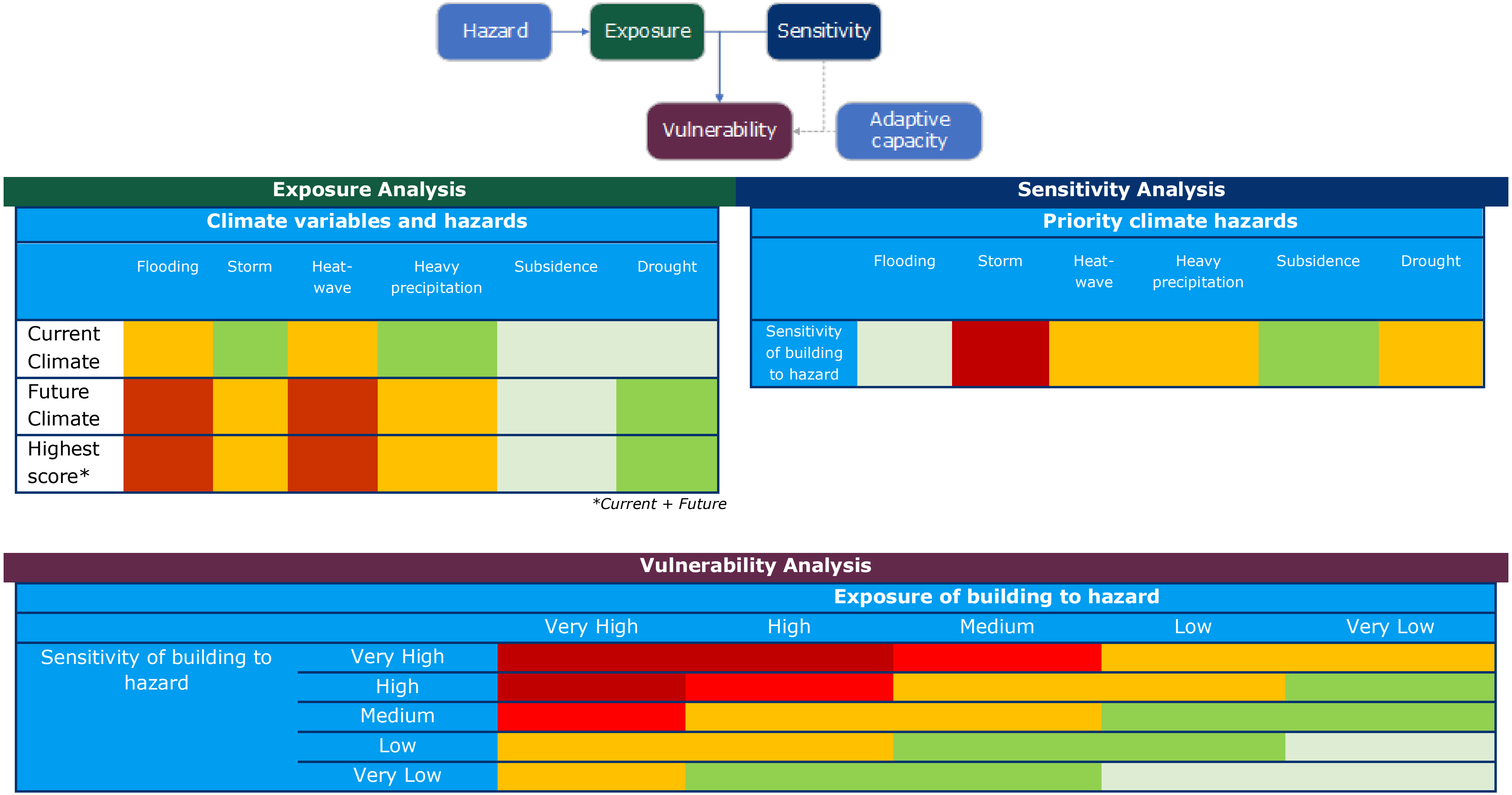
[47] These are computerised processes that simulate potential catastrophic events and estimate the amount of loss due to the events. See: https://content.naic.org/cipr-topics/catastrophe-models-property

[48] Scenario analysis is a method for predicting the possible occurrence of an object or the consequences of a situation, assuming that a phenomenon or a trend will be continued in the future.

Figure 3.4 below. To simplify the approach, as outlined in *Climate proofing of infrastructure*, a phased approach is recommended to enable users to focus first on the vulnerability analysis (Phase 1), and then on the risk assessment (Phase 2), depending on the outcome of Phase 1. Although the interaction between the components deviates slightly from the IPCC when compared with Figure 3.1 the key components and interactions included in Phase 1 and Phase 2 are considered an important addition to ensure a practical approach that is applicable to a variety of users. The following sections provide further explanation on each of the components illustrated in Figure 3.4.

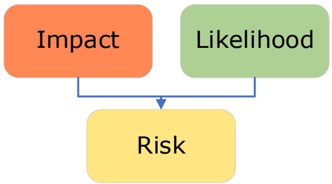
Figure 3.4 Phased approach to CVRA based on guidance from *Climate proofing of infrastructure*

Phase 1 (Screening)



Vulnerability should be assessed separately for each relevant hazard.

Phase 2 (Subject to outcome of Phase 1)



Impact analysis

Consequence level	Health and safety	Financial impacts
Very high	Multiple fatalities	>10 % of the building/development value
High	Single fatality / multiple long-term injuries	8-10 % of the building/development value
Medium	Long-term injury or illness, prolonged hospitalisation, or inability to work	4-8 % of the building/development value
Low	Lost time, injury or medical treatment required, short-term impact on persons affected	1-3 % of the building/development value
Very low	Minor harm or near miss	<1 % of the building/development value

The scale of the impact analysis provides a flexible approach which should be relevant the full range of building typologies.

Likelihood analysis

Likelihood level		
Unlikely	**Possible (as likely as not)**	**Likely**
The climate impact is not anticipated to occur during the lifetime of the proposed development.	The climate impact may occur a limited number of times during the lifetime of the proposed development.	The climate impact may occur multiple times during the lifetime of the proposed development.

The likelihood analysis focuses on the likelihood of the impact occurring during the lifetime of the building or block of buildings.

Risk assessment

Consequence level	Likelihood of impact		
	Unlikely	Possible	Likely
Very high	Medium	High	High
High	Medium	High	High
Medium	Low	Medium	High
Low	Low	Low	Medium
Very low	Low	Low	Medium

This approach is based on the guidance in *Climate proofing of infrastructure* with suggested modifications to maximise the applicability to buildings and the relevant user groups. The key components of a CVRA for a building are described in more detail below.

3.4.1 Phase 0 – Pre-screening

In addition to the steps outlined in the guidance in *Climate proofing of infrastructure*, it is useful to begin with a review of all possible climate hazards that could be relevant to the building, such as those listed by the EU Taxonomy (Table 3.3) and other secondary/indirect hazards. These hazards should be screened, based on the following criteria:

- Relevance to location: for example, hazards such as permafrost thaw will only be applicable to specific regions of Europe;
- Possibility of causing adverse effects on a building: for this criterion, it is important to consider all relevant receptors. For example, while a hazard such as heat waves is unlikely to cause damage to the building structure, it may impact the function and therefore the value if the building is not useable during hot weather.

Hazards that either will not occur at the site location or do not pose a material risk to the building and its function can then be filtered out in order to avoid unnecessary analysis. For any hazards filtered out of the assessment, it is recommended to provide a brief justification before moving to phase 1.

Table 3.3 List of climate hazards as presented in the EU Taxonomy Climate Delegated Act, Appendix A

	Temperature-related	Wind-related	Water-related	Solid mass-related
Chronic	Changing temperature (air, freshwater, marine water)	Changing wind patterns	Changing precipitation patterns and types (rain, hail, snow/ice)	Coastal erosion
	Heat stress		Precipitation or hydrological variability	Soil degradation
	Temperature variability		Ocean acidification	Soil erosion
	Permafrost thawing		Saline intrusion	Solifluction
			Sea-level rise	
			Water stress	
Acute	Heat wave	Cyclone, hurricane, typhoon	Drought	Avalanche
	Cold wave	Storm (including blizzards, dust and sandstorms)	Heavy precipitation	Landslide
	Wildfire	Tornado	Flood (coastal, fluvial, pluvial, groundwater)	Subsidence
			Glacial outburst	

3.4.2 Phase 1 – Screening

3.4.2.1 Hazards and exposure

The IPCC AR6 defines a **hazard** as *'the potential occurrence of a natural or human-induced physical event or trend that may cause loss of life, injury, or other health impacts, as well as damage and loss to property, infrastructure, livelihoods, service provision, ecosystems and environmental resources'*.

The types of hazards to consider (as in the EU Taxonomy Regulation[49]) include:

- temperature-related (e.g. heat stress, wildfire, frost);
- water-related (e.g. flooding, heavy precipitation);
- wind-related (e.g. storm, tornado); and
- solid mass-related (e.g. subsidence, landslide).

[49] Regulation (EU) 2020/852 of the European Parliament and of the Council of 18 June 2020 on the establishment of a framework to facilitate sustainable investment, and amending Regulation (EU) 2019/2088. Available at: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32020R0852

Exposure in IPCC AR6 is defined as 'the presence of people; livelihoods; species or ecosystems; environmental functions, services, and resources; infrastructure; or economic, social, or cultural assets in places and settings that could be adversely affected'.

In the built environment, exposure refers to the fact of the built asset being in a particular situation or place and therefore subject to a potential loss[50]. The 'exposure' component of a CVRA approach is more specific to the location than the type of asset, and as such does not require adjustment from a more general CVRA methodology to be made applicable to a buildings assessment.

Climate data and projections

The exposure analysis should begin with a baseline review to identify hazards that currently pose a threat to the building. This could be based on weather station data, as well as any historic events at the site (e.g. flooding). As climate data is generally limited to a spatial scale in the order of kilometres, site-specific information is particularly important in the context of buildings that are generally small-scale sites.

Additionally, the exposure analysis should consider regional variations. For example, due to the wide range of climatic conditions across Europe, the importance of different hazards varies by region. This means that issues such as extreme heat being likely to pose a higher risk in Southern Europe than in other parts of Europe should be considered.

An assessment of how the climate will change over the appropriate timescale (e.g. lifespan of the building) should then be undertaken, for comparison with the current baseline in order to identify trends. To fully assess the exposure, an analysis of the climate data available for the location of the building or block of buildings would ideally be conducted in order to identify the relevant climate hazards. However, an ongoing issue with the development of CVRA approaches for Europe is the limited technical understanding of climate data and projections. Although most identified CVRA methodologies suggest a list of sources for data, potential building sector practitioners do not always have access to or a clear understanding of the use of climate data. Further guidance may therefore be needed in order to help some user groups identify the best source of data for each assessment.

Given the small spatial scale of most building projects, it is recommended that the exposure analysis is based on the highest resolution data possible. For example, the Copernicus Climate Change Service[51] is often recommended as a source of projections (e.g. guidance in Climate proofing of infrastructure[52]), providing a range of data outputs for Europe, while some countries have their own regional climate projections available (e.g. UKCP18[53]; DRIAS[54]).

[50] UKGBC (2022). A Framework for Measuring and Reporting of Climate-related Physical Risks to Built Assets. Available at: https://www.ukgbc.org/ukgbc-work/measuring-and-reporting-framework/
[51] Copernicus CDS: https://cds.climate.copernicus.eu/#!/home
[52] European Commission (2021). Technical guidance on climate-proofing of infrastructure projects for the period 2021-2027. Available at: https://op.europa.eu/en/publication-detail/-/publication/23a24b21-16d0-11ec-b4fe-01aa75ed71a1/language-en
[53] See: https://www.metoffice.gov.uk/research/approach/collaboration/ukcp
[54] See: http://www.drias-climat.fr/

The Royal Netherlands Standardization Institute Foundation[55] provides a list of climate projection sources for each country in Europe, which can be a starting point for the exposure analysis where the best available national projections are not known. Where regional projections or the required technical expertise are not available, a 'minimum required' exposure analysis could utilise a web-based hazard identification tool, such as the ThinkHazard tool[56] (see Table 3.4). Additionally, for a high-level CVRA, data sources such as national risk assessments, Climate ADAPT[57] or the IPCC AR6 WG1 Interactive Atlas[58] should be sufficient to provide an overview of the applicable hazards. However, the most comprehensive form of assessment would include an analysis of regional climate projections for multiple future time periods and scenarios (e.g. representative concentration pathways).

A table such as Table 3.4 below may be used to present the exposure analysis, with each hazard rated from very low to very high. This 5-level rating scale allows for a more detailed analysis and captured nuances in the exposure of different buildings.

Table 3.4 Example of a table to assess overall exposure of the building to each applicable hazard[59]

Climate variables and hazards						
	Flooding	**Storms**	**Heat wave**	**Heavy precipitation**	**Subsidence**	**Drought**
Current climate	Medium	Low	Medium	Low	Very low	Very low
Future climate	High	Medium	High	Medium	Very low	Low
Highest score (current + future)	High	Medium	High	Medium	Very low	Low

3.4.2.2 *Sensitivity*

Sensitivity is 'the degree to which a system or species is affected, either adversely or beneficially, by climate variability or change'.[60] The term 'sensitivity' is sometimes replaced with 'susceptibility' in the literature, although there is a subtle difference between the two.

For a CVRA of a building, it is recommended to carry out the sensitivity analysis as the second step of the assessment for the relevant hazards identified through the exposure analysis. The *Climate proofing of infrastructure* guidance[61] recommends that the sensitivity analysis should identify which climate hazards are relevant to the specific type of project, irrespective of its location. However, it is suggested that the exposure analysis is a more practical first step for a building's CVRA, as the relevant hazards will be determined primarily by location, and the structural elements will be broadly the same each time.

[55] CEN-CENELEC (2021). Tailored guidance for standardization technical committees: How to include climate change adaptation in European infrastructure standards.

[56] See: https://thinkhazard.org/en/

[57] See: https://climate-adapt.eea.europa.eu/

[58] See: https://interactive-atlas.ipcc.ch/

[59] Adapted from the European Commission (2021). Technical guidance on climate-proofing of infrastructure projects for the period 2021-2027. Available at: https://op.europa.eu/en/publication-detail/-/publication/23a24b21-16d0-11ec-b4fe-01aa75ed71a1/language-en

[60] IPCC (2021). Sixth Assessment Report. Impacts, Adaptation, and Vulnerability. Available at: https://www.ipcc.ch/report/sixth-assessment-report-working-group-ii/

[61] European Commission (2021). Technical guidance on climate-proofing of infrastructure projects for the period 2021-2027. Available at: https://op.europa.eu/en/publication-detail/-/publication/23a24b21-16d0-11ec-b4fe-01aa75ed71a1/language-en

The type and use of a building should be a key consideration in assessing its sensitivity. For critical buildings such as hospitals, a more comprehensive assessment may be required given the sensitivity of the patients in the building. The type of building structure will influence its sensitivity to specific hazards – for example, a high-rise building is likely to be sensitive to high winds, while buildings with levels below ground may be more sensitive to flooding. Additionally, building occupancy is an important factor and should be taken into account because the sensitivity may vary greatly and will influence the potential impacts identified in Section 3.4.3.1 below. For example, the residents of a care home are likely to be significantly more sensitive to the effects of heat waves than office users so additional adaptation measures may be required to minimise harm to this category of building users.

Sensitivity may be assessed for the building and its occupants as a whole; however, it is recommended that each of the following components are considered when assessing sensitivity to specific hazards, where relevant / appropriate:

- Indoor space,
- Foundations,
- Outdoor space,
- Basement,
- Ground floor,
- Roof,
- Utilities (such as water and electricity), and
- Building function and occupants.

Other components of a building that may need to be considered include any infrastructure within the site boundary, such as paths, car parks and bridges connecting buildings. These are likely to be more relevant in the case of a block of buildings, for example a campus.

The Government of Quebec have produced guidance for the vulnerability and adaptation of buildings to climate change, which includes a profile of a 'standard' building (see Appendix 4), indicating which components of a building (roof, electrics, etc.) are at risk from each climatic hazard. A similar approach would be useful for the European context, in order to encourage the assessment of specific components where expert judgement is not available – for example the output provided by the Bat-ADAPT tool. However, assigning sensitivity scores is best carried out by technical experts[62].

Table 3.5 Example of a table to assess overall sensitivity of the building to each relevant hazard

	Priority climate hazards					
	Flooding	**Storms**	**Heat wave**	**Heavy precipitation**	**Subsidence**	**Drought**
Sensitivity of building to hazard	Very low	High	Medium	Medium	Low	Medium

[62] European Commission (2021). Technical guidance on climate-proofing of infrastructure projects for the period 2021-2027. Available at: https://op.europa.eu/en/publication-detail/-/publication/23a24b21-16d0-11ec-b4fe-01aa75ed71a1/language-en

3.4.2.3 *Adaptive capacity*

Adaptive capacity is the ability of systems, institutions, humans and other organisms to adjust to potential damage, to take advantage of opportunities, or to respond to consequences.[63] This component is particularly relevant to buildings due to the wide range of potential audiences, and forms a key component of the vulnerability analysis. The adaptive capacity may influence both the sensitivity and the vulnerability of an asset[64,65]: a higher adaptive capacity will reduce the vulnerability or sensitivity of a building to climate change. Therefore, the adaptive capacity analysis can either be carried out in conjunction with or following the sensitivity analysis. The specific factors to include when assessing the adaptive capacity of a building include:

- the ability of building users to adapt to climate change (linked strongly to vulnerability);
- the financial constraints (of a building's owners or users), which limit the potential for adaptation measures to be taken;
- spatial limitations and flexibility (both interior and exterior);
- legislative or planning restrictions, for example heritage conservation requirements which restrict adaptation measures;
- cultural limitations and considerations;
- any existing or planned adaptation measures (for example, cooling systems, shading or green roofs), which may improve a building's capacity to adapt to climate change; and
- the adaptive capacity of the wider community (highlighted below).

Adaptive capacity of building users and communities

Vulnerability reduction in the building sector 'cannot be attained in isolation or without considering factors of the non-built environment'.[66] Building users and communities play a key role when it comes to adaptive capacity. On the one hand, building users are affected by climate hazards, and different types of building users might be affected in different ways, e.g. the elderly, the very young, or people with health pre-conditions or lower socio-economic status tend to be most affected by negative impacts of heat stress. On the other hand, building users constitute the human response to climate hazards within the buildings. In this context, and when analysing adaptive capacity, the ability or interest in using, or not using, different approaches to adapt the building to climate change should be taken into consideration. This ability can be affected by multiple factors, including knowledge of adaptation measures and how to implement them, financial resources and other contextual factors.

3.4.2.4 *Vulnerability*

The IPCC[67] defines vulnerability as the propensity or predisposition to be adversely affected and states that it is a combination of susceptibility and adaptive capacity. It is recommended that for a more practical methodology, vulnerability is determined as the product of both the exposure and sensitivity analyses (as in European Commission 2021, Umweltbundesamt 2017). The extent to which a system is vulnerable to climate change is therefore determined by its exposure, sensitivity and adaptive capacity.

[63] MA, 2005: Appendix D: Glossary. In: Ecosystems and Human Well–being: Current States and Trends. Findings of the Condition and Trends Working Group [Hassan, R., Scholes, R. and Ash N. (eds.)]. Millennium Ecosystem Assessment (MA). Island Press, Washington DC, USA, pp. 893-900.

[64] European Commission (2021) .Technical guidance on climate-proofing of infrastructure projects for the period 2021-2027. Available at: https://op.europa.eu/en/publication-detail/-/publication/23a24b21-16d0-11ec-b4fe-01aa75ed71a1/language-en

[65] Umweltbundesamt (2017). Guidelines for Climate Impact and Vulnerability Assessments. Available at: https://www.umweltbundesamt.de/sites/default/files/medien/376/publikationen/guidelines_for_climate_impact_and_vulnerability_assessments.pdf

[66] UNEP (2021). Practical guide to climate-resilient buildings and communities. Available at: https://www.unep.org/resources/practical-guide-climate-resilient-buildings#:~:text=This%20UNEP%20publication%20demonstrates%20how,structures%20are%20largely%20self%2Dbuilt

[67] IPCC (2014). Fifth Assessment Report. Impacts, Adaptation, and Vulnerability. Available at: https://www.ipcc.ch/report/ar5/wg2/

The vulnerability analysis of a building should consist of the exposure to each hazard identified in 3.4.2.1, combined with the sensitivity of the building to each hazard as identified in 3.4.2.2. The table below presents a matrix that can be used to determine the overall vulnerability of a building, rated from very low to very high.

Table 3.6 Matrix of sensitivity and exposure to assess risk (adapted from EC 2021). The colour scale indicates a range from very high (dark red), medium (amber) and very low (light green) vulnerability levels.

		Exposure of building to hazard				
		Very high	High	Medium	Low	Very low
Sensitivity of building to hazard	Very high					
	High					
	Medium					
	Low					
	Very low					

3.4.3 Phase 2 – Risk assessment based on Phase 1 outcomes

Once significant hazards have been identified in Phase 1, it is recommended that a detailed analysis of the likelihood of climate hazards and their potential impacts on the building / building users is carried out, in line with what is proposed in the *Climate proofing of infrastructure* guidance [68]. This is similar to IEMA's recommendation[69], which is to conduct an assessment of magnitude of an impact based on a combination of probability and consequence. This stage of the assessment may be omitted if the building is not deemed to be vulnerable to climate hazards following the Phase 1 assessment.

3.4.3.1 Impact/consequence analysis

Building on the information gained from the vulnerability analysis, Phase 2 of the risk assessment should begin with an analysis of each potential impact. Potential areas of impact include:

- physical impacts to the building (damage),
- impacts to health and safety of building users,
- financial impacts (cost of damage, loss of value of property),
- heritage impacts (loss of cultural value),
- environmental impacts, and
- reputational impacts.

The impacts to consider will depend on the building type, its occupants and purpose of the assessment. For example, reputational impacts would not be as relevant for an individual as for a company. However, wherever possible, due consideration should be given to the vulnerability of the users of the building, drawing on the outcomes of Phase 1.

In line with Phase 1, it is suggested that impacts are assessed from 'very low' to 'very high'. Each impact should be assessed separately using estimated quantitative information wherever possible and can be divided into categories of impact, see for example in Table 3.7. The assessment of impact should be carried out for each applicable hazard identified.

[68] European Commission (2021). Technical guidance on climate-proofing of infrastructure projects for the period 2021-2027. Available at: https://op.europa.eu/en/publication-detail/-/publication/23a24b21-16d0-11ec-b4fe-01aa75ed71a1/language-en

[69] IEMA (2020). IEMA EIA Guide to: Climate Change Resilience and Adaptation.

Table 3.7 Climate change impact criteria for example categories[70]

Consequence level	Health and safety	Financial impacts
Very high	Multiple fatalities	>10 % of the building/development value
High	Single fatality / multiple long-term injuries	8-10 % of the building/development value
Medium	Long-term injury or illness, prolonged hospitalisation or inability to work	4-8 % of the building/development value
Low	Lost time, injury or medical treatment required, short-term impact on persons affected	1-3 % of the building/development value
Very low	Minor harm or near miss	<1 % of the building/development value

3.4.3.2 *Likelihood analysis*

For a building's CVRA, this step should consider how likely it is that the impacts identified in 3.4.3.1 (e.g. damage to the roof) will occur over the lifespan of the building, considering any steps that have been taken to avoid the impact. This method would allow for assessment of both existing and planned buildings and provide a more realistic assessment of risk. Any existing or planned climate adaptation measures would reduce the likelihood of impact. For example, it could be highly likely that there will be a heavy rainfall event during the lifetime of the building, but it could be unlikely the building will flood during a heavy rainfall event due to flood mitigation measures.

The likelihood should be assessed as summarised in the table below, taking into account the lifetime of the building or block of buildings.

Table 3.8 Probability of climate change impact criteria

Likelihood level		
Unlikely	**Possible (as likely as not)**	**Likely**
The climate impact is not anticipated to occur during the lifetime of the proposed development.	The climate impact may occur a limited number of times during the lifetime of the proposed development.	The climate impact may occur multiple times during the lifetime of the proposed development.

If the relevant climate change expertise is available, this step of the assessment should also consider the probability of climate hazards occurring at the building location, with a more quantitative analysis based, where possible, on the confidence levels assigned to climate projections. Some recognition should also be given to the uncertainty underlying all climate projections. This should give an indication of how probable it is that a climate hazard (e.g. flooding) will occur at a given location within the appropriate time frame, which may influence the likelihood levels in Table 3.8.

3.4.3.3 *Risk assessment*

The overall risk assessment should be a combination of the likelihood and impact analyses. For some user groups (e.g. insurers), a level of risk tolerance may be assigned to each physical hazard, so that risks that are outside of tolerance can be identified[71]. The user can then decide whether to re-assess insurance, dispose of the asset, or incorporate adaptation measures as appropriate.

[70] Adapted from IEMA (2020). IEMA EIA Guide to: Climate Change Resilience and Adaptation.

[71] UKGBC (2022). A Framework for Measuring and Reporting of Climate-related Physical Risks to Built Assets. Available at: https://www.ukgbc.org/ukgbc-work/measuring-and-reporting-framework/

The level of risk assigned to each hazard can be calculated using a matrix such as the one presented in the table below. This analysis should be completed for each applicable hazard, as with the impact analysis. For any risks deemed to be significant (i.e. medium-high risks), further assessment and consideration of relevant adaptation measures may be required. Given the uncertainty in the assessment of likelihood, a scale of low-to-high is recommended for risk.

Table 3.9 Climate change risk rating

Consequence level	Likelihood of impact		
	Unlikely	Possible	Likely
Very high	Medium	High	High
High	Medium	High	High
Medium	Low	Medium	High
Low	Low	Low	Medium
Very low	Low	Low	Medium

3.4.4 Recommended next steps following CVRA

3.4.4.1 Monitoring

For hazards where (1) insufficient information on either exposure or sensitivity is available to provide a robust vulnerability rating, or (2) the climate projections used are highly uncertain, it is recommended to monitor the hazard as climate change progresses.

Some monitoring for unanticipated indirect impacts may also be advisable – for example, increased incidence of pests such as woodworm, which have the potential to damage a building as climatic factors become more favourable to their presence.

3.4.4.2 Adaptation options appraisal

Once the key risks to a building from climate change have been identified, further assessment may be required to identify potential adaptation measures, which could allow the risk level to be lowered. A comprehensive assessment of potential adaptation options is provided in the separate report entitled *Best practice guidance*.

There may be some residual risks which cannot be eliminated through adaptation measures. Additionally, some adaptation measures may be unsuitable due to spatial and financial limitations or impacts on cultural / heritage values. A further assessment of whether the residual risks are tolerable / acceptable may then be required.

3.5 Conclusions

In conclusion, following the evaluation of existing approaches for conducting a CVRA for a building, the following steps are considered to be most appropriate and widely useable for a range of audiences. It is recommended that the **exposure** analysis is carried out as the first step for a building, and that **sensitivity** is then assessed but only for the hazards that are found to be relevant. **Vulnerability** should then be assessed based on exposure and sensitivity. For any building components or areas found to be vulnerable to climate hazards, a further assessment of the **likelihood** and **impacts** should be carried out. **Risks** found to be above an acceptable level should then be reduced where possible through the appropriate adaptation measures.

In some cases, conducting a detailed CVRA may be impractical, for example due the scale of a development or a lack of technical expertise in climate resilience. In Section 4, practical approaches and tools are explored for evaluating the resilience of a building, including those deemed accessible for all user groups.

4. CLIMATE RESILIENCE RATING APPROACH REVIEW

4.1 Introduction

This chapter provides a synthesis review of existing approaches currently used to rate the resilience of buildings, a set of recommendations for future developments and an outline approach, which could be used as the basis for an approach to rate the climate resilience of buildings.

This chapter provides:

- an overview and assessment of existing resilience rating approaches;
- recommendations on the future development of climate resilience rating approaches for buildings;
- an outline approach for rating the climate resilience of buildings, focused on user groups such as small-scale developers or building owners.

This part of the guidance is most relevant for:

- building users, managers, administrators and owners;
- investors, insurers and developers.

4.1.1 Key concepts and definitions

Resilience to climate change is defined as the capacity of interconnected social, economic and ecological systems to cope with a hazardous event, trend or disturbance, responding or reorganising in ways that maintain their essential function, identity and structure.[72]

In the building sector, the terms 'resilience' can have multiple meanings. However, a definition can be identified based on different sources. For instance, the OECD defines **climate-resilient infrastructure** as infrastructure that 'is planned, designed, built and operated in a way that anticipates, prepares for, and adapts to changing climate conditions. It can also withstand, respond to, and recover rapidly from disruptions caused by these climate conditions. Ensuring climate resilience is a continual process throughout the life of the asset'[73]. Likewise, the EU Taxonomy Classification Regulation (EU) 2020/852 could also be utilised to define the main elements of **climate-resilient buildings** as, in line with the Taxonomy lexicon, these could be buildings that are built or renovated in a way that 'should contribute substantially to reducing or preventing the adverse impact of the current or expected future climate, or the risks of such adverse impact, whether on that building itself or on people' that inhabit it, or the nature that surrounds it, and the assets that compose it.

4.2 Identified buildings' resilience rating approaches

The literature review identified 9 resilience-rating approaches, as outlined in the table below. Out of the 9 approaches, 5 are directly relevant for buildings, 3 focus on the asset/project level (which can also relate to buildings, but not directly) and 1 focuses on the country-regional-level.

A longer version of the table, with additional details concerning each of the rating approaches is presented in 0.

[72] IPCC (2021). Sixth Assessment Report. Impacts, Adaptation, and Vulnerability. Available at: https://www.ipcc.ch/report/sixth-assessment-report-working-group-ii/

[73] See: https://www.oecd.org/environment/cc/policy-perspectives-climate-resilient-infrastructure.pdf

Table 4.1 Identified buildings' resilience rating approaches

Name	Approach type	Strengths	Limitations
Bat-ADAPT (OID)	Web-based tool	• Easy to use • Provides rating of different aspects of vulnerability, also based on adaptation measures implemented • Provides suggestions for adaptation options • Differentiated assessments based on different time horizons	• Only France • Focus on rating risk more than rating resilience (for now) *Bat-ADAPT is in the process of being updated to a new tool, R4RE, which will supersede the previous version. R4RE covers all European countries, (currently only for heat parameters outside of France) and has a stronger focus on assessing resilience of the building and adaptation measures that can be implemented thereof.
REDi (ARUP)	Check-list-based methodology	• Very detailed guidelines / requirements to comply with, specific to the hazard • Takes into account both the resilience of the structure of the building, but also the process of enhancing resilience	• Only currently available for two (non-climate-related) hazards • More applicable to new buildings, or buildings undergoing refurbishment • More of a certification system than a rating tool
Building Resilience Index (IFC)	Web-based tool	• Detailed list of factors taken into account (incl. risk mitigation measures) • Based on self-assessment and external / independent assessment	• More specific to natural disasters than climate trends • Some hazards are only available for the Philippines but it is soon to be expanded • External assessment could entail a lengthy process
Klimasken (LIFE programme-funded)	Web-based tool	• Detailed list of factors taken into account (incl. risk mitigation measures)	• Limited geographical scope • Also includes climate mitigation indicators • Indicators concerning adaptation do not take into account many factors / hazards • Methodology for the assignment of the rating to each of the indicators is unavailable
Resilience Rating System (World Bank)	Decision trees / checklist methodology	• Easy to use • Takes into account the process of enhancing resilience	• Not specific to buildings • Only looks into 'procedure' within project documents, not the actual project • Not very detailed
Flood resilience measurement for communities (Zurich Flood Resilience Alliance)	Hybrid: indicator-based methodology, building on online and offline data collection, incl. web-based tool	• Very comprehensive list of indicators, looks into different aspects of resilience • Takes community resilience / human factor into account	• Not specific to buildings • Only looking into one hazard • Not 'open-source': people need to apply to use the framework • On-the-ground data collection can be burdensome
Earthscan (CERVEST)	Web-based tool	• Easy to use • Assessment across groups of assets (which can be buildings) • Assessments based on different time-horizons	• Paid service Portfolio – asset level High level Methodology for the rating is not public • Rating risk rather than resilience
Skyfall (Fastigh-etsägarna)	Methodology based on online and offline data collection	• Based on self-assessment and external / independent assessment	• Paid service • Only for Sweden • Methodology not available online
Think Hazard (GFDRR)	Web-based tool	• Easy to use • Provides recommendations on adaptation measures	• Not specific to buildings • Not able to take existing adaptation measures into account • Only based on location (i.e. considers only the exposure factors) • Rating risk rather than resilience

4.1 Assessment of identified buildings' resilient rating systems

Applicability to buildings

Of the 9 most relevant approaches and the documents identified, 4 are specific to buildings (Bat-ADAPT; Building Resilience Index; Klimasken; REDi, Skyfall) and 3 could potentially be applied to buildings, with some modifications (Resilience Rating System; Earthscan, Flood resilience measurement for communities). The ThinkHazard tool is available at regional or country level only.

Types of approaches

The majority of approaches identified for climate resilience rating are web-based tools, where users are either directly asked to enter information themselves (e.g. Bat-ADAPT), or that work as platforms where the information is collected, stored and organised (e.g. Flood resilience measurement for communities). Other approaches are checklist-based methodologies (e.g. REDi, Resilience Rating System), i.e. not based on a web application.

All approaches collect information on several factors / indicators and produce a rating on this basis. The complexity and comprehensiveness of the factors / indicators considered varies, from fairly simple approaches (e.g. Bat-ADAPT) to more complicated and comprehensive ones (e.g. REDi). The factors / indicators that data is collected about usually comprise a mix of:

- background information about the building / project, e.g. building type, year of construction, year of last renovation;
- information about the exposure to particular hazards, e.g. building location;
- information about the sensitivity to climate hazards, e.g. type of roof / facade, presence of basement or green areas, etc.;
- information about the adaptation measures put in place, e.g. cooling equipment, ventilation, flood protection systems, etc.;
- information about procedural issues, e.g. whether resilience planning or CVRA has been performed on the building;
- information about adaptive capacity of the inhabitants / community involved, e.g. environmental management awareness, evacuation and safety knowledge, first aid knowledge, etc.;
- information about financial aspects, e.g. business continuity, disaster response budgets, etc.

For some approaches, details on the factors / indicators considered were unavailable (e.g. Skyfall, Earthscan).

The way that the information provided is translated into ratings varies, and in some cases is not made transparent. With some, the web-based tool directly provides the rating (e.g. Bat-ADAPT, Klimasken). In others, a self-assessment performed by the user needs to be complemented by an external / independent assessment (e.g. REDi, Building Resilience Index), sometimes even performed in person (e.g. Skyfall, Flood resilience measurement for communities) for the rating or certification to be used for reporting / public purposes.

All approaches result in a rating of the resilience of the building / project, which is articulated either in colour grading, letter grading, scores or a mix of all three. Only the checklist-based approaches (e.g. REDi and Resilience Rating System) clearly pre-define the elements that need to be complied with to attain a specific rating, i.e. if the building complies with all of the prescribed requirements, it can obtain a gold rating under REDi. Only one tool (Earthscan) provides an assessment based on different climate scenarios, while a couple provide differentiated assessments based on different time-horizons (Bat-ADAPT and Earthscan).

Climate hazards and regions included[74]

All but one (Resilience Rating System) of the resilience rating approaches identified are relevant for only a select number of hazards. Some approaches are only relevant for one hazard in particular (e.g. REDi and Flood resilience measurement for communities), while others encompass a broader range of climate-related (and non-climate-related) hazards (Building Resilience Index and Bat-ADAPT).

Six of the tools have a global scope, either declared or assumed for lack of further specification. The other 3 tools focus on specific countries, namely Sweden (Skyfall), France (Bat-ADAPT) and Slovakia and Czechia (Klimasken), though the latter 2 are soon to be expanded to other countries.

Ease of use

In general, ease of use varies depending on the final goal of the rating approach. If the rating tool is used for awareness raising purposes (e.g. Bat-ADAPT, Klimasken) in order to enable users to understand the risks and current level of resilience of a building and consider the relevant adaptation measures on this basis, the tools can be quite simple and easy to use, providing a rating based on a set of simplified factors / indicators. When the rating tool is used for reporting or disclosure purposes (e.g. Skyfall, Earthscan, REDi, Building Resilience Index), the set of factors / indicators increase in complexity and comprehensiveness, and can include an external / independent verification process – and therefore implementation can be more burdensome.

Limitations of existing approaches

Limitations identified across the different approaches regard assessment level, geographical scope and the burden imposed by the assessment (e.g. when external verification or more detailed information needs to be provided). Some of the assessed tools require a fee for use (e.g. Earthscan, Skyfall), which can also be seen as a limitation.

A key limitation to all of the existing approaches to rating a building's climate resilience is the practical constraint in the amount of detail that can realistically be incorporated within a single approach, tool or checklist. Climate hazards and relevant mitigation measures vary depending on geography, the function, lifetime and size of the building. Assessing and rating all of the possible options within a single rating approach or tool is challenging; there is a clear trade-off between the accuracy of the rating approach and the ease of use.

Some of the approaches identified through this study work around this limitation by focusing on a single climate hazard (e.g. REDi), whereas some focus on a specific geography (e.g. Bat-ADAPT) or very high-level resilience measures. Depending on the focus chosen, there will be a limit in how widely the approach or tool can be used across all geographies and building types.

As illustrated in the *Best practice guidance*, there are a wide range of measures that can be utilised within a building to increase its resilience to climate change. Incorporating all such measures in a single tool, rating all of those measures depending on the climate hazards relevant to the site, and then scoring to provide a resilience rating is clearly a significant challenge. The next section provides recommendations for the next steps, which will help address this challenge, building on existing tools and approaches.

[74] Inferred, based on available information within the guidance of approaches and tools.

4.2 Recommendations for further development of a range of resilience rating approaches

Currently, very few approaches exist for rating the climate resilience of a building. The tools that are publicly available are limited in scope to a specific hazard, geography or are not easily useable for all groups.

Our **core recommendations** for how to further develop approaches and tools for rating a building's resilience are summarised briefly in the bullet points below, with further details provided in the subsequent sections:

- Ensure any ratings approach is **underpinned by an initial CVRA** or at least a high-level assessment of climate vulnerability;
- Further **develop existing approaches using a tool** such as Bat-ADAPT, which focuses on high-level resilience measures underpinned by a vulnerability assessment;
- Further develop the approaches using a tool such as REDi, which provides the **detailed assessment** of resilience measures to address a specific climate hazard;
- Ensure that the approaches are designed so they are **accessible to a variety of audiences** and promote transparency.

Following the review of existing approaches, it is evident there are clear barriers to encouraging the development of a detailed approach or tool that could be applied to any building in any geography to give a robust assessment of the building's climate resilience. In particular, the development of such a comprehensive, detailed approach or tool would require significant time and funding in order to ensure that it accurately assesses the resilience measures at a particular location.

In addition, a highly detailed approach or tool may be inaccessible to particular audiences with less available data or technical expertise. The core recommendations summarised above are discussed in more detail below to provide insight on the suggested next steps to build on existing work, whilst ensuring that all users are able to make use of the suggested approaches.

Ratings approach should be underpinned by a CVRA

It is recommended that a climate resilience rating approach for a building should be based on an initial CVRA, in order to identify the key hazards to which the building will need to be resilient. The approach should not be limited to a certain number of hazards, but could instead be a more high-level review that can be adapted to the context of the location. In the absence of a powerful web-based tool that is accessible to all user groups, a checklist-based approach may be more appropriate, as illustrated in Section 4.3. Where possible, tools should be used in conjunction with technical expertise.

Development of approaches that recommend high-level resilience measures to reduce vulnerability

Approaches or tools such as Bat-ADAPT provide a building-specific climate vulnerability assessment and recommendations for relevant adaptation measures. Given the high-level nature of these types of approaches, it fulfils a similar role as the Phase 1 screening as discussed in Section 3.4.2, by providing an overview of the hazards and resilience considerations for a particular building.

A challenge to expanding the development of tools like Bat-ADAPT is that it is underpinned by site-specific climate projections, which are the best way to determine what level of climate adaptation measures are needed.

An important element of a high-level approach is that the output should be easily translated into actions for improving resilience. For example, the Bat-ADAPT tool provides a high-level list of recommended adaptation actions for each hazard. For some user groups, e.g. individuals looking to assess the properties they inhabit, the output may be primarily focused on comfort and safety. For others, such as the insurance sector, the context may need to be more in terms of financial resilience. The Building Resilience Index uses a standardised letter grading system to rate how likely a building is to survive applicable hazards, by assigning a probable maximum loss cost – this output may be more relevant for insurance purposes.

Development of approaches that provide a detailed assessment of resilience measures to address a specific hazard

To complement the high-level resilience rating approach as outlined above, rating approaches that focus on specific hazards should also continue to be developed to provide a more robust, detailed guidance on measures that improve resilience to a specific hazard.

Approaches such as REDi provide detailed technical information but are currently only available for flooding and wind events. Drawing on best practice measures, such as those identified in separate report *Best practice guidance*, could enhance ratings approaches focusing on a specific hazard to ensure that users of these approaches are directed towards the best, most resilient measures available.

A challenge with more detailed resilience ratings approaches such as these is that regular updates are required to ensure that the adaptation measures included remain relevant in light of new engineering solutions and accepted best practices.

Approaches that are accessible to all audiences

A key feature of best-practice rating approaches will be their suitability for different purposes and their ability to accommodate constraints relating to available budget, time and technical expertise. For some user groups (for example, small-scale developers or facility managers), a high-level approach may be the most appropriate with a basic output of resilience rating to allow decisions such as where to focus resilience investments. This high-level approach is the focus of the outline approach developed in Section 4.3.

In addition, a more solutions-focused approach (for example, those required by design teams or insurers) could allow for a certification of resilience – for example, a high resilience rating from REDi can allow a building to be awarded LEED credits.

As well as a range of outputs, the approaches should also allow for a range of inputs to reflect variability in resources, technical expertise and available information. This ability to be fully adaptable for different purposes, whilst still providing a detailed methodology, is a key feature that is lacking in the approaches currently available. Given the significant challenge in creating a single tool that addresses all user needs, it is recommended that efforts should continue with the development of the different approaches discussed above, whilst ensuring that these efforts are coordinated.

4.3 Outline approach for rating the climate resilience of buildings

The approach described in this section is aimed at an audience of small-scale developers, facility managers or investors. As discussed in Section 4.2, a range of rating approaches are required to meet the needs of all potential user groups; this outline approach is targeted at users with limited technical experience in conducting climate vulnerability assessments in order to encourage the consideration of climate change in a pragmatic and non-technical way.

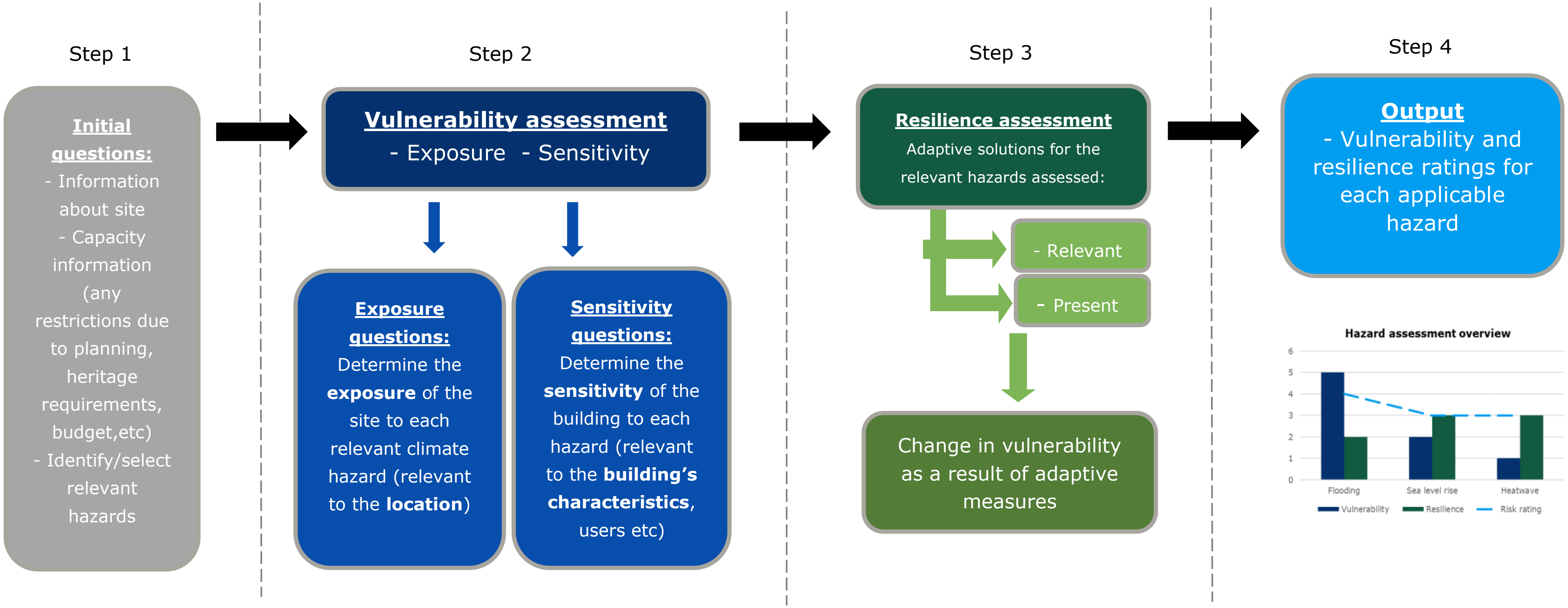
The objective of the approach is to increase the visibility of climate resilience through a high-level climate vulnerability assessment, identifying how climate change may affect an existing or proposed building, and how resilient the building is to identified hazards. The output of the approach will be a qualitative resilience rating of the building based on existing or planned adaptation measures.

Developing a user-friendly, transparent assessment tool

The proposed resilience rating approach attempts to deliver a straightforward experience for the user through basic automation between the steps, a high-level assessment of vulnerability and resilience, and a clear output providing transparency of results. This approach could eventually be an Excel-based tool, with a tab for each step highlighted in the process diagram below (Figure 4.1).

Figure 4.1 Outline approach to a climate resilience rating

Process overview



Each of the elements of this process is explained in further detail below.

Step 1: Initial questions

The purpose of Step 1 is to gather basic information on the building in question, including its location, adaptive capacity and relevant hazards. Selecting the relevant hazards as shown below will enable a tailored assessment and simpler user experience, with the tool only showing assessment questions relevant to the site. This would eventually be possible through some basic automation, using a hidden look-up sheet in Excel, for example. It would also be possible to have fixed hazards that must be assessed regardless of the site location.

The list of hazards below is currently limited to the 6 priority hazards, but could, ultimately, be expanded to include all the hazards included in the EU Taxonomy to help ensure this approach can support CVRAs required for taxonomy alignment.

Step 1: Initial questions

Enter site information	
Site location	
Building typology	
GFA (m^2)	
…	
…	

Select relevant hazards	
Flooding	Y
Drought	N
Heavy precipitation	N
Storm	Y
Heat wave	Y
Subsidence	N

This step could also include a series of questions that relate to the adaptive capacity of the building. This could be designed to capture information on the adaptive capacity whilst still encouraging the user to consider adaptation measures. For example, it could capture potential limitations due to planning / heritage / conservation restrictions or spatial issues and then filter the adaptation solutions suggested in Step 3 to focus on the solutions most relevant for a restricted site.

Adaptive capacity	
1. Would planning restrictions limit adaptation options?	
2. Is there a low/limited budget for adaptation?	
3. Are there spatial limitations?	
4. Are there community-level measures in place or in progress to enhance resilience to climate change?	
…	
…	
…	

Step 2: Vulnerability assessment

Upon completion of Step 1, the user moves to Step 2: Vulnerability assessment, an illustration of which is provided on the following page. In this table, there are a series of questions relevant to the selected hazards to assess both the exposure to the hazard and the sensitivity of the building and its occupants / functions.

This checklist approach would provide an overview of the building's exposure to the relevant climate hazard and sensitivity, using questions rather than requiring the user to work with climate data and projections. Both sets of questions will require a Yes or No response. If the approach was set up as an Excel tool, these responses would be captured in another hidden calculation sheet, which computes an initial vulnerability rating (very high, high, medium, low, very low).

In the following example of a vulnerability assessment, the exposure section relates specifically to flooding, although questions could be modified for other relevant hazards. For example, exposure questions relating to subsidence may include:

- Is the site on soils with a high clay content?
- Are high temperatures and dry spells projected to increase at the site?

The sensitivity section of the approach example is generic to all hazards; however, specific questions could also be included. For example, for heat waves:

- Does the building have a ventilation system?
- Are the building materials able to withstand high temperatures?
- Is there currently (or the potential for) vegetation on site to provide shading?

Step 2: Vulnerability assessment

Please assess the exposure of and sensitivity of the site, responding to each question with Yes, No or not applicable

Exposure			
Hazard	Question number	Question	Response
Flooding	1	Has the site ever experienced flooding before?	Y
Flooding	2	Has the site experienced flooding in the last ten years that caused a significant amount of damage or disruption?	N
Flooding	3	Is the site located in an area at risk of riverine flooding?	Y
Flooding	4	Is the site located in an area at risk of coastal flooding?	Y
Flooding	5	Is there a high proportion of impermeable surfaces nearby that increase the risk of surface water flooding?	N
Flooding	6	If climate projections have been reviewed for the site, do they indicate a trend of increasing heavy rainfall events?	Y
Flooding	7	...	

Sensitivity			
Hazard	Question number	Question	Response
Flooding	1	Are there building features that are particularly sensitive to the hazard?	Y
Flooding	2	Are the occupants of the building sensitive to the hazard?	Y
Flooding	3	Are the occupants of the building classed as vulnerable in a medical context?	Y
Flooding	4	Would the function of the building exacerbate the hazard (e.g. a building that requires water for cooling or industrial processes)?	N
Flooding	5	...	
Flooding	6	...	
Flooding	7	...	

Step 3: Resilience assessment

Following the calculation of the vulnerability rating based on the building's exposure and sensitivity, a list of relevant adaptation solutions is then presented in Step 3. In order to assess resilience, the user should mark whether the solutions are a) relevant to their site / building, and b) present at the site or will be present once the site is complete. Once all of the relevant solutions have been reviewed, the vulnerability rating from Step 2 can be reviewed and updated by the user, including reasoning behind the changed rating. For example, the user may decide that given the adaptation solutions incorporated in the design of the building, the building will have a vulnerability rating of medium, rather than very high.

It is important that the user completes this as a self-assessment rather than an automated calculation. The extent to which different adaptation solutions reduce vulnerability at a particular building will vary from site to site. For this reason it is important that the user, potentially with help from a design engineer, completes the assessment based on their own in-depth understanding of the site.

Step 3: Resilience assessment

Please assess the relevance of each of the adaptive solutions listed, and state whether these measures are present or planned at the site.

Adaptive solutions		
Solution	**Relevant?**	**Present?**
Building on stilts	N	N
Temporary flood barriers	N	N
Electrical services above flood level	Y	Y
Elevated placement of bedrooms and emergency supplies	Y	Y
Permanent flood barriers	Y	N
Water resistant materials	Y	Y
Dry floodproofing	N	N
Wet floodproofing	N	N

Initial vulnerability rating (from Step 2)	Based on the adaptive solutions, how would you rate your new vulnerability score?	Please provide a commentary explaining reasoning behind the new rating, linking to the solutions listed.
6	3	

Step 4: Review output

The final step of the process will ultimately be visual outputs from the tool, which should be peer-reviewed for quality assurance purposes where possible. Here the results from each of the previous steps are combined and presented as a visual summary across the different hazards, taking into account exposure, sensitivity, vulnerability and resilience. The matrix is completed by translating the numeric scores into qualitative ratings, from very low to very high (this is carried out in the hidden output calculations sheet). The table and column chart highlight how the vulnerability score is impacted by the various adaptation measures assessed in Step 3. Finally the factors driving the vulnerability and resilience of the site can be presented, summarised and visualised, as shown below.

Figure 4.2 Sample output from the resilience-rating tool

Climate resilience rating: results

Relevant hazards	Vulnerability	Updated vulnerability	Resilience rating
Flooding	5	3	3
Storms	2	1	5
Heat wave	3	2	4
Heavy precipitation	4	3	3
Subsidence	*not assessed*	*not assessed*	*not assessed*
Drought	*not assessed*	*not assessed*	*not assessed*
Overall	3.5	2.25	3.75

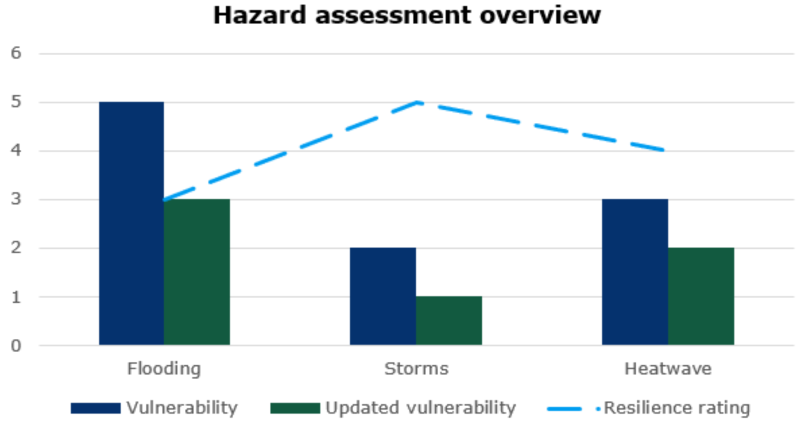
		Exposure of building to hazard				
		Very high	High	Medium	Low	Very low
Sensitivity of building to hazard	Very high					
	High				X	
	Medium					
	Low					
	Very low					

Drivers of vulnerability:

Present the hazards driving the risk

Drivers of resilience

Resilience measures impacting the score



Appendix 1– LIST OF REVIEWED LITERATURE FOR CVRA

Table 4.2 Complete list of reviewed literature for CVRA

Name	Organisation	Year
Climate proofing of infrastructure	European Commission	2021
EIA Climate Change Resilience	IEMA	2020
Practical guide to climate-resilient buildings and communities	UNEP	2021
Guidelines for climate and vulnerability assessments	Umweltbundesamt	2017
ISO 14091 Adaptation to climate change	BSI	2021
Boston climate resilience template for buildings	Boston Green Ribbon Commission	n/a
National climate change vulnerability and risk assessments in Europe	EEA	2018
Guide des actions adaptatives au changement climatique	OID	2021
Quantifying the effects of projected climate change on the durability and service life of housing in Wales, UK	Hales et al. (*Buildings* journal)	2022
Probabilistic methodology for the assessment of the impact of climate change on structural safety	University of Pisa	2020
Checklists to assess vulnerabilities in health care facilities in the context of climate change	WHO	2021
Zurich Climate Change White Paper	Zurich Alliance	2019
Climate Change Risk Assessment for the Insurance Industry	The Geneva Association	2021
Insuring the climate transition: enhancing the insurance industry's assessment of climate change futures	PSI-TCFD	2021
Managing the impacts of climate change: risk management responses – second edition	Zurich Alliance	2019
Physical Climate Risk Assessment Methodology	PCRAM	2021
Advancing TCFD Guidance on Physical Climate Risks and Opportunities	EBRD	2018
Physical risk framework: Understanding the impacts of climate change on real estate lending and investment portfolios	CISL	2019
MSCI Real Estate Climate Value-at-Risk (Climate VaR) Methodology	MSCI and Climate-KIC	2021
Catastrophe Modelling Framework	RMS	n/a
How to perform a robust climate risk and vulnerability assessment for EU Taxonomy reporting? Recommendations for companies – Draft	Umwelt Bundesamt	2022

Appendix 2 – SHORT LIST OF CVRA METHODOLOGIES

Table 4.3 Overview of identified CVRA methodologies and relevant approaches

Name	Methodology type	Concepts	Audience	Assessment level	Hazards covered	Approach	Strengths	Limitations
European Commission (2021). Climate proofing of infrastructure	Process-based methodology based on 2 phases: Phase 1. Screening Phase 2. Detailed analysis	Sensitivity x Exposure = Vulnerability Likelihood x Impact = Risks + Adaptation measures	Not stated – assumed broad	Infrastructure (incl. buildings)	Not stated – assumed broad	Technical guidance outlining 'climate proofing' process for infrastructure, based on 2 pillars (mitigation, adaptation) and 2 phases (screening, detailed analysis). The approach for climate proofing of infrastructure, for adaptation purposes, is built around two phases: Phase 1: Screening a. Sensitivity b. Exposure c. Vulnerability Phase 2: Detailed analysis d. Likelihood e. Impact f. Risks • Adaptation measures	Clear, detailed methodology for use in practice	• Not specific to buildings • Vulnerability definition does not factor in building inhabitants or the use of different buildings
IEMA (2020). EIA Climate Change Resilience	Process-based methodology based on 7 steps to consider climate resilience in the EIA process. Also includes a CVRA methodology (pre-EIA) based on 3 steps: identifying risks assessing/prioritising them formulating mitigation actions to reduce impacts	Probability x Consequence = Magnitude Susceptibility x Vulnerability = Sensitivity Magnitude x Sensitivity = Significance + Impact + Adaptation	Decision-makers	Infrastructure (incl. buildings)	• Temperature rise • Precipitation • Snow • Sea-level rise	• This guide provides a framework for the effective consideration of climate change resilience and adaptation in the EIA process, through a 7-step approach. Steps 2 to 5 of this approach deal with CVRA: • Step 2 – Defining the future (climate) baseline • Step 3 – Identifying and determining sensitivity of receptors • Step 4 – Reviewing and determining magnitude of the effect • Step 5 – Determination of significance	• Detailed methodology for use in practice • Widely used (in the UK)	• UK-orientated (link to EIA) • Not specific to buildings

Name	Methodology type	Concepts	Audience	Assessment level	Hazards covered	Approach	Strengths	Limitations
						• Alternatively, the guidance informs that if done before the EIA, building climate resilience can be integrated into the project by carrying out an *ex-ante* climate change risk assessment. The guide includes a climate change risk assessment methodology, the steps for which are: • identifying potential climate change risks to a scheme or project • assessing these risks (potentially prioritising to identify the most severe) • formulating mitigation actions to reduce the impact of the identified risks		
Umwelt Bundesamt (2017). Guidelines for climate and vulnerability assessments	• Process-based methodology and recommendations for CVRA, based on the development of impact chains and the evaluation of climate impact, adaptive capacity and vulnerability.	• Climate impact x Adaptive capacity = Vulnerability	• Aimed at professionals: • Authorities • Funding agencies • Research institutes • Advisory bodies	Regional / national level, also including buildings	• Extreme events (heavy rain, storm, hail) • Precipitation • Temperature rise • Sea-level rise These are identified in buildings impact chain	• Recommendations for climate impact & vulnerability assessments: • Working step 1: Plan and prepare the assessment • 1.1 Involving experts from a responsible institution • 1.2 Specifying the methodological framework and key terms • 1.3 Specifying scenarios for climate stimuli, spatial exposure and sensitivity • Working step 2: Step-by-step execution of the climate impact and vulnerability assessment	• Builds on IPCC definitions of a CVRA • Provides a description of the steps to implement a CVRA	• Not specific to buildings but contains an example of impact chain for buildings

Name	Methodology type	Concepts	Audience	Assessment level	Hazards covered	Approach	Strengths	Limitations
						• 2.1. Developing impact chains (climate stimuli + direct climate impacts + climate impacts) • 2.2 Operationalising selected sectoral climate impacts • 2.3 Evaluating and aggregating climate impacts • 2.4 Evaluating adaptive capacity • 2.5 Evaluating vulnerability • Working step 3: Communicating and using results		
BSI (2021). ISO 14091 Adaptation to climate change	• Process-based methodology based on the development of impact chains, assessing risks and adaptive capacity, analysing cross-sectorial interdependencies and independent review.	• Hazard • Exposure • Sensitivity • Climate change impact (i.e. risk without adaptation) • Vulnerability • Risk (with adaptation)	• Any organisation: • Financial institutions • Companies • Local governments	Projects in general	• Extreme events • Precipitation • Temperature change • Change in wind patterns • Changes • in the jet • stream • Sea-level rise • Ocean acidification	Steps to implementing a climate change risk assessment: • Screening impacts and developing impact chains • Identifying indicators • Acquiring and managing data • Aggregating indicators and risk components • Assessing adaptive capacity • Interpreting and evaluating the findings • Analysing cross-sectoral interdependencies • Independent review The guide includes examples of indicators for risk and vulnerability assessments.	• Provides a description of the steps to implementing a CVRA • Includes examples of indicators for CVRA	• Not specific to buildings

Name	Methodology type	Concepts	Audience	Assessment level	Hazards covered	Approach	Strengths	Limitations
Green Ribbon Commission (2019). Climate Resilience Template for Buildings	• Process-based methodology for resilience planning based on 9 steps, including CVRA.	• Exposure x Vulnerability = Risk	• Commercial real estate property owners and managers	Buildings	• Extreme heat • Sea-level rise • Extreme precipitation	The template outlines a typical resilience planning process that includes 9 steps. Steps 2 to 4 are relevant for a CVRA: Step 2. Identify climate risks that are relevant to the property. Step 3. Establish a property baseline to ensure all team members understand the building's characteristics and assets. Step 4. Conduct a vulnerability analysis to determine the exposure and sensitivity of building assets to climate impacts, as well as the likelihood and magnitude of the risk posed to the property. This includes: • Determining the exposure of each building asset • Determining the vulnerability of each building asset • Determining risks	• Specific to buildings • Describes a comprehensive resilience planning process for buildings, incl. steps for a CVRA	• Focussed on Boston (USA)
UNEP (2021). Practical guide to climate-resilient buildings and communities	• No methodology, but infrastructure and community-scale considerations – in relation to building structures and surroundings.	• Exposure x Sensitivity / Adaptive capacity = Vulnerability	• Broad audience, (incl. those with little experience in building and construction)	Buildings	• Sea-level rise • Humidity and rain changes • Higher temperatures	• The guide provides an overview of important infrastructure and community-scale considerations, principally focused on building structures and their immediate	• Specific to buildings • Useful detail on vulnerability determinants and wider impacts /	• Does not describe the steps of a specific methodology

Name	Methodology type	Concepts	Audience	Assessment level	Hazards covered	Approach	Strengths	Limitations
					• Evaporation changes • Wind changes	surroundings • It does not specify a CVRA methodology	social factors • Provides details on adaptation measures	
UKGBC (2022). A Framework for Measuring and Reporting of Climate-related Physical Risks to Built Assets	Reporting framework, containing elements of process-based CVRA	Hazard x Exposure x Vulnerability x Capacity = Risk	Broad audience (in relation to the Task Force on Climate-related Financial Disclosures – TCFD)	Buildings	• Heat stress • Temperature variability • Changing wind patterns • Wildfire • Flood • Heavy precipitation • Drought • Subsidence • Soil erosion • Coastal erosion	• The framework includes different sections relevant to CVRA: • Section 1: Initial information • Sections 2 and 3: Assessing baseline and future risk from physical hazards • Previous physical risk assessments (review) • Historic impacts (provide records of) • Describing inherent vulnerabilities and resilience measures • Assessing the likelihood of impacts • Assessing the consequence of impact • Assessing risk rating • Assumptions and limitations (document) • Section 4: Assessing overall risk rating • Interdependencies analysis • Cost impact • Overall risk rating • Adaptation measures • Section 5: Using the framework to disclose physical risk The reporting FWC is linked	• Clear methodology and accompanying framework • Practical guidance with a focus on buildings • Aligned with TCFD recommendations	• Reporting framework rather than CVRA methodology

Name	Methodology type	Concepts	Audience	Assessment level	Hazards covered	Approach	Strengths	Limitations
						to the TCFD recommendations.		
Observatoire de l'immobilier durable (2022). Guide des actions adaptatives au changement climatique	No methodology, rather an introduction to components of climate hazard risks for buildings	Climate hazard risk = Exposure x Vulnerability	Broad audience (in relation to built environment)	Buildings	• Heatwave • Drought • Wind changes • Flooding • Coastal flooding • Wildfire	The guide provides an introduction to the components of climate hazard risks for buildings: Climate hazard risk = Exposure x Vulnerability. Exposure is dependent on: a. climate hazard = the nature of the climate hazard, the intensity, location and frequency (probability and duration) b. other environmental factors = factors that aggravate or mitigate exposure, related to the environment Vulnerability is dependent on: c. sensitivity = technical criteria such as choices related to construction, the reliability of networks and the measures to improve resilience Issues related to usage = ability to manage a crisis and difficulties in doing so, because of economic, social and demographic factors	• Aligned with IPCC 2014 risk definition • Specific to buildings • Accompanying guidance notes on the impacts of key hazards on buildings	• Does not describe steps of a specific methodology
The Geneva Association (2021). Climate Change Risk Assessment	No methodology. Suggests taking into account the physical risk on business lines / assets through quantitative or	N/A	Insurance industry	Business line / Assets	Not specified	The report informs that climate change-related physical risk on business lines and assets can be considered by performing quantitative or qualitative	• Draws attention to the need to assess climate risks	• Not specific to buildings • Does not describe steps of a specific

Name	Methodology type	Concepts	Audience	Assessment level	Hazards covered	Approach	Strengths	Limitations
for the Insurance Industry	qualitative scenario analysis[75], or alternatively through catastrophe analysis.					scenario analysis. The report mentions that natural catastrophe models can also be used to integrate these concerns. * The Geneva Association Task Force on Climate Change Risk Assessment aims to advance and accelerate the development of holistic methodologies and tools for conducting climate risk assessment and scenario analysis.	for businesses / assets, and in particular suggests quantitative / qualitative scenario analysis[76]	methodology
PSI-TCFD (2021). Insuring the climate transition: enhancing the insurance industry's assessment of climate change futures	The report proposes an approach for 'physical risk scenario analysis' comprising 6 steps and including definitions of impact pathways and modelling approaches.	N/A	Insurance industry	Assets	• Not specified	The report proposes an approach for 'physical risk scenario analysis', comprised of 6 steps: • Step 1: Define scope of analysis • Step 2: Define impact pathways; • Step 3: Obtain climate data; • Step 4: Develop modelling approach; • Step 5: Construct a model; • Step 6: Test the model.	• Clear definition of steps and concepts for scenario analysis	• Not specific to buildings • Does not describe steps of a specific methodology • Based on modelling
Zurich (2019). Managing the impacts of climate change: risk management responses – second	No methodology, but suggests using a catastrophe model to identify, assess and manage natural catastrophe risk for climate change-	• N/A	• Private companies • Investors • Insurance industry	Business line	Not specified	The report identifies 3 key steps that are crucial for companies to develop a climate-resilience adaptation strategy: Step 1: Identify the broad business and strategic risks; Step 2: Develop a granular view of the risks involved;	• Draws attention to the need to assess climate risks for businesses /	• Not specific to buildings • Does not describe steps of a specific methodology • Involves

[75] The Geneva Association Task Force on Climate Change Risk Assessment aims to advance and accelerate the development of holistic methodologies and tools for conducting climate risk assessments and scenario analyses.

[76] Scenario analysis is a method for predicting the possible occurrence of an object or the consequences of a situation, assuming that a phenomenon or a trend will be continued in the future.

Name	Methodology type	Concepts	Audience	Assessment level	Hazards covered	Approach	Strengths	Limitations
edition	related hazards.					Step 3: Develop a mitigation strategy involving insurance. They suggest using a catastrophe model to identify, assess and manage the natural catastrophe risk for climate change-related hazards.	assets • Defines CVRA-related concepts from the point of view of the industry	modelling
PCRAM (2021). Physical Climate Risk Assessment Methodology	Process-based methodology, based on 4 steps and including the identification of relevant climate hazards and an economic / financial analysis of the risks.	• N/A	• Private companies • Investors • Insurance industry	Assets	Not specified	The methodology foresees 4 steps: • Data audit; • Materiality assessment: identifying climate hazards that will have the most impact for each component of the asset and assessing the asset managers operational objectives; • Resilience options identification; • Economic and financial analysis.	• Defines steps for the quantification of climate impacts on assets	• Not specific to buildings • No details on how CVRA is specifically carried out
EBRD (2018). Advancing TCFD Guidance on Physical Climate Risks and Opportunities	• The report recommends using scenario analysis to consider physical risk. This includes identifying drivers of change, ranking them in terms of importance and building scenarios around them.	• N/A	• Private companies • Investors • Insurance industry	Business line / assets	Not specified	• The report makes recommendations for scenario analysis disclosures in relation to the assessment of physical risk. The report identifies key steps to scenario planning, which can be relevant in the context of a CVRA: • Define the geographic scope and the planning goal; identify relevant stakeholders and facilitators.	• Provides recommendations for scenario analysis disclosures in relation to physical risk (concrete steps)	• Not specific to buildings • Does not describe steps of a specific methodology

Name	Methodology type	Concepts	Audience	Assessment level	Hazards covered	Approach	Strengths	Limitations
						• Define the most relevant drivers of change (climate and non-climate). • Address questions about certainties or uncertainties of the relevant physical climate risks and opportunities. • Address other drivers of change (socio-economic, political). • Rank these factors based on their level of uncertainty and importance. • Procure data. • Build scenarios. • Define strategy. • Identify opportunities to monitor change.		
CISL (2019). Physical risk framework: Understanding the impacts of climate change on real estate lending and investment portfolios	The report suggests that natural catastrophe models can be used to understand changing physical risks and the impacts on investors / lenders' portfolios	• N/A	• Private companies • Investors • Insurance industry	Buildings Assets	Not specified	The report suggests that natural catastrophe models can be used to understand changing physical risks and the impacts on investors / lenders' portfolios. This can be done in 4 main steps: • Data collection; • Selection of natural catastrophe model; • Selection of climate change scenarios; • Execution of natural catastrophe model.	• Describes steps to applying catastrophe modelling to understand the physical risks and impacts on investors / lenders' portfolios	• Does not describe steps of a specific methodology • Involves modelling
MSCI and Climate-KIC (2021). MSCI Real Estate Climate Value-at-Risk	The physical risk impact on an asset is quantified by assessing the exposure of a	• Expected cost = vulnerability * hazard * exposure.	• Private companies • Investors • Insurance industry	Buildings	• Temperature changes (extreme heat, and extreme	To quantify physical risks and opportunities, MSCI applies a process used in most hazard models in the insurance industry, which can be represented as	• Clear, detailed methodology for use in practice	• Not specific to buildings • Vulnerability definition does not factor in

Name	Methodology type	Concepts	Audience	Assessment level	Hazards covered	Approach	Strengths	Limitations
(Climate VaR) Methodology	property to a hazard and computing the costs associated with that risk using vulnerability functions specific to the real estate market.				cold) • Tropical cyclones • Flooding (coastal and fluvial)	follows: Expected cost = vulnerability * hazard * exposure. The physical risk impact on an asset is quantified by assessing the exposure of a property to a hazard and computing the costs associated with that risk using vulnerability functions specific to the real estate market.		building inhabitants or the use of different buildings

Appendix 3 - LIST OF BUILDING RATING APPROACHES

Table 4.4 Identified building resilience rating approaches

Name	Approach type	Audience	Assessment level	Geographical scope	Hazards considered	Approach	Rating system	Strengths	Limitations
Bat-ADAPT **(OID)**	Web-based tool	Not specified, assumed broad	Building	France *Soon to be expanded	Heatwaves Droughts Floods Coastal flooding	The tool allows the user to perform an assessment of climate vulnerability of a building based on the assessment of exposure and sensitivity factors. It consists of 3 phases: **Phase 1 -** Assessment of exposure; **Phase 2** - Sensitivity assessment; **Phase 3 -** Vulnerability analysis. Based on all the specifications provided by the user, the tool provides a synthesis of the results in a fiche. The fiche presents an assessment of: exposure of the location; sensitivity of the building and each of the building elements (for each of the hazards identified); vulnerability of the building for each of the hazards identified, with a grading (over 5). The fiche also includes a list of proposed adaptation measures for each of the hazards.	Exposure: 0-100 % rating and colour coding Sensitivity: High/Medium/Low and colour coding (green/orange/red) Vulnerability: 5 bars histogram	Easy to use Provides rating of different aspects of vulnerability, also based on adaptation measures implemented Provides suggestions for adaptation options Differentiated assessments based on different time-horizons	France only Focus on rating risk more than rating resilience (for now) *Bat-ADAPT is in the process of being updated to a new tool, R4RE, which will supersede the previous version. R4RE covers all European countries, (currently it is only for heat parameters outside of France) and has a stronger focus on assessing resilience of the building and adaptation measures that can be implemented thereof.
REDi **(ARUP)**	Checklist-based methodology	Developers, owners, engineers, and architects. This was deliberately written like a building code for ease of use.	(New / refurbished) Buildings	Assumed global	Earthquakes Wind Flooding* *The guidance will be made available in 2022	REDi is a set of prescriptive guidelines for owners, engineers and architects to implement resilience-based design to achieve beyond-code resilience objectives. The guidelines establish requirements for each of the 4 pillars of resilience-based design (i.e. operational resilience, building resilience, site resilience, resilience assessment). The requirements include, for instance, the need to perform resilience planning, requirements on enhanced structural / non-structural design, business continuity. REDi outlines three rating tiers (platinum, gold, and silver) that are each focused on continuity or recovery of core services. The prescriptive guidelines are written to achieve the corresponding pre-identified tier. Platinum and gold-rated buildings are both designed to be relatively undamaged after major natural disaster events. Silver-rated buildings are expected to sustain some damage and may not be re-occupiable or functional for several months.	Resilience rating: Platinum/Gold/Silver	Very detailed guidelines / requirements to comply with, specific to the hazard Takes into account both the resilience of the structure of the building, but also the process of enhancing resilience	• Currently only available for two (non-climate-related) hazards • More applicable to new buildings, or buildings undergoing refurbishment" • More of a certification system than a rating tool
Building Resilien ce Index **(IFC)**	Web-based tool	National and local governments, financiers, developers, buyers, end-users	Building	Global	Four main hazard categories: Wind (downburst, tornado, storms); Water (flooding, storm surge, tsunami); Fire (local fire, wildfire)	The Building Resilience Index provides a web-based hazard mapping and resilience assessment framework, to assess, improve and disclose resilience of projects / portfolios. The index measures a building's exposure to natural hazards and factors in the upgrades already made to mitigate these risks. The rating process is based on 2 phases: **Phase 1. Self-Assessment**: the user enters information concerning project background, location and adaptation measures implemented for specific hazards. A Resilience Index Rating (letter grading rating system, 5 levels) is identified, based on the information provided. Earning the highest index level also requires operational continuity, which includes factors such as power, water, telecom and access. **Phase 2. Verification:** the Resilience Index rating identified during Phase 1	Resilience Index Rating: letter grade rating system (A+/A/B/C/R) and colour-grading (green to red)	Detailed list of factors taken into account (incl. risk mitigation measures) Based on self-assessment and external / independent assessment Aligned with World Bank's Resilience Rating System	• More specific to natural disasters than climate trends • External assessment could entail a lengthy process

Name	Approach type	Audience	Assessment level	Geographical scope	Hazards considered	Approach	Rating system	Strengths	Limitations
					Geoseismic (Subsidence, landslide, earthquake).	can be verified by two licensed code-responsible engineers or parties, which review all information contained in the self-assessment, to certify that this is current and accurate.			
Klimasken **(LIFE programme-funded)**	Web-based tool	Not specified	Cities, city districts and buildings	Slovakia and Czechia	Flood Extreme meteorological phenomena Heat stress / heat waves *Not specified but deduced by the exposure indicators	Klimasken is a web-based tool for assessing cities, municipalities and buildings' contribution to climate change and their adaptation to it. The user is asked to fill in information for a list of indicators, divided into 5 areas (descriptive, exposure, sensitivity, emission, readiness balance). Based on the information entered by the user, the tool provides a 'climate label'. The climate label is a fiche containing a summary representation of the overall rating in the form of several concentric circles divided into four quadrants, which are sub-divided into smaller slices that represent each of the indicators. Five colours (red, orange, yellow, light green and dark green) are used throughout the label to indicate the negative (red) or positive (dark green) status or development of the system described by the indicators used. The climate label fiche also provides a rating on a scale from 0 to 100 % (in addition to the colour scale). The labels of different cities / buildings can be compared with the tool.	Climate label rating: 0-100 % scale for each of the indicators + comprehensive rating. Incl. color-coding (green to red)	Detailed list of factors taken into account (incl. risk mitigation measures)	Limited geographical scope Also includes climate mitigation indicators Indicators concerning adaptation do not take into account many factors / hazards Methodology for the assignment of the rating to each of the indicators was unavailable
Resilience Rating System **(World Bank)**	Decision-trees / checklist methodology	Decision-makers, investors and other stakeholders	Project level	Global	Not specified	The RRS methodology evaluates the resilience of the project design and resilience through project outcomes, based on project documents. The methodology includes a series of decision trees and checklists (e.g. does the project document include a risk screening? Does the project document provide a qualitative estimate of residual risk and review of possible mitigation interventions?). Based on the answers to the questions included in the decision trees, a resilience rating is attributed to the project, expressed in letter grades A+ to C. A high rating denotes higher confidence that an investment will achieve its expected rate of return and the project will remain beneficial, despite the impacts of climate change. A low rating indicates that the project has not fully explored the impacts of disasters and climate change on its performance, so may be at higher risk of underperforming or failing to achieve its development objectives. Ratings reflect a project's assessment of risks to assets and outcomes, not the risk profile of the project itself.	Resilience rating: A+ to C	Easy to use Takes into account the process of enhancing resilience	Not specific to buildings; Only looks into the 'procedure' within project documents, not the actual project Not very detailed
Flood resilience measurement for communities **(Zurich Flood Resilience Alliance)**	Hybrid: Indicator-based methodology, building on online and offline data collection, incl. a web-based tool	Decision-makers, NGOs	Community-level	Global	Flood *Zurich is developing a similar framework for heatwaves	Under the FRMC, the assessment of resilience is based on a community data collection (mixed data collection methods, based on context) on a set of 44 indicators, called 'sources of resilience'. After data is collected on the app, it is uploaded to the web application, and trained assessors grade each of the 44 sources of resilience on a scale of A to D (A being best practice, D being poor). Each source of resilience is then scored based on the assigned grade (from 0 to 100).	Resilience rating: letter-grading system (A-D) and score (0-100) for each of the sources of resilience + a comprehensive score for the project	Very comprehensive list of indicators, looks into different aspects of resilience Takes community resilience / human factor into account	Not specific to buildings Only looking into one hazard Not 'open-source': people need to apply to use the framework On-the-ground data collection can be burdensome
Earthscan **(CERVEST)**	Web-based tool	People who own, manage, depend on assets / portfolio of assets	Asset-level	Global	Heat stress Precipitation Flooding Wind Drought	Earthscan is a science-based and AI-driven climate intelligence platform that enables users to discover, quantify and share climate risk on assets. The user builds a portfolio of assets on the platform and receives on-demand insights from a dashboard (at both asset and portfolio level). Users can explore climate risks, by selecting specific climate scenarios (e.g. business as usual, 2040 emissions peak and Paris Agreement-aligned) and risk categories (i.e. specific hazards), for different time horizons (from the 1970s to 2100). Users	Combined physical risk: very low / low / medium / high / very high, and colour-grading	Easy to use Assessment across groups of assets (which can be buildings) Assessments based on	Paid service; Portfolio – asset level High-level Methodology for the rating is not public Rating risk rather than

Name	Approach type	Audience	Assessment level	Geographical scope	Hazards considered	Approach	Rating system	Strengths	Limitations
						can visualise the overall risks for the portfolio, risk distribution within and across the portfolio, and changes in mean risk over the portfolio. Earthscan rates combined the physical risk from very low to very high. Users can also generate and share standardised risk reports based on the tool.		different time horizons	resilience
Skyfall **(Fastighetsägarna)**	Methodology based on online and offline data collection	Property owners	Buildings	Sweden	Heavy rains Floods Heat waves Droughts Landslides and erosion Snowfall and intense snow loads	The Skyfall service maps the climate risks faced by a given property and provides suggestions on how property owners can work preventively to address these risks. The service works in 2 steps: Step 1 - Climate screening: the service analyses a property based on selected data and expected scenarios, and determines the climate risk, mostly based on the building's location. Step 2 - In-depth analysis: the service analyses the building's vulnerability in a future climate, and identifies and priorities risk-reducing measures for the individual building. For residual risks, the service provides suggestions for development and maintenance efforts. The in-depth analysis can involve site visits to the specific property, interviews and additional data collection or modelling. Step 3 - Certificate of completed analysis.	Not specified. Rather the service provides a certificate of completed analysis.	Based on self-assessment and external / independent assessment	Paid service; Only for Sweden Methodology not available online
Think Hazard **(GFDRR)**	Web-based tool	Non-specialists	Country or region level	Global with data gaps for some hazards	River flood Urban flood Coastal flood Earthquake Landslide Tsunami Volcano Cyclone Water scarcity Extreme heat Wildfire	Web-based tool enabling non-specialists to consider the impacts of disasters on new development projects, based on project location. A user is only required to enter their project location – national, provincial or district name. The results interface shows a user whether they require high, medium or low awareness of each hazard when planning their project. ThinkHazard! also provides recommendations and guidance on how to reduce the risk from each hazard within the project area and provides links to additional resources, such as country risk assessments, *Best practice guidance*, additional websites. ThinkHazard! also highlights how each hazard may change in the future as a result of climate change.	Hazard level: high/medium/low/very low and colour coding (red to yellow)	Easy to use Provides recommendations on adaptation measures	Not specific to buildings Not able to take existing adaptation measures into account Only based on location (i.e. only considers exposure factors) Rating risk rather than resilience

Appendix 4 – EXAMPLE OF A STANDARD PROFILE OF A BUILDING

Figure 4.3 – Standard profile of a building, showing which elements (roof, electrics, etc.) are likely to be vulnerable to each climatic hazard[77]

Divisions Uniformat		Infrastructure A	Superstructure B10	Outer envelope B20	Roof B30	Interior fittings C	Plumbing D20	CVCA* D30	Electricity D50	Layout of the site G
Climatic areas						**Building**				
1	More frequent freeze-thaw cycles			Y	Y					Y
2	Increased water content of snow		Y		Y					
3	More frequent and longer heat waves			Y	Y			Y		
4	Increased urban heat island effect			Y	Y			Y		Y
5	Longer and more frequent droughts									Y
6	Increase in instances where the humidity index is >40 units							Y		
7	Melting permafrost	Y	Y	Y						Y
8	Deterioration of air quality							Y		
9	Deterioration of water quality						Y			
10	Flooding	Y				Y				Y
11	Coastal erosion	Y	Y							Y
12	Landslides	Y	Y							Y
13	More frequent storms			Y	Y				Y	

*CVCA – Heating, ventilation and air conditioning

[77] Changements climatiques: Vulnérabilité et adaptation des immeubles. Gouvernement du Québec, 2017.