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# BALANCING SUSTAINABILITY AND RESILIENCE IN BUILDINGS: A RESILIENCE MODULE FOR AN EXISTING SUSTAINABILITY RATING SYSTEM

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**CZECH TECHNICAL UNIVERSITY IN PRAGUE**

**Faculty of Civil Engineering**

**Department of Architectural Engineering**

# Balancing Sustainability and Resilience in Buildings:

## a Resilience Module for an Existing Sustinability Rating System

## DOCTORAL THESIS

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Doctoral study programme: Building Structures

Branch of study: Building Engineering

Doctoral thesis tutor:

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**Prague, 2024**

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# DECLARATION

Ph.D. student's name: Licia Felicioni

Title of the doctoral thesis: Balancing Sustainability and Resilience in Buildings: a Resilience Module for an Existing Sustainability Rating system

I hereby declare that this doctoral thesis is my own work and effort written under the guidance of the tutor Assoc. Prof. Ing. Antonín Lupíšek PhD and Assoc. Prof. Ing. Arch. Jacopo Gaspari PhD.
All sources and other materials used have been quoted in the list of references.

The doctoral thesis was written in connection with research on the project:

Principal investigator
• Environmental Impacts of Radon Control Technologies, Grant ID GS22/084/OHK1/2T/11, 2021-2023 (2-years)

• Sustainability and Resilience in Buildings: Indicators and Metrics for a Balanced Integration, Grant ID: SGS23/007/OHK1/1T/11, 2022-2023 (1-year)

Co-investigator
• Sustainable extension of student dormitories - Support of participation of CTU team in Solar Decathlon Europe 21/22 contest, Grant ID SGS22/010/OHK1/1T/11, 2021-2022 (1-year)

• Resilient and circular principles in sustainable building design, Grant ID SGS24/008/OHK1/1T/11, 2023-2024 (1-year)

• Adaptation of Schools for Climate Change – Methodology for the City of Prague (Metodika adaptace školských zařízení na území hl. m. Prahy), FIS number: 8302125V100

European projects
• Horizon Europe NBSINFRA – City Nature-based Solutions Integration to Local Urban Infrastructure Protection for a Climate Resilient Society, Grant Agreement No. 101121210. 2023-2027 (co-investigator)

• Interreg Central Europe SuPeRBE – Supporting Cross-scale Planning and Policy readiness for a Resilient Built Environment, 2024-2026 under the INTERREG

Central Europe programme under grant agreement CE0200768 (principal investigator)

- INDICATE – National Building LCA Data Accelerator, 2023-2024, grant from the Laudes Foundation (grant number GR-077634) (team member)

- Horizon 2020 ARV - Climate Positive Circular Communities (CPCCs), Grant Agreement 101036723, 2022-2025 (team member)

- Horizon 2020 RadoNORM - Towards effective radiation protection based on improved scientific evidence and social considerations – focus on Radon and NORM, Grant Agreement No. 900009, 2021-2023 (team member)

In Prague on 27/09/2029

signature

# Preface

*This work was carried out as part of a PhD study in cotutelle at the Department of Architectural Engineering at the Czech Technical University in Prague (CTU) and the Department of Architecture at the University of Bologna (UNIBO) from October 2020 to September 2024.*

*This project was funded by the Department of Architectural Engineering at the Czech Technical University in Prague (CTU). The work was supervised by Assoc. Prof.. Ing. Antonín Lupíšek PhD (CTU) and Assoc. Prof. Arch. Jacopo Gaspari PhD (UNIBO).*

*Four papers are appended as supporting documents to the thesis, which demonstrated the recognition of the importance of the topic by peers of the sector.*

*This PhD thesis represents a significant personal achievement, and I hope it also inspires others to join in transforming the building sector for a more sustainable and resilient future.*

*Prague, September 2024*

Licia Felicioni

# Abstract in English

*The built environment is increasingly vulnerable to the frequent and severe hazards posed by climate change. The majority of existing buildings need to be more adequately equipped to withstand these threats, highlighting the need for adaptation strategies that enhance both resilience and sustainability for new and existing building stock. Green building rating systems, developed and adopted since the 1990s, provide a framework for measuring sustainability; however, they largely lack the integration of resilience principles, indicating a critical gap in implementation. A comprehensive literature review identified that sustainability and resilience in building design share common grounds, allowing for their potential coexistence to create more resilient and sustainable solutions. The primary objective of this PhD thesis is to develop a new Resilience Module, structured in a manner similar to existing building rating systems, and integrate it into the SBToolCZ framework, using this Czech national sustainability rating system as a case study. An extensive review of existing literature was conducted to identify recurring elements of sustainability and resilience in buildings, examining various sustainability and resilience rating systems. This informed the selection of relevant criteria and indicators for developing the Resilience Module. A weighting process was then performed, with input from a panel of experts, to determine the significance of each criterion. The Resilience Module was subsequently tested as a standalone system on three building case studies located in the Czech Republic, assessing its effectiveness in measuring and improving building resilience. Finally, the Resilience Module was integrated into the SBToolCZ rating system, with support from its development team, and tested in a building case study to compare the standard and integrated versions, demonstrating the feasibility and added value of the integration. The primary outcome of this research is a Resilience Module that can function independently as a tool for guiding designers toward more resilient projects while also being adaptable for incorporation into any green building rating system by integrating the criteria into existing categories. This work marks a significant advancement in incorporating resilience principles into building design, ensuring that both sustainability and resilience are considered, thereby enhancing the built environment's preparedness for future climate change-related hazards.*

*Keywords: resilience, sustainability, climate change adaptation, assessment rating systems, building design, hazards, integration.*

# Abstract in Czech

*Zastavěné prostředí je ohrožováno častějšími a intenzivnějšími vlivy klimatických změn. Většina stávajících i nově stavěných budov není dostatečně připravena čelit těmto hrozbám, což zdůrazňuje potřebu tvorby strategií, které posílí nejen jejich odolnost, ale i udržitelnost. Systémy posuzování udržitelnosti budov, které se vyvíjejí od 90. let, poskytují rámec pro měření udržitelnosti. Nicméně, do těchto systémů zatím nejsou dostatečně integrovány principy resilience, což vytváří významnou mezeru při jejich využití. Na základě rozsáhlé rešerše literatury bylo zjištěno, že udržitelnost a resilience v návrhu budov sdílejí společné základy, což umožňuje jejich vzájemné propojení a tvorbu odolnějších a udržitelnějších řešení. Hlavním cílem této disertační práce je vytvoření nového Modulu Resilience, který bude strukturován podobně jako stávající systémy posuzování budov, a jeho integrace do systému SBToolCZ, což je český národní nástroj pro certifikaci kvality budov, a který je zde použitý jako případová studie. Po rozsáhlé rešerši dostupné literatury byly identifikovány klíčové prvky udržitelnosti a resilience u budov, přičemž byly zkoumány různé nástroje. Na základě těchto informací byly vybrány relevantní kritéria a indikátory pro vytvoření Modulu Resilience. Dále byl za pomoci panelu expertů proveden proces váhování, aby se určila důležitost jednotlivých kritérií. Následně byl tento modul testován jako samostatný systém na třech případových studiích, kde byla posuzována jeho účinnost při měření a zlepšování odolnosti budov. Nakonec byl Modul Resilience integrován do nástroje SBToolCZ za podpory jeho vývojového týmu, a aplikován na konkrétní budovu, což umožnilo srovnání standardní a integrované verze a prokázalo proveditelnost a přidanou hodnotu této integrace. Hlavním výsledkem této práce je Modul Resilience, který lze využít jak samostatně k vedení architektů při navrhování odolnějších projektů, tak ho lze adaptovat a integrovat do jakéhokoli systému posuzování udržitelnosti budov, a to tím, že se kritéria rozdělí do příslušných kategorií. Tento výzkum představuje významný pokrok v začleňování principů resilience do návrhu budov, čímž se zajistí, že bude zohledněna jak jejich udržitelnost, tak i odolnost, a zvýší se připravenost zastaveného prostředí na budoucí hrozby související se změnou klimatu.*

*Klíčová slova: resilience, udržitelnost, adaptace na klimatické změny, systémy hodnocení, návrh budov, rizika, integrace.*

# Abstract in Italian

*L’ambiente costruito è sempre più esposto ai rischi frequenti e intensi legati ai cambiamenti climatici. La maggior parte degli edifici attuali non è adeguatamente preparata per affrontare queste minacce, evidenziando la necessità di sviluppare strategie di adattamento che migliorino sia la resilienza sia la sostenibilità, sia per gli edifici nuovi che per quelli esistenti. I sistemi di valutazione della sostenibilità degli edifici, introdotti dagli anni '90, offrono un quadro per misurare la sostenibilità. Tuttavia, la mancanza di integrazione dei principi di resilienza in questi sistemi rappresenta una lacuna significativa. Un'analisi approfondita della letteratura ha dimostrato che sostenibilità e resilienza nella progettazione edilizia condividono principi comuni, rendendo possibile una loro integrazione per creare soluzioni più efficaci e resistenti. L’obiettivo principale di questa tesi di dottorato è la creazione di un nuovo Modulo di Resilienza, strutturato in modo simile ai sistemi di valutazione esistenti, e la sua integrazione nel sistema SBToolCZ, utilizzando quest’ultimo come caso di studio. Dopo un’ampia revisione della letteratura, sono stati individuati i principali elementi di sostenibilità e resilienza, esaminando diversi sistemi di valutazione. Questo ha permesso di selezionare i criteri e gli indicatori utili per sviluppare il Modulo di Resilienza. Successivamente, un gruppo di esperti ha partecipato al processo di ponderazione per definire l’importanza di ciascun criterio. Il modulo è stato poi testato come sistema autonomo su tre edifici campione in Repubblica Ceca per valutarne l’efficacia nel misurare e migliorare la resilienza degli edifici. Infine, il Modulo di Resilienza è stato integrato nel sistema di valutazione SBToolCZ, in collaborazione con il team di sviluppo, e applicato in un caso studio per confrontare le versioni standard ed integrata, dimostrando così la fattibilità e il valore aggiunto dell’integrazione. Il risultato principale di questa ricerca è un Modulo di Resilienza che può essere utilizzato come strumento autonomo per orientare i progettisti verso edifici più resilienti, ma che può anche essere adattato e integrato in qualsiasi sistema di valutazione della sostenibilità esistente, distribuendo i criteri nelle categorie pertinenti. Questo lavoro rappresenta un passo avanti significativo nell'integrare i principi di resilienza nella progettazione edilizia, garantendo una maggiore preparazione del’ambiente costruito ai possibili rischi futuri legati ai cambiamenti climatici.*

*Parole chiave: resilienza, sostenibilità, adattamento ai cambiamenti climatici, sistemi di valutazione, progettazione edilizia, rischi, integrazione.*

## Contribution of the appended papers

One journal paper and three conference papers built the foundation of this PhD thesis – they are reported in Appendix C. Furthermore, the activities in this thesis led to collaborations with other researchers, yielding to research projects, which are listed in the following section. The main topics of each paper are described below:

**Journal paper**

**Felicioni L.**; Lupíšek A.; Gaspari, J. *Exploring the Common Ground of Sustainability and Resilience in the Building Sector: A Systematic Literature Review and Analysis of Building Rating Systems*, Sustainability **2023**, 15(1),884. DOI: 10.3390/su15010884

**Conference paper 1**

**Felicioni L.**; Lupíšek A.; Gaspari J.; Antonini E. *Sustainability and Resilience in Building Design: Discussion on Two Case Studies.* Central Europe towards Sustainable Building **2022**, Acta Polytechnica CTU Proceedings 38:456‑462 (2022). DOI: 10.14311/APP.2022.38.0456

**Conference paper 2**

**Felicioni L.**; Lupíšek A.; Volf, M. *Environmental, social and economic resilience in multi-residential buildings: assessing SBToolCZ rating system* in: CEES 2023 - International Conference on Construction, Energy, Environment and Sustainability Proceedings, Coimbra, ITeCons - Institute for Research and Technological Dev. In Construction Sciences, **2023**, pp. 1 - 10 (Proceedings of: International Conference on Construction, Energy, Environment and Sustainability, Funchal, 27-30/06/2023)

**Conference paper 3**

**Felicioni L.**; Lupíšek A.; Gaspari J. *Implementing resilience in sustainable building design: Testing selected resilience criteria in a case study* in NEXTBUILT 2024 – International Conference on Challenges for the next generation built environment. IOP Conference Series: Earth and Environmental Science. *(Accepted for publication as per 13/09/2024)*

The entire list of author's publications can be found on the author's ORDIC profile; see orcid.org/0000-0003-0133-6887.

## Follow-up projects

The PhD candidate has received partial funding through grants for PhD students awarded by the Department of Building Structure at the Czech Technical University in Prague. The focus of the research primarily centres on resilience within the built environment and environmental impacts. Throughout her doctoral study, the candidate actively participated in multiple European projects related to the sustainability and resilience of buildings. During her time at the University of Bologna (September 2022 to August 2023), she served as a tutor for two Master's courses.

**Principal investigator**

- Environmental Impacts of Radon Control Technologies, Grant ID SGS22/084/OHK1/2T/11, **2021-2023 (2-years)**
- Sustainability and Resilience in Buildings: Indicators and Metrics for a Balanced Integration, Grant ID: SGS23/007/OHK1/1T/11, **2022-2023 (1-year)**

**Co-investigator**

- Sustainable extension of student dormitories - Support of participation of CTU team in Solar Decathlon Europe 21/22 contest, Grant ID SGS22/010/OHK1/1T/11, **2021-2022 (1-year)**
- Resilient and circular principles in sustainable building design, Grant ID SGS24/008/OHK1/1T/11, **2023-2024 (1-year)**
- Adaptation of Schools for Climate Change – Methodology for the City of Prague (Metodika adaptace školských zařízení na území hl. m. Prahy), FIS number: 8302125V100, **2022**

**Tutoring activities**

- Building Quality Complex Assessment – Doc. Ing. Antonín Lupíšek. **2020-2022** (CTU) Bacher study programme in Civil Engineering.
- Integrated Building Design – Doc. Ing. Antonín Lupíšek. **2020-2022** (CTU) Master study programme in Civil Engineering.
- Building Design for Climate Change (Module of Sustainability Issues and Targets Lab) – Prof. Ernest Antonini. **2022-2023** – Bologna Campus (UNIBO), Second cycle degree programme (LM) in Architecture and Creative Practices for the City and Landscape.
- Research on Historic Building – Prof. Ernest Antonini. **2022-2023** – Ravenna Campus (UNIBO) Second cycle degree programme (LM) in Engineering of Building Processes and Systems

**European projects**

- Horizon Europe **NBSINFRA** – City Nature-based Solutions Integration to Local Urban Infrastructure Protection for a Climate Resilient Society, Grant Agreement No. 101121210. **2023-2027** (**co-investigator**)
- Interreg Central Europe **SuPeRBE –** Supporting Cross-scale Planning and Policy readiness for a Resilient Built Environment**, 2024-2026** under the INTERREG Central Europe programme under grant agreement CE0200768 (**principal investigator**)
- **INDICATE** – National Building LCA Data Accelerator, **2023-2024**, grant from the Laudes Foundation (grant number GR-077634) (**team member**)
- Horizon 2020 **ARV** - Climate Positive Circular Communities (CPCCs), Grant Agreement 101036723, **2022-2025** (**team member**)
- Horizon 2020 **RadoNORM -** Towards effective radiation protection based on improved scientific evidence and social considerations – focus on Radon and NORM, Grant Agreement No. 900009, **2021-2023** (**team member**)

# Table of Content

# 1. Introduction

*This Ph.D. research addresses the pressing issue of climate change adaptation of the built environment, focussing on European regions experiencing increased climatic impacts. The study emphasises challenges such as extreme weather events and their consequences on ecosystems and built environments. It highlights the accelerated transition in environmental conditions that affect human life. The research aligns with the EU's climate resilience goals, intending to enhance existing rating systems to incorporate resilience principles. The workflow involves international context exploration, literature review, case study analysis, tool development, and practical testing in three case studies. The ultimate objective is to integrate a resilience module into existing sustainability tools, contributing to building designs that prioritise both sustainability and resilience. This chapter introduces the study by outlining the rationale for the research and presenting the problem statement, research questions, aims, and objectives. It also addresses the scope, limitations, and assumptions of the study, highlighting its significance. The chapter concludes with a definition of the key terms that will be used throughout the work.*

## 1.1 Framing the topic

Climate change adaptation has become a dominant concern in policy agendas, particularly in European regions where the impacts of climatic changes and the increase in the frequency and severity of extreme weather events are evident (1). Challenges include increased precipitation, mudslides, flooding, intensified storms, and extreme heat or cold periods. These evolving climate patterns jeopardise the livelihoods and economic activities of millions of people, posing threats to vulnerable ecosystems and the built environment (2,3). Indeed, the alteration of environmental conditions on Earth represents a natural and perpetual phenomenon. Consequently, human habitation is subject to modification, leading to an irreversible transformation of biodiversity. Historically, this process unfolded over extended periods, allowing successive adaptations of life forms, including humans, to ameliorate environmental circumstances. However, in contemporary times, there has been an acceleration in the pace of this transition.

Data from the Intergovernmental Panel on Climate Change (IPCC) (4) and the National Aeronautics and Space Administration (NASA) (5) indicate that intensification of climate change-related phenomena is occurring. These include shifts in precipitation patterns, more frequent and severe droughts, and changes in local climatic conditions, such as the formation of heat islands. Such alterations are expected to impact cities, neighbourhoods, and buildings.

Recognising the urgency, there is a growing consensus on the need for proactive measures not only to mitigate human-induced climate change but also to adapt to current and anticipated impacts.

The European Union (EU) has been at the forefront of addressing this issue, releasing an adaptation strategy in 2013 and adopting a new strategy on February 24, 2021, intending to achieve climate resilience by 2050 (7). The approach focuses on making adaptation smarter, faster, and more systemic while also emphasising international collaboration.

The latest report from the European Environment Agency underscores the pressing requirement to tailor cities, especially those in Europe, to climate change as they increasingly experience its consequences (8). In fact, urban areas in Europe accommodate 547 million inhabitants, which is 74% of the total European population. Within the EU-28, 39% of the overall population resides in metropolitan regions, defined as areas with a minimum of 1 million inhabitants, generating 47% of the total GDP (9). By 2050, up to 75% of the population is expected to reside in cities. Currently, the impact of natural disasters on humans is expected to increase (Figure 1). These issues highlight the increasing need to focus on risk mitigation and adaptation of urban systems (10,11).

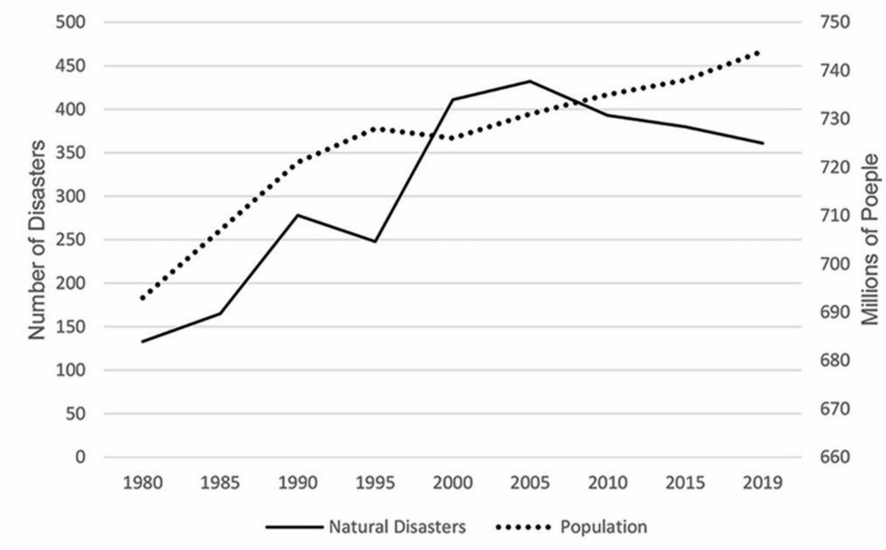


*Figure 1 Trends in population growth and natural disasters in Europe since 1980. Source of data: European Environment Agency (EEA) and United Nations, Department of Economic and Social Affairs: Our World in Data. Source of visualisation:* (12)

The resilience of a city extends beyond urban settlements to include energy and transport systems, along with crucial sectors such as tourism, industry and business (Figure 2). These elements are essential for the livelihoods of residents, economic prosperity, and well-being. Many cities are grappling with ageing sewer systems, with a life of more than 40 years, which could diminish their effectiveness in coping with intensified pluvial flooding. Urbanisation emerges as a significant factor that increases flood risk by increasing impervious surfaces. Flash floods pose specific challenges, including flooding in the drainage system, disruptions to urban transport, and the health and pollution ramifications of untreated sewage discharges. In particular, more than 25% of the population in nearly 13% of cities in the EU resides within potential river floodplains (13). In numerous instances, such as in 50% of UK cities, a substantial increase in the 10-year high river flow is plausible beyond a 2°C Global Warming Level under a high-impact scenario, as projected in the 90th percentile (14).

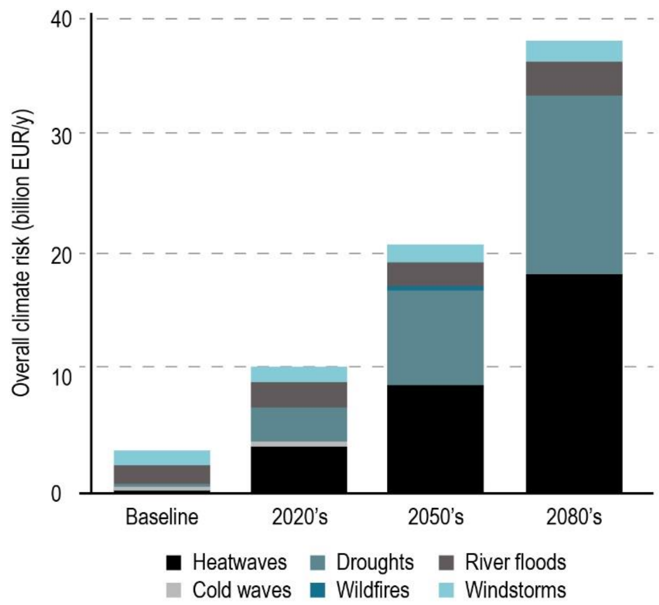


*Figure 2 Forecasted climate risks in Europe in economic terms. Visualisation re-adapted from* (13).

### 1.1.1 Importance of the topic

Research on the resilience of ecological systems began in the 1970s and has seen remarkable growth in recent decades, driven by daily environmental challenges, particularly the sharp increase in natural disasters (15). A significant increase in global interest underscores the contemporary understanding of resilience as countries address the problem of climate change, a gradual process with measurable impacts, as detailed in the IPCC report (16). Additionally, disasters such as floods require more attention due to their potential to cause extensive losses, including financial deficits, housing collapses, and casualties (17). The improvement of resilience is often linked to specific sectors (18), and different scales are used to measure resilience, ranging from single buildings to the urban, community, municipal, and national levels. Actions vary by scale; for example, at the building level, resilience includes the capacity of the building to absorb and adapt to shocks so that the building continues its operation. At the urban level, resilience also encompasses managing stress, avoiding shocks, restoring services, and repairing infrastructure or buildings (12).

Resilience analysis proves to be effective when focused on individual buildings. This approach allows for a better understanding of how building operators and managers, as key figures, handle disruptions within the building system. This focus is significant because end users, who are the most affected by resilience efforts, often have limited control over the building system. In many cases, residential buildings are multifamily structures where owners and managers, having more authority than the occupants, can implement strategies to improve resilience and ensure acceptable living conditions during extreme events.

In the 1990s, various standards and certifications started to be developed to improve building sustainability, including Leadership in Energy and Environmental Design (LEED) (19) in the United States, the Building Research Establishment Environmental Assessment Method (BREEAM) (20) in the United Kingdom, and Deutsche Gesellschaft für Nachhaltiges Bauen (DGNB) in Germany (21). Architects have frequently used these standards to design projects that focus on aspects such as high energy performance, water efficiency, and optimal use of materials and resources.

Currently, resilience has become a significant priority in the construction sector, often overlapping with the concept of sustainability (22). This overlap raises the question of whether resilience is a subset of sustainability or a separate concept (23). However, resilience to natural and man-made hazards is still rarely included in green building rating systems (GBRSs) (24).

This PhD project aligns with the European agenda by aiming to enhance the capacity of already existing GBRSs to implement resilience principles in their frameworks. Resilience principles align with broader EU initiatives like the EU Taxonomy (25), specifically Appendix A, which lists the climatic hazards, and the common EU framework "Level(s)", in particular Objective 5, dedicated to Climate Adaptation (26). The PhD project recognises the imperative for collaborative, agile and integrated climate adaptation planning to promote effective risk mitigation measures and ensure the resilience of European regions.

## 1.2 Knowledge gaps

Since the 1987 Brundtland Commission report, sustainable development has been widely accepted (27). However, in recent years, the increased risk to the built environment has underlined the need to design and progress towards a resilient built environment (24). This has led to criticism of the sustainability assessment framework, which focuses primarily on energy consumption and carbon reduction and often overlooks resilience (28). Consequently, the design and construction of buildings, including those considered green buildings, is imperative. Green buildings must not only reduce environmental emissions but also withstand external stress over their lifetime (29). The current literature recognises the need to integrate resilient design indicators into the assessment framework (29). For example, Achour et al. (30) reviewed ten international sustainability evaluation tools and deemed the Japanese CASBEE® and the German DGNB to be the only ones that incorporate resilience. They recommend the use of CASBEE® as a model for integrating sustainability and resistance as it engages with technical, strategic, social, and political stakeholders. Likewise, Champagne and Aktas (29) studied the overlaps between the principles of adaptive design and LEED v4 (31) and found that LEED v4 did not address about half of the identified principles. They propose prioritising regional resilience grants adapted to specific local risks to address this gap. The literature also points to tensions between sustainability and resilience that may hamper their integration (24,32,33).

## 1.3 Objective and Scope

The main goal of this PhD research is to integrate resilience principles into an existing sustainability rating system, specifically designed for the planning and construction of multi-residential buildings that may be susceptible to natural hazards, particularly those associated with climate change. This is essential because architects and designers commonly utilise such tools in their daily routines for building design. The focus on multi-residential buildings is deliberate, as these structures often accommodate vulnerable populations, including children and the elderly, who spend considerable time at home rather than in offices or other building types.

This integration ensures that the design not only prioritises sustainability but also incorporates elements of resilience to some extent. Resilience, in this context, transcends a purely reactive response to shocks; instead, it requires a systematic emphasis on risk management and the improvement of building resilience from the initial design phase to reduce vulnerability to potential disaster events.

The attempt to refine the interconnection between sustainability and resilience is pivotal. This entails a concerted effort to design buildings that are not only more resilient but also integrally sustainable. By discerning and increasing the synergies between these two approaches, the research aims to contribute to the creation of structures that exhibit both resilience and sustainability, thus fortifying their capacity to withstand and recover from adverse events. To examine this matter, the following research questions will be addressed:

1. What are the main elements that define each domain, sustainability and resilience, respectively, at the building level?
2. What is known from the existing literature about the coexistence of these two domains?
3. Can a resilience module integrated effectively within an existing green building rating system?
4. Is it possible to reach and measure the right balance between sustainability and resilience at the building level?

5. What are the most important research gaps for this integration?

In pursuit of responding to the aforementioned questions, the research endeavours to carry out a comprehensive investigation on sustainability and resilience principles in building design. This involves conducting an extensive literature review and scrutinising various Green Building Rating Systems (GBRS) and Resilience Assessment Tools (RATs) to discern common ground within these domains. Furthermore, the research aims to survey the international background, systematically mapping successful strategies that can be emulated to enhance the nexus between sustainability and resilience in buildings. As a crucial aspect of this effort, a Resilience Module is proposed for integration into an existing tool, with the dual objectives of fortifying building resilience and raising sustainability standards. This multifaceted approach seeks to contribute valuable insights and practical applications to foster a more robust integration of sustainability and resilience in the field of building design. However, the Resilience Module could also be used as a stand-alone system to guide architects and designers on how to build resiliently.

## 1.4 Work plan

The study incorporates methodologies and approaches commonly found in the domain of technological architecture, seamlessly integrating them with the considerations inherent in urban planning. The research project received support from the Faculty of Civil Engineering of the Czech Technical University in Prague.

The primary objective of the research is to delve into the resilience of multi-residential building designs in response to climate change hazards. This involves examining both the design strategies applicable during the early design phase and the responsiveness of the building in extreme events. The focus lies on maintaining the functionality of its occupants without causing adverse impacts. The overarching goal of the research is to contribute to enhancing the resilience of multi-residential buildings. This involves the development of a tool that serves a dual purpose: an impact analysis framework and a design guide to implement resilience principles. The aim is to introduce a new module to assess the resilience level of multi-residential buildings, pinpoint critical issues, and suggest corrective actions in the design stage. The approach does not mean imposing rigid guidelines but rather addressing the complexity of hazards that require mitigation based on location and vulnerability. The proposed tool seeks to offer design guidance, promoting the pursuit of ambitious goals akin to the characteristic approach of the green building rating system—encouraging actions that lead to higher certification levels. Based on these foundational principles, the specific focus of the research is on integrating the resilience component of residential buildings into existing green building rating systems.

The study aims to offer a practical tool that could guide architects, designers, and project developers in improving strategies for the creation of more resilient and sustainable buildings.

The research activities carried out throughout the doctoral study can be summarised in the following manner (Figure 3):

- Review of the literature and contextual analysis
  Conduct an extensive review of the existing literature to understand the international context, focussing on the United Nations and European priorities.
  Explore sustainability and resilience concepts within buildings by studying Green Building Rating Systems (GBRS) and Resilience Assessment Tools (RAT).
  Result: Common ground between sustainability and resilience design processes.
- Data Collection and Analysis
  Gather data from GBRS, RATs, and resilience guidelines for buildings.
  Focus on European GBRSs and RATs due to their specific relevance and applicability.
  Analyse international case studies recognised for exemplary applications of sustainable and resilient strategies in buildings to extract resilience principles and identify common design elements.
  Result: Resilience principles definitions.
- Development of criteria and indicators
  A matrix defined by sustainable protocols and resilience tools will be used to establish a system of criteria and indicators.
  Apply the typical GBRS system (i.e., structure, methods, and procedures) as the foundational structure for developing the resilience module.
  Specific indicators within the module are harmonised with Level(s) – Objective 5 Adaptation to climate change, aligned with the new common framework for building sustainability in Europe.
  Result: Different categories, criteria, and indicators for a brand-new Resilience Module. Calculation tool designed.
- Expert Involvement and Weighting
  Involve a panel of experts in the field from all over the EU to define the weights of each criterion of the resilience module using the pairwise comparison method and, with the average of the experts' value, obtain the final weighting system for the resilience module.

Result: Weights for each criterion of the Resilience Module used as a standalone system.

- Testing and Validation of the Brand New Module

  Conduct rigorous testing and validation of the resilience module using three real building case studies to assess the accuracy and effectiveness of the requirements and, in case, rephrase the demands for the stand-alone Resilience Module.

  Result: Assessment of the case studies in their current status and provided recommendations for enhancing their resilience. Identify potential areas for criteria refinement (including description and requirements adjustments) based on insights gained during the testing phase.

- Integration into an existing Rating System

  Integrate the module into SBToolCZ, the Czech national rating system developed at the Czech Technical University in Prague, by inserting the Resilience Module criteria within the existing SBToolCZ categories and weighting adjustment with a panel of experts support.

  Testing of the new version of SBToolCZ in a previously certified case study.

  Bridge the gap between sustainability and resilience at the building level, aiming to design buildings that exhibit both sustainability and resilience to specific climate change hazards.

  Result: An adjusted SBToolCZ version where the Resilience Module criteria are incorporated, either as new criteria or integrated into existing ones as modules, and the test is on a case study to observe the differences with the standard version.

The ultimate goal of these research activities is to contribute to the development of buildings that are not only sustainable but also resilient, addressing the challenges posed by climate change.

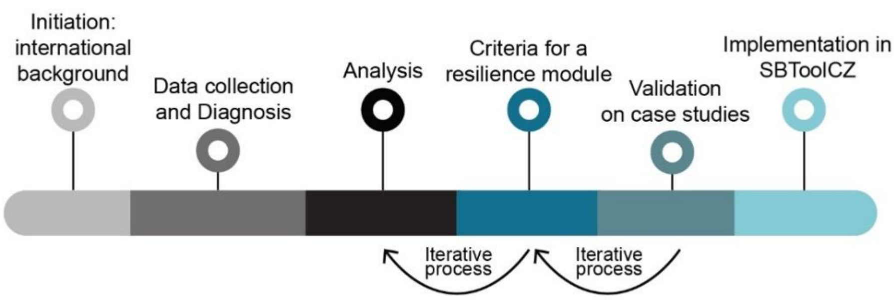


*Figure 3 Line diagram of the PhD study.*

### 1.5 Outline of the thesis

The arrangement of the thesis is shown in Figure 4. The content of each of the chapters is as follows:

Chapter 1: Introduction

Provides an overview of the research, including its scope, limitations, and overall content.

Chapter 2: International background and knowledge gaps

Review of the international context, agenda, and priorities related to building resilience and adaptation to climate change.

Chapter 3: Current state of the art on sustainability and resilience principles in buildings

Examines literature on green building rating systems and building resilience assessment tools in order to identify intersections between sustainability and resilience. Presents exemplary practices in resilient building design.

Chapter 4: Resilience Module: Methodological backbone and tool selection

Offers an overview of the methodology employed, from gathering best practices and literature review to providing a case study tool for implementing the Resilience Module.

Chapter 5: Resilience Module: Development, criteria definition and weightings

Outlines the structure of the Resilience Module, detailing its categories and criteria and providing examples of qualitative and quantitative criteria. Moreover, it details the process of defining the Resilience Module's weights with input from an expert panel.

Chapter 6: Resilience Module: Testing and validation as a stand-alone system

Validates the Resilience Module through application to three existing multi-residential buildings certified by SBTool-CZ, focusing on addressing each criterion individually and recommending how to enhance the resilience for each specific criterion.

Chapter 7: Resilience Module: Integration into SBToolCZ System

Describes the potential integration of the resilience module into the SBToolCZ system, including redefining criteria to align with the existing framework, adjusting certification weights, and final validation and comparison through a residential case study.

Chapter 8: Conclusions

The author presents conclusions drawn from the study, exploitation in the Czech Republic, scalability of the work to other contexts, and suggests directions for future research.

Appendix A: Resilience Module for Multi-Residential Buildings Manual.

Appendix B: Exctracts from the Calculation tool.

Appendix C: Appended articles with greater relevance to the thesis.

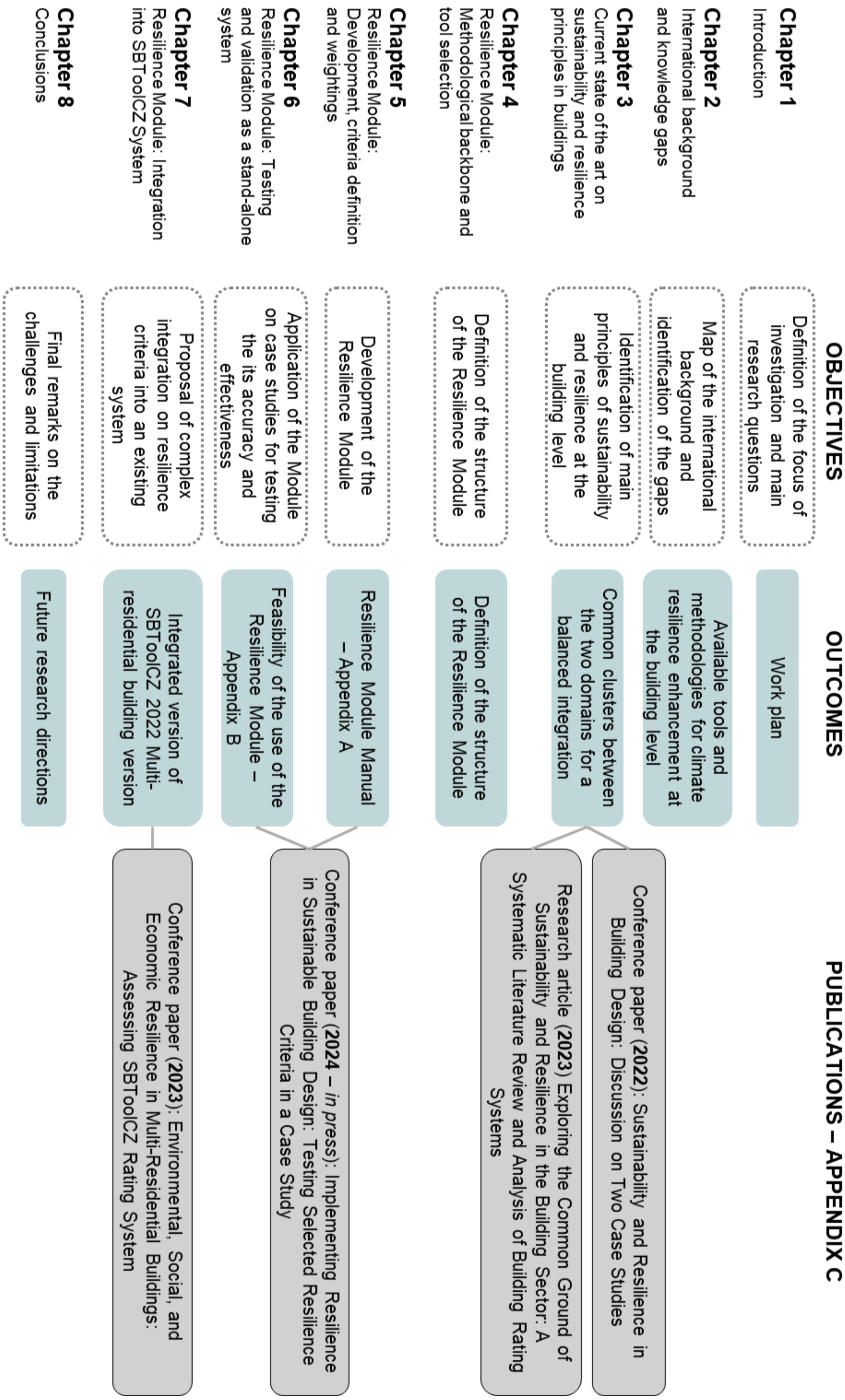


*Figure 4 Thesis chapters' outline and related obejctives, outcomes and publications.*

## 1.6 Definition of key concepts

*Adaptation to climate change*

The United Nations Framework Convention on Climate Change (UNFCCC) defines it as: “Adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities” (34). The focus of this thesis is on the adaptation of buildings to climate change.

*Climate Change*

The United Nations Framework Convention on Climate Change (UNFCCC) defines it as: “’Climate change’ means a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods” (9).

*Disaster*

The United Nations Office for Disaster Risk Reduction (UNDRR) defines it as: “A serious disruption of the functioning of a community or a society involving widespread human, material, economic or environmental losses and impacts, which exceeds the ability of the affected community or society to cope using its own resources.“ (35,36). A disaster is likely to occur when a vulnerable community/building/infrastructure/etc. faces natural hazards.

*Exposure*

The United Nations Environment Programme (UNEP) defines: “People, property, systems, or other elements present in hazard zones that are thereby subject to potential losses“ (37).

*Mitigation*

The United Nations Office for Disaster Risk Reduction (UNDRR) defines it as: “The adverse impacts of hazards, in particular natural hazards, often cannot be prevented fully, but their scale or severity can be substantially lessened by various strategies and actions. Mitigation measures include engineering techniques and hazard-resistant construction, as well as improved environmental and social policies and public awareness. It should be noted that, in climate change policy, “mitigation” is defined differently, and is the term used for the reduction of greenhouse gas emissions that are the source of climate change” (38).

*Natural Hazards*

The European Environment Agency defines them as: “Violent, sudden and destructive changes in the environment without cause from human activity due to phenomena such as floods, earthquakes, fire and hurricanes” (39)

*Resilience*

Resilience refers to the ability of a structure to balance resisting, adapting to, and recovering from extreme events. It encompasses several key features for both physical and social systems (40,41).

*Robustness*

This involves designing the structure to be more reliable in specific situations, allowing it to tolerate stress without damage or collapse. Robustness is considered a component of resilience (42).

*Redundancy*

This refers to the extent to which elements or systems can be substituted to maintain functionality despite degradation or loss. Relevant building parameters include water pipes in the building and electrical and power lines (43).

*Resourcefulness*

This is the capability to identify problems, establish priorities, and mobilise resources when conditions threaten to disrupt systems. It includes the ability to apply materials (monetary, physical, technological, informational) and human resources to meet priorities and achieve goals (12).

*Rapidity of Recovery*

The capacity to meet priorities and achieve goals promptly to minimise losses and prevent future disruptions (44).

*Risk*

As the UN Environment Programme defines: “The combination of the probability of an event and its negative consequences“ (37).

*Vulnerability*

The United Nations Environment Programme (UNEP) defines it as: “The characteristics and circumstances of a community, system or asset that make it susceptible to the damaging effects of a hazard“ (37). Vulnerability can be the result of a variety of factors, but in order to justify the choice of a case study for the thesis, certain indicators must be mentioned.

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# 2. International background and knowledge gaps

*This chapter explores the concept and significance of resilience in the built environment, its connection to sustainability, and its level of integration within Green Building Rating Systems (GBRSs). It delves into international legislations, agreements, frameworks, roadmaps, and action plans related to climate adaptation and resilience at the global level, considering frameworks like Level(s) and the EU Taxonomy. Additionally, the chapter provides a concise overview of Climate Risk Assessment methodologies, highlighting critical gaps in this domain for the construction sector.*

The 2021 Intergovernmental Panel on Climate Change (IPCC) report [AR6] (1) indicated that the severity and frequency of "low probability high impact events," such as natural disasters, are expected to rise due to climate change on the natural and built environment (2). Consequently, extreme heat events are becoming more frequent and occurring with greater intensity compared to the pre-industrial era, resulting in significant losses of life and economic damage (3).

For instance, the European State of the Climate Summary 2023 (4), compiled by the Copernicus Climate Change Service (C3S) and the World Meteorological Organization (WMO), highlights significant contrasts in temperature and precipitation patterns across Europe from June to September 2023. Heatwaves impacted large areas, breaking multiple daily temperature records. At the peak of a heatwave in July, a record 41% of southern Europe experienced ‘strong’, ‘very strong’, or ‘extreme heat stress’. While some regions in southern Europe faced drought, areas in northeastern Europe received lower-than-average precipitation. These dry conditions led to the intensification and spread of wildfires, especially during July and August (4).

Given the increasing frequency and severity of disruptive events, the concept of resilience to climate change-related hazards has garnered significant attention in the construction sector. However, it is still not clear what resilience entails and how it can be achieved. At the same time, another main question is about what measures European countries can take to adapt to climate change and enhance the resilience of their built environment. These questions will be examined in the following subsections.

## 2.1 Concept of resilience

Obtaining a comprehensive definition of resilience is still challenging because researchers from various academic disciplines approach the concept with different objectives (5). The term resilience originates from the Latin word "risilio," meaning "to bounce" (6). Generally, resilience refers to the ability of an entity or system to return to its normal condition after a disruptive event.

For instance, the Rockefeller Center refers to *City resilience* as the “overall capacity of a city (individuals, communities, institutions, businesses and systems) to survive, adapt and thrive no matter what kinds of chronic stresses or acute shocks they experience” (7).

According to the Sendai Framework (8), resilience is *the ability of a system, community or society exposed to hazards to resist, absorb, accommodate, adapt to, transform and recover from the effects of a hazard in a timely and efficient manner, including through the preservation and restoration of its essential basic structures and functions through risk management*; instead, The New Urban Agenda (9) further describes the resilient city as a city *that is able to absorb, adapt, and recover from the shocks and stresses that are likely to happen, transforming itself in a positive way toward sustainability*.

Within this research, resilience is assumed as the ability of a system, entity, community, or person to adapt to changing conditions, resist shocks while still preserving the essential functions, and recover all system features to a pre-disaster level. In the urban environment, improving building resilience has been associated with disaster risk reduction; moreover, when combined with urban resilience strategies, it can serve as a driving force for urban planning in the future (5, 10).

In the context of the built environment, three main perspectives of resilience emerge from the literature: engineering resilience, ecological resilience, and adaptive resilience (11).

- *Engineering resilience* is defined as a system's ability to return to its pre-disturbance equilibrium state following a disturbance (12). This perspective emphasises the predictability of adverse events, relying on the assumption that human-made prediction systems are reliable. Recovery speed is a measure of resilience that focuses on efficiency, constancy, and predictability, which are desired traits in fail-safe engineering designs (13).
- *Ecological resilience* rejects the notion of a single equilibrium state, introducing the concept of multiple equilibria and the potential to shift between them. This type of resilience highlights a system's capacity to absorb changes while retaining its fundamental structure and function. The resilience measure here is the magnitude of disturbance the system can absorb before transitioning to a different equilibrium state. This perspective focuses on persistence, change, unpredictability, and safe-fail designs.
- *Adaptive resilience* refers to complex, dynamic socio-ecological systems that evolve over time, both in external disturbances and in their absence. Unlike other forms of resilience, adaptive resilience involves a return to normalcy and the capacity to change, adapt, and transform in response to challenges. This type of resilience incorporates short-term coping strategies and long-term adaptation, highlighting the importance of bouncing back and moving forward. Key characteristics include adaptability, flexibility, self-organisation, and learning from disturbances.

When assessing the resilience of the built environment, various levels of interventions become crucial (Figure 5). At the urban scale, effective improvements have been achieved using nature-based solutions (14). For instance, these solutions help mitigate extreme heat and reduce runoff during heavy rains (15,16). Moving to the building scale, adaptation strategies—such as passive measures —have proven effective in enhancing user comfort and minimising both heating and cooling demands (17). Lastly, from a user perspective, community cohesion activities like urban gardening, common areas, and training programs have demonstrated their effectiveness in responding to the impacts of climate change (18).

Building performance faces a range of uncertainties, both predictable and unpredictable. Therefore, adaptability, flexibility, and the ability to learn from disturbances are crucial, especially in the context of climate change. Consequently, adaptive resilience forms the foundation of the definition of building resilience in this work.

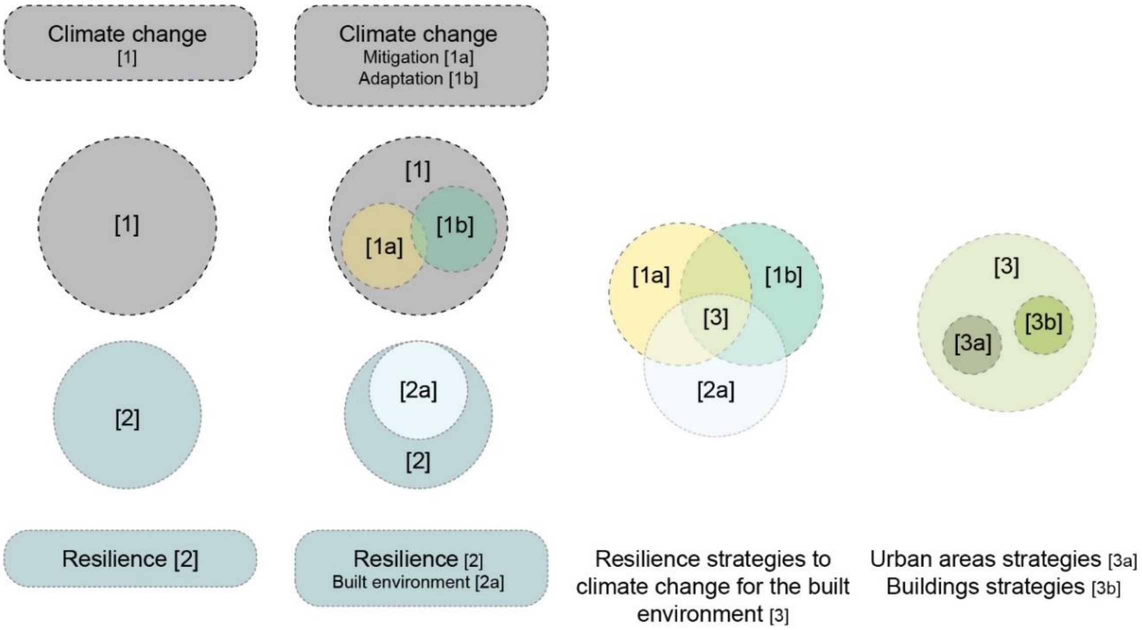


*Figure 5 Investigation process and final domain of study.*

Disaster risk is defined as "the potential loss of life, injury, or destroyed or damaged assets which could occur to a system, society or a community in a specific period of time" (19). Disaster risk can be best described as a function of hazard, exposure, and vulnerability and shown using the equation shown in Figure 6.

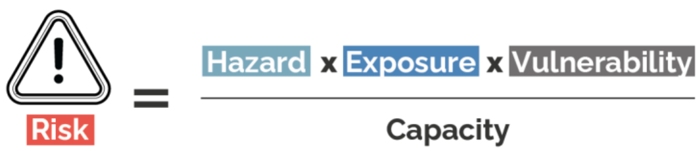

*Figure 6 A risk defined as an existing hazard with exposure, vulnerability, and capacity to deal with it or overcome it. Visualisation readapted from (19).*

Thus, the three risk components can be described as follows:

- Hazard – the possible future occurrence of a natural or human-induced event in a specific place and time that adversely affects lives, properties, and activities.
- Exposure – valued societal elements (lives, buildings, cultural heritage, etc.) in a hazard-prone area. It is possible to be exposed but not vulnerable (for example, living in a floodplain but having sufficient means to modify building structure and behaviour to mitigate potential loss).
- Vulnerability – the propensity of exposed elements (e.g., human beings, livelihoods, and assets) to suffer adverse effects when impacted by risk events.

Each of these components is assessed independently (1). Based on a systemic analysis of resilience, shocks are defined as "events occurring suddenly, leading to adverse effects manifested within hours or days within urban areas, while stresses are defined as chronic pressures that over time can reduce a city's capacity for resilience" (20).

Identifying and prioritising specific actions that will reduce risk and build resilience can be made easier by knowing each of the components of risk and their likely trends.

In any case, resilience as such is a part of overarching sustainability; it influences all three pillars of sustainability (economic, environmental, and social) because the impacts of geophysical phenomena, including climate change and different kinds of natural and human-made disasters, affect all three pillars of sustainability. Thus, focusing on environmental, social, and economic resilience and their mutual interaction is essential for building a resilience module for an existing rating system.

Currently, resilience is a big priority in the construction sector and often overlaps with the concept of sustainability, which has existed for a much longer time. As a consequence, a question arises as to whether resilience is a subset or something independent of sustainability (21). Still, resilience to natural and manmade hazards is rarely included in GBRSs (22).

## 2.2 Resilience at different scales

As the 2022 UN Climate Change Conference (COP27) convened last fall in Sharm-el-Sheik (Egypt), delegates, attendees, and industry practitioners agreed that attempts to prevent global warming from reaching 1.5 degrees warmer than preindustrial levels are falling short (23). The rise in temperatures has contributed to devastating weather events, from wildfires to flooding, and last year's climate summit goals placed a greater focus on mitigating the worst consequences of these events and adapting to the changing climate. However, public authorities, industry and citizens are still failing to prepare sufficiently for climate change and must focus much more on resilient design and retrofitting solutions for the built environment. The Sixth Intergovernmental Panel on Climate Change (IPCC) assessment report (1) blamed the decision makers for a "lack of climate-sensitive planning" and proposed ways to redesign homes, neighbourhoods and districts to protect citizens from extreme weather or sea-level rise. Buildings constructed today will still be used in 2080 and beyond, but the climate they will encounter will have changed significantly. Several of the most important elements of buildings' design are usually derived from historical records of climate data that, even now, are several decades old. At best, this means they may not function as intended, and at worst, they could be downright dangerous.

Decision-makers in public authorities, real estate owners and especially the owners of private homes must acknowledge that our climate is already changing and, at the very least, recognise the risks to their properties. Buildings should respect the minimal standards for sustainability, but contextually, they can also give a minimal response to the concept of resilience. However, resilience and already well-established sustainability analyses are important in assessing the built environment, and both must be addressed. Accelerated action is required to adapt to climate change while making rapid, deep cuts in greenhouse gas emissions (1). In recent years, there has been a considerable debate about sustainability and resilience in the construction sector; the main question was whether they are synonyms and whether they can be used almost interchangeably.

Indeed, a persistent knowledge and implementation gap between these two domains must be resolved (21). Many public authorities have already developed adaptation plans, but only a few have been implemented, so gaps exist in all world regions, including the EU. It has been reported that the main reason for the slow implementation is a lack of an integrated framework and effective digital planning tools that can combine both resilience and sustainability indicators for assessing design and renovation measures of the built environment.

The need to adapt has been recognised by Europewide, with the release of the EU strategy on adaptation to climate change already in 2013 advocating action at all levels of government (24). The European Commission adopted its new EU strategy on adaptation to climate change on 24 February 2021 (25). The new Strategy outlines how the European Union can adapt to the inevitable impacts of climate change and achieve climate resilience by 2050. It has four primary objectives: to enhance the intelligence, speed, and systemic approach to adaptation and to increase international efforts in addressing climate change adaptation. The Next

Generation EU – the Recovery Plan for Europe also addresses climate change adaptation issue (26). The central pillar of Next Generation EU is the "Recovery and Resilient Facility" (RFF), which, among other goals, aims to support actions that assist the implementation of the Paris Agreement and the UN Sustainable Development Goals, in line with the European Green Deal (27).

Indeed, the current concept of resilience to natural hazards is indicated by a globally notable increment in interest: countries are trying to face the problem of climate change, a gradual process that can be measured and its impact relatively accurately foreseen, as shown in the 2022 IPCC's report (28–30). However, disasters, such as floods, also deserve more attention because they may cause a series of losses (e.g., financial deficits, housing collapses, and casualties) (31) (Figure 7).

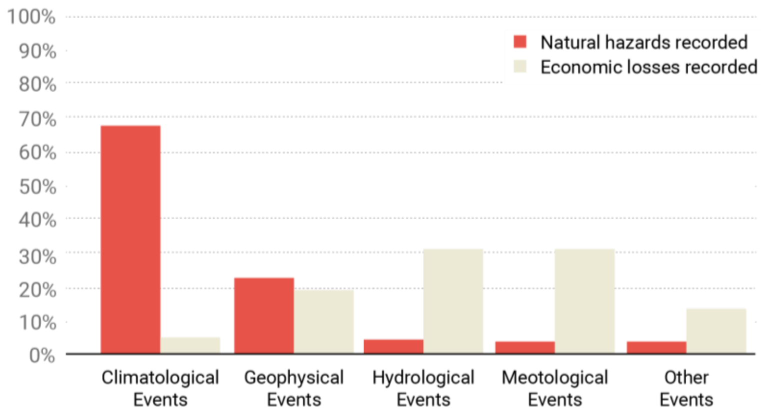


*Figure 7 Percentage of natural hazards recorded in EU and EEA Member States compared to the breakdown of recorded economic losses (1980–2017). Source of data: European Environment Agency (EEA). Source of visualisation: (3).*

The 2022 report of the Intergovernmental Panel on Climate Change (IPCC) (32) shows that emissions of greenhouse gases (GHG) from human activities are responsible for approximately 1.1°C of warming from 1850-1900 and significantly contributed to the alteration of the local climatic conditions in the built environment (i.e. urban heat islands) (33). In their report, IPCC experts have emphasised the irreversible consequences of temperature increase and urged action to reduce $CO_2$ emissions in the short term.

Currently, there is a crucial need to expedite the progress of resilience building at the local level to bring cities on to the resilience pathway towards achieving the Sendai Framework for Disaster Risk Reduction (8), the New Urban Agenda (9), the Paris Agreement (34), and the already mentioned SDGs (35), by 2030.

Resilience can be assessed at different scales —from a single building to the urban, community, municipal, and national levels (3). Actions vary according to the scale (Figure 8).

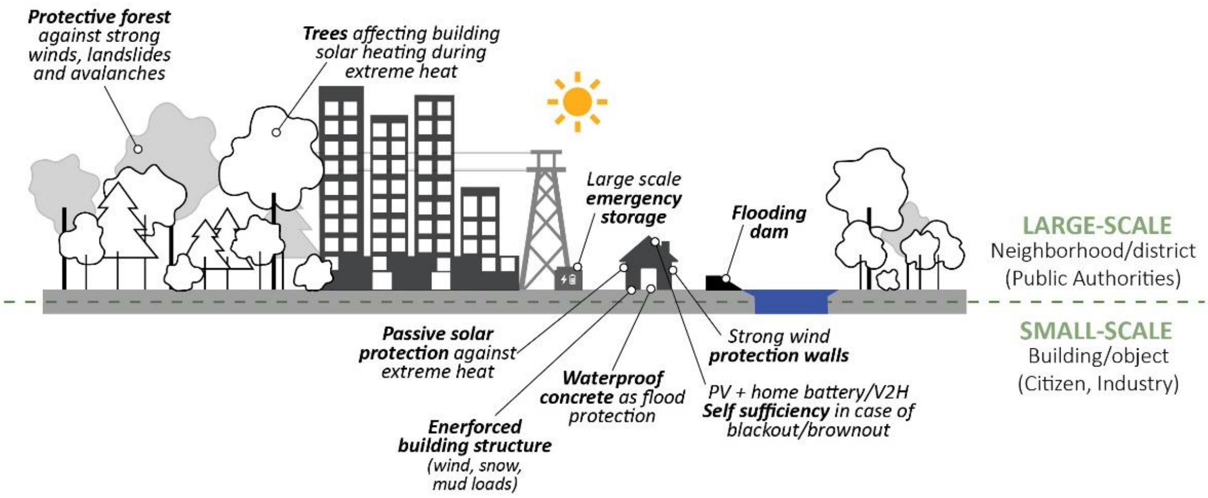


*Figure 8 Resilience measures at different scales and interactions.*

At the building level, for example, resilience ornament would be focused on the capacity to manage shocks and avoid the impact of stressors. At the urban level, resilience measures include the capacity to manage stress or avoid a shock and restore services and repair damages to infrastructures or buildings in a prompt way (3).

However, when a building is viewed as the unit for enhancing resilience instead of an entire neighborhood, it enables a clearer understanding of how building operators and managers—key players within the system—address disruptions (5). This aspect is particularly important because the group most affected by any resilience efforts, regardless of scale, consists of end-users who often have limited control over the building system. In many cases, as residential buildings are typically multifamily structures, owners and managers—who possess more authority than the occupants—can influence and implement targeted actions within the building system to enhance resilience and ensure acceptable living conditions during extreme events (36).

## 2.3 International legislations, agreements, frameworks, roadmaps and action plans

Climate adaptation and resilience of the built environment is a global priority in every country. This ambition necessitates that all stakeholders acknowledge the threat posed by climate change, assess the associated risks, and diligently pursue adaptation and resilience solutions.

For instance, the UK Green Building Council (UKGBC) is developing a roadmap to support the achievement of a climate-resilient built environment by 2050 (37). The roadmap will establish metrics to measure climate resilience, identify urgent priorities and industry-wide targets, and outline essential actions and policies needed to achieve these goals.

Another example of a resilience roadmap is provided by the Making Cities Resilient (MCR2030) initiative (38). They recommend that cities complete a questionnaire (i.e., stage assessment) to determine their current stage (Figure 9). The goal of MCR2030 is to guide cities to the final stage, Stage C, where disaster risk reduction and resilience are fully integrated into city planning. At this stage, cities focus on continuous monitoring and evaluation to maintain their achieved level of resilience.

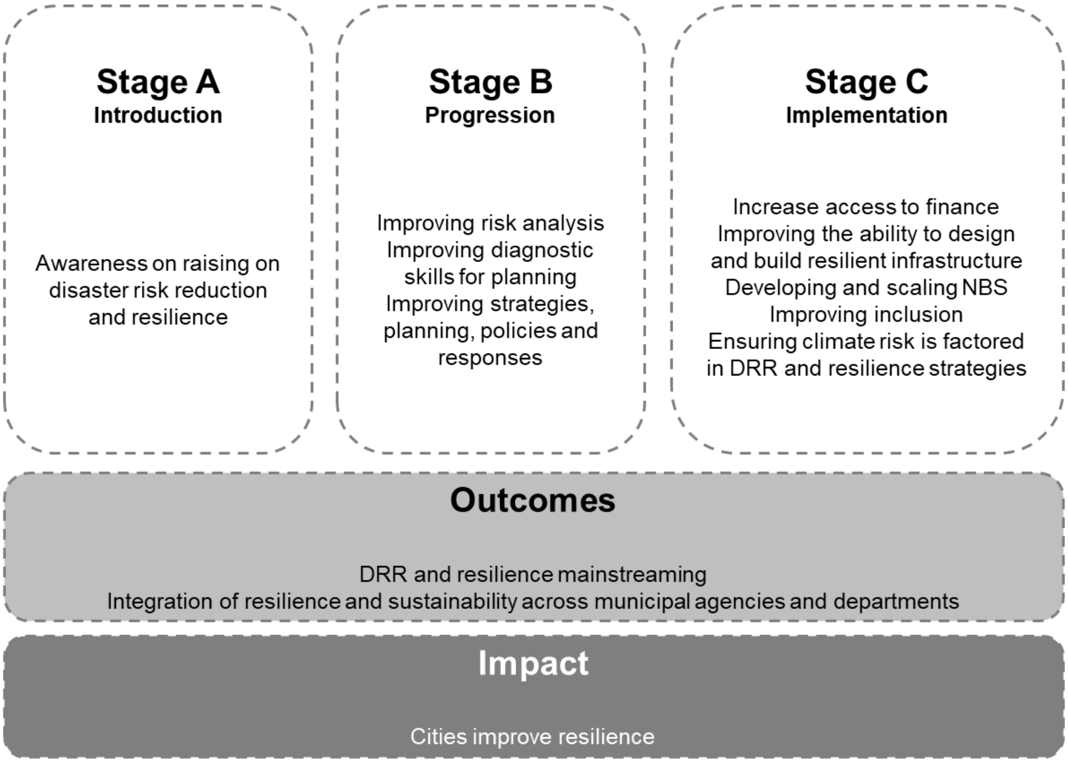


*Figure 9 MCR2030 Resilience roadmap for cities. Visualization readapted from (38).*

More broadly, the Global Alliance for Buildings and Construction (GlobalABC) has developed global and regional roadmaps as a framework and process to address emission reductions in the built environment throughout its entire lifecycle (38). These roadmaps outline a comprehensive strategy with ambitious short-term, medium-term, and long-term targets aligned with the MPGCA Human Settlements Pathways. They aim to achieve zero-emission, efficient, and resilient buildings and construction from 2020 to 2050. Covering eight themes—urban planning, new buildings, existing buildings, building operations, appliances and systems, materials, resilience, and clean energy—the roadmaps seek to leverage the sector's significant decarbonization potential and support the Sustainable Development Goals (Figure

10) (39). Based on a global methodology, these roadmaps are tailored to reflect regional specificities, highlighting regional priorities and data gaps.

| | ISSUE | SOLUTION |
|---|---|---|
| **Urban planning** | Urban planning decisions and strategies | Prioritise integration in rapidly expanding cities, developing urban plans |
| **New buildings** | Respect mandatory codes for minimum energy performance | Prioritise high efficiency standards and incentivize high performance |
| **Existing buildings** | Only a few are energy driver retrofits | Accelerate action on building retrofits with decarbonization strategies |
| **Building operations** | Minimal use of tools for energy performance and management | Facilitate maintenance and building management with tools and monitoring systems |
| **Appliances and systems** | Average efficiency of appliances and system is lower than the best available technology | Stimulate demand for energy efficient appliances in public procurement |
| **Materials** | High embodied carbon | Promote the use of low carbon materials |
| **Resilience** | Some planning strategies against natural disaster but not widespread | Build-in resilience for buildings and communities through the development of an integrated risk assessment and adaptation strategies |
| **Clean energy** | Significant use of fossil fuel | Accelerate the decarbonization of electricity and heat by developing clear regulatory frameworks, financial incentives and encourage onsite renewable energy production. |

*Figure 10 Roadmap themes for Climate action for buildings and construction. Visualization readapted from (39).*

In addition, buildings and construction roadmaps are being developed by the WorldGBC and national GBCs as part of the #BuildingLife Project (40), including the European countries (Figure 11), such as Italy and the Czech Republic, which have already developed their own roadmaps, respectively (41) and (42,43).

*Figure 11 Worldwide overview of planned/in progress/published Climate Action Roadmaps for building and construction for climate action. Visualisation readapted from (39).*

### 2.3.1 EN ISO 14091:2021 - Adaptation to climate change

The first edition of the standard for assessing risks associated with the potential impacts of climate change was published in 2021 (44), aligned with the IPCC Assessment Report 6 (1). This standard outlines how to understand vulnerability and develop and implement a risk assessment within the context of climate change, considering both current and future risks. The assessment can be conducted to facilitate climate change adaptation planning, implementation, and monitoring and evaluation considering three main phases - Figure 12.

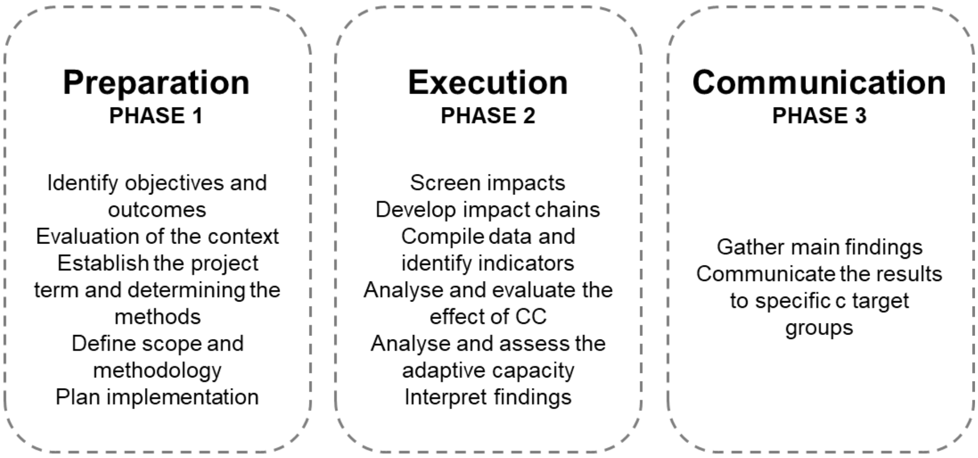


*Figure 12 Workflow for implementation of a Climate Risk Assessment based on ISO 14091:2021.*

### 2.3.2 EU Level(s) and resilience

The European Commission proposes Level(s) as a solution to a very relevant and important issue, which is the absence of a globally recognised standard for measuring the sustainability of buildings (45). This voluntary framework provides a means for European building specialists to measure, report, and share the environmental performance of their buildings. By addressing climate change and resource depletion challenges, Level(s) facilitates the construction of greener, more efficient, and more resilient buildings. Its most significant feature is that it takes a life-cycle approach, understanding building performance over its entire lifespan. This is important because decisions based on the whole life cycle of a building ensure sustainability from the cradle to the grave rather than the short-term, which might contribute to higher carbon emissions.

Table 1 shows the 14 indicators covering six areas of sustainability in Level(s).

*Table 1 Overview of the Level(s) methodology categories and indicators. Source: (45).*

| **Indicator** | **Unit of performance measurement** |
|---|---|
| **Macro-objective 1: Greenhouse gas emissions along a building life cycle** | |
| **1.1 Use stage energy performance**<br>**1.1.1 Primary energy demand**<br>1.1.2 Delivered energy demand (supporting indicator) | kilowatt hours per square metre per year (kWh/m2/yr) |
| 1.2 Life Cycle Global Warming Potential | kg CO2 equivalents per square metre per year (kg CO2 eq./m2/yr) |
| **Macro-objective 2: Resource-efficient and circular material life cycles** | |
| **2.1 Bill of quantities, materials and lifespans** | Report on the bill of materials for the building and the four main types of materials used. |
| 2.2 Construction and demolition waste and materials | According to the performance assessment level:<br>1. Design aspects that are proposed/have been implemented (common performance assessment)<br>2. Semi-qualitative assessment giving a score (comparative performance assessment)<br>3. LCA-based assessment of scenario performance (design optimisation) |
| 2.3 Design for adaptability and renovation | kg waste and materials per m2 of total useful floor area (per life cycle and project stage reported on) |

| | |
|---|---|
| 2.4 Design for deconstruction, reuse and recycling | Seven environmental impact category indicators |
| **Macro-objective 3: Efficient use of water resources** | |
| 3.1 Use stage water consumption | m3 of water per occupant per year |
| **Macro-objective 4: healthy and comfortable spaces** | |
| 4.1 Indoor air quality | 4.1.1 Good quality indoor air: Parameters for ventilation, CO2 and humidity<br>4.1.2 Target list of pollutants: Emissions from construction products and external air intake. |
| 4.2 Time outside of thermal comfort range | % of the time out of range of defined maximum and minimum temperatures during the heating and cooling seasons |
| 4.3 Lighting and visual comfort | |
| 4.4 Acoustics and protection against noise | |
| **Macro-objective 5: Adaptation and resilience to climate change** | |
| 5.1 Protection of occupier health and thermal comfort | Scenario 1: Protection of occupier health and thermal comfort<br>Simulation of the building's projected time out of thermal comfort range for the years 2030 and 2050. |
| 5.2 Increased risk of extreme weather events | |
| 5.3 Increased risk of flood events | |
| **Macro-objective 6: Optimised life cycle cost and value** | |
| 6.1 Life cycle costs | Euros per square metre of useable floor area per year (€/m2/yr) |
| 6.2 Value creation and risk exposure | Reliability ratings of the data and calculation methods for the reported performance of each indicator and life cycle scenario tool. |

### 2.3.2 EU Taxonomy and resilience for the construction sector

In the context of the European Green Deal initiatives (27), the EU taxonomy for sustainable activities (46) (also known as the "green taxonomy") is a classification system which identifies investments that are environmentally sustainable and entered into force in July 2020.

EU taxonomy is a scheme that assesses the environmental objectives of specific economic activities through a green classification scheme. A company can calculate its sustainability turnover using the EU Taxonomy, which identifies environmentally sustainable activities. After its endorsement by the European Parliament on 18 June 2020, the EU Taxonomy Regulation was published on 22 June 2020 by the EU and came into effect on 12 July 2020 (46). As of now, the EU taxonomy is considered one of the main pacesetters that assist the financial system in redirecting capital towards a low-carbon economy that conforms to the Paris Agreement.

The EU Taxonomy is a classification system that establishes a list of environmentally sustainable economic activities. It is crucial to promote sustainable investment within the EU and implement the European Green Deal (27). By providing companies, investors, and policymakers with clear definitions of what constitutes an environmentally sustainable economic activity, the EU Taxonomy aims to create certainty for investors, protect them from greenwashing, assist companies in becoming more climate-friendly, reduce market fragmentation, and channel investment to where it is most needed.

To meet the EU's climate and energy targets for 2030 and achieve the goals of the European Green Deal, it is vital to direct investment towards sustainable projects and activities (27). The ongoing COVID-19 pandemic has further underscored the necessity of reallocating funds to sustainable initiatives to enhance the resilience of European economies, businesses, and societies against climate and environmental shocks.

As a common classification system for sustainable economic activities, the EU Taxonomy was created to clearly define sustainability and the means for achieving it within the Sustainable Growth Financing Action Plan by 2030. The Taxonomy lists the six environmental objectives that should be considered during investments and economic activities: climate change mitigation, climate change adaptation, the transition to a circular economy, pollution prevention and control, sustainable use and protection of water and marine resources, and the protection and restoration of biodiversity and ecosystems.

These criteria include reducing greenhouse gas emissions, improving water and air quality, and conserving biodiversity. The Taxonomy provides investors with a framework for assessing the sustainability of the projects they are considering investing in. Furthermore, the Taxonomy Regulation specifies four overarching conditions that must be met in order for economic activity to be considered environmentally sustainable:

1. Making a substantial contribution to at least one environmental objective;
2. Doing no significant harm to any of the other five environmental objectives (better known as DNSH criterion);
3. Complying with minimum safeguards;
4. Complying with the technical screening criteria set out in the Taxonomy delegated acts.

Moreover, the criteria of the Taxonomy will form the basis of the legal framework for green bonds and loans, which will increasingly be the focus of the strategies of financial institutions and the financial market as a whole. The taxonomy will also de facto set the conditions that public funding will follow in the next step.

The Taxonomy Regulation contains detailed criteria that must be met in order for specific activities to be classified as green and, therefore, sustainable. A green activity must make a significant contribution to addressing one of the stated objectives, such as climate change mitigation. At the same time, it must not be fundamentally detrimental to other objectives, such as the protection of biodiversity. This is the 'do no significant harm' rule. What is meant by significant harm to environmental objectives is generally defined for each of them. In addition, the technical screening criteria set out in more detail for each green activity the limits and measures that must be met to avoid significant harm to other environmental objectives.

Business activities related to green activities must generally refrain from leading to human rights violations. Green activities must be carried out in such a way as to ensure that the economic activity complies with: the OECD Guidelines for Multinational Enterprises, the UN Guiding Principles on Business and Human Rights, the eight fundamental conventions referred to in the International Labour Organisation Declaration on Fundamental Principles and Rights at Work, the Universal Declaration of Human Rights.

In the construction sector, the following activities can be classified as green activities leading to climate change mitigation:

- construction of new buildings,
- renovation of existing buildings,
- installation, maintenance and repair of energy-efficient equipment.

Table 2 presents the list of climate-related hazards listed in the EU taxonomy.

*Table 2 Classification of climate-related hazards from Appendix A of 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*** | Heatwave | Cyclone, hurricane, typhoon | Drought | Avalanche |
| | Cold wave/frost | Storm (including blizzards, dust and sandstorms) | Heavy precipitation (rain, hail, snow/ice) | Landslide |
| | Wildfire | Tornado | Flood (coastal, fluvial, pluvial, groundwater) | Subsidence |
| | | | Glacial lake outburst | |

The mean air temperature is projected to exhibit a gradual increase continent-wide. In terms of precipitation, distinct alterations are expected, with heightened rainfall in the North, increased extremes in Central Europe, and an augmented risk of drought in the South. Wind dynamics will undergo changes, with an overall escalation in storm intensity, although the frequency of such events is projected to vary across regions. Snow and ice dynamics are also anticipated to shift, with decreased snowfall expected in central and southern Europe and mixed changes predicted for the northern regions. Specifically, when examining the Central European region, the trajectories of these hazards are anticipated to exhibit variations in increments or decrements distinct from those observed in other geographical areas. Central Europe is anticipated to encounter diminished summer rainfall and heightened severe weather conditions such as heavy precipitation, river floods, droughts, and fire hazards. Annual precipitation and aridity alterations are expected to vary (Figure 13).

| | | |
|---|---|---|
| MEAN AIR TEMPERATURE | MEAN TEMPERATURE | ↗ |
| | HEATING DEGREE DAYS | ↘ |
| | COOLING DEGREE DAYS | ↗ |
| EXTREME HEAT | HOT DAYS | ↗ |
| | CLIMATOLOGICAL HEATWAVE DAYS | ↗ |
| FROST | FROST DAYS | ↘ |
| MEAN PRECIPITATION | TOTAL SUMMER PRECIPITATION | ↘ |
| HEAVY PRECIPITATION AND RIVER FLOOD | FREQUENCY OF EXTREME PRECIPITATION | ↗ |
| | MAXIMUM CONSECUTIVE 5-DAY PRECIPITATION | ↗ |
| | RIVER FLOOD INDEX USING RUNOFF | ↗ |
| DROUGHT | MAGNITUDE OF METEOROLOGICAL DROUGHTS | ↗ |
| FIRE WEATHER | DAYS WITH FIRE DANGER EXCEEDING A THRESHOLD | ↗ |
| SEVERE WIND STORM | EXTREME WIND SPEED DAYS | ↗ |
| SNOW, GLACIER AND ICE SHEET | SNOWFALL AMOUNT | ↘ |
| | PERIOD WITH SNOW WATER EQUIVALENT ABOVE THE THRESHOLD | ↘ |

*Legend: ↗ Likely to increase throughout most of the Central European region. ↘ Likely to decrease throughout most of the Central European region.*

*Figure 13 EU Taxonomy climate-related hazards in the Central European region. Source of visualisation: (47).*

### 2.3.4 Climate risk and vulnerability assessment methodologies

The complexities arising from the interplay among diverse drivers of climate change risk and the compounded or cascading impacts of multiple risks are evident in real-world scenarios. However, as of now, there is a lack of a comprehensive framework to assess the intricacies of these climate change risks. There is an urgent need for clarity in understanding the interactions leading to risks, incorporating the influences of adaptation and mitigation responses.

The EU Adaptation Strategy outlines a framework for the European Union to effectively address the inevitable consequences of climate change and reach climate resilience by 2050. A pivotal element of the strategy is the proposal to intensify adaptation planning and risk assessments, representing a crucial stride towards achieving more sophisticated and systematic adaptation practices across Europe. Explicitly articulated under No. 14, the strategy emphasises the Commission's commitment to formulating an EU-wide climate risk assessment. This commitment draws on an extensive analysis of both natural and man-made disaster risks, informed by research projects and sector regulations. Furthermore, a resolution passed by the European Parliament on September 15, 2022, reinforces this directive, urging the Commission to undertake a comprehensive EU-wide climate risk assessment with particular attention to the risks associated with droughts, forest fires, and health threats.

Concludingly, a climate risk assessment seeks to discern the likelihood of future climate hazards and their potential effects on various targets, specifically buildings, in this context. This process is pivotal for effectively guiding the prioritisation of climate-related actions and investments in adaptation.

For instance, the German Environmental Agency published a paper providing recommendations for the effective implementation of the standard in cities and municipalities. (48).

Climate Vulnerability and Risk Assessments (CVRAs) are widely used to evaluate the potential impacts of climate change on various systems. They serve as a critical tool to identify the need for adaptation to future climate conditions and to inform the prioritisation and implementation of design and mitigation strategies.

CVRAs are often conducted on both mandatory and voluntary bases. The EU policy framework increasingly mandates and supports actions to adapt assets to climate change. Even when not obligatory, stakeholders frequently undertake CVRAs voluntarily to understand the risks to an asset and enhance its resilience. Specific requirements and recommendations for CVRAs include:

- The EU Taxonomy Regulation: Mandates that companies conduct comprehensive CVRAs to report on their contributions to climate change adaptation and mitigation goals.
- Financial Disclosures: The Task Force on Climate-related Financial Disclosures (TCFD) recommends using CVRAs to inform financial disclosures.
- Eurocodes: Although structural design standards like Eurocodes typically consider current climate conditions, future iterations may incorporate climate change impacts.
- The Environmental Impact Assessment (EIA) Directive: Stipulates the necessity to assess project vulnerability to climate change.

*European climate risk assessment*

In May 2022, the Directorate-General for Climate Action of the European Commission (DG CLIMA) and the European Environment Agency (EEA) began preparations for the first

European Climate Risk Assessment (EUCRA). This assessment aims to evaluate the current and future impacts and risks of climate change on the environment, economy, and society across Europe (49).

This initial EUCRA is a rapid, expert-driven assessment that synthesises existing data and knowledge from various sources. It specifically addresses complex climate risks, including cross-border, cascading, and compound risks, but it must still be explicitly focused on buildings.

*Policy Context*

The EU Adaptation Strategy outlines how the European Union can adapt to the inevitable impacts of climate change and achieve climate resilience by 2050 (50). A key component of the Strategy is enhancing adaptation planning and risk assessments to ensure more intelligent, swift, and systematic adaptation across Europe.

The European Parliament resolution of 15 September 2022 also called on the Commission to prepare an EU-wide climate risk assessment, emphasising the risks of droughts, forest fires, and health threats.

The first EUCRA assists in identifying adaptation-related policy priorities in Europe and in shaping EU policies in climate-sensitive sectors. It will also serve as a reference point for conducting and updating national or subnational climate risk assessments across the EU, relying on the climate risk concept of the Intergovernmental Panel on Climate Change (IPCC) Sixth Assessment Report (AR6) (30) and follow the risk assessment guidelines of ISO 31000 (51) (Risk Management - Guidelines) and ISO 14091 (Adaptation to climate change — Principles, requirements and guidelines) (44).

*C40 Rapid risk assessment*

The C40-developed assessment (52) is another example of an assessment method for risks and vulnerabilities; however, it concentrates on the city level rather than the building level. The C40 guide recommends a strategic approach, advising cities to establish objectives, identify stakeholders, both internal and external, and assess existing resources and datasets before embarking on a comprehensive risk assessment. It further furnishes a systematic checklist outlining essential and recommended components for inclusion in the risk assessment. C40 has also devised the *Rapid Site Risk Assessment* (53), tailored for non-experts. This methodology empowers cities to utilise non-technical information and data for:

- Offering a qualitative overview of pertinent climate hazards, encompassing historical trends and future projections.
- Compiling a prioritised list of impacts across the city's sectors.
- Summarizing key climate risks prevalent in the city's sectors.

This module encapsulates the critical facets of three assessments integral to a Climate Risk Assessment:

*Hazard Assessment:* This involves sourcing information on past occurrences of heatwaves, droughts, storms, and floods, scrutinising historical climate trends, and projecting future scenarios. Hazard maps prove especially efficacious in correlating climate science with vulnerable locations.

*Impact Assessment:* Focusing on the consequences of climate change for social, natural, and economic capital in the city, this assessment aims to diagnose and prioritise these impacts, necessitating input from various stakeholders and relevant city sectors.

*Risk Assessment:* Facilitating the identification of key climate risks and formulating a concrete strategy to address them, this assessment guides cities in prioritising actions and investments for climate adaptation and resilience. This approach empowers cities to undertake ambitious measures.

A notable deficiency in current practices lies in the underutilisation of maps depicting changing trends and patterns despite our awareness of such transformations and access to forecasts spanning the next 80 years. Recognising this gap underscores the potentially transformative impact of conducting a risk assessment for the location where a building is to be constructed. Such an assessment could prove fundamental in extending the service life of a building and avoiding potential damages during disruptive events.

This PhD study, as its foundational approach, seeks to leverage the methodology pioneered by C40, mainly focusing on the screening of pertinent hazards specific to a context. This proactive approach aims to integrate irreplaceable elements and components into the initial design, fortifying the building's resilience from the outset.

*Other climate vulnerability and risk assessment methodologies applicable to the built environment*

Through desk research, 12 documents relevant to Climate Vulnerability and Risk Assessments (CVRAs) for the built environment were identified. The focus was on methodologies that (i) are directly applicable to buildings or easily adaptable for building use, (ii) offer a transparent and comprehensive approach, (iii) apply to European countries, and (iv) align with the IPCC AR5 and AR6 definitions of vulnerability and risk. Table 3 presents these 12 methodologies and their respective strengths and weaknesses.

*Table 3 Internationally identified Climate vulnerability and risk assessment methodologies: strengths and weaknesses. Source: (54).*

| | |
|---|---|
| *Methodology* | **Climate proofing of Infrastructure** (55) |
| *Author* | *European Commission* |
| *Year* | *2021* |
| *Context* | *European* |
| *Strengths* | *Clear, detailed methodology for use in practice* |
| *Weaknesses* | ***• Not specific to buildings*** |
| | *• Vulnerability definition does not factor in building inhabitants or the use of different buildings* |
| *Methodology* | **Environmental Impact Assessment Climate Change Resilience** (56) |
| *Author* | *Institute of Environmental Management and Assessment* |
| *Year* | *2020* |
| *Context* | *National (UK)* |
| *Strengths* | *• Detailed methodology for use in practice* |
| | *• Widely used* |
| *Weaknesses* | *• UK-orientated (link to EIA Directive)* |
| | ***• Not specific to buildings*** |
| *Methodology* | Guidelines for climate and vulnerability assessments (57) |
| *Author* | *Umweltbundesamt* |
| *Year* | *2017* |
| *Context* | *National (DE)* |
| *Strengths* | *• Aligned with definitions of IPCC* |
| | *• Clear step-by-step approach* |
| *Weaknesses* | *Not specific to buildings* |
| *Methodology* | **ISO 14091. Adaptation to climate change** (44) |
| *Author* | *International Standardisation Organization* |
| *Year* | *2021* |
| *Context* | *International* |
| *Strengths* | *• Clear step-by-step approach* |
| | *• Example of indicators* |
| *Weaknesses* | ***Not specific to buildings*** |
| *Methodology* | **Climate Resilience Template for Buildings** (58) |
| *Author* | Green Ribbon Commission |
| *Year* | 2019 |
| *Context* | Local (Boston – USA) |

| | |
|---|---|
| *Strengths* | • Specific to buildings<br>• Steps for CVRA |
| *Weaknesses* | **Focused on Boston only** |
| *Methodology* | **A practical guide to climate-resilient buildings and communities** (59) |
| *Author* | United Nations Environment Programme |
| *Year* | 2021 |
| *Context* | International |
| *Strengths* | • Specific to buildings<br>• Details on adaptation measures |
| *Weaknesses* | No specific methodology |
| *Methodology* | **A Framework for Measuring and Reporting of Climate-related Physical Risks to Built Assets** (60) |
| *Author* | UKGBC |
| *Year* | 2022 |
| *Context* | International |
| *Strengths* | • Clear methodology and framework<br>• Guidance on buildings |
| *Weaknesses* | Reporting framework rather than a methodology |
| *Methodology* | **Guide des actions adaptatives au changement climatique** (61) |
| *Author* | Observatoire de l'immobilier durable |
| *Year* | 2022 |
| *Context* | International |
| *Strengths* | • Specific to buildings<br>• Aligned with IPCC 2014 risk definition<br>• Guidance notes on the impacts of key hazards on buildings |
| *Weaknesses* | No specific methodology |
| *Methodology* | **How to perform a robust climate risk and vulnerability assessment for EU taxonomy reporting? Recommendations for companies** (62) |
| *Author* | Umweltbundesamt |
| *Year* | 2022 |
| *Context* | National (DE) |
| *Strengths* | • Aligned with EU Taxonomy<br>• Step by step approach |
| *Weaknesses* | Not specific to buildings |
| *Methodology* | **Climate Change Risk Assessment for the Insurance Industry** (63) |
| *Author* | The Geneva Association |
| *Year* | 2021 |
| *Context* | International |
| *Strengths* | Awareness of the need to assess climate risks |
| *Weaknesses* | • Not specific to buildings |

| | |
|---|---|
| | • No specific methodology |
| *Methodology* | **Ensuring the climate transition: enhancing the insurance industry's assessment of climate change future** (64) |
| *Author* | PSI-TCFD |
| *Year* | 2021 |
| *Context* | International |
| *Strengths* | Clear steps and concepts for scenario analysis |
| *Weaknesses* | • Not specific to buildings |
| | • No specific methodology |
| *Methodology* | **Physical Climate Risk Assessment Methodology** (66) |
| *Author* | Coalition for Climate Resilient Investment |
| *Year* | 2021 |
| *Context* | International |
| *Strengths* | Steps for the quantification of climate impacts on assets |
| *Weaknesses* | • Not specific to buildings |
| | • No details on how CVRA is carried out |
| *Methodology* | **Physical risk framework: Understanding the impacts of climate change on real estate lending and investment portfolios** (67) |
| *Author* | Cambridge Institute for Sustainability Leadership |
| *Year* | 2019 |
| *Context* | International |
| *Strengths* | Steps for catastrophe modelling |
| *Weaknesses* | • No specific methodology |
| | • It requires modelling |
| *Methodology* | **Managing the impacts of climate change: risk management responses** (65) |
| | Zurich Insurance Group |
| *Author* | 2019 |
| *Year* | International |
| *Context* | Awareness of the need to assess climate risks |
| *Strengths* | • Not specific to buildings |
| *Weaknesses* | • No specific methodology |

It is also important to note that the recently funded SuPeRBE project (Supporting Cross-scale Planning and Policy Readiness for a Resilient Built Environment) [2024-2026] (68) under the Interreg Central Europe programme is currently developing a methodology for assessing the climate change adaptation levels, risks, and vulnerabilities of buildings, neighbourhoods, and community/cities. The outcomes will assist local and regional authorities in their adaptation efforts. Within the project framework, a new digital toolkit will be developed, featuring a multi-scale assessment tool for building adaptation, namely the Resilient Built Environment Central

Europe assessment system (RBE-CE), decision-making methodologies, and a 3D simulation platform. Figure 14 presents the structure of the RBE-CE system. Several Central European municipalities will participate in local pilots to test integrated and agile adaptation plans and implement tailored climate support services.

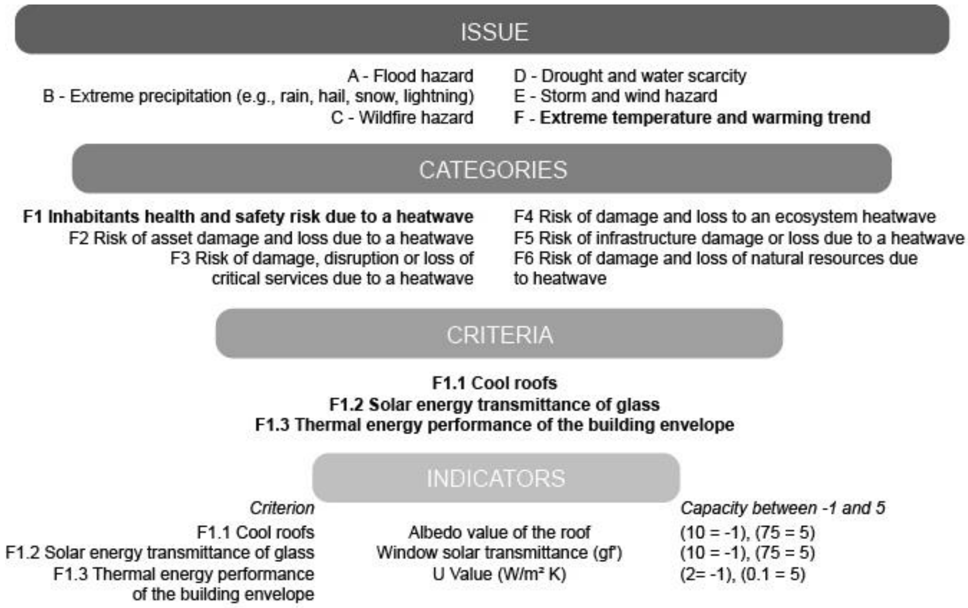


*Figure 14 Structure of the RBE-CE assessment system. Source: (68).*

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# 3. Current state of the art on sustainability and resilience principles in buildings

*This chapter presents a comprehensive overview of current knowledge concerning sustainability and resilience, alongside existing methodologies for evaluating the resilience of buildings. The state-of-the-art assessment utilises diverse methods, encompassing both theoretical analyses and case studies. Notably, the examination reveals that resilience, in comparison to sustainability, is a relatively recent conceptual development, gaining prominence in the last five years. Completing this phase was imperative to identify critical gaps and assess the feasibility of integrating resilience principles into established sustainability rating systems. This chapter is based on the following author's publications: Felicioni et al., Exploring the Common Ground of Sustainability and Resilience in the Building Sector: A Systematic Literature Review and Analysis of Building Rating Systems, Sustainability 2023, 15(1),884. and Felicioni et al., Sustainability and Resilience in Building Design: Discussion on Two Case Studies. Central Europe towards Sustainable Building 2022, Acta Polytechnica CTU Proceedings 2022, 38, 456–462.*

## 3.1 Sustainability assessment for buildings

Since the 1990s, various standards and certifications have been developed and implemented to enhance building sustainability – they are known as Green Building Rating Systems (GBRSs) (1). These include Leadership in Energy and Environmental Design (LEED) (2) in the United States, Building Research Establishment Environmental Assessment Method (BREEAM) (3) in the United Kingdom, and Deutsche Gesellschaft für Nachhaltiges Bauen (DGNB) (4) in Germany. It is widely accepted that using GBRSs during the design phase ensures the entire project is claimed as sustainable.

GBRSs are designed to address a wide range of project types, from single-family homes and commercial buildings to entire neighbourhoods. These systems provide frameworks for both new constructions, focusing on planning, design, and construction phases, as well as existing buildings, emphasising operations and maintenance throughout the building's lifespan. The primary purpose of these rating systems is to clearly define, implement, and measure green strategies and their impacts. They also support architects in translating sustainability objectives into design criteria. Given that these goals are grounded in environmental performance evaluations, it is essential to assess the anticipated performance of the design and evaluate its effectiveness in achieving the desired outcomes.

The motivations for seeking green building certification vary. Certification verifies a project's green attributes and serves as an educational and marketing tool for owners, designers, and construction teams. It incentivises clients, owners, designers, and users to adopt and promote sustainable construction practices.

GBRSs help to clarify a market saturated with "green" options by explicitly defining the standards and types of environmentally friendly products that should be included in construction specifications.

Ultimately, the selection of a certification system is contingent upon the specific project, as these systems are not universally applicable. The dynamic nature of projects may render one system more appropriate than another, with the decision influenced by factors such as location, size, budget, and overall project objectives. Comparing key elements like cost, usability, and building performance is essential in identifying the most suitable rating system and achievable certification level.

Building rating and certification systems continually evolve to reflect new standards and goals for higher sustainability levels. Therefore, reviewing the most current versions of their manuals is crucial to understanding the specific requirements for achieving the best results.

## 3.2 Resilience assessment for buildings

Research has predominantly focused on examining resilience at the city and community scales, with significantly less attention given to the resilience of individual buildings (5).

McAllister (6) has underscored the lack of metrics for measuring resilience and emphasised the need for such metrics to evaluate the built environment's resilience across different scales, from buildings to cities.

In contrast, as mentioned in the previous section, numerous tools (e.g., BREEAM, LEED) are available for assessing the sustainability of individual buildings, while tools for evaluating building-level resilience are still in their early stages of development. For individual buildings, resilience can be defined as the ability to maintain or restore functionality within a specific timeframe following a damaging event or occurrence.

Measuring resilience is crucial for identifying and addressing weaknesses and gaps, thereby enhancing the protection of the built environment and its functionality, along with the associated economic and social domains. Improving resilience is essential for safeguarding the sustainability of the built environment. A building or community may be sustainable, but if it lacks resilience to disruptions and disturbances, its sustainability is compromised and becomes vulnerable to risks. To effectively manage uncertainty, designing for both resilience and sustainability is necessary.

The sections below provide a detailed description of the most known tools and guidelines for building resilience assessment.

## 3.3 Searching for commonalities

For the research purposes of defining the commonalities between sustainability and resilience at the building level for new construction, a literature review has been conducted to highlight the quantity of production and knowledge about these domains within the scientific community. The purpose of this study has not been to review the investigated articles in-depth but rather to acquire an overview of the available literature on the topic (7). The subjects, research methods, and main findings of articles concerning the two domains have been mapped to provide an overview of the extent of scientific studies in this field of research. This overview was then used as a basis for defining the common clusters. Three different approaches have been considered to map the state-of-the-art:

- Methodological approach in which different electronic engines were consulted;
- Rating system approach in which the most known and used sustainability and resilience assessment tools have been investigated;

- Case studies approach in which it was highlighted that buildings claimed sustainable may not be resilient to certain hazards and vice versa.

Figure 15 illustrates the domain under investigation.

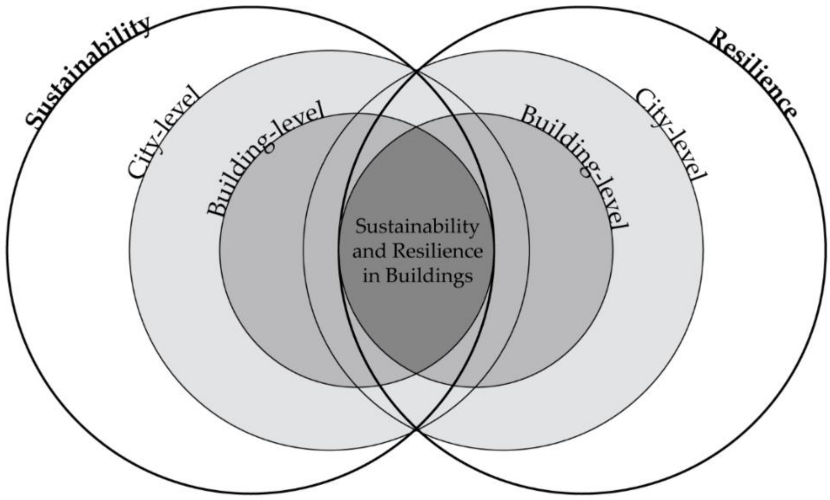


*Figure 15 Venn diagram to identify the area of investigation. Source:* (7).

### 3.3.1 Methodological approach

A literature review was conducted using the Web of Science, Scopus, and Science Direct databases, selected for their reputation for indexing high-quality, peer-reviewed papers and their management by third parties. To ensure data quality and consistency, document types were limited to "reviews," "articles," "conference papers," and "books/book chapters," and the language was restricted to English. The investigation covered a timespan from 2002 to 2022, considered the "maturation period" for both domains with significant scientific output. Papers were identified by their titles, keywords, and abstracts using the following search strings:

- Sustainable building OR sustainable design OR sustainable construction OR sustainable built environment.
- Resilient building OR resilient design OR resilient construction OR resilient built environment.

Figure 16 shows the PRISMA diagram (8) that resumes the second-phase reviewing process. Upon completing the data search, which identified 1,659 records, an additional 7 records were found through hand-searching. After removing 744 duplicate records, 922 records remained for the screening process. Titles and abstracts were screened, and irrelevant results were excluded due to marginal consideration of the resilience aspect. Consequently, 86 full-text records were selected for an eligibility check. After reviewing the full texts, 47 records were included in this study.

The literature research was conducted between July and November 2022. The initial search yielded 8,437 results for the sustainability domain and 1,130 results for the resilience domain. The combined distribution of these results over the 20-year period is shown in Figure 17. Unsurprisingly, while sustainability has been extensively studied over the past 20 years, resilience appears to be a relatively more recent field of study.

Therefore, in the second round of research, since resilience is a more recent and less established concept, only the last 10 years (2012 to 2022) were considered (Figure 18) to refine the process with a more balanced background knowledge.

VOSviewer tool (open-source software) (9,10) was used to identify patterns and trends because it provides some analysis of the recurrence of keywords that are useful to direct the search and immediately have insights on emerging aspects.

The analysis focused on the co-occurrence of words in titles, abstracts, and keywords of the resulting publications. Binary counting was used, with a minimum of ten occurrences required for a keyword to appear on the map. Normalisation was performed using the association strength method, identifying four clusters: blue, light blue, green, and yellow. In the VOSviewer occurrence analysis, the distance between two words represents the conceptual distance between research topics. The blue cluster in Figure 19 is dominated by words related to sustainability, resilience, and implementation. The light blue cluster pertains to management and monitoring. The green cluster includes terms related to building performance. The yellow cluster, which contains the fewest words, covers topics related to vulnerability and risk analysis.

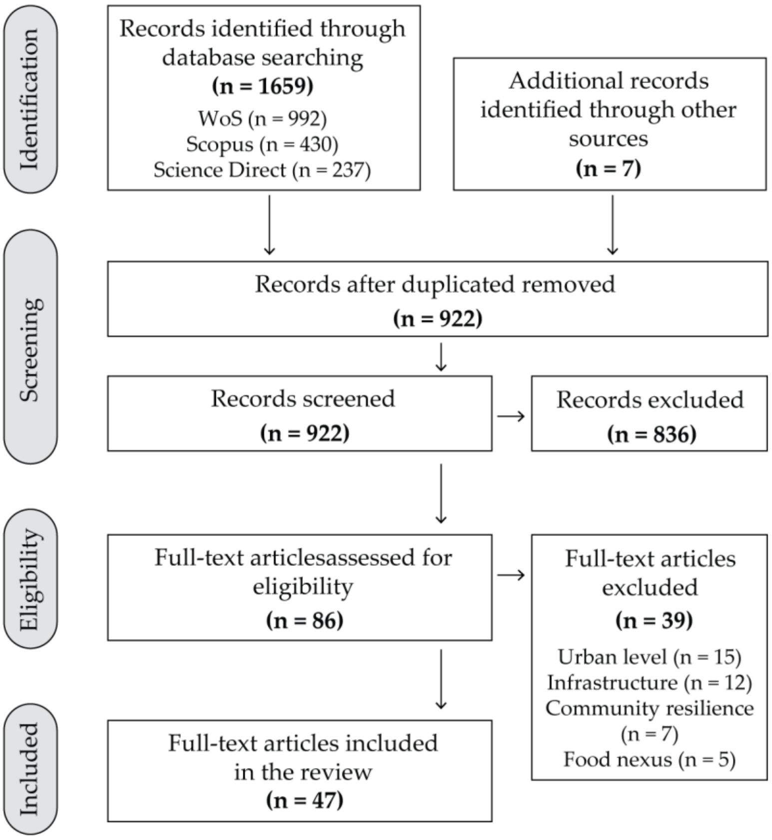


*Figure 16 Literature review search strategy based on the PRISMA workflow. Source:* (7).

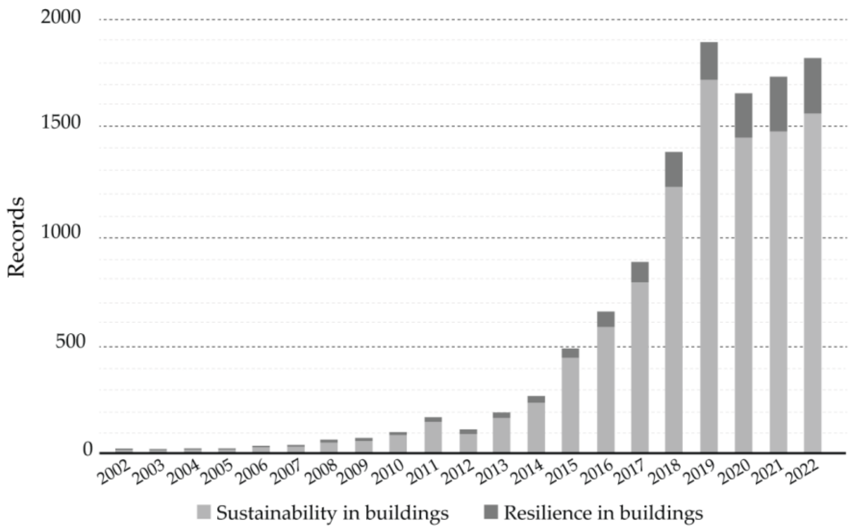


*Figure 17 Records from the electronic databases divided by topic (including duplicates). Source:* (7).

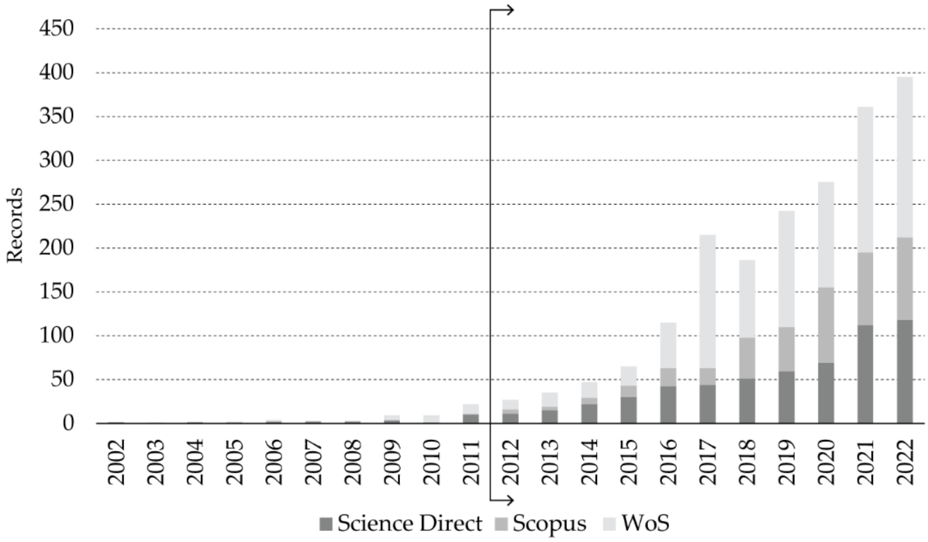


*Figure 18 Records from the electronic databases (including duplicates). Source:* (7).

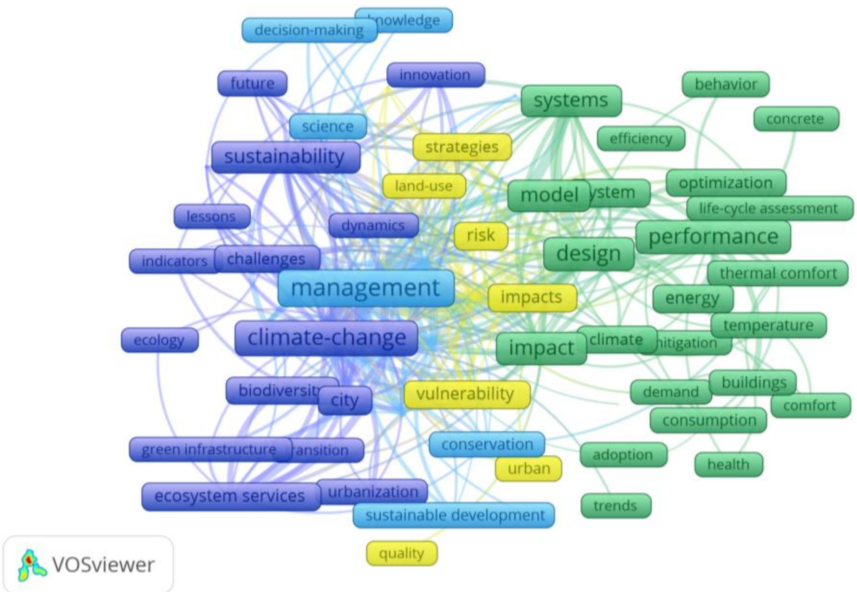


*Figure 19 The output of the keywords' analysis from the literature research, performed in VOSviewer. The figure shows the clusters of keywords considering their occurrences. Source:* (7).

Figure 20 illustrates the annual distribution of records from 2012 to 2022. In comparison with Figure 18, the number of records decreased after duplicates were removed and only the most eligible documents were considered. However, it is evident that the topic has garnered increasing attention over the past seven years.

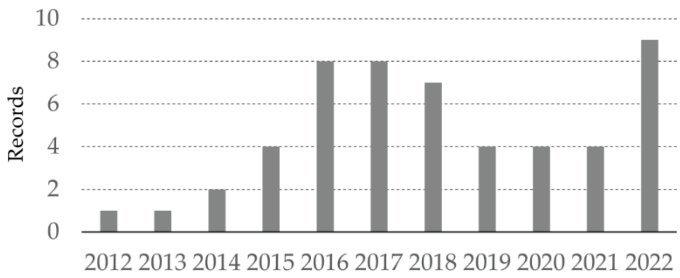


*Figure 20 Annual distribution of the literature that considers both sustainability and resilience in buildings. Source:* (7).

The analysis of records on the combination of sustainability and resilience identified nine recurring clusters (Figure 21), demonstrating that the simultaneous consideration of both domains has already been recognised in specific instances.

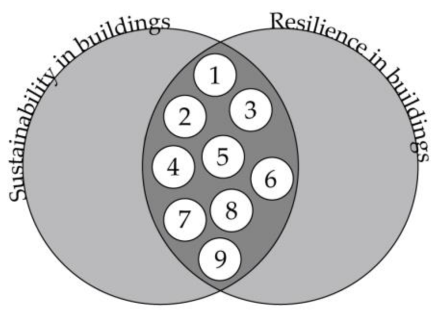


*Figure 21 Venn diagram for common ground between sustainability and resilience in buildings. Nine clusters have been identified. Source:* (7).

The identified clusters are detailed in Table 4. Many records highlight achieving sustainable and resilient buildings through low-energy solutions, as noted by references (11) and (12), categorising them under "Energy Performance." For instance, studies such as those by Menna et al. (13) or Marini et al. (14) focus on Life Cycle Assessment for structural retrofitting against seismic hazards and environmental impacts, fitting into the "Life Cycle Thinking" category.

*Table 4 Publications classified by cluster.*

| S.No. | Cluster | References | No. of Records |
|---|---|---|---|
| 1 | Energy Performance | (11,12,15–20) | 8 |
| 2 | Life Cycle Thinking | (13,14,21–26) | 8 |
| 3 | Vulnerability | (27–34) | 8 |
| 4 | Flexibility | (35–41) | 7 |
| 5 | Indoor Comfort | (42–47) | 6 |
| 6 | Materials Effectiveness | (48–51) | 4 |
| 7 | Passive Solutions | (52–54) | 3 |

| | | | |
|---|---|---|---|
| 8 | Water Efficiency | (55,56) | 2 |
| 9 | Biodiversity | (57) | 1 |
| | **Total Number of Records** | | **47** |

*Each record falls into one category only, even if it would be possible for some records to consider more than one topic per time.*

These clusters organise the topics investigated in the selected records, as depicted in Figure 22, which highlights primary and secondary references. Primary references primarily focus on the specific topic at hand, while secondary references touch on the topic in a more generalised manner. Various subsets of topics pertain to different clusters, such as adaptable technologies (e.g., as studied in references (37) or (44)), which align with categories like Indoor Comfort and Flexibility.

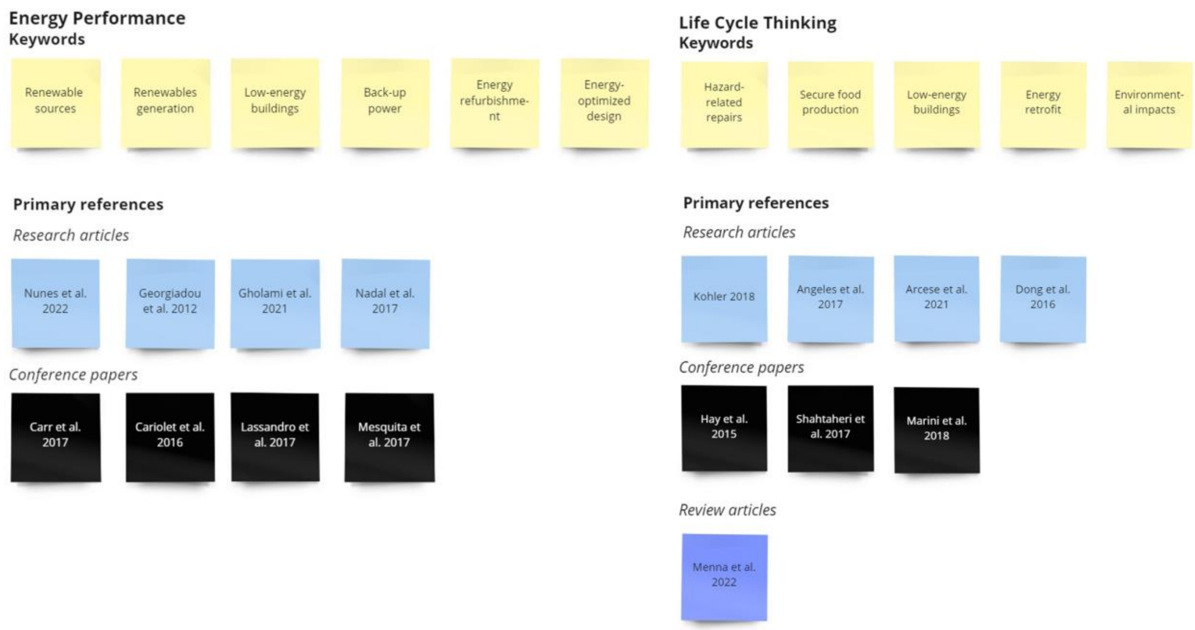


*Figure 22 Clusters (specifically Energy Performance and Life Cycle Thinking) and selected records (keywords found in the records belonging to each thematic category in yellow stickers, research articles in light blue ones, review articles in blue ones and conference papers in black ones). The other clusters can be found in* (7) *– Appendix C.*

### 3.3.2 Rating systems-based approach

Each chosen Green Building Rating System (GBRS) and Resilience Assessment Tool (RAT) underwent thorough analysis, covering a) core objectives, b) required data collection methods, and c) metrics used for rating generation. Subsequently, a comparative evaluation was conducted to identify commonalities, including significant metrics, among the tools.

After conducting a comprehensive analysis of these rating systems (RSs) using a criterion-by-criterion approach, several criteria were grouped into clusters. From this analysis, common clusters were identified, considering the indicators and primary impacts of the strategies. Once the clusters for both design processes were defined, their overlap was examined to identify shared clusters (Figure 23).

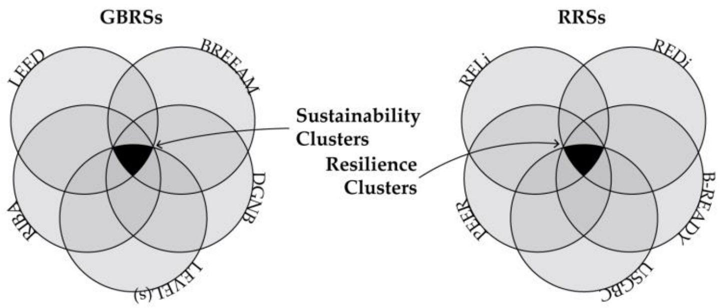


*Figure 23 Clusters definition strategy – sustainability clusters on the left and resilience clusters on the right. Source:* (7).

*Sustainability clusters*

GBRS and RAT play a dual role in identifying clusters for both sustainability and resilience at the building level. Marchi et al. (1) delineate the spectrum of available GBRSs in Europe; indeed Table 5 presents crucial details on the prevalence and usage of the three most frequently cited systems in Europe, as discussed also by Cordero et al. (58).

For example, BREEAM also has some criteria focused on resilience enhancement to hazards such as floods, droughts or wildfires. Still, their weightings are very light compared to its other topics. In DGNB, particularly in its criterion, SITE1.1 - Local environment, the weight of 1.1% in the tool is dedicated to protecting the building and its users from the impact of adverse environmental disasters and extreme events and improving the building's resilience. Concerning the In-Use DGNB version 2020 (59)The criterion ECO2-B/Risk management and long-term asset value, the weight of 15% in the tool, intend to have a resilient building stock by managing risk proactively, guaranteeing structural safety after environmental risks, and promoting cost-optimised change processes and action plan. This criterion generally focuses on natural hazards that are likely to strike existing buildings (earthquakes, volcanic eruptions, avalanches, storms, floods, heavy rain, hail, landslides, climatic extremes, forest fires, etc.) (13).

*Table 5 Summary of the most popular GBRSs.*

| Name | Year (from) | Main market | Type of certification | Managing Organization | Area of focus/categories |
|---|---|---|---|---|---|
| Building Research Establishment Environmental Assessment Method (BREEAM) | 1990 - 79,418 certified buildings (60) | UK and International | New Construction<br>In-Use<br>Refurbishment & Fit Out<br>Communities | BRE Global | Energy<br>Health & Well-being<br>Transport<br>Water<br>Materials<br>Waste<br>Land Use & Ecology<br>Management<br>Pollution |
| Leadership in Energy and Environmental Design (LEED) | 1998 - 594,011 certified buildings (61) | USA and International | New Construction (NC)<br>Existing Buildings, Operations & Maintenance (EB O&M)<br>Commercial Interiors (CI)<br>Core & Shell (CS)<br>Schools (SCH)<br>Retail<br>Healthcare (HC)<br>Residential<br>Cities and Communities | US Green Building Council | Sustainable Sites<br>Water Efficiency<br>Integrative Process<br>Location & Transportation<br>Energy & Atmosphere<br>Materials & Resources<br>Indoor Environmental Quality<br>Innovation<br>Regional Priority |
| Deutsche Gesellschaft für Nachhaltiges Bauen (DGNB) | 2007 - 8,700 certified buildings (62) | Germany and International | New Buildings, Interiors, Renovations, Existing buildings, Districts | DGNB | Environmental quality<br>Economic quality<br>Sociocultural and functional quality<br>Technical quality<br>Process quality<br>Site quality |
| Level(s) | 2017 | Europe | Residential Buildings and Office Buildings (New and Existing) | European Commission – Joint Research Centre (JRC) | Greenhouse gas emissions along a building's life cycle<br>Resource-efficient and circular material life cycles<br>Efficient use of water resources<br>Healthy and comfortable spaces<br>Adaption and resilience to climate change<br>Optimised life cycle cost and value |
| RIBA design process (Sustainable outcomes) | 2019 | UK | Every design project | Royan Institute of British Architect (RIBA ) | Whole life carbon emissions [SDG13]<br>Net zero operational carbon emissions [SDG7]<br>Net zero embodied carbon emissions [SDG12]<br>Sustainable Water Cycle [SDG6]<br>Sustainable connectivity and transport [SDG 9]<br>Sustainable land use and ecology [SDG15]<br>Good health and Wellbeing [SDG3]<br>Sustainable communities and social value [SDG11]<br>Sustainable life cycle cost [SDG8] |

Therefore, the New Construction versions of (3), DGNB (4) and LEED (2) were carefully selected to outline the sustainability clusters for this second approach, given their pivotal role in guiding future sustainable strategies. Additionally, consideration was given to the new European sustainable framework, Level(s) (63), which aims to establish a common language across GBRSs. Furthermore, within the sustainable design domain, the RIBA design process (64), renowned for its industry-standard planning methods, particularly RIBA Sustainable Outcomes (65), was included.

The Sustainability clusters have been identified and categorised within the framework of the five major tools - Table 6 presents the percentage of criteria or weightings that each cluster has within each specific tool. Table 7 illustrates an example of the LEED certification and how its credits are associated with key sustainability clusters. These clusters have been identified and categorised within the framework of the five major rating systems.

*Table 6 Overview of GBRSs and the percentage of their tool corresponding to the main Sustainability Clusters.*

| **Sustainability Cluster** | **LEED** | **BREEAM** | **DGNB** | **LEVEL(s)** | **RIBA** |
|---|---|---|---|---|---|
| *Energy performance - EP* | 17% | 11% | 2% | 14% | 9% |
| *Greenhouse gas and air pollutant emissions cycle - GH* | 15% | 21% | 2% | 5% | 26% |
| *Sustainable connectivity and transport - ST* | 10% | 7% | 12% | 2% | 9% |
| *Land use and ecology - LU* | 12% | 7% | 7% | 2% | 9% |
| *Resource efficient and circular material life cycles - MR* | 8% | 15% | 22% | 18% | 9% |
| *Healthy and comfortable spaces - HC* | 17% | 16% | 24% | 23% | 17% |
| *Efficient use of water resources - WA* | 12% | 7% | 2% | 5% | 9% |
| *Adaptation and resilience to climate change - CC* | 6% | 9% | 2% | 23% | 4% |
| *Other - OT* | 4% | 7% | 24% | 9% | 9% |

*Table 7 Analysis of LEED v4.1 criteria and association to the main Sustainability clusters.*

| | | Criterion name | Indicator | Points | Weight | Sustainability Cluster(s) |
|---|---|---|---|---|---|---|
| **Integrative Process (IT)** | | | | 1 | 1% | |
| **Credit** | IT1 | Integrative Process | - | 1 | 100% | LC |
| **Location and Transportation (LT)** | | | | 16 | 15% | |
| **Credit** | LT1 | LEED for Neighbourhood Development Location | - | 16 | 100% | ST |
| **Credit** | LT2 | Sensitive Land Protection | [Y/N] | 1 | 6% | ST - LU |
| **Credit** | LT3 | High Priority Site and Equitable Development | [Y/N] | 2 | 13% | ST - LU |
| **Credit** | LT4 | Surrounding Density and Diverse Uses | [m2/acre buildable land] or [number] | 5 | 31% | ST - HC |
| **Credit** | LT5 | Access to Quality Transit | [number] | 5 | 31% | ST |
| **Credit** | LT6 | Bicycle Facilities | [number] | 1 | 6% | ST |
| **Credit** | LT7 | Reduced Parking Footprint | [Y/N] | 1 | 6% | ST - GH |
| **Credit** | LT8 | Electric Vehicles | [Y/N] | 1 | 6% | ST |
| **Sustainable Sites (SS)** | | | | 10 | 9% | |
| **Prereq** | SS1 | Construction Activity Pollution Prevention | [Y/N] | - | | LU |
| **Credit** | SS2 | Site Assessment | [Y/N] | 1 | 10% | LU - CC |
| **Credit** | SS3 | Protect or Restore Habitat | [m2] | 2 | 20% | LU |
| **Credit** | SS4 | Open Space | [m2] | 1 | 10% | LU - WR |
| **Credit** | SS5 | Rainwater Management | [percentile] | 3 | 30% | LU - WR |
| **Credit** | SS6 | Heat Island Reduction | [m2] | 2 | 20% | LU - GH |
| **Credit** | SS7 | Light Pollution Reduction | [%] | 1 | 10% | LU - HC |
| **Water Efficiency (WE)** | | | | 11 | 10% | |
| **Prereq** | WE1 | Outdoor Water Use Reduction | [Y/N or %] | - | | WR |
| **Prereq** | WE2 | Indoor Water Use Reduction | [% reduction] | - | | WR |
| **Prereq** | WE3 | Building-Level Water Metering | [Y/N] | - | | WR |
| **Credit** | WE4 | Outdoor Water Use Reduction | [Y/N or %] | 2 | 18% | WR |
| **Credit** | WE5 | Indoor Water Use Reduction | [% reduction] | 6 | 55% | WR |
| **Credit** | WE6 | Optimize Process Water Use | [Y/N or %] | 2 | 18% | WR |
| **Credit** | WE7 | Water Metering | [number] | 1 | 9% | WR |
| **Energy and Atmosphere (EA)** | | | | 33 | 30% | |
| **Prereq** | EA1 | Fundamental Commissioning and Verification | [Y/N] | - | | EP |
| **Prereq** | EA2 | Minimum Energy Performance | [Y/N] | - | | EP |
| **Prereq** | EA3 | Building-Level Energy Metering | [Y/N] | - | | EP |
| **Prereq** | EA4 | Fundamental Refrigerant Management | [Y/N] | - | | EP |
| **Credit** | EA5 | Enhanced Commissioning | [Y/N] | 6 | 18% | EP |
| **Credit** | EA6 | Optimize Energy Performance | [% improvement ] | 18 | 55% | EP - GH |
| **Credit** | EA7 | Advanced Energy Metering | [Y/N] | 1 | 3% | EP |
| **Credit** | EA8 | Grid Harmonization | [Y/N] | 2 | 6% | EP |
| **Credit** | EA9 | Renewable Energy | [% renewable energy] | 5 | 15% | EP - GH |
| **Credit** | EA10 | Enhanced Refrigerant Management | [Y/N] | 1 | 3% | EP - GH |
| **Materials and Resources (MR)** | | | | 13 | 12% | |
| **Prereq** | MR1 | Storage and Collection of Recyclables | [Y/N] | - | | MA - GH |

| | | | | | | |
|---|---|---|---|---|---|---|
| **Credit** | MR2 | Building Life-Cycle Impact Reduction | [% reused] | 5 | 38% | MA - GH |
| **Credit** | MR3 | Environmental Product Declarations | [number] | 2 | 15% | MA - GH |
| **Credit** | MR4 | Sourcing of Raw Materials | [Y/N] | 2 | 15% | MA - GH |
| **Credit** | MR5 | Material Ingredients | [number] | 2 | 15% | MA - GH |
| **Credit** | MR6 | Construction and Demolition Waste Management | [Y/N] | 2 | 15% | MA - GH |
| **Indoor Environmental Quality (IEQ)** | | | | 16 | 15% | |
| **Prereq** | IEQ1 | Minimum Indoor Air Quality Performance | [Y/N] | - | | HC |
| **Prereq** | IEQ2 | Environmental Tobacco Smoke Control | [Y/N] | - | | HC |
| **Credit** | IEQ3 | Enhanced Indoor Air Quality Strategies | [reverberation time] | 2 | 13% | HC - GH |
| **Credit** | IEQ4 | Low-Emitting Materials | [number] | 3 | 19% | HC - GH |
| **Credit** | IEQ5 | Construction Indoor Air Quality Management Plan | [Y/N] | 1 | 6% | HC - GH |
| **Credit** | IEQ6 | Indoor Air Quality Assessment | [Y/N] | 2 | 13% | HC |
| **Credit** | IEQ7 | Thermal Comfort | [Y/N] | 1 | 6% | HC - EP |
| **Credit** | IEQ8 | Interior Lighting | [cd/m2] | 2 | 13% | HC - EP |
| **Credit** | IEQ9 | Daylight | [%] | 3 | 19% | HC - EP |
| **Credit** | IEQ10 | Quality Views | [m2 perimeter] | 1 | 6% | HC |
| **Credit** | IEQ11 | Acoustic Performance | [composite sound transmission class] | 1 | 6% | HC |
| **Innovation (IN)** | | | | 6 | 5% | |
| **Credit** | IN1 | Innovation | - | 5 | 83% | Variable |
| **Credit** | IN2 | LEED Accredited Professional | - | 1 | 17% | - |
| **Regional Priority (RP)** | | | | 4 | 4% | |
| **Credit** | RP1 | Regional Priority: Specific Credit | - | 1 | 25% | Variable |
| **Credit** | RP2 | Regional Priority: Specific Credit | - | 1 | 25% | Variable |
| **Credit** | RP3 | Regional Priority: Specific Credit | - | 1 | 25% | Variable |
| **Credit** | RP4 | Regional Priority: Specific Credit | - | 1 | 25% | Variable |
| | | | | **110** | | |

*Legend: ST - Sustainable connectivity and transport, LU - Land use and ecology, WR - Efficient use of water resources, EP - Energy performance, MA - Resource efficient and circular material life cycles, GH - Greenhouse gas and air pollutant emissions cycle, HC - Healthy and comfortable spaces, CC - Adaptation and resilience to climate change, LC - Life cycle cos, OT – Other. – The text in grey represents the mandatory criteria for achieving the certification.*

*Resilience clusters*

Regarding the assessment of building resilience, five specific tools and guidelines were selected for evaluation. These tools have been carefully chosen based on their relevance and effectiveness in measuring various aspects of building resilience. Each tool provides a unique perspective and set of criteria for assessing resilience, ensuring a comprehensive and multifaceted approach as Table 8 and Table 9 present.

*Table 8 RATs brief description.*

| RAT | Acronym | Country | Typology | Source |
|---|---|---|---|---|
| Resilience Action List and Credit Catalog | RELi | US | tool | (66) |
| Resilience-based Earthquake Design Initiative | REDi | US | tool | (67) |
| B-Ready | - | NO | tool | (68) |
| Performance Excellence in Electricity Renewal | PEER | US | tool | (69) |
| United States Green Building Council (USGBC) Green Building and Climate Resilience Guidelines | USGBC | US | guidelines | (70) |

*Table 9 RATs characteristics. Source:* (7).

| Name | Approach Type | Characteristics |
|---|---|---|
| *RELi (USGBC)* (66) | Point-based methodology | Easy to use<br>Suggestions on adaptation options<br>Synergies with sustainability (LEED)<br>Not open source |
| *REDi (ARUP)* (67) | Check-list based methodology | Very detailed guidelines/requirements to comply, specific to the hazard<br>Resilience of the building structure and enhancement of the resilience process<br>Two hazards only<br>New buildings or buildings under refurbishment<br>Not open source |
| *Envision v3 (Institute for Sustainable Infrastructure)* (71) | Point-based methodology | Comprehensive list of indicators<br>Mostly used for infrastructure<br>Takes community resilience into account<br>Not open source |
| *USGBC Climate resilience guidelines (USGBC) Source: USGBC, 2011* | Guidelines | Comprehensive list of indicators<br>Provides recommendations on adaptation measures<br>Only for USA |

RELi was selected for its specific application to LEED-certified buildings, with REDi, highlighted within RELi, focusing on enhancing seismic resilience. B-Ready was chosen for its development beyond the U.S. context. PEER emphasises energy efficiency and environmental considerations, while USGBC represents the primary solution endorsed by the United States Green Building Council. The Resilience clusters have been identified and categorised within the framework of the five major tools and guidelines - Table 10 presents the percentage of criteria or weightings that each cluster has within each specific tool. Table 11 illustrates an example of the RELi certification and how its credits are associated with crucial resilience clusters. The same process was performed for every other tool.

*Table 10 Overview of RATs and the percentage of their tools corresponding to the main Resilience Clusters.*

| Resilience Clusters | RELi | REDi | USGBC | PEER | B-READY |
|---|---|---|---|---|---|
| *Thermal safety and passive survivability – PS* | 3% | 3% | 38% | 9% | 19% |
| *Back-up energy system and on-site renewable energy - BU* | 8% | 6% | 3% | 35% | 13% |
| *Water management - WM* | 7% | 2% | 26% | 2% | 13% |
| *Location and biodiversity - LB* | 14% | 5% | 16% | 2% | 6% |
| *Transportatio n system protection - TS* | 8% | 6% | 2% | 2% | 3% |
| *Material effectiveness - ME* | 19% | 5% | 4% | 2% | 13% |
| *Passive lighting and ventilation - LV* | 5% | 2% | 7% | 2% | 19% |
| *Community education and training - CE* | 19% | 2% | 2% | 9% | 6% |
| *Other - OT* | 17% | 70% | 1% | 35% | 6% |

*Table 11 Analysis of RELi criteria and association with the main Resilience clusters. Source: (66).*

| | | Criterion name | Indicator | Points | Weight | Resilience Cluster |
|---|---|---|---|---|---|---|
| **Panoramic approach (PA)** | | | | **64** | **8%** | |
| Prereq | PA1r | Study: Short-Term Hazard Preparedness + Mitigation | [Y/N] | - | 0% | CE - ME |
| Prereq | PA2r | Integrative Process, Development + Community Stakeholder Involvement | [Y/N] | - | 0% | CE - ME |
| Prereq | PA3r | Commissioning + Long-Term Monitoring/Maintenance | [Y/N] | - | 0% | OT |
| Credit | PA1 | Business + Community Case Analysis, Post-Development Evaluation + Reporting | [Y/N] | 16 | 25% | OT |
| Credit | PA2 | Establish a Sustainability + Resiliency Management System | [Y/N] | 3 | 5% | OT |
| Credit | PA3 | Address Conflicting Regulations + Policies | [Y/N] | 3 | 5% | OT |
| Credit | PA4 | Study + Design for Byproduct + Underutilization Synergies | [Y/N and % improvement] | 6 | 9% | ME |
| Credit | PA5 | Study and Design for Improved Project Element + Infrastructure Integration | [Y/N and % cost] | 9 | 14% | TS |
| Credit | PA6 | Study + Design for Long-Term Adaptability, Diversity + Redundancy | [Y/N and % improvement] | 12 | 19% | LB - CE |
| Credit | PA7 | Study + Living Design for Advanced Resiliency Using a Diversity of Ecology Based Perspectives | [Y/N] | 15 | 23% | CE |
| **Hazard preparedness, short-term hazard preparedness, mitigation + adaptation (HP)** | | | | **27** | | |
| Prereq | HP1r | Fundamental Emergency Planning for Common Hazardous Events | [Y/N] | - | 0% | CE |
| Prereq | HP2r | Fundamental Access To: First Aid, Emergency Supplies, Water, Food, Communications | [Y/N] | - | 0% | OT |
| Credit | HP1 | Enhanced Emergency Planning for Common Hazards + Extreme Events | [Y/N] | 5 | 19% | OT |
| Credit | HP2 | Enhanced Access: Emergency Care+ Supplies, Water, Food, Communications | [number] | 8 | 30% | OT |
| Credit | HP3 | Provide Additional Emergency Provisions for the Community + for Longer Timeframes | [Y/N] | 10 | 37% | OT |
| Credit | HP4 | Community Education: Authentic Dialogues on ever-increasing Weather, Safety + Resiliency Risks | [Y/N] | 4 | 15% | CE |
| **Hazard mitigation + adaptation (HA)** | | | | **200** | **25%** | |
| Prereq | HA1r | Sites of Avoidance + Repair: 500-Year Floodplain, Storm Surge + Sea Rise | [Y/N] | - | 0% | LB |
| Prereq | HA2r | Fundamental Emergency Operations: Back-up Power + Operations | [Y/N and hours] | - | 0% | BU |
| Prereq | HA3r | Fundamental Emergency Operations: Thermal Safety (Passive Survivability) During Emergencies | [Y/N and m2 and degrees] | - | 0% | BU |
| Prereq | HA4r | Safer Design for Extreme Weather, Wildfire + Seismic Events | [Y/N] | - | 0% | BU |
| Credit | HA1 | Adaptive Design for Extreme Rain, Sea Rise, Storm Surge + Extreme Weather, Events + Hazards | [Y/N] | 53 | 27% | WM |
| Credit | HA2 | Advanced Emergency Operations: Thermal Safety, Lighting, Critical Services, Water | [Y/N and %] | 76 | 38% | PS - BU |
| Credit | HA3 | Passive Thermal Safety, Thermal Comfort + Lighting Design Strategies | [Y/N] | 30 | 15% | LV - PS |
| Credit | HA4 | Transit + Transportation System Protection + Continuous Operations | [Y/N] | 23 | 12% | TS |
| Credit | HA5 | Environmental Protection + Remediation for Parks & Preserves | [Y/N] | 18 | 9% | LB |
| **Community cohesion, social + economic value (CV)** | | | | **200** | | |
| Prereq | CV1r | Improve Common Quality of Life | [Y/N] | - | 0% | OT |
| Credit | CV1 | Incorporate Important Community Views and Aspects of Local Landscape | [Y/N] | 11 | 6% | CE |
| Credit | CV2 | Community Connectivity, Walkability, Public Transit, Non-motorized Transit | [Y/N and number] | 49 | 25% | TS |
| Credit | CV3 | Community Connectivity: Mixed-Use Commercial, Housing + Public/ Community Space | [Y/N and number] | 53 | 27% | TS |
| Credit | CV4 | Expand Citizen Participation: Public Amenities, Councils, Organizations, Communications | [Y/N and number] | 20 | 10% | CE |
| Credit | CV5 | Resilient Organizations: Cooperative + B Corporation(s), Nonprofits + Social Equity Measures | [Y/N] | 30 | 15% | CE |
| Credit | CV6 | Develop or Expand Local Skills, Capabilities + long-Term Employment + Mix | [Y/N] | 15 | 8% | CE |
| Credit | CV7 | Use Regionally Sourced + Manufactured Materials + Products | [% regionally sourced materials ] | 6 | 3% | ME |
| Credit | CV8 | Stimulate Sustainable Growth + Development | [Y/N] | 16 | 8% | CE |
| **Productivity, health + diversity (PH)** | | | | **82** | **10%** | |
| Prereq | PH1r | Minimum IAQ Daylight + View, Thermal Safety: Operable Windows in Residences | [Y/N] | - | 0% | LV |
| Prereq | PH2r | Minimum Protection for Prime Habitat + Floodplain Functions | [Y/N] | - | 0% | LB |
| Credit | PH1 | Human HDP: Expanded IAQ, Daylight + Views, Fresh Air | [Y/N] | 12 | 15% | LV |
| Credit | PH2 | Human HDP: Active Design for Buildings, Communities, and Urban Environments | [Y/N and number] | 9 | 11% | TS |
| Credit | PH3 | Human HDP: Provide for Social Equity + Interdisciplinary/ Intercultural Opportunities | [Y/N] | 8 | 10% | OT |
| Credit | PH4 | Human + Eco HPD: Reduce Pesticides, Prevent Surface + Groundwater Contamination | [Y/N] | 13 | 16% | ME |
| Credit | PH5 | Ecological HPD: Protect Wetlands + Avoid Slopes and Adverse Geology | [Y/N] | 24 | 29% | LB |
| Credit | PH6 | Ecological HPD: Biodiversity, Habitat + Soil | [Y/N and %] | 16 | 20% | LB |
| **Energy, water + on-site food production (EW)** | | | | **147** | **18%** | |
| Prereq | EW1r | Minimum Water Efficiency + Resilient Water and Landscapes | [% and percentile] | - | 0% | WM |
| Prereq | EW2r | Minimum Energy Efficiency + Atmospheric Impacts | [%] | - | 0% | PS |
| Credit | EW1 | Plan for Rainwater Harvesting, Resilient Landscapes + Food Production | [%] | 2 | 1% | WM |
| Credit | EW2 | Plan the Site and Orientation for Sun + Wind Harvesting, Natural Cooling | [Y/N] | 5 | 3% | PS |
| Credit | EW3 | Water Efficiency + Resilient Water and Landscapes | [%] | 45 | 31% | WM |
| Credit | EW4 | Energy Efficiency + On-Site and/or Neighborhood Renewable Energy | [%] | 71 | 48% | BU |
| Credit | EW5 | Edible Landscaping, Urban Agriculture + Resilient Food Production | [Y/N] | 14 | 10% | LB |
| Credit | EW6 | Reduced Site Environmental Impacts: Lighting, Heat-Island, Airborne Toxins | [Y/N and %] | 10 | 7% | LB |
| **Materials + artifacts (MA)** | | | | **30** | **4%** | |
| Prereq | MA1r | Minimum Material Effectiveness + Life Cycle Planning | [Y/N] | - | 0% | ME |
| Credit | MA1 | Safer, Non-Toxic Infrastructure Materials | [Y/N] | 4 | 13% | ME |
| Credit | MA2 | Material + Artifact Effectiveness: Full Life Cycle Design for Durability, Adaptability, Flexibility | [Y/N and %] | 4 | 13% | ME |
| Credit | MA3 | Material + Artifact Effectiveness: Design for Disassembly, Reuse, Remanufacturing, Recycling +Compost | [Y/N] | 4 | 13% | ME |

| | | | | | | |
|---|---|---|---|---|---|---|
| **Credit** | MA4 | Material Effectiveness: Use Recycled Content Materials, Salvaged Materials + Local Materials | [%] | 8 | 27% | ME |
| **Credit** | MA5 | Use Legally Logged Wood from Ecologically Managed Forests | [%] | 4 | 13% | ME |
| **Credit** | MA6 | Reduce Net Embodied Energy + Carbon, Water, and Toxins | [%] | 2 | 7% | ME |
| **Credit** | MA7 | Divert Waste from Landfills, Reduce Excavated Soils Taken from Site | [%] | 4 | 13% | ME |
| **Applied creativity (AC)** | | | | **50** | **6%** | |
| **Credit** | AC1 | Applied Creativity in Resiliency & Integrative Design | | | | OT |
| | ACa11 | Resilient Economics, Equity, Education And/or Ecology Indicators | | | 10% | |
| | ACa12 | Green, Healthy, Living, Restorative, Regenerative of Sustainable Indicators | | | 10% | |
| | ACa13 | Leadership Metrics and Measures from sources beyond RELi | | | 10% | |
| **Credit** | AC2 | Contextual Factors & Project Responsive Topics | | | | OT |
| | ACa21 | Project specific Leadership & Next Generation Certification/Program Indicato | | | 10% | |
| | ACa22 | Improving Safety & Resiliency | | | 10% | |
| | ACa23 | Influential Regional, District or Site Contextual factors | | | 10% | |
| | ACa23 | Leadership Metrics and Measures from sources beyond RELi | | | 10% | |
| **Credit** | AC3 | Exemplary performance | | | | OT |
| | ACa31 | Performance exceeding the Credits identified in the RELi 2.0 Rating Guidelines | | | 30% | |
| | | | | **800** | **100%** | |

*Legend: TS - Transportation system protection, LB - Location and biodiversity, WM - Water management, PS - Thermal safety and passive survivability, BU - Back-up energy system and on-site renewable energy, ME - Material effectiveness, LV - Passive lighting and ventilation, CE - Community education and training, OT – Others. Text in grey represents the mandatory criteria to achieve the certification.*

### 3.3.3 Case studies-based approach

As mentioned in Table 5, there are numerous examples of certified buildings worldwide, usually listed in databases owned by tool developers. These databases contain extensive and comprehensive information about sustainable certified buildings under various certification systems (e.g., LEED, DGNB, etc.). However, equivalent repositories for resilient or hazard-resistant buildings are notably lacking. Typically, the term "resistant" is linked to the specific hazard a building can withstand, such as a flood-resistant structure.

*Database of resilient residential buildings*

Table 12 provides a list of buildings claimed to be resistant or resilient to certain hazards, sourced from architectural databases such as Dezeen or ArchDaily, which are popular websites for architects and designers. The table is structured to highlight the main characteristics of these buildings, enabling the identification of key aspects of resilience that can be transferred and replicated in other structures.

For example, the Blooming Bamboo Hone has a vernacular structure that can be assembled in as little as 25 days and is adapted to suit varying local climates and sites. Each house is simply assembled with bolting, binding, hanging, and placing from the bamboo module of f8-f10cm and f4-f5cm diameter and 3.3m or 6.6 lengths. Another illustrative example is the Maasbommel project in the Netherlands, located along the Maas river, which tackles the challenge of constructing in flood-prone areas to adapt to the growing risk of river flooding. The city's primary goal was to test and demonstrate the Amphibious House concept in a real-world setting. This innovative solution offers a practical adaptation strategy for urban settlement and development in flood zones while maintaining both water storage capacity and the area's economic value. The houses are designed to float vertically up to 5.5 meters. For safety purposes, each house includes an escape route (20,72).

*Table 12 List of residential building case studies claimed as resilient to certain hazards.*

| Name of project | Building typology | Year | Location | Status | Sustainability strategies | Hazard | Resilience strategies |
|---|---|---|---|---|---|---|---|
| **Blooming Bamboo Home (H&P Architects)** | Single-family house | 2013 | Vietnam | Constructed (prototype) | Local and renewable materials (bamboo, fibreboard, coconut leaves), customizable (modular), filtering system that collects and stores rainwater | Flood | Vernacular structure features, it can withstand flood up to 3m above the ground - the structure is elevated above the ground on stumpy pilots. |
| **The Kentish Classic (D*Haus Company)** | Multi-residential | *n/a* | London (UK) | Design | Renewable materials (timber), prefabrication and modularity | Flood | Prefabricated timber homes elevated above the rising water levels by 3D-printed concrete platforms |
| **The LIFT House (Prithula Prosun)** | Single-family house | 2010 | Dhaka (Bangladesh) | Constructed | Low cost, reuse of materials (plastic bottles), modularity | Flood | The house floats upward with rising water levels and returns to the ground level as the water recedes. |
| **Flood-Proof House (Studio Peek Ancona)** | Single-family house | 2010 | Stinson Beach (USA) | Constructed | Hybrid prefabricated elements, passive solar design, optional star-glazing roof/emergency hatch | Flood and sea level rise | Cost efficient floating foundation - ground floor garage can be detached from the foundation and float away |
| **The Float House (Morphosis Architects)** | Single-family house | 2009 | New Orleans (USA) | Constructed | Prefabrication and modularity, self-sufficiency, low-income house, solar power – pursuing LEED certification | Flood and storm | 4-foot base as a porch, rainwater collection, geothermal heating and cooling |
| **Farnsworth House (Ludwig Mies van der Rohe)** | Single-family house | 1951 | Plano, (USA) | Constructed | Open spaces and natural ventilation, integration with the natural surroundings | Flood | Design for the 100-year flood, foundations raised - below-grade retrofit installation that would raise and float the house |
| **Casa Anfibia** | Single-family house | n/a | Malacatoya (Nicaragua) | Constructed | Low cost, reuse of materials (i.e. plastic bottles), renewable and local materials (i.e. bamboo) | Flood | Foundations raised |
| **Amphibious House (Site-Specific Co Ltd)** | Single-family/community house | 2011 | Thailand | Constructed | Rainwater collection, prefabrication, light construction | Flood | Vernacular strategies, prefabricated steel floating system, back-up systems including food storage, rain collection and power generation systems |
| **Amphibious Housing** | Houses | 2006 | Maasbommel (Netherlands) | Constructed | Renewable materials (i.e. timber) | Flood | Floating house, clear wayfinding in case of emergency |
| **Host House (Kipp Edick and Joe Sadoski architec** | Single-family house | 2021 | Salt Lake City (USA) | Constructed | Net zero building, daylight, high-performance building envelope and triple- and quadruple-pane windows | Heat wave | Ground-source heat pumps and low-lying buildings, limited glazing |
| **Flat House (Practice Architecture)** | Single-family house | n/a | Cambridgeshire (England) | Constructed | Zero-carbon house, use of Hempcrete – a mix of hemp shiv (the woody stem of the plant) and a lime binder | Heat wave | Exposed thermal mass |
| **Casa Banlusa (Sara Acebes Anta studio)** | Single-family house | 2021 | Valladolid (Spain) | Constructed | Good orientation for the sun exposure | Heat wave | Light materials for contrasting the sun, use of thermoclay |
| **Apartment block in Paris (Mars Architectes)** | Multi residential building | 2021 | Paris (France) | Renovated | Wooden prefabicated modules, renewable materials, greenery | Heat wave | Efficient appliances, greenery |
| **3D-printed houses (ICON)** | Single-family house | 2019 | Austin (USA) | Constructed | Well-insulated walls and central heating, low carbon footprint, locally sources materials | Wind | Exposed thermal mass |
| **Hill Country House (Miró Rivera Architects)** | Rural single-family house | 2018 | Austin (USA) | Constructed | Renewable production, rainwater collection, purification filters, roof with double-lock standing-seam arrangement | Flood and storms | Independency from the water network, geothermal system, a pier and beam foundation allow water to pass below the house |
| **Villa Rieteiland-oost (Egeon Architecten)** | Single-family house | 2013 | Amsterdam (Netherlands) | Constructed | Renewable materials, floor-to-ceiling windows | Heat wave | Heat pump and low temperature underfloor heating, natural ventilation, high insulation values of roof walls and floor, special heat-resistant glass, a sedum roof |
| **Schlotfeldt Residence (Omar Gandhi Architect)** | Residence | 2021 | British Columbia (Canada) | Constructed | Daylight and view, renewable materials | Fire and storm | Deep overhangs protect the perimeter of the home, elevated above the landscape and has no windows on the ground floor, weathering steel shell |
| **La Ribera housing block (Zeller & Moye)** | Multi residential building | 2022 | Mexico City (Mexico) | Constructed/re | Reuse of materials, daylight, durable finishes | Earthquake | Light colours, robust steel structure |
| **Template House (Ramboll)** | Single family house | 2019 | Lombok (Indonesia) | Constructed | Locally sourced and renewable materials, reuse of recycled materials | Earthquake | Roof as reflective surface, flexible structure |
| **Building Hat (Apollo Architects)** | Single family house | 2016 | Tokyo (Japan) | Constructed | Wooden beams, daylight and view | Earthquake | Pointy wooden Hat roof, cube-shaped structure with thick reinforced-concrete walls |
| **Pyramidal Montana (TW Ryan Architecture)** | Single family house | | Montana (USA) | Constructed | Solar orientation and views, a radiant system provides heat, and fresh air flows in through operable windows | Fire | Corten steel exterior, passive solution for ventilation and lighting |

*Assessment of two case studies*

A central issue revolves around whether a building claimed as sustainable is also intrinsically resilient, and vice versa. To ascertain this correlation, a comparative analysis was conducted as an example between two office buildings (73) —One claimed it was sustainable (Prague, CZ), and the other claimed it was flood-resistant (Brooklyn, NYC, USA) - Figure 24.

a b

*Figure 24 a) Main Point Karlin, Prague (Czechia), designed by DAM Architeki. Details of the façade that works as sun shading. (b) Dock 72 at the Brooklyn Navy Yard (NYC), designed by S9 Architecture. Source:* (73).

After initially identifying the specific criteria linked to sustainability and resilience from the aforementioned approaches, the buildings underwent a qualitative assessment to explore how sustainability and resilience relate to design principles. Qualitative assessment methods are well-established in scientific literature as universal approaches for examining entire structures and specific building components (74).

Once the criteria and benchmarks were chosen, four levels of attainment (poor, sufficient, good, and excellent) were defined to evaluate how well each criterion was met - Table 13 and Table 14 present the criteria considered for the assessment, which results from the literature and rating systems review presented in Sections 3.3.1 and 3.3.2.

The findings underscore the possibility that in buildings where only sustainability is prioritised, certain resilience aspects may need to be addressed. Conversely, focusing solely on resilience principles could neglect essential sustainability values (Figure 25).

*Table 13 Compilation of criteria for the qualitative evaluation related to a few sustainability principles. Source:* (73).

| Criteria | Poor | Sufficient | Good | Excellent |
|---|---|---|---|---|
| *Connectivity and Transport* | Public traffic connection > 1 km | Public traffic connection within 1 km | Public traffic connection within 800 m | Public traffic connection within 400 m |
| *Land use and ecology* | Using native vegetation | Green roof and native vegetation | Previous plus installed rainwater collection system | All the techniques before mentioned and other innovative solutions |
| *Reduction of indoor water consumption* | >0% | >30% | > 40% | >50% |
| *Improvement of energy performance (compared to the baseline building performance)* | >5 | >20% | >30% | >40% |
| *Resource-efficient and circular material life cycles* | Surface area reused >0% | Surface area reused >25% | Surface area reused >50% | Surface area reused >75% |
| *Renewable energy procurement* | >2% (on-site) >20% (off-site) | >5% (on-site) >30% (off-site) | >10% (on-site) >40% (off-site) | >20% (on-site) >50% (off-site) |
| *Daylight* | <55% of occupied floor area | 55% of the occupied floor area | 75% of occupied floor area | 90% of the occupied floor area |

*Table 14 Compilation of criteria for the qualitative evaluation of a few resilience principles. Source:* (73).

| Criteria | Poor | Sufficient | Good | Excellent |
|---|---|---|---|---|
| *Building surroundings protection* | Reduced run-off | Develop Nature-based Solutions that protect the surrounding | Plan system for 100-year floods for the building | Protect below-ground system vents and entrances from floods and 100-year floods in the surrounding |
| *Passive heating* | Only active solutions | Direct gain via glazing | Direct gain via storage + glazing | All the strategies mentioned + indirect gain via sunspace |
| *Passive cooling* | Orientation | Orientation, cross-ventilation | Solar shading, building facades | All the strategies mentioned |
| *Passive lighting* | Minimum daylight | Daylight from multiple sides | Intermediate light shelves and skylights | All the strategies mentioned |
| *Water harvesting* | None | <50% of the roof area | >50% of the roof area | >50% of the roof area and parking areas for reuse |
| *Resilience to climate/natural hazards* | None | Identification of regional hazards | Location hazards assessment + passive solutions | Location hazards assessment + passive solutions and resilience emergency plan |

The findings underscore the possibility that in buildings where only sustainability is prioritised, certain resilience aspects may need to be addressed. Conversely, focusing solely on resilience principles could neglect essential sustainability values (Figure 25). Indeed, in terms of sustainability performance, the building claimed to be sustainable, Main Point Karlin, outperforms the one claimed to be resilient, Dock 72, because it excels in more categories with grades of “Excellent” or “Good”. These include Land Use and Ecology, and Reduction of Indoor Water Consumption, thanks to runoff reduction and a rainwater harvesting system. However, Dock 72 shows similar strong results in Connectivity and Transport, attributed to its proximity to various public transportation options (ferry, bus, metro, and bicycle lanes), but falls short in reusing building materials and recycling.

In terms of qualitative resilience assessment, Dock 72 excels in three out of six categories, primarily due to its flood-resistant design. For instance, positioning the main entrance and mechanical systems at higher levels helps maintain the building’s functionality or facilitates easier recovery during heavy rain or other climate-related hazards (73).

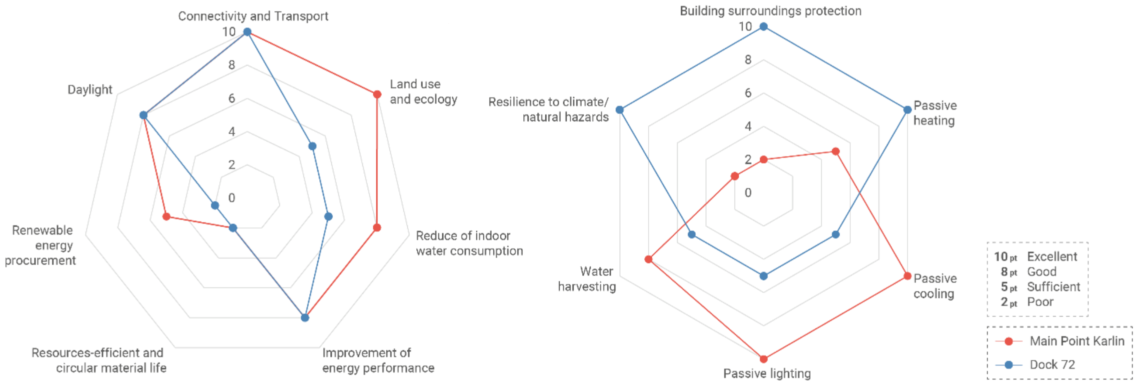


*Figure 25 Analysis of the two case studies for sustainability (left) and resilience (right) according to the defined criteria. Source:* (73).

A key takeaway from this exercise is the imperative to envision a new generation of buildings that integrates both sustainability and resilience considerations, striking a balanced approach between them.

## 3.4 Commonalities and potential development

The findings from the three primary methods of literature review underscore shared clusters and metrics within the domains of sustainability and resilience in buildings. This suggests that integrating resilience principles into existing rating systems may positively impact the overall framework; instead, it could strengthen the tool by incorporating aspects that have been historically overlooked in GBRSs. Such alignment could better prioritise objectives at both international and national levels. Finally, Table 15 presents the common clusters identified by the three approaches, demonstrating that sustainability and resilience principles in building design share significant common ground. This finding should be duly considered in the development of a Resilience Module for an existing GBRS.

*Table 15 Common clusters between sustainability and resilience of new building construction – description. Source:* (7).

| **Common cluster** | **Description** |
|---|---|
| Thermal safety | Criteria that promote energy efficiency and user comfort, including the provision of a backup power generator for emergencies. |
| Renewables generation | Criteria that encourage self-sufficiency and independence from the grid, thereby reducing emissions. |
| Access to quality transit | Criteria that promote the use of diverse transport options and clear wayfinding to ensure safe exit from the building in case of an emergency. |
| Daylight and ventilation | Criteria that promote the use of design solutions to incentivize passive strategies for heating, cooling, ventilation, and lighting, ensuring the building remains operational during energy disruptions. |
| Hazards assessment | Criteria that aim to identify the most likely hazards in the building's location and adopt specific adaptation design strategies. |
| Water efficiency and rainwater management | Criteria that encourage the use of appropriate landscaping and vegetation, including rainwater collection and reuse. |
| Easy of recovery and recycling | Criteria that promote the use of low embodied carbon and locally sourced materials that are durable and flexible for future use. |
| Site ecology | Criteria that encourage the enhancement of biodiversity levels. |

Thus, while the resulting Resilience Clusters will primarily guide the development of the Resilience Module as an independent add-on, the common clusters will be considered when integrating the newly developed Resilience Module into an existing rating system (in this case, SBToolCZ). This approach ensures a proper balance between the existing criteria in the system and the newly introduced ones.

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# 4. Resilience Module: Methodological backbone and tool selection

*This chapter presents the methodology for developing the Resilience Module, an independent product to assess and enhance building resilience. Ideally, it can be integrated as an additional module within existing rating systems. The chapter emphasises the significance of assessments for 'green' and 'sustainable' buildings, referencing systems like LEED and BREEAM. However, a few gaps in these systems are highlighted, particularly the lack of context-specific criteria and essential indicators related to resilience. Introducing the Sustainable Building Tool (SBTool) rating system, specifically the Czech version (SBToolCZ), the chapter evaluates environmental, social, and economic criteria towards resilience principles. It suggests that SBToolCZ could enhance its approach by incorporating new criteria, resulting in sustainable buildings capable of withstanding climate-related events.*

## 4.1 Overall methodology

The overarching methodology of this work is structured and multifaceted, encompassing distinct stages to address the research objectives comprehensively. The methodology unfolds as follows and is based on previous preliminary actions, such as a literature review and data collection and analysis already presented in Chapter 3:

### Phase A: Criteria and Indicator Development:

Utilize a matrix defined by resilience tools and literature to determine a system of criteria and indicators.

Apply this system as the foundational structure for developing the resilience module.

*This phase is presented in Chapter 5 – Module development, criteria definition and weightings.*

### Phase B: Definition of the structure of the Resilience Module:

Employ the structure, methods, and procedures akin to building sustainability certification protocols, specifically modelled after SBToolCZ. Moreover, involve a panel of experts to define the weights of each newly established criterion within the resilience module.

*This phase is presented in Chapter 5 – Resilience Module: development, criteria definition and weightings.*

### Phase C: Testing and Validation:

Conduct rigorous testing and validation of the developed Resilience Module using three real building case studies to assess its accuracy and effectiveness.

Identify potential areas for refinement based on insights gained during the testing phase.

*This phase is presented in Chapter 6 – Resilience Module: testing and validation as a stand-alone system.*

Moreover, the module has been integrated into an existing rating system, the SBToolCZ 2022 version for Multi-residential buildings, with the support of the SBToolCZ research and development team, and validated on a building case study to highlight the difference between the standard and the integrated versions.

*This phase is presented in Chapter 7 – Resilience Module: integration into SBToolCZ.*

The Resilience Module is configured as an autonomous product, and the construction procedure and the main assumptions are explained in the following sections. The concrete results are in Appendix A, 'Resilience Module for Multi-Residential Buildings Manual'. The whole structure of criteria and indicators is based on the Resilience Clusters derived from the literature review (see Chapter 3) and by best practices.

## 4.2 Sustainable Building Tool (SBTool)

Constant efforts are made to improve the building's performance, but to do so, it must be measured to determine if measurable enhancements have been made over time. During operations, it is quite easy to calculate the energy, water, or air quality consumption (e.g., using metering systems); however, at the design stage, energy can be predicted using simulation programs (such as EnergyPlus (1) or IES.VE (2)) and other parameters can be assessed according to standards or equipment type.

Nevertheless, given the widespread popularity of "green" and "sustainable" buildings, a wide range of performance assessments are required, including water, land, and material consumption, greenhouse gas emissions, and indoor air quality.

Since the 1990s, performance rating systems, such as LEED (3) and BREEAM (4), have been developed to meet this need. Most systems have been designed as point-based structures representing specific indicators. Although this structure is designed to be easy to use in principle, the weighting process can sometimes be complex due to the need for specific context-based procedures reflecting the actual relevance of the investigated parameters. Similarly, benchmarks of what is considered good performance tend to have limited application in local situations. The LEED certification was developed in the United States by USGBC (3), where the conditions are very different from those in Europe, e.g., the typical size of a city block in the USA (5).

However, it is important to note that frameworks such as LEED or BREEAM assess the sustainability of buildings with an unweighting point system that can easily be misled by the results that designers expect. For example, the same number of points (i.e. 2 points) would be achieved if a brownfield close to the proposed development's location were decontaminated or a bike rack was built near the entrance (6). While the first option would certainly be costlier and more time-consuming than the second, it would benefit the surroundings and biodiversity.

Indeed, in 1998, iiSBE (International Initiative for a Sustainable Built Environment) developed the Sustainable Building Tool (SBTool), formerly known as the Green Building Tool (GBTool), to assist countries in developing an international open-source methodology for assessing buildings' sustainability based upon the contextualized-weighted process. Although SBTool considers regional conditions and values, the calibration of the model to local conditions does not affect the value of the typical structure and related terminology. The tool produces both relative and absolute results. SBTool's flexibility and ease of adaptability to local conditions -

even down to the scale of a municipality or university campus - make it more relevant and finely graduated than other commercial systems, even in regions where other systems, such as BREEAM or LEED, are predominant.

SBTool is a multicriteria tool that measures the sustainability of buildings by considering more than 200 criteria. In recent years, custom versions of SBTool have been developed for several European countries, including Italy (the Protocollo ITACA (7)), Spain (the VERDE (8)), Portugal (the SBToolPT (9)), and the Czech Republic (the SBToolCZ (10)). All deriving from the same structure. The methodology remains the same, but the criteria are selected according to the context of the general list. Taking the Italian version of SBTool as an example, it has been further contextualised for different regions, from Regione Piemonte (North Italy) to Regione Puglia (South Italy), due to the different climatic conditions.

## 4.3 SBToolCZ

SBToolCZ is the national Czech version of SBTool (11) developed in 2010 by a team of experts from the Faculty of Civil Engineering of the Czech Technical University in Prague. It derives from the generic SBTool framework that was then contextualised for the Czech context. SBToolCZ is an independent, voluntary, and freely available evaluation and certification tool based on Czech construction practice and legislation. During the last 10 years, more than 20 buildings have been certified with it (12).

The evaluation process is highly complex as it complies with a set of criteria inclusive of all three pillars of sustainable development (i.e., environmental, social, and economic). SBToolCZ reports a different distribution of weights among those categories based on the type of building. For example, the version dedicated to schools presents a different ratio (environmental 35%/ social 50%/ economic 15%) (13). Figure 26 charts the weight distribution for the multi-residential building version (14).


*Figure 26 Actual categories and respective weights of SBToolCZ– these shares are valid for office buildings, multi-residential buildings and family houses. Source: (14).*

The Environmental group of criteria is the most influential among the others, while the Location section does not weigh within the system, even if it has several evaluation criteria.

The rationale is that the Location category itself cannot directly depend on the design of the building, so it is indicated separately in the certification. Therefore, the assessment of the sustainability features of the building's location is added as an additional certification module without directly impacting the final certification score. The approach chosen for SBToolCZ for defining the weights of each criterion can be classified as a method of preference-based weights with collectively stated preferences provided by a panel of experts based on significant boundary conditions and practical problems encountered by humankind.

Presently, SBToolCZ does not include specific criteria for assessing resilience (environmental, social and economic); however, in 2017, the RESBy - Environmentally friendly resilient residential buildings (15), method was developed as a part of a national-funded project, which had specific criteria to address mostly environmental resilience in buildings (see Chapter 7). One of the main objectives of RESBy is the development of a methodology for the evaluation of new buildings in the planning phase for resilience, climate change mitigation, and adaptation, with a focus on Central European residential buildings (16). Yet, the principles outlined in RESBy have not been incorporated into SBToolCZ.

By modifying and adding these features to existing frameworks, designers would be inspired to integrate resilience into their projects, reducing the impact on the environment, society and the economy when climate-related events strike a building. This, in turn, would create healthier, more sustainable buildings that are better equipped to handle the unpredictability of the climate, as clearly supported by the European framework Level(s) (17).

### 4.3.1 SBToolCZ methodology

The SBToolCZ methodology is based on the multi-criteria principle, where a set of different criteria from the field of sustainable construction enters the evaluation. Their scope varies according to the type of building and the phase of the life cycle being assessed. The SBToolCZ methodology evaluates criteria divided into four groups – environmental, social, economic and management, and location – as mentioned in Section 4.3. Each version of the system follows the same methodology; the only differences are the weights of the criteria and the activation or deactivation of specific criteria in accordance with the situation.

*Labelling system*

For a better understanding of how the SBToolCZ systems work, there is a uniform labelling system throughout the methodology, as Table 16 shows. This labelling system is typical of the SBTool family of certification systems. Each criterion (e.g., E.PEE) consists of at least one module (e.g., PEE.ST). The assessment process begins in sub-modules.

Modules can include option tables, formulas, and other evaluation methods. The result of the module is always a value ($H_{xxx.xx}$) or a credit rating ($K_{xxx.xx}$). Finally, the criterion always contains the "Overall evaluation of the criterion" algorithm. This determines how the resulting value ($H_{xxx.xx}$) or the resulting criterion evaluation ($K_{xxx.xx}$) is determined from the relevant modules, which enter the criterion limits. At the end of the criterion, there is a table of criterion limits, which, using benchmarks, normalises the resulting value or the resulting credit rating to total points in the range of 0 to 10 by linear interpolation.

*Table 16 SBToolCZ labelling system. Source: (10).*

| Structure | | Example | |
|---|---|---|---|
| **Group of criteria** | X | E | Environmental criteria |
| **Criterion** | X.XXX | E.PEE | Primary energy from non-renewable sources |
| **Module** | XXX.XX | PEE.ST | Relative annual consumption of embodied primary energy |
| **Value** | $H_{xxx.xx}$ | $H_{PEE.ST}$ | Specific annual consumption of embodied primary energy [MJ/(m 2 ·a)] |
| **Credits/credit assessment** | $To_{xxx.xx}$ | $To_{CRI.RA}$ | Credit assessment of crime risk assessment. |
| **Result** | $H_{xxx}$ | $H_{PEE}$ | Resulting in specific annual consumption of primary energy from non-renewable sources [MJ/(m 2 ·a)] |
| **Resulting credit rating** | $To_{xxx.xx}$ | $To_{CRI}$ | The resulting crime prevention credit rating |

*SBToolCZ main phases*

Phase 1 – Specifics is focused on gathering information and specifics about the building. Once the necessary information regarding the building has been gathered, according to the design stage, it will be possible to begin the assessment criterion by criterion and, more specifically, module by module (Phase 2 - Assessment). Upon completion of the assessment, a score will be determined on a scale of 0 to 10 based on the evaluation algorithm associated with each criterion – the so-called normalisation process (Phase 3). The points obtained are added up after multiplying by the weights of the criteria - the so-called aggregation (Phase 4). As with other certification systems, some points may be added for exceptional design and innovation (Phase 5). As part of Phase 4 - Aggregation, the points from all criteria are aggregated, meaning that the normalised points for each criterion are multiplied by predetermined weights developed with the assistance of an expert panel. The weighted points for each criterion are combined to determine the overall (aggregated) result (again between 0 and 10), the value of which represents the overall sustainability level of the building (Phase 6 - Result). Thus, aggregation aims to combine diverse criteria scores into a single indicator. It is, therefore, possible to present the result in a simple and clear manner to professional and lay audiences (Phase 7 - Certificate). As a result, the purpose of the evaluation process is to provide one summary indicator (certificate) of the comprehensive sustainability level of the building – Table 17.

*Table 17 Basic steps in the SBToolCZ evaluation process. Source: (10).*

| **Phase 1** | **Phase 2** | **Phase 3** | **Phase 4** | **Phase 5** | **Phase 6** | **Phase 7** |
|---|---|---|---|---|---|---|
| Specifics | Assessment | Normalisation | Aggregation | Bonus | Result | Certificate |
| Characteristics of the building and surroundings | Criteria with evaluation modules | Criterion limits and conversion to a single-point scale of 0 to +10 | Multiplying the normalised points by weights and their sum in individual groups of criteria | Possibly adding bonuses for innovations | Total score corresponding to the resulting quality of the building | Final total score in a certification |

The SBToolCZ methodology uses a numerical scale in the interval 0 to 10 for normalisation in the following meaning:

- interval 0 to 3.9 – the usual state in the Czech Republic or the fulfilment of legislative or normative requirements (if they are defined) – this state can be called standard,
- interval 4 to 5.9 – above-standard (good) quality,
- interval 6 to 7.9 – high quality,
- interval 8 to 10 – the highest (best) quality, in some cases also the achievement of BAT (best available technologies), or a targeted trend in the field of sustainable construction.

Points are always rounded to 1 decimal place.

It is important to note that the Location group of criteria is considered not directly to influence the design of the building. Therefore, the points gained do not enter into the overall evaluation of the quality of the building. However, the resulting points earned from the Location category are always listed on the certificate (Phase 7) separately, thus providing information about the quality of the location independent of the building design.

*SBToolCZ certificate*

The above-mentioned processes of normalisation and aggregation lead to a unified point indicator of the sustainability level of the building, ranging from 0 to 10 points. Based on the points achieved according to the calculation procedures mentioned above, certificates will be assigned to the building as follows:

- Gold quality certificate – 8 to 10 points
- Silver quality certificate – 6 to 7.9 points
- Bronze quality certificate – 4 to 5.9 points
- Basic quality certificate – 0 to 3.9 points

To obtain a silver or gold certificate, it is essential to meet the minimum point requirements set by the mandatory criteria. If these minimum points are not achieved and the building's design is not adjusted to meet the necessary standards, the quality certificate will be downgraded to a lower level.

### 4.3.2 SBToolCZ and resilience principles

The 2022 SBToolCZ version only considers a few principles for resilience to climate-related events. A few are included in the Location group of criteria, but this category does not affect the overall sustainability level score. Further analysis has been conducted to determine how resilience is considered in the SBToolCZ multi-residential building version to demonstrate that designers could benefit from an additional resilience module.

The principles and criteria for designing resilient buildings were drawn from previous studies (18,19) developed based on an analysis of resilience assessment tools (RATs) available worldwide. These tools include RELi (20), REDi (21), Envision (22), and United States Green Building Council (USGBC) Climate Resilience guidelines (23). These RATs are American because there are only a handful of systems available in Europe that rate resilience, and they are mostly based on regional characteristics.

While the cumulative list of principles proposed by (18,19) may be exhaustive, these principles have been condensed and listed below, and they are divided into environmental resilience criteria (Table 18), social resilience criteria (Table 19) and economic resilience criteria (Table 20) and are associated with the SBToolCZ criteria for similarity in intent (14).

*Table 18 Environmental resilience principles for multi-residential buildings. Source: (14).*

| Principle | Description | SBToolCZ | Weight |
|---|---|---|---|
| *Avoidance of specific sites* | Avoidance of high ecological value sites and 500-year floodplains and establishment of protective buffer zones. Hazard risk identification based on project geographic location and climate forecasts. | 3 criteria | 5.8% |
| *Oversized drainage systems* | Account for linear increases in precipitation over a 30-year period. Proof of installed oversized rainwater pipes based on future forecasts. | n.a. | n.a. |
| *Passive survivability* | Extend to which passive solutions for landscape cooling, passive heating, passive cooling, passive lighting, and passive ventilation are provided. | n.a. | n.a. |
| *Locally sourced resistant materials* | Average distance (km) to the building site. Percentage of the project materials that are locally sourced. | 1 criterion | 1.9% |
| *Protection of wilderness* | Number of ecologically significant species in different habitats. Use native or adapted vegetation to restore the portions of the site identified as previously disturbed. | 1 criterion | 2.9% |
| *Back-up energy system* | Provide permanent backup power, switching gear, and/or power hook-ups, as well as infrastructure (above 500-year floodplain) for temporary generators to provide power for critical utilities such as HVAC and boilers. | n.a. | n.a. |

*Table 19 Social resilience principles for multi-residential buildings. Source: (14).*

| Principle | Description | SBToolCZ | Weight |
|---|---|---|---|
| *Safe and appropriate access* | Incorporating and providing clear access, safety, and wayfinding measures to accommodate emergency services and regular vehicular or pedestrian traffic. | 1 criterion | 2.4% |
| *Perception of safety* | Proof of clear and attractive views and the minimization of unwanted insights. Site identification and crime risk assessment report. | 1 criterion | Available but not weighted |
| *Community disaster preparedness* | Guarantee at least 1 meeting/workshop per year that should cover forecasts for climate change and weather-related impacts and 2 meetings per year covering food, energy, and water. | n.a. | n.a. |

| | | | |
|---|---|---|---|
| *Inclusive design* | Demonstrate increased access beyond local regulatory requirements by including strategies for interior and exterior spaces, inclusive spaces, and mental health. | 2 criteria | 4.7% |
| *Environmentally friendly transport* | Provision of community access to useful space (number of spaces). | 2 criteria | 1.9% |

*Table 20 Economic resilience principles for multi-residential buildings. Source: (14).*

| **Principle** | **Description** | **SBToolCZ** | **Weight** |
|---|---|---|---|
| *Food security* | Urban farming area (m2) by the number of residents. The extent to which the site's final vegetated area is dedicated to food production. | n.a. | n.a. |
| *Independence from the grid* | The extent to which renewable energy sources are incorporated. | 1 criterion | 4.2% |
| *User comfort* | The extent to which both thermal and visual comfort is guaranteed even in case of a disruption event. | 4 criteria | 5.7% |
| *Affordability and flexibility* | The extent of the affordability of the building for different user groups and its versatility to change its use to prolong its service life. | 2 criteria | 2.8% |
| *Water catchment and reuse* | Degree to which the project reuses, and/or treats rainwater. Provide recycled water storage to cover operations, including toilet flushing and mechanical equipment for emergency stand-alone operations. | 2 criteria | 7.5% |

Regarding the oversized drainage system, for example, the Czech rating does not include specific criteria related to this aspect. Designers aiming to create a resilient building should calculate the system dimensions based on projected water flow, considering local topography, soil type, and future forecasts. However, there is a criterion for the general management of rainwater and slowing runoff, which can be accounted for under the economic resilience criteria.

Regarding site selection and wilderness protection, the Czech tool employs various criteria for site protection, including biodiversity preservation and management of excavated land. Under the Site category, which does not influence the overall framework and therefore does not affect the building's sustainability rating, there is a specific criterion regarding Locality Risks. This criterion requires assessing whether the land is prone to flooding or seismic activity, ensuring the chosen site is resilient and safe to inhabit. Neglecting resilience and weather forecasts could compromise the site's safety and durability. Additionally, SBToolCZ suggests evaluating the building's environmental impact, with six criteria dedicated to this purpose.

SBToolCZ includes several relevant criteria for using locally sourced resistant materials. These criteria cover certified products, such as those with an Environmental Product Declaration, and wood-based materials more likely to resist environmental changes, thereby reducing the project's cost and environmental impact.

Passive survivability is another critical resilience principle often associated with backup energy systems. The Czech tool assesses thermal comfort in both summer and winter, focusing on air temperature and humidity parameters. However, it does not guide achieving optimal results using passive heating, cooling, and daylighting solutions, particularly during disruptions. Strategies such as increasing thermal mass, applying green roofs to mitigate heat shocks, and installing shading devices are included in the tool and play a key role in reducing a building's energy needs. However, RATs recommend additional passive design strategies to ensure building functionality during energy or water disruptions. Examples include waterless human waste disposal toilets and elevator systems with backup power sources or automatic return to the ground floor, with machinery located above flood levels.

Table 19 illustrates that the social resilience principles within the Czech rating system have limited overlap. A crucial aspect of social resilience is ensuring safe and appropriate public access. This means that the project should have multiple access points designed to provide broad accessibility and clear wayfinding. These principles also address the ageing population trend by ensuring barrier-free access and mitigating flood hazards by identifying safe and convenient routes during such events.

Regarding the perception of safety, the tool includes a criterion for criminality prevention; however, it is under the Site category, which does not affect the overall rating. Additionally, emergency and community disaster preparedness planning are proactive principles widely used in resilience programs. These principles would inform residents about potential future risks, but SBToolCZ currently does not account for this.

Lastly, the tool includes criteria for both inclusive design (designing for a diverse user base) and environmentally friendly transport (non-motorised vehicles, car sharing, public transport), each represented by two criteria. By enhancing these principles, the tool can help designers create buildings that meet the needs of the local population while reducing emissions and conserving energy. This approach can achieve sustainability and resilience goals while improving the quality of life for all residents.

Table 20 The overlap between economic resilience principles and the SBToolCZ system is depicted through various criteria. Two key criteria address affordability and flexibility, which are indicators of building durability. This allows for the forecasting of potential changes throughout a building's lifecycle. A critical principle of resilience is maintaining grid independence during blackouts caused by climate-related events such as floods, storms, or heavy snowfall. While SBToolCZ includes a criterion for using on-site renewable energy sources, it lacks provisions for backup energy systems and generators necessary to keep the building operational during such shocks.

Low operating costs, resulting from low energy consumption, ensure that users do not experience energy poverty. Low energy consumption can be achieved through well-designed insulation systems that reduce thermal envelope conduction, lowering indoor air temperature, peak electrical demand, and annual cooling requirements during summer. A combination of shading, light-coloured roofs, and effective insulation systems can reduce the amount of heat absorbed by buildings, decreasing cooling costs while maintaining high levels of comfort for occupants. SBToolCZ includes four criteria that ensure residents can live in thermally and visually comfortable spaces without incurring high costs.

Another strategy related to user comfort and economic resilience is educating users to maximise the potential of the technology installed in their homes. Education can help users become confident and comfortable using technology, reducing their energy consumption and saving money.

The capture and reuse of rainwater is a fundamental principle of environmental and economic resilience, and this principle is partially addressed in SBToolCZ. Collecting and reusing rainwater can reduce reliance on other water sources, mitigate water scarcity, lower costs, and decrease the environmental impact of water consumption. Additionally, growing food in common spaces within the building can enhance access to healthy food, support food security, build community resilience, and create opportunities for meaningful work, which increases a sense of belonging and strengthens social cohesion. This also supports the creation of green spaces, which can help mitigate the urban heat island effect and reduce air pollution. However, SBToolCZ does not currently cover this principle.

Overall, SBToolCZ primarily evaluates the sustainability of buildings, including aspects related to resilience, such as a building's ability to withstand natural disasters and its energy efficiency.

However, it does not explicitly measure building resilience, and the framework lacks specific indicators. Some resilience-related principles are included in the Site category but do not directly impact the overall project evaluation. By modifying and adding these features, designers could be encouraged to integrate resilience into their projects, reducing climate-related events' environmental, social, and economic impacts. This would lead to sustainable buildings better equipped to handle climate unpredictability, also aligning with the European framework Level(s) (24).

## 4.4 Adapting buildings to priority hazards

So far, energy efficiency, sustainability and smartness have recently been the main drivers of the real estate market in the EU. However, disruptive events caused by natural disasters (e.g., 2021 floods in Germany, 2021 wildfires and extreme heat waves in Europe are on the rise. Floods are the most frequently recorded type of natural disaster in Europe. From 2001 to 2020, flooding accounted for 41 per cent of all weather-related disasters reported, while extreme temperatures comprised 23 per cent of natural disaster occurrences during that period. As of 2021, the deadliest flood in Europe was the 1953 storm surge in the Netherlands and Belgium, which resulted in over 2,000 fatalities. In comparison, the 2021 river and flash floods in Germany and Belgium led to 209 deaths. In addition to environmental destruction, weather-related disasters have significant impacts on local populations, hinder economic growth, and incur substantial insurance costs. Between 1980 and 2020, climate-related extremes caused economic losses estimated at EUR 487 billion across the EU-27 Member States.

The EU adaptation strategy aims to build resilience and ensure that Europe is well prepared to manage the risks and adapt to the impacts of climate change, thus minimising economic losses and other harms (25). Therefore, while the built environment is vulnerable to a range of hazards, six are designated as 'priority hazards' for buildings and are included in the EU taxonomy list of hazards (31). These particular threats (Table 21) significantly affect both the structures and their occupants and are frequently encountered throughout the European Union.

*Table 21 The climate-related hazards presented in the EU Taxonomy most relevant to buildings. Source: (31).*

| Hazard | Description |
|---|---|
|  *Flood* | Flooding can occur through water overflow from rivers (fluvial flooding) or the accumulation of rainwater on saturated ground (pluvial flooding). Anticipated climate change is projected to increase the frequency and severity of floods in Europe (26). Coastal flooding, driven by rising sea levels and intensified by events like high tides or |

| | |
|---|---|
| | storm surges, presents a significant risk. While approximately 75% of European coastal nations plan for sea-level rise, 25% do not (27). Understanding the impact and implementing suitable adaptation measures for buildings and their surroundings is crucial to addressing the rising flood risk. Buildings at the base of slopes, on low terrain, or in areas with low infiltration rates are particularly vulnerable. Flooding adversely affects basements, ground floors, street-level access, and, in some cases, the entire structural integrity of buildings. |
| <br>*Heavy rain* | Heavy precipitation, encompassing extreme rainfall, snow, and hail, is expected to intensify in both duration and frequency due to climate change. Elevated temperatures and warmer oceans contribute to increased moisture in the air, fostering more frequent and intense precipitation events. The impact of heavy precipitation varies based on factors like duration, precipitation type, and land characteristics such as slopes and surface permeability (28). Buildings, particularly roofs, are directly vulnerable to snow, hail, or rainfall damage. Urbanisation, a growing trend in Europe, heightens the risk of pluvial flooding in cities. Impermeable surfaces and inadequately sized drainage systems in urban areas hinder water infiltration, increasing flood risks. Prolonged heavy rainfall poses a threat, potentially causing pluvial flooding and building interior damage. |
| <br>*Storm* | A storm is a comprehensive term denoting a deep and active low-pressure centre coupled with robust winds, cloud cover, and precipitation. The term encompasses various atmospheric disturbances, including high winds exceeding 100 kilometres per hour, thunderstorms, blizzards (with or without snow, speeds over 56 km/h), tornadoes, cyclones, tropical storms (speeds over 63 km/h), typhoons (speeds over 120 km/h), hurricanes (speeds over 120 km/h), and sand or dust storms. The classification of storms is based on factors such as wind speed, size, visibility, presence of lightning, hail, snow, dust, sand, debris, clouds, rain, location (cold/warm sea, mainland, arid/semi-arid region), temperature, and region.<br>When a building faces a storm, its structure and equipment are at risk of damage or even detachment, potentially causing casualties. To mitigate these risks, it is imperative to ensure that the building and surrounding infrastructure can withstand wind pressure and associated hazards. The subsequent sections delve into technical solutions to reduce the risks posed to building elements by storm events, including high winds, rain, and lightning. Intense meteorological events, commonly occurring in summer and characterised by high winds, hail, torrential rain, and lightning, are called thunderstorms, which may also give rise to tornados. |
| <br>*Drought* | A drought arises from a prolonged deficiency in precipitation (29). Anticipated shifts in temperature, precipitation patterns, and excessive water resource exploitation are expected to amplify the frequency and severity of droughts across Europe. Droughts manifest in three primary types:<br>• Meteorological drought: Insufficient rainfall compared to the area's average, based on the degree of deficit and the dry period's duration. |

- Hydrological drought: The impact of rainfall deficits on water supply.
- Agricultural drought: The repercussions of meteorological or hydrological drought on agricultural activities.

Droughts can induce soil moisture deficits, restricting water for natural vegetation and hastening soil degradation. Such conditions challenge building structures and users, including drought-induced subsidence, water supply shortages, material damage from extreme heat, and heightened fire risk (30). Building adaptation measures emphasise water conservation, rainwater harvesting, and greywater recycling to address the multifaceted impacts of drought.

*Heatwave*

A heat wave denotes an extended period of exceptionally high temperatures in a specific region. In Europe, the intensity and duration of high temperatures and heat waves are expected to escalate due to climate change, particularly accentuated in urban areas by the urban heat island effect resulting from extensive heat-absorbing materials and limited green spaces. This phenomenon poses a heightened risk to residents and building occupants in both urban and rural settings, impacting human health, well-being, and productivity through elevated indoor temperatures. Consequently, the primary focus of the identified solutions for heat waves is to preserve well-being within buildings and ensure thermal comfort for users. It is crucial to emphasise that these solutions apply to high-temperature conditions in general and are not exclusively designed for specific heat wave events.

*Subsidence*

Climate change can profoundly impact ground conditions, affecting soil moisture levels and composition due to shifting precipitation patterns and temperature variations. The increasing risk of soil shrinkage and swelling, particularly in clay-rich soils, is a notable concern across Europe. Subsidence, resulting from changes in soil volume beneath a building, leads to ground instability and downward sinking, posing a detrimental effect on ground-bearing foundations. Various dynamics contribute to changes in soil volumes:

- Precipitation-induced subsidence: Excessive and prolonged rainfall raises groundwater levels, causing soil swelling.
- Drought-induced subsidence: Extended dry periods lead to soil shrinkage as water evaporates.
- Vegetation-induced subsidence: Tree roots, especially from willow, elm, ash, and oak, can cause subsidence by extracting more water than is available during a drought.

Human activities, such as groundwater exploitation and land reclamation, can also induce subsidence. This report focuses on guiding building adaptations to climate-related subsidence, emphasising the serious risks posed to structures and user safety by pronounced soil movements within a 5-meter depth from the ground surface, rarely exceeding 150 mm horizontally or vertically.

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# 5. Resilience Module: Development, criteria definition and weightings

*This chapter is dedicated to the detailed development of the Resilience Module customised for seamless integration into an established sustainability rating system but also to be used as a stand-alone product. Each stage of the module's construction, ranging from the formulation of categories to the definition of criteria and indicators, is comprehensively outlined. Climate change-related hazards have been chosen based on their greater relevance to buildings, as outlined in the EU Taxonomy. The module has been meticulously structured as a calculation tool to facilitate rapid resilience assessments for potential assessors. Illustrative examples of qualitative and quantitative criteria are thoughtfully presented to deepen the understanding of the module's operational intricacies. A systematic comparative analysis is executed, evaluating the alignment and degree of congruence between the stipulated criteria and the EU Level(s).*

## 5.1 The Resilience Module

As previously discussed in Chapter 3, no specific resilient design features are included in most of the available green building rating systems at the international level (1).

Thus, a module for evaluating and promoting resilience in multi-residential buildings has been developed by combining the resilience principles outlined in the state-of-the-art (Chapter 3). The module provides a clear and comprehensive framework for evaluating and promoting resilience in new multi-residential buildings, helping designers to ensure that all the criteria are met and that the project is resilient to a wide range of potential hazards and could still be operative even after a disruptive event. It helps to ensure that buildings are designed with resilience in mind, rather than as an afterthought.

As with other rating systems, the Module is based on a point-based rating system that utilises iterative evaluation procedures: in fact, since this is a framework with a number of criteria that can be difficult to quantify, the evaluator is encouraged to repeat the evaluation process, including corrections as necessary, until a satisfactory level of building resilience is achieved. This approach helps ensure that the rating system is accurate and considers all important aspects of building resilience. It also allows the evaluator to make adjustments as needed and refine the evaluation to ensure the desired outcome (final score) is achieved. This module is suitable for a variety of existing sustainability rating systems and provides a solution to the question of how to balance sustainability and resilience. Therefore, if properly integrated within a rating system, it can help achieve sustainability objectives while also improving resilience to extreme weather events.

### 5.1.1 Potential stakeholders

The method illustrated is conceived as a project aid tool for voluntary adoption: the user (evaluator) is a designer who intends to analyse the degree of resilience of his/her project and, on this basis, identify possible preventive actions. The module can be applied either as a guideline to design resilient multi-residential buildings or to get a final score of resilience achievement, configuring itself as a structured method that helps bring order to the project based on specific initial objectives. In this case, the assignment will require the assistance of a competent professional (e.g., engineer, landscape architect, another technician), who is also responsible for involving the stakeholders, where specified and in the most appropriate manner.

### 5.1.2 Categories

Defining the interrelationship between resilience design indicators and sustainable design principles is essential to integrating resilience indicators into sustainable assessment frameworks. Several resilience design parameters have been derived from existing resilience assessment tools (RATs). Specifically, RELi (3), REDi (4), Envision (5), and USGBC Climate Guidelines (6). Additionally, other sources of resilience strategies have been examined, such as Level(s) (7), which presents one of its six objectives devoted to resilience to climate hazards, or databases such as 2030 Palettes (8) that provide strategies for designing climate-resilient buildings; legislative standards and publications on specific topics have also been considered. These sources provide a comprehensive set of strategies to build resilience to climate hazards. Finally, resilience strategies were converted to criteria and organised into five resilience themes — preparedness, redundancy, robustness, response capacity, and community cohesion. These five categories are defined as follows:

| | |
|---|---|
| *Preparedness* | This category refers to the adoption of resilience strategies that reduce risk exposure. Conducting a Site risk assessment, conserving and using local vegetation, and avoiding floodplains are examples of preparedness measures (9). |
| *Redundancy* | This category refers to the ability of a building to maintain critical life-support conditions for occupants without relying on external power or other resources. Strategies in this category include cooling load reduction, natural ventilation capabilities, highly efficient thermal envelopes, passive solar gain, and natural daylighting or even backup generators. All strategies that support the main functions with minimal external input if the primary system is disrupted (3). |
| *Robustness* | This category raises the ability of a building to absorb and adapt to disruptions and changes provided by different hazards. As part of this category, it is important to use materials that are resistant to natural disasters, use in-depth solid construction techniques, and use traditional building forms that have been used in the region for centuries and have proven to be resilient over the years (principles of vernacular architecture) (10). |
| *Response capability* | This category includes actions and strategies to minimise damage and save lives after accidents. The strategies presented in the criteria should be applied after an emergency has passed, and they should include activities to resume normal building systems activity, such as providing access to water or energy for critical loads (11). |
| *Community cohesion* | This category presents criteria established to improve the net quality of life of the residents. This means that efforts are being made to ensure that communities are safe, secure and productive by providing access to community spaces to strengthen their relationship (5). |

### 5.1.3 Criteria

The evaluation criteria and documentation section outline what is required to demonstrate achievement within each criterion. The same labelling system as SBToolCZ (i.e. the tool used as a case study) is valid for the Resilience Module. The criteria include both qualitative and quantitative requirements. The evaluation criteria are structured as questions requiring answers and supporting documentation. Examples of evaluation criteria are as follows:

- Yes/No: An action taken or an outcome achieved (e.g., the project presents antiflood measures).
- Target: A specified outcome with discrete, quantifiable levels (e.g., the indoor temperature is below 27 Celsius degrees).
- Accomplishment: A process carried out with a general or unspecified result (for example, a rapid site assessment has been carried out).

Due to the point-based nature of the system, the number of points awarded for the accomplishment of an item depends on the level of safety that it would enhance within a building. The higher the level of safety, the more points it will receive. Some criteria modules allow the summation of scores from multiple items (typically a Yes/No-based module). In contrast, others allow only the selection of one item (usually a target-based module).

An overview of the 18 criteria and a brief description of how the principles would enhance resilience are provided in Table 22. Each criterion can be broken down into smaller modules, which can then be evaluated to determine the overall result of the criterion. This allows for a more accurate evaluation of the criterion. The criterion and indicators are a result of the matrix presented in Table 23 where the similarities with the main RATs are highlighted.

Each category contains two to four criteria, while the Robustness category provides six. However, this category is directly related to the results of the criterion known as *Site risk assessment*, which is part of the Preparedness category. Specifically, this criterion aims to identify the hazards most pertinent to the assessed location. Following this analysis, the most likely hazards are identified, and only those will be addressed in the Robustness category - a maximum of three hazards of six. This is a limitation of the system, but since the general objective is to achieve a balance between sustainability and resilience, the measures to control these hazards are most likely to be in conflict between them, which would adversely affect the overall sustainability of the project. Therefore, the choice has been made to ensure at least some degree of resilience to the three main hazards of the location. As a result, once the *Site risk assessment* is completed, the Robustness category counts 3 criteria, similar to the other categories. Also, it should be noted that this number of criteria (a maximum of 15 active criteria) is intended to be integrated into a sustainability rating system, specifically SBToolCZ; thus, the number of criteria could not exceed 15 to keep it feasible.

*Table 22 Overview of the 18 criteria of the Module and their correlation with the Resilience Clusters.*

| Preparedness | Indicator | Resilience Clusters association |
|---|---|---|
| Wayfinding and accessibility | Qualitative | Transportation system protection |
| Site risk assessment | Qualitative | Location and biodiversity |
| Avoid specific sites | Qualitative | Location and biodiversity |
| Conserve and use appropriate vegetation | Qualitative | Location and biodiversity |
| **Redundancy** | | |
| Passive survivability | Qualitative/ Quantitative | Thermal safety and passive survivability and Passive lighting and ventilation and Water management |
| Alternative power sources | Qualitative/ Quantitative | Back-up energy system and on-site renewable energy |
| **Robustness** | | |
| Flood-resistant building envelope and structure | Qualitative | Water management and Material effectiveness |
| Heavy precipitation-resistant building envelope and structure | Qualitative | Water management and Material effectiveness |
| Storm-resistant building envelope and structure | Qualitative | Water management and Material effectiveness |
| Subsidence-resilient building envelope and structure | Qualitative | Water management and Material effectiveness |
| Drought-resistant building envelope and structure | Qualitative | Water management and Material effectiveness |
| Heat wave-resistant building envelope and structure | Qualitative | Water management and Material effectiveness |
| **Response capability** | | |
| Safe equipped space | Qualitative | Community education and training |
| Emergency power supply | Qualitative | Back-up energy system and on-site renewable energy |
| Emergency water supply | Qualitative | Water management and Thermal safety and passive survivability |
| **Community cohesion** | | |
| Access to useful shared spaces | Qualitative/ Quantitative | Community education and training |
| Urban gardening | Qualitative | Community education and training |
| Emergency preparedness | Qualitative | Community education and training |

*Table 23 Matrix for the definition of criteria and indicators.*

| **Criterion** | **RELi** | **REDi** | **USGBC Guidelines** | **Envision v3** | **Level(s)** |
|---|---|---|---|---|---|
| *Wayfinding and accessibility* | No | No | Partially [Transportation access] | No | No |
| *Site risk assessment* | Yes [Identify hazards] | Partially | Yes [Identify hazards] | Yes [Identify hazards] | Partially [Adaptation solutions] |
| *Avoid specific sites* | Yes [Identify hazards] | No | Yes [Identify hazards] | Yes [Preserve specific areas] | No |
| *Conserve and use appropriate vegetation* | Yes | No | Yes [No water for landscaping] | No | No |
| *Passive survivability* | Yes [Passive strategies] | Yes [Passive strategies] | Yes [Passive strategies] | Yes [%] | Yes [% of time out of the range] |
| *Alternative power sources* | Yes [%] | Yes [%] | Yes [%] | Yes [%] | No |
| *Flood-resistant building envelope and structure* | Yes [Safe design solutions] | Partially [Safe design solutions] | Yes [Safe design solutions] | Yes [Safe design solutions] | Partially [Safe design solutions] |
| *Heavy precipitation-resistant building envelope and structure* | Yes [Safe design solutions] | No | Yes [Safe design solutions] | Yes [Safe design solutions] | Partially [Adaptation solutions] |
| *Storm-resistant building envelope and structure* | Yes [Safe design solutions] | No | Yes [Safe design solutions] | Partially [% of excavated material] | Partially [Adaptation solutions] |
| *Subsidence-resilient building envelope and structure* | Yes [Safe design solutions] | Yes [Safe design solutions] | Yes [Safe design solutions] | Partially [Protect soil health] | No |
| *Drought-resistant building envelope and structure* | Yes [Safe design solutions] | No | Yes [Safe design solutions] | Yes [Safe design solutions] | Partially [Adaptation solutions] |
| *Heat wave-resistant building envelope and structure* | Yes [Safe design solutions] | No | Yes [Safe design solutions] | Yes [Safe design solutions] | Partially [Adaptation solutions] |
| *Safe equipped space* | No | Partially | No | No | No |
| *Emergency power supply* | Yes [System available] | Yes [System available] | Yes [System available] | No | No |
| *Emergency water supply* | Yes [System available] | Partially | Yes [System available] | Yes [Water manag.] | Partially |
| *Access to useful shared spaces* | Yes [Spaces available] | No | No | No | No |
| *Urban gardening* | Yes [%] | No | No | No | No |
| *Emergency preparedness* | No | Partially [Trainings] | Partially [Sensor system] | Partially [Operarting plans] | No |

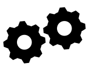
### 5.1.4 Criterion Sheet

The Resilience Module is based on a number of sheets that are designed to be user-friendly and provide clear guidance to the user to accomplish the criteria's requirements (see Appendix A). Each sheet contains step-by-step instructions and suggestions to help users address the requirements. The sheets provide links to additional resources for further guidance. Specifically, each sheet contains the following information:

a) Intent: This indicates the purpose of each criterion.
b) Action level: this indicates whether the criterion is applied to the building itself, its surroundings, its systems, or it is aimed at the whole process.
c) Description: This is a paragraph with a description of the criterion.
d) Hazards: in this section, the acute and chronic shocks the strategy tries to mitigate are indicated and highlighted.
e) SBToolCZ-related criteria: this section lists the criteria of the SBToolCZ multi-residential building version that are similar in objectives to the resilience criterion.
f) Indicator: this indicates whether the criterion is qualitative or quantitative.
g) Evaluation modules: this section lists the modules of which each criterion is composed.
h) Overall evaluation of the criterion: the final criterion rating is derived from summing the results of the different modules.
i) Documentation guidance: Documentation needed to prove that the modules have been achieved.
j) Specific criterion limits: According to the value achieved at point 10, several points are assigned to the criterion.
k) Literature: References used to design the criterion.

Each criterion is described with a level of action in relation to its relevant target, as specified in point (b). A description of the action levels can be found in Table 24.

*Table 24 Descriptions of action levels.*

| Level | Definition |
|---|---|
|  *Structure* | The criteria focus on improving the building envelope and structures and thermal properties of the building shell to respond to temperature-driven impacts, wind-driven rain (storms), etc. |
|  *Equipment* | The criteria focus on heating, cooling, and lighting strategies that focus on improving the performance of mechanical and electrical systems in buildings to impacts of response to climate change. |
|  *Surrounding* | The criteria focus on improving the effectiveness of a site or landscape to respond to temperature and water/precipitation impacts and to other climate impacts, such as storms or subsidence. |

| | |
|---|---|
| *Community* | The criteria are based on equipping operations and maintenance personnel to respond effectively to climatic events. This involves appointing a designated staff member as the focal point of contact, establishing designated areas of refuge within the building, and formulating a comprehensive emergency management plan. |

### 5.1.5 Resilience calculation tool

The Module methodology has been provided with a calculation tool developed in MS Excel to make it easy for potential users to use. The Calculation tool allows for the easy input of data, as well as the ability to analyse and present the results quickly. MS Excel has been chosen as software because it is widely available, making it an accessible solution.

In fact, all criterion sheets are converted into dedicated Excel sheets, one for each criterion, containing information concerning the name of the criterion, its purpose, a brief description of its benefits if achieved, the indicator – qualitative or quantitative – and the evaluation modules. Each module consists of a list of items to which points are assigned if implemented successfully (Figure 27). Depending on the importance of the item to the building in terms of safety, the number of points per item can vary. Each item and, therefore, its points may be simply summed up in some cases; in others, a single item may be selected from the list, in which case the number of points of that item determines the final score of the module. Following the calculation of each module, based on the method of evaluating the criterion, which is usually a sum of modules' scores, the final value of the criteria can then be normalised in a range of 0 (minimum number of points achievable from the item list) to 10 (maximum number of points achievable from the item list) by linear interpolation. The final results will then be multiplied by the weight assigned to each criterion.

| | | |
|---|---|---|
| REDUNDANCY | | |
| **RED.PS – Alternative power sources** | | |
| ***Intent of the evaluation*** | | |
| Reduction of the amount of operational non-renewable primary energy (PERNT) in the building, meeting the energy demand with renewable energy (PERT). | | |
| ***Description*** | | |
| The relatively low price of fossil fuels has made them the primary energy source in the energy sector. Nevertheless, it is better to refrain from relying on finite and polluting energy sources in the future as the global energy demand is forecast to rise. Over the past decade, there has been a positive shift towards the expansion of renewable energy capacity, both locally and internationally. | | |
| ***Indicator (qualitative and quantitative)*** | | |
| Annual PERNT and PERT consumption in kWh per 1 m2 [kWh/(m2.a)] and list of renewable energy sources. | | |
| ***Evaluation modules*** | | |
| RED.AP1 – Annual primary energy consumption | | |
| RED.AP2 – Renewable power sources | | |
| **RED.AP1 - Annual primary energy consumption** | Select just one option | |
| Item | YES/NO | pt |
| **DIRECT GAIN** | | |
| <5% of energy needs from renewable sources | - | 0 |
| <15% of energy needs from renewable sources | - | 0 |
| <30% of energy needs from renewable sources | - | 0 |
| <50% of energy needs from renewable sources | - | 0 |
| Net positive amount from renewable sources | - | 0 |
| **Value KPS1** | | **0** |
| **RED.AP2 – Renewable power sources** | | (max 4 points) |
| Item | YES/NO | pt |
| On-site solar energy production, e.g., PV panels | - | 0 |
| Connection to district heating and/or cooling | - | 0 |
| Wind access | - | 0 |
| Biomass | - | 0 |
| Geothermal | - | 0 |
| Hydrogen/fuel cells | - | 0 |
| **Value KPS2** | | **0** |
| ***Overall evaluation*** | | |
| KRED.PS = KRED.PS1+KRED.PS2 | **Total value K** | **0** |
| | **pt** | 0 |
| | | *min 0 - max 10* |

*Figure 27 Example of a sheet in the calculation tool dedicated to a specific criterion.*

## 5.2 Example of a qualitative criterion

Resilience criteria can be measured quantitatively or qualitatively. To illustrate the use of qualitative criteria, an example of a criterion with a qualitative indicator is presented as a case study, which may represent the other qualitative criteria incorporated into the module. The criterion selected is *Flood-resistant building structure and envelope* which belongs to the Robustness category. This criterion aims to make a building more resilient and resistant to floods (such as pluvial, fluvial, and coastal flooding) when they occur, active ing on the building design. It is possible to design buildings so that when a flood occurs, the damage to the structure of the building and the occupants is reduced or avoided entirely.

As this is a qualitative indicator based on reports, there is no unit of measurement.

*ROB.FR – Flood-resistant building structure and envelope*

**Intent of the evaluation**
Minimization of flood damage. The building is prepared for a possible water level of 1 m above the surrounding ground level.

**Description**
The installation of flood adaptation solutions for buildings, such as the use of flood-resistant materials, the elevation of structures, and flood barriers, can reduce the vulnerability to flood events. These measures can help protect buildings and the people inside them from flooding damage.

**SBToolCZ-related criteria**
L.RIZ Location risks

**Indicator (qualitative)**
Rating of readiness in terms of solutions implemented in the building for coping with a flood event.

**Evaluation modules**
• $RES.FR_1$ - Flood-resistant building solutions

**RED.FR$_1$ | Flood-resistant building solutions**

Consider this module if flood risk has been identified as high in the PRE.SA – Site risk assessment.

| Item | Description | Points $K_{ROB.FR}$ | Impact on others risks |
|---|---|---|---|
| **Building shape** | | | |
| A | Square building shape<br>Square-shaped houses are preferred as they are generally stronger in flood conditions. Long and narrow building shapes that intercept the direction of flow should be avoided. | +0.5 | *Storms<br>*Heavy rain |
| **Foundations** | | | |
| B | Elevating the building<br>The structure should be built above the flood level to minimise damage when a flood occurs. Elevating a building on columns or stilts or raising the foundation could be a solution. | +0.5 | +Subsidence |
| C | Preliminary soil study<br>Soil permeability could affect water infiltration on the site, leading to potential damage to the safety of the foundations or basement structure. A preliminary soil study is needed to detect all risks of ground movement. | +0.5 | +Heavy rain |
| D | Dry-proofing foundations<br>Dry floodproofing aims to make a building watertight below the flood level. | +0.5 | +Heavy rain<br>+Storm |
| E | Wet proofing foundations (e.g., internal drainage systems, vents, etc.).<br>These allow for temporary flooding of the lower parts of the building using openings or breakaway walls. This method can include stilts or a sacrificial basement (uninhabitable spaces such as car parks). | +0.5 | +Heavy rain<br>+Storm |
| **Openings** | | | |
| F | Permanent flood barriers<br>These can be appropriate for windows and doors that are below a floodplain and are the first to flood in the case of high water, e.g., flood walls, automatic barriers, and retractable barriers. | +0.5 | +Drought<br>+Storms |
| G | Temporary flood barriers<br>These can be installed in preparation for potential flooding, or after a flood warning is issued, e.g., flood shields, sandbags, deployable barriers. Flood shields are typically made of aluminium, stainless steel, or plastic and use neoprene rubber or similar materials to seal the barrier. | +0.5 | +Drought<br>+Storms |
| H | Effective sealants and waterproof membranes<br>Effective in sealing a wall, reducing or preventing the penetration of flood water through the wall. | +0.5 | +Heavy rain<br>+Storm |
| **Preferred materials** | | | |
| I | Water-repellent finishes | +0.5 | +Heavy rain<br>+Storm |

| | | | |
|---|---|---|---|
| | Choose paints and plasters that offer increased water resistance and cannot be permanently damaged by water. | | *Heat waves |
| J | Water-resistant insulation<br>Materials such as expanded polystyrene (EPS) and extruded polystyrene (XPS) rigid foam panels that can withstand water for at least 72 hours, without significant damage. | +0.5 | +Heavy rain<br>+Storm<br>+Heat waves |
| K | Water-resistant materials<br>The walls of the building that are at greatest risk from flooding are in the lower part of the building and, therefore, part of the foundation and basement. To preserve the interior spaces and particularly the lower floors, select this kind of material, e.g., plasterboard coating or water-repellent mortars, that can withstand water for at least 72 hours without significant damage. | +0.5 | *Storms<br>*Heavy rain |
| **Building services** | | | |
| L | Building systems above flood level (i.e., mechanical and electrical systems)<br>When designed for submerged installations, the buried portions of underground electrical utilities are also generally resistant to flood damage, but above-ground components of underground electrical utilities, such as below-grade electrical vaults, pad-mounted transformers, pad-mounted switchgear, and electrical substations, can be damaged by floods when located below the flood level | +0.5 | +Heavy rain<br>+Storm |
| M | Devices anti-backflow<br>Inside the building, devices to prevent backflow can be installed in sewage pipes to prevent contaminated water from flowing back into a building through the plumbing due to flood-induced sewage overflow. | +0.5 | +Heavy rain |
| N | Basement with non-essential functions<br>If the building is designed to resist short-duration flooding and intends the basement to be used for non-essential functions only (such as parking or storage), the outer walls and floors can be lined with water-resistant concrete to improve flood resilience. | +0.5 | +Heavy rain |
| **Surroundings** | | | |
| O | Buffer zones in the building surroundings<br>To combat hydrostatic and buoyancy forces, these zones should be installed with a setback distance from the edge of the flood hazard area. The fill soil should be homogeneous and of low permeability. | +0.5 | +Heavy rain<br>+Storm |
| P | Drainage systems in the building surroundings (e.g., sump pump, rain gardens, swales).<br>Sump pumps can be installed to compensate for leaks inside basements. | +0.5 | +Heavy rain<br>+Storm |

* Negative effect on another hazard, + positive effect on another hazard

## Documentation guidance

- Include cross sections of the building with terrain markings.
- Provide maps indicating the location of electrical equipment.

- Flood protection measures typically are not included in standard project documentation; thus, they should be explicitly specified in the project documentation for resilience assessment purposes.

**Overall evaluation of the criterion**

The final criterion rating is calculated according to the following equation:

$$K_{ROB.FR} = K_{ROB.FR1}$$

**Specific criterion limits**

The final criterion score is calculated according to the following table for linear interpolation directly in the Excel tool:

| *Points* $K_{ROB.FR}$ | *Points* |
|---|---|
| 0 | 0 |
| 8 | 10 |

**Literature**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## 5.3 Example of a quantitative criterion

To illustrate the use of quantitative criteria, an example of a criterion with a quantitative indicator is presented as a case study, which may represent the other quantitative criteria incorporated into the module (see Appendix A). The selected criterion is *Alternative power sources,* which is included in the response capacity category. This criterion aims to ensure self-sufficiency by utilising alternative energy sources, thus eliminating dependence on the electricity grid, which may experience blackouts and other disruptions.

*RED.AP – Alternative power sources*

**Intent of the evaluation**

Reduction of nonrenewable primary the amount of operational energy (PERNT) in demand for building, meeting the energy demand with renewable energy (PERT).

**Description**

The dominant position of fossil fuels as the primary energy source in the energy sector is largely due to their relatively low price. However, considering the projected increase in global energy demand, it is advisable to break away from relying on finite and polluting energy sources in the future. Over the past decade, there has been a noticeable positive shift towards the expansion of renewable energy capacity, both on local and international scales. The reliance on alternative sources helps reduce greenhouse gases and other emissions.

**SBToolCZ-related criteria**

E.PEE Primary energy from non-renewable sources

E.OZE Renewable energy sources

**Indicator (quantitative)**

The extent to which renewable energy sources are incorporated.

**Evaluation modules**

- RED.AP1 - Annual primary energy consumption
- RED.AP2 – Renewable power sources

**Overall evaluation of the criterion**

The final criterion rating is calculated according to the following equation:

$$K_{RED.PS} = K_{RED.PS1} + 2 \text{ x } K_{RED.PS3}$$

**RED.AP1 - ANNUAL PRIMARY ENERGY CONSUMPTION**

Calculate the baseline annual consumption of PERNT and PERT in kWh per 1 $m^2$ [kWh/($m^2$.a)], i.e. kilowatt hours of energy per square metre of building per year, to finally determine the percentage of PERT over the total, considering loads coming from heating, cooling, hot water preparation, mechanical ventilation, lighting, and auxiliary energies.

| Item | Description (select one item only) | Points $K_{RED.PS1}$ (only one item) |
| --- | --- | --- |
| A | <5% of energy needs from renewable sources | +1 |
| B | <15% of energy needs from renewable sources | +2 |
| C | <30% of energy needs from renewable sources | +3 |
| D | <50% of the energy needs from renewable sources | +4 |
| E | Net positive amount from renewable sources | +5 |

By way of explanation:

$$Annual\ energy\ consmption\ [kWh/(m2.a)] = \frac{(A\ [kWh/a]) + (B\ [kWh/a])}{(C\ [m2])}$$

(A) = Annual consumption of imported (grid) energy.
The kWh energy consumption figures (A) can be taken directly from gas and electricity utility bills or BMS reports or as the difference between manual metre readings taken one year apart (or monthly over a year).

(B) = Annual consumption of renewable energy
If there are on-site renewables (such as PV panels), the renewable energy in kWh (B) that is used directly on-site, i.e., not sold back to the grid, must be calculated.

The sum of (A) and (B) will provide the annual operational energy consumption of the property.

Lastly, the gross internal floor area (GFA) of the building must be obtained in square meters. This can be taken from the building plans. All floors must be included (C).

**RED.AP1 – RENEWABLE POWER SOURCES**

| Item | Description | Points $K_{RED.PS1}$ (max 2 points) |
| --- | --- | --- |
| A | On-site solar energy production, e.g., PV panels | +1 |
| B | Connection to district heating and/or cooling | +1 |
| C | Wind access | +1 |
| D | Biomass | +1 |
| E | Geothermal | +1 |
| F | Hydrogen/fuel cells | +1 |

**Documentation guidance**

- Documentation reporting the analysis performed to calculate the annual energy consumption.
- Report listing the breakdown of renewable energy sources by type. Renewable energy can include solar energy (thermal heating, both active and passive, and photovoltaic); wind (electricity generation); water (hydro or tidal for electricity generation); biomass (electricity generation or as fuels); geothermal (electricity generation or heating and cooling); and hydrogen/fuel cells (used as a fuel).

**Specific criterion limits**

The final criterion score is calculated according to the following table for linear interpolation:

| *Points* $K_{RED.PS}$ | *Points* |
|---|---|
| 0 | 0 |
| 11 | 10 |

**Literature**


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### 5.4 Alignment with Objective 5 of the Level(s) Framework

The Common Frameworks of the EU for building sustainability assessment, Level(s) (12), consider six main categories and one of these is specifically focused on climate risk and adaptation, objective 5. This objective aims to assess the performance of futureproofing buildings according to three main objectives:

- Adapting to changes in future climate impacting on thermal comfort;
- Making the building more resilient and resistant to extreme weather events (including flooding: fluvial, pluvial, and coastal) (13);
- Improving the design of the building to reduce the chances of pluvial/fluvial flood events in the local area (i.e. increasing sustainable drainage).

These objectives are then reflected in three indicators:

- 5.1 Protection of occupier health and thermal comfort
- 5.2 Increased risk of extreme weather
- 5.3 Sustainable drainage

The sections below present a brief overview of how these criteria must be achieved and their alignment with the Resilience Module.

#### 5.4.1 5.1 Protection of occupier health and thermal comfort

Due to increasingly extreme heatwaves in Europe during the summer, significant attention is being placed on user comfort, mainly during that season. Table 25 outlines the required actions based on the project level by the Level(s) framework.

In the Resilience Module, this aspect is addressed under the RED.PS Passive Survivability criterion, specifically through the module that calculates the indoor temperature in the building's warmest room. This temperature can be mitigated by passive design solutions incorporated into the building, which are covered in the other three modules of this criterion (see Appendix A for further details).

*Table 25 Activities required to address indicator 5.1. Source: (12).*

| Level of the project | Activities |
|---|---|
| 1. Conceptual design (following design principles) | • Assessment of thermal comfort risk as part of the design of the building.<br>• Selection of custom solutions for major renovation works. |
| 2. Detailed design and construction (based on calculations, simulations and drawings) | • Calculated building permitting assessment as part of an overheating assessment<br>• Consideration of different aspects of thermal comfort, including localised discomfort effects |
| 3. In-use performance (based on commissioning, testing and metering) | n/a |

### 5.4.2 5.2 Increased risk of extreme weather

This Level(s) indicator addresses several key hazards, including wildfires and related droughts, floods, extreme temperatures, wind, and snowstorms (12). The primary objective is to first identify these hazards as potential risks for the building's location and then adapt the design accordingly, incorporating factors such as building orientation, materials, and landscaping (Table 26). As outlined in Level(s), a dedicated team should assess the likelihood of these hazards and explore potential adaptation strategies during the design phase. The Resilience Module aligns with this Level(s) objective through the PRE.SA Site Risk Assessment criterion and its two modules, which identify location-specific hazards and link adaptation strategies to relevant criteria within the Robustness category (see Appendix A for more details on these criteria).

*Table 26 Activities required to address indicator 5.2. Source: (12).*

| Level of the project | Activities |
|---|---|
| 1. Conceptual design (following design principles) | • Information is provided to prompt discussion and decision-making for the project about aspects that will directly or indirectly influence the resilience of the building to extreme weather events. |
| 2. Detailed design and construction (based on calculations, simulations and drawings) | n/a |
| 3. In-use performance (based on commissioning, testing and metering) | n/a |

### 5.4.3 5.3 Sustainable drainage

This Level(s) indicator is closely tied to the increasing occurrence of heavy rainfalls across Europe and highlights the importance of enhancing sustainable drainage solutions within cities, starting with buildings and their surroundings to manage runoff volumes and flow rates from hard surfaces, reducing the impact of urbanisation on flooding (as outlined in Table 27). The Resilience Module also addresses this issue, particularly through criteria focused on hazards that can lead to flooding, such as PRE.FR Flood-resistant structure and envelope or PRE.HR Heavy rain-resistant structure and envelope. Several measures listed under these criteria, like rain gardens and green roofs, are key elements of sustainable drainage systems (see Appendix A for further details).

*Table 27 Activities required to address indicator 5.3. Source: (12).*

| Level of the project | Activities |
|---|---|
| 1. Conceptual design (following design principles) | • Information is provided to prompt discussion and decision-making for the project about aspects that will influence pluvial flood risk directly at the site and that will indirectly influence fluvial flood risk downstream. The overall performance requirements of the drainage system should be agreed with the planning authorities at this stage. |
| 2. Detailed design and construction (based on calculations, simulations and drawings) | n/a |
| 3. In-use performance (based on commissioning, testing and metering) | n/a |

The Resilience Module is not only aligned with Level(s) Objective 5 but also with others, such as the 1.1 indicator, which focuses on energy performance during the building's use stage, particularly in the context of alternative energy sources (12). Additionally, it aligns with indicator 4.2, which addresses time spent outside the thermal comfort range.

## 5.5 Weighting system

Building rating systems are typically defined by a set of criteria divided into categories, each with varying levels of importance. Assigning different weights to criteria allows prioritisation of specific aspects or principles in the overall evaluation. The extensive literature discusses the differences in weighting systems among popular green building rating systems (14,15)). For example, LEED and RELi use a point-based system where the points assigned to each credit indicate its importance in the overall system. In contrast, DGNB also uses a point-based system but incorporates weighted criteria. Similarly, SBToolCZ relies on weighting three main categories (environmental, social, and management) and further dividing each criterion into different weights.

The Resilience Module has been weighted to align structurally with these building rating systems. The process of establishing the weightings for the Module involved three main phases:

1. The Pairwise Comparison method was used to compare each category/criterion with the others in two matrices (5x5 and 18x18).
2. These matrices were sent to a panel of experts in the field who were asked to fill them out based on their experience and knowledge.

3. The final weighting system was derived from the average results the panel of experts provided for each criterion and category.

### 5.5.1 Pairwise comparison method

Green building rating systems, such as BREEAM (16) or CASBEE (17), offer a comprehensive set of evaluation criteria, properly weighted within the overall framework (18,19). Consequently, upon the creation of the Resilience module, a tailored weighting system needed to be developed using a pairwise comparison method, also known as Fuller's triangle (20–22), to assign weights to individual categories and criteria. The Fuller method is one of the subjective weighting methods, such as the Analytic Hierarchy Process - AHP (23), Best-Worst Method — BWM (20), or Stepwise Weight Assessment Ratio Analysis — SWARA (24).

Another approach that could have been utilised is the DEMATEL method (24), which involves identifying and interviewing a designated panel of experts to delineate the interdependencies among the criteria. Roostaie et al. (25) illustrate the application of the DEMATEL method in determining which resilience indicators could be integrated into a sustainability framework.

The entire method relies on the comparison of each pair of criteria separately. Specifically, it is necessary to design a matrix that lists, in both rows and columns, the same objects, in this case, categories and criteria of the Resilience Module. Experts are then be asked to enter values only in the upper triangle, as shown in Figure 28 - the two triangles are divided by dark, grey-coloured cells. The values in the lower triangle are automatically calculated and are reciprocal. A value of 1 is entered if the criterion in the row is more relevant than the criterion in the column. A value of 0 is entered if the criterion in the row is less important than the criterion in the column. Finally, if the criterion in the row and the criterion in the column are equally important, the expert enters 0.5.

| *Category* | *Short* | PRE | RED | ROB | CAP | COM |
|---|---|---|---|---|---|---|
| Preparedness | PRE | | - | - | - | - |
| Redundancy | RED | | | - | - | - |
| Robustness | ROB | | | | - | - |
| Response capability | CAP | | | | | - |
| Community cohesion | COM | | | | | |

(a)

| *Category* | *Short* | PRE | RED | ROB | CAP | COM |
|---|---|---|---|---|---|---|
| Preparedness | PRE | | 0 | 0.5 | 1 | 0.5 |
| Redundancy | RED | 1 | | 1 | 0 | 0.5 |
| Robustness | ROB | 0.5 | 0 | | 0 | 1 |
| Response capability | CAP | 0 | 1 | 1 | | 0 |
| Community cohesion | COM | 0.5 | 0.5 | 0 | 1 | |

(b)

*Figure 28 Example of the pairwise matrix for the resilience module weighting process. (a) Empty matrix and (b) Fulfilled matrix.*

After the expert has completed the matrix, in the very right column, the calculated weights are displayed based on the values in the pairwise comparison matrix. Weights are calculated using the geometric mean method. The weights are instantly recalculated as values are entered into pairwise comparison matrices, allowing the expert to experiment with more variants if not satisfied with the results (Figure 29).

| Category | Short | PRE | RED | ROB | CAP | COM | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Preparedness | PRE | | 0 | 0.5 | 1 | 0.5 | 2 | 3 | 3 | 0.20 | 20% | PRE |
| Redundancy | RED | 1 | | 1 | 0 | 0.5 | 2.5 | 1 | 5 | 0.33 | 33% | RED |
| Robustness | ROB | 0.5 | 0 | | 0 | 1 | 1.5 | 5 | 1 | 0.07 | 7% | ROB |
| Response capability | CAP | 0 | 1 | 1 | | 0 | 2 | 3 | 3 | 0.20 | 20% | CAP |
| Community cohesion | COM | 0.5 | 0.5 | 0 | 1 | | 2 | 3 | 3 | 0.20 | 20% | COM |
| | | | | | | | | $\sum w_{un} =$ | 15 | | 100% | |

*Figure 29 Completed matrix with weights for each category.*

The Resilience Module needs to be weighted according to five different steps. First, the weighing process of the resilience categories will be addressed since their weights will be fixed and will not be affected by the activation or deactivation of certain criteria. Secondly, categories are considered individually, i.e., Preparedness, Redundancy, Response Capability, and Community Cohesion; however, the principle behind the calculation stays the same.

### 5.5.2 Panel of experts' formation

In order to complete the Pairwise comparison matrix and determine the weightings of the resilience criteria and categories, it was imperative to ensure the accurate representation of criteria and categories within the matrix, along with appropriate weightings. Consequently, an expert panel was convened in November 2023 to deliberate on allocating weights to each criterion and category for the Resilience Module. This approach facilitated a quick assessment of the criteria and categories by experts, enabling them to leverage their expertise and knowledge in determining the weights. As a result, they could offer a comprehensive and well-informed analysis of the module.

Invitations were sent by email to over 25 field experts, asking for their involvement in the process by completing an Excel spreadsheet delineating the details of the PhD research. In addition, instructions were provided on how to fill the comparison matrix. Of these invitations, 12 experts volunteered to participate. The expert panel for this study encompasses five specialists in resilience and sustainability within rating systems, a policy officer from the municipal office of climate change adaptation, a GIS software engineer, a senior economic expert specialising in resilience, a mid-level officer from a sustainability consultancy firm, and three senior-level researchers in sustainability and resilience.

Given the anticipation of adapting the Resilience Module for utilisation across various European regions, volunteers hailed from various countries, including Western Europe (Belgium and the United Kingdom), Southwestern Europe (Portugal), Southern Europe (Italy and Turkey), Central Europe (Germany and Czechia) and Eastern Europe (Poland and Hungary) - Figure 30.

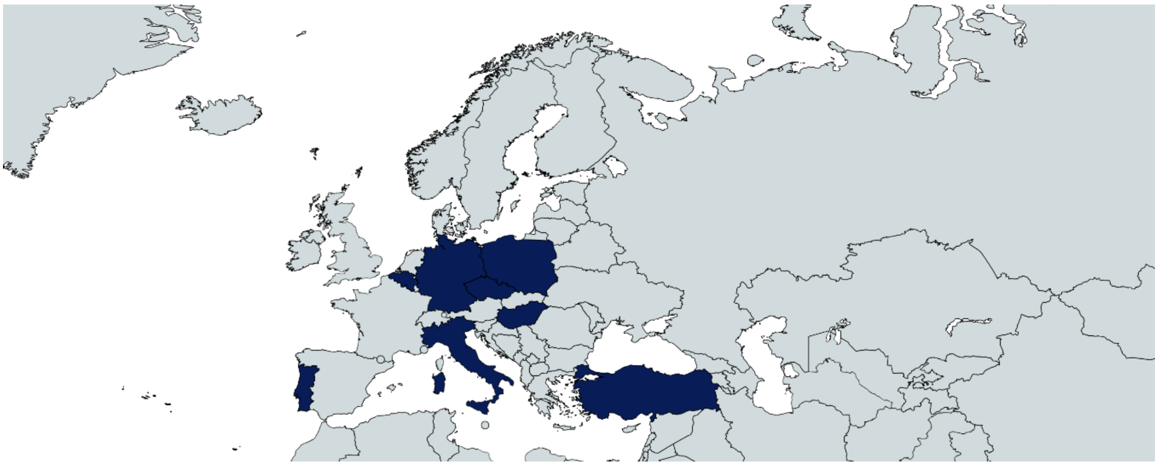


*Figure 30 Europe map showing the countries from which the experts were from (i.e. blue coloured filled countries). Map created with Mapchart.net/.*

To facilitate the scoring process for the participants, the pairwise comparisons were divided into five sequential steps (Figure 31 and Figure 32). Initially, participants were asked to fill out the weights of the categories. Subsequently, they proceeded to address the criteria for each category individually. The primary approach involved starting with the criterion in the row and asking whether a specific criterion, such as PRE.WA, was more, less, or equally important compared to others like PRE.SA or PRE.SS. Based on their response, a value of 1, 0, or 0.5 was assigned, which would automatically adjust the weighting for the PRE.WA criterion within the Preparedness category.

Finally, a pie chart was used to visually display the weightings of the criteria within the overall structure (Figure 33). If the participants were not satisfied with the results from this broader perspective, they had the option to revisit and adjust their responses, either by modifying the weightings of the categories or the individual criteria.

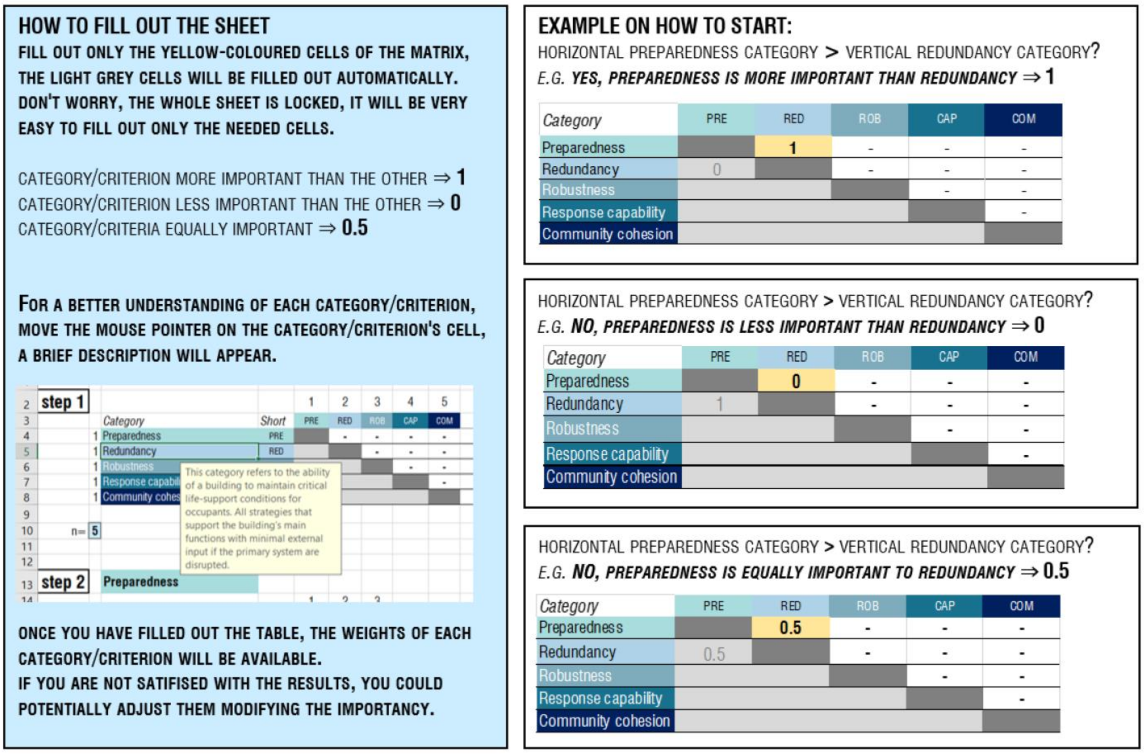



*Figure 31 Instructions for filling out the comparison matrix sent to the experts.*

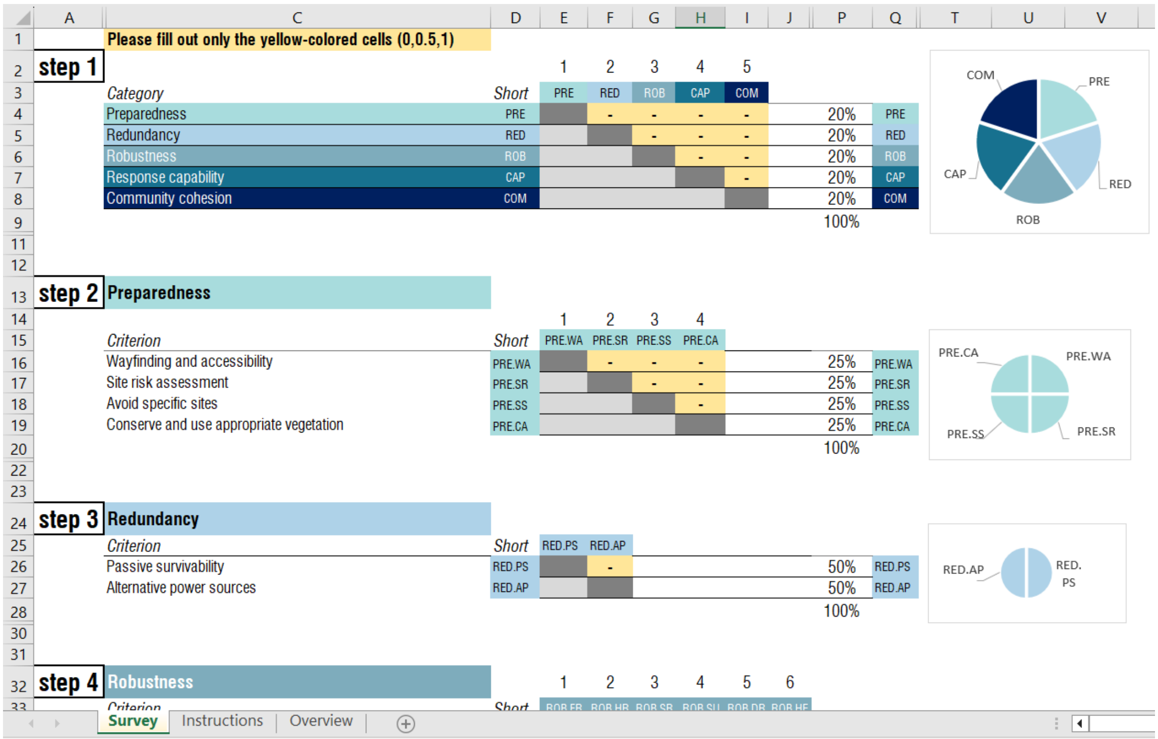
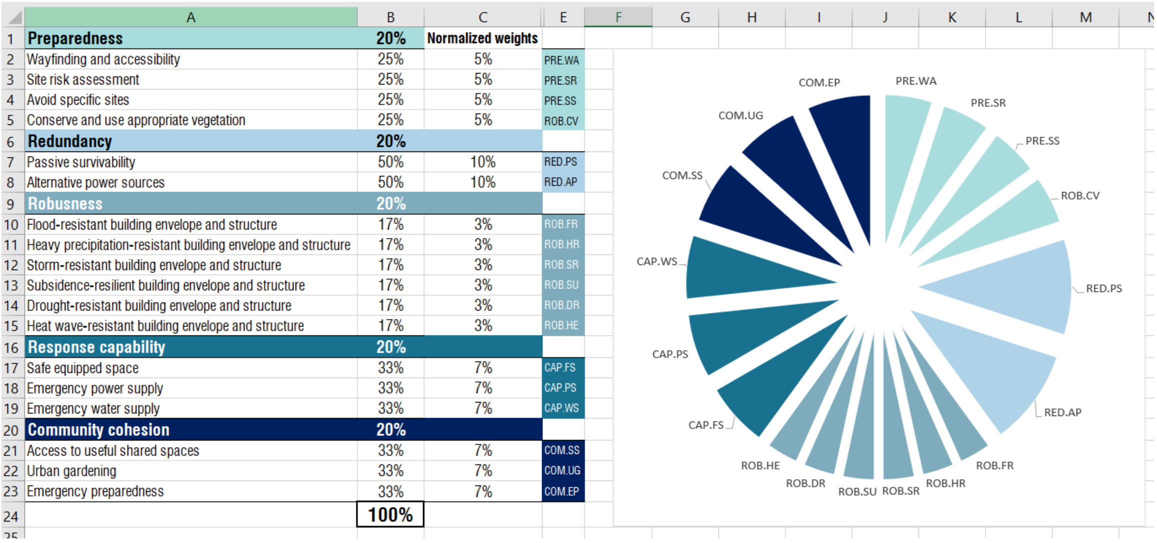



*Figure 32 Instructions for filling the comparison matrix (step by step).*



| | A | B | C | E |
|---|---|---|---|---|
| 1 | **Preparedness** | **20%** | **Normalized weights** | |
| 2 | Wayfinding and accessibility | 25% | 5% | PRE.WA |
| 3 | Site risk assessment | 25% | 5% | PRE.SR |
| 4 | Avoid specific sites | 25% | 5% | PRE.SS |
| 5 | Conserve and use appropriate vegetation | 25% | 5% | ROB.CV |
| 6 | **Redundancy** | **20%** | | |
| 7 | Passive survivability | 50% | 10% | RED.PS |
| 8 | Alternative power sources | 50% | 10% | RED.AP |
| 9 | **Robusness** | **20%** | | |
| 10 | Flood-resistant building envelope and structure | 17% | 3% | ROB.FR |
| 11 | Heavy precipitation-resistant building envelope and structure | 17% | 3% | ROB.HR |
| 12 | Storm-resistant building envelope and structure | 17% | 3% | ROB.SR |
| 13 | Subsidence-resilient building envelope and structure | 17% | 3% | ROB.SU |
| 14 | Drought-resistant building envelope and structure | 17% | 3% | ROB.DR |
| 15 | Heat wave-resistant building envelope and structure | 17% | 3% | ROB.HE |
| 16 | **Response capability** | **20%** | | |
| 17 | Safe equipped space | 33% | 7% | CAP.FS |
| 18 | Emergency power supply | 33% | 7% | CAP.PS |
| 19 | Emergency water supply | 33% | 7% | CAP.WS |
| 20 | **Community cohesion** | **20%** | | |
| 21 | Access to useful shared spaces | 33% | 7% | COM.SS |
| 22 | Urban gardening | 33% | 7% | COM.UG |
| 23 | Emergency preparedness | 33% | 7% | COM.EP |
| 24 | | **100%** | | |



*Figure 33 Overview of the whole Resilience Module with the split into criteria according to their weight – this graph changes as the survey begins to be filled out.*

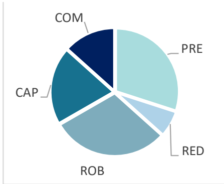
*Panel of experts' example of weightings*

The panel of experts used an integer scale ranging from 0 to 1 (i.e., from 'less important' to "more important") to make pairwise comparisons between the components of the Resilience Module. Each expert was asked to fill out the matrices, and the process would not take longer than 1 hour to be completed. Figure 34 shows an example of matrices completed by one of the experts; the pie charts on the right side helped to graphically visualise the weighting they assigned.

In general, the category that achieved unanimous agreement among all experts, representing more than 20% of the total weight, is Preparedness - Figure 35. In particular, Community Cohesion received significant weight from experts from both Poland and Portugal, diverging from the perspectives of other experts who deemed it less critical relative to other categories. The experts were prompted to envision the module's application in their respective countries, influencing the varied weights assigned to the Robustness category. This discrepancy is attributed to the different regions in Europe under consideration, each facing diverse threats of varying severity. In fact, experts were asked to evaluate the category considering that the assessment would have been carried out in their country or specific region.

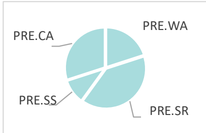
**step 1**

| Category | Short | 1 PRE | 2 RED | 3 ROB | 4 CAP | 5 COM | | |
|---|---|---|---|---|---|---|---|---|
| Preparedness | PRE | | 1 | 0.5 | 1 | 1 | 30% | PRE |
| Redundancy | RED | 0 | | 0 | 0.5 | 0 | 7% | RED |
| Robustness | ROB | 0.5 | 1 | | 1 | 1 | 30% | ROB |
| Response capability | CAP | 0 | 0.5 | 0 | | 1 | 20% | CAP |
| Community cohesion | COM | 0 | 1 | 0 | 0 | | 13% | COM |
| | | | | | | | 100% | |



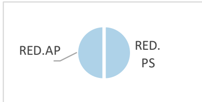

**step 2** **Preparedness**

| Criterion | Short | 1 PRE.WA | 2 PRE.SR | 3 PRE.SS | 4 PRE.CA | | |
|---|---|---|---|---|---|---|---|
| Wayfinding and accessibility | PRE.WA | | 0 | 1 | 0.5 | 20% | PRE.WA |
| Site risk assessment | PRE.SR | 1 | | 1 | 0.5 | 40% | PRE.SR |
| Avoid specific sites | PRE.SS | 0 | 0 | | 0 | 10% | PRE.SS |
| Conserve and use appropriate vegetation | PRE.CA | 0.5 | 0.5 | 1 | | 30% | PRE.CA |
| | | | | | | 100% | |



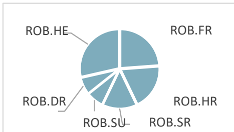

**step 3** **Redundancy**

| Criterion | Short | RED.PS | RED.AP | | |
|---|---|---|---|---|---|
| Passive survivability | RED.PS | | 0.5 | 50% | RED.PS |
| Alternative power sources | RED.AP | 0.5 | | 50% | RED.AP |
| | | | | 100% | |



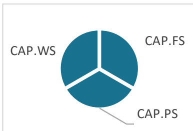

**step 4** **Robustness**

| Criterion | Short | 1 ROB.FR | 2 ROB.HR | 3 ROB.SR | 4 ROB.SU | 5 ROB.DR | 6 ROB.HE | | |
|---|---|---|---|---|---|---|---|---|---|
| Flood-resistant building envelope and structure | ROB.FR | | 0.5 | 1 | 1 | 1 | 0.5 | 24% | ROB.FR |
| Heavy precipitation-resistant building envelope and structure | ROB.HR | 0.5 | | 1 | 1 | 1 | 0 | 19% | ROB.HR |
| Storm-resistant building envelope and structure | ROB.SR | 0 | 0 | | 0.5 | 0.5 | 0 | 14% | ROB.SR |
| Subsidence-resilient building envelope and structure | ROB.SU | 0 | 0 | 0.5 | | - | 0 | 7% | ROB.SU |
| Drought-resistant building envelope and structure | ROB.DR | 0 | 0 | 0.5 | | | 0 | 7% | ROB.DR |
| Heat wave-resistant building envelope and structure | ROB.HE | 0.5 | 1 | 1 | 1 | 1 | | 29% | ROB.HE |
| | | | | | | | | 100% | |




**step 5** **Response capability**

| Criterion | Short | 1 CAP.FS | 2 CAP.PS | 3 CAP.WS | | |
|---|---|---|---|---|---|---|
| Safe equipped space | CAP.FS | | 0.5 | 0.5 | 33% | CAP.FS |
| Emergency power supply | CAP.PS | 0.5 | | 0.5 | 33% | CAP.PS |
| Emergency water supply | CAP.WS | 0.5 | 0.5 | | 33% | CAP.WS |
| | | | | | 100% | |




**step 6** **Community cohesion**

| Criterion | Short | 1 COM.SS | 2 COM.UG | 3 COM.EP | | |
|---|---|---|---|---|---|---|
| Access to useful shared spaces | COM.SS | | 1 | 0 | 33% | COM.SS |
| Urban gardening | COM.UG | 0 | | 0 | 22% | COM.UG |
| Emergency preparedness | COM.EP | 1 | 1 | | 44% | COM.EP |
| | | | | | 100% | |

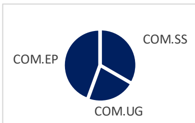



*Figure 34 Example of a completed template by an expert.*

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **CZ** | **CZ** | **PT** | **PT** | **PL** | **BE** | **IT** | **HU** | **TU** | **UK** | **IT** | **DE** |
| **Preparedness** | **20%** | **33%** | **23%** | **20%** | **23%** | **20%** | **30%** | **27%** | **27%** | **13%** | **30%** | **23%** |
| Wayfinding and accessibility | 10% | 15% | 20% | 10% | 35% | 15% | 10% | 15% | 15% | 10% | 20% | 15% |
| Site risk assessment | 30% | 35% | 10% | 25% | 20% | 15% | 40% | 35% | 30% | 30% | 40% | 35% |
| Avoid specific sites | 20% | 35% | 40% | 25% | 35% | 35% | 30% | 35% | 40% | 20% | 10% | 35% |
| Conserve and use appropriate vegetation | 40% | 15% | 30% | 40% | 10% | 35% | 20% | 15% | 15% | 40% | 30% | 15% |
| **Redundancy** | **27%** | **23%** | **7%** | **13%** | **33%** | **20%** | **20%** | **33%** | **13%** | **33%** | **7%** | **7%** |
| Passive survivability | 67% | 67% | 67% | 67% | 33% | 67% | 50% | 50% | 67% | 50% | 50% | 67% |
| Alternative power sources | 33% | 33% | 33% | 33% | 67% | 33% | 50% | 50% | 33% | 50% | 50% | 33% |
| **Robusness** | **13%** | **23%** | **33%** | **7%** | **23%** | **20%** | **30%** | **20%** | **33%** | **23%** | **30%** | **13%** |
| Flood-resistant building envelope and structure | 29% | 29% | 19% | 26% | 24% | 19% | 26% | 17% | 19% | 17% | 24% | 26% |
| Heavy precipitation-resistant building envelope and stru | 21% | 24% | 19% | 5% | 14% | 5% | 19% | 17% | 14% | 17% | 19% | 17% |
| Storm-resistant building envelope and structure | 21% | 10% | 19% | 19% | 19% | 19% | 26% | 17% | 24% | 17% | 14% | 26% |
| Subsidence-resilient building envelope and structure | 7% | 5% | 29% | 26% | 29% | 19% | 7% | 17% | 29% | 17% | 7% | 17% |
| Drought-resistant building envelope and structure | 14% | 14% | 7% | 12% | 5% | 19% | 7% | 17% | 7% | 17% | 7% | 5% |
| Heat wave-resistant building envelope and structure | 7% | 19% | 7% | 12% | 10% | 19% | 14% | 17% | 7% | 17% | 29% | 10% |
| **Response capability** | **33%** | **10%** | **13%** | **27%** | **13%** | **20%** | **13%** | **13%** | **20%** | **23%** | **20%** | **33%** |
| Safe equipped area | 44% | 33% | 33% | 22% | 44% | 22% | 22% | 22% | 28% | 22% | 33% | 33% |
| Emergency power supply | 22% | 33% | 33% | 39% | 33% | 39% | 39% | 39% | 44% | 39% | 33% | 44% |
| Emergency water supply | 33% | 33% | 33% | 39% | 22% | 39% | 39% | 39% | 28% | 39% | 33% | 22% |
| **Community cohesion** | **7%** | **10%** | **23%** | **33%** | **7%** | **20%** | **7%** | **7%** | **7%** | **7%** | **13%** | **23%** |
| Access to useful shared spaces | 39% | 28% | 39% | 22% | 39% | 33% | 33% | 44% | 33% | 22% | 33% | 28% |
| Urban gardening | 22% | 28% | 39% | 33% | 22% | 33% | 33% | 22% | 22% | 44% | 22% | 28% |
| Emergency preparedness | 39% | 44% | 22% | 44% | 39% | 33% | 33% | 33% | 44% | 33% | 44% | 44% |

*Figure 35 Overview of weightings of expert panel.*

However, it is important to note that the Robustness category requires criteria to be activated or deactivated based on the Site Risk Assessment (PRE.SA) results, which determine which hazards are most likely to occur at the building location. Thus, the weighting of the criteria within that category may change accordingly, but the weight of the Robustness category will remain the same; there will only be an internal adjustment to reach 100% within the category. For example, if from the PRE.SA, it has been highlighted that floods, heavy rain and extreme temperatures are the most important risks for a particular building location, then the criteria pertaining to those hazards in the Robustness category must be active. At the same time, those relating to drought, subsidence and storms must be deactivated. In this case, the resilience calculation tool will automatically perform this operation, and as a result, the internal weight of the Robustness category will alter - Figure *36*.

| **Robustness** | | 1 | 2 | 3 | 4 | 5 | 6 | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Flood-resistant building envelope and structure | ROB.FR | | - | - | - | - | - | 0 | 3.5 | 0 | 0.00 | 0% | ROB.FR | 0 | NOT considered |
| Heavy precipitation-resistant building envelope and structure | ROB.HR | | | - | - | - | - | 0 | 3.5 | 3.5 | 0.33 | 33% | ROB.HR | 1 | Considered |
| Storm-resistant building envelope and structure | ROB.SR | | | | - | - | - | 0 | 3.5 | 3.5 | 0.33 | 33% | ROB.SR | 1 | Considered |
| Subsidence-resilient building envelope and structure | ROB.SU | | | | | - | - | 0 | 3.5 | 0 | 0.00 | 0% | ROB.SU | 0 | NOT considered |
| Drought-resistant building envelope and structure | ROB.DR | | | | | | - | 0 | 3.5 | 0 | 0.00 | 0% | ROB.DR | 0 | NOT considered |
| Heat wave-resistant building envelope and structure | ROB.HE | | | | | | | 0 | 3.5 | 3.5 | 0.33 | 33% | ROB.HE | 1 | Considered |
| | | | | | | | | | $\sum w_{un}=$ | 10.5 | | 100% | | | |

| Robustness | | 1 | 2 | 3 | 4 | 5 | 6 | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Flood-resistant building envelope and structure | ROB.FR | | - | - | - | - | - | 0 | 5.5 | 0 | 0.00 | 0% | ROB.FR | 0 | NOT considered |
| Heavy precipitation-resistant building envelope and structure | ROB.HR | | | 1 | 0 | 1 | 0.5 | 2.5 | 1 | 6 | 0.43 | 43% | ROB.HR | 1 | Considered |
| Storm-resistant building envelope and structure | ROB.SR | | 0 | | 0.5 | 1 | 0.5 | 2 | 2 | 5 | 0.36 | 36% | ROB.SR | 1 | Considered |
| Subsidence-resilient building envelope and structure | ROB.SU | | 1 | 0.5 | | - | - | 1.5 | 3 | 0 | 0.00 | 0% | ROB.SU | 0 | NOT considered |
| Drought-resistant building envelope and structure | ROB.DR | | 0 | 0 | | | - | 0 | 5.5 | 0 | 0.00 | 0% | ROB.DR | 0 | NOT considered |
| Heat wave-resistant building envelope and structure | ROB.HE | | 0.5 | 0.5 | | | | 1 | 4 | 3 | 0.21 | 21% | ROB.HE | 1 | Considered |
| | | | | | | | | | $\sum w_{un}=$ | 14 | | 100% | | | |

Figure 36 Changes in the weights of the Robustness matrix according to the considered criteria.

### 5.5.3 Final criteria weighting

Consequently, an arithmetic average formula was applied to determine the final weights, ensuring the equal influence of all experts in the decision-making process. Figure 37 shows the average outcomes from the 12 experts involved in the weighting process. Figure 37 (a) shows the results, excluding the weighting of the Robustness category, as it needs a specification based on Site Risk Assessment. Figure 37 (b) illustrates a hypothetical scenario with all criteria considered simultaneously.

The weighting of each criterion, such as Wayfinding and Accessibility, which received 15.8%, was normalised by factoring in the weight of its respective category; in this case, 24%. This resulted in the Wayfinding and Accessibility criterion accounting for 4% of the total weight of the module.

The experts' consensus identified the Preparedness category as the most significant (24%), indicating a preference for prevention over reaction to disruptive events. The Robustness category followed (22%), consistent with the aforementioned principles, while the Community Cohesion category received the lowest weighting (14%). This could be due to its criteria being perceived as less critical and more focused on people rather than direct building features.

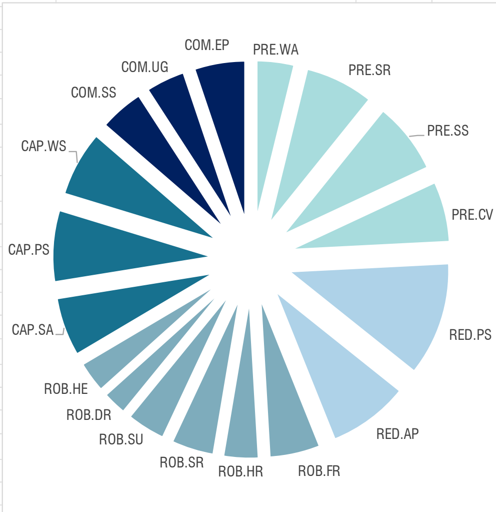
These weightings may change if other experts are asked to fill out the matrix, but the current results are provided to give an indication of the potential weighting for the Resilience Module.

These weightings are applicable only if the Module is used as a standalone resilience assessment tool. Integration into an existing rating system would necessitate adjustment of the weightings, as detailed in Chapter 7.

| | AVG. | normalized | |
|---|---|---|---|
| **Preparedness** | | **24%** | 100% |
| Wayfinding and accessibility | 15.8% | **4%** | PRE.WA |
| Site risk assessment | 28.8% | **7%** | PRE.SR |
| Avoid specific sites | 30.0% | **7%** | PRE.SS |
| Conserve and use appropriate vegetation | 25.4% | **6%** | PRE.CV |
| **Redundancy** | | **20%** | 100% |
| Passive survivability | 58.5% | **11%** | RED.PS |
| Alternative power sources | 41.5% | **8%** | RED.AP |
| **Robustness** | | **22%** | 100% |
| **Response capability** | | **20%** | 100% |
| Safe equipped area | 29.9% | **6%** | CAP.SA |
| Emergency power supply | 36.4% | **7%** | CAP.PS |
| Emergency water supply | 33.3% | **7%** | CAP.WS |
| **Community cohesion** | | **14%** | 100% |
| Access to useful shared spaces | 32.8% | **4%** | COM.SS |
| Urban gardening | 29.1% | **4%** | COM.UG |
| Emergency preparedness | 37.7% | **5%** | COM.EP |
| | | **100%** | |

(a)

| | AVG. | normalized | |
|---|---|---|---|
| **Preparedness** | | **24%** | 100% |
| Wayfinding and accessibility | 15.8% | **4%** | PRE.WA |
| Site risk assessment | 28.8% | **7%** | PRE.SR |
| Avoid specific sites | 30.0% | **7%** | PRE.SS |
| Conserve and use appropriate vegetation | 25.4% | **6%** | PRE.CV |
| **Redundancy** | | **20%** | 100% |
| Passive survivability | 58.5% | **11%** | RED.PS |
| Alternative power sources | 41.5% | **8%** | RED.AP |
| **Robustness** | | **22%** | 100% |
| Flood-resistant building envelope and structure | 22.9% | **5%** | ROB.FR |
| Heavy precipitation-resistant building envelope and stru | 15.9% | **4%** | ROB.HR |
| Storm-resistant building envelope and structure | 19.3% | **4%** | ROB.SR |
| Subsidence-resilient building envelope and structure | 17.4% | **4%** | ROB.SU |
| Drought-resistant building envelope and structure | 10.9% | **2%** | ROB.DR |
| Heat wave-resistant building envelope and structure | 14.0% | **3%** | ROB.HE |
| **Response capability** | | **20%** | 100% |
| Safe equipped area | 29.9% | **6%** | CAP.SA |
| Emergency power supply | 36.4% | **7%** | CAP.PS |
| Emergency water supply | 33.3% | **7%** | CAP.WS |
| **Community cohesion** | | **14%** | 100% |
| Access to useful shared spaces | 32.8% | **4%** | COM.SS |
| Urban gardening | 29.1% | **4%** | COM.UG |
| Emergency preparedness | 37.7% | **5%** | COM.EP |
| | | **100%** | |




(b)

*Figure 37 (a) Overview of the final weightings of the Resilience Module as a standalone system. (b) Potentially considering all criteria belonging to the Robustness category.*

### 5.5.4 Scoring system

Similar to the SBToolCZ system, the processes of normalisation and aggregation of scores from each criterion can result in a unified point indicator of a building's resilience level, ranging from 0 to 10 points, for use as a stand-alone system.

The final score is calculated by multiplying the weight of each criterion (derived from the average value provided by the expert panel) by the overall weight of the respective category, resulting in the normalised weight of the criterion (Table 28). This value is then multiplied by the points awarded to the criterion to obtain the normalised score. The sum of the normalised scores for all criteria within a category gives the category's score, and the final score is determined by adding together the scores of all categories.

*Table 28 Example of category score calculation.*

| | Pt | Weight | Norm. weight | Norm. score |
|---|---|---|---|---|
| **Preparedness- R.PRE** | **18.0** | | **24%** | **1.13** |
| PRE.WA – Wayfinding and accessibility | 5 | 16% | 3.8% | 0.19 |
| PRE.SA – Site risk assessment | 0 | 26% | 6.2% | 0.00 |
| PRE.US – Unsuitable sites | 10 | 32% | 7.5% | 0.75 |
| PRE.VE – Conserve and use appropriate vegetation | 3 | 26% | 6.0% | 0.18 |

Based on the points achieved through the calculation procedures described above, certificates can be awarded to the building as follows:

- Gold certificate – 8 to 10 points
- Silver certificate – 6 to 7.99 points
- Bronze certificate – 4 to 5.99 points
- Basic certificate – 0 to 3.99 points

This scoring system may be updated, but it is provided to offer an indication of a building's potential performance. A building receiving fewer than 4 points indicates that only a few resilience principles have been met, suggesting a need for improvements to achieve a higher score and enhance its resilience level.

## 5.6 References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# 6. Resilience Module: Testing and validation as a stand-alone system

*This chapter offers a detailed analysis of the testing and validation processes applied to real-building case studies across various regions in the Czech Republic, focusing on evaluating the Resilience Module's accuracy and effectiveness for comprehensive resilience assessment as stand-alone system. The process systematically identifies gaps or limitations that need to be addressed to refine and optimise the Module. Following the evaluation of each criterion and the presentation of recommendations for improving scores and overall resilience—along with some adjustments in the building layout and technology installation—certain criteria were revised to better meet initial expectations. This phase also demonstrates that the Resilience Module can serve as a valuable guideline for incorporating resilience principles more effectively during the early stages of the design process. This chapter includes content partially adapted from the conference paper by Felicioni et al. 2024 titled "Implementing resilience in sustainable building design: Testing selected resilience criteria in a case study" (Article in press).*

The primary objective of the testing and validation phase is to evaluate the effectiveness of the Resilience Module criteria in measuring the building's resilience. This involves assessing their feasibility, accuracy, and consistency, as well as identifying the time and data requirements necessary for their successful implementation. This phase is crucial to ensure that the Module meets stakeholder needs and expectations and adheres to the design specifications established during the planning phase.

Upon assessing each criterion, recommendations for enhancing resilience are provided, demonstrating how adherence to these recommendations could improve the overall score. Additionally, this serves as a guide for potential stakeholders, such as architects, on how to better integrate resilience principles using the Resilience Module as a framework.

## 6.1 Selection of case studies

The Resilience Module criteria were applied to three multi-residential buildings located in different regions of the Czech Republic.

These buildings were selected for specific reasons, one of which is their geographical diversity, as they are located in different regions and potentially exposed to varying local hazards. The building in Prague was among the first to be assessed using the SBToolCZ system, making it a significant case for comparison. The second building, located near the Bohemian Forest, was chosen due to its unique characteristics, offering an atypical case study. The third building provided an opportunity to validate the assessment system on a structure that was explicitly designed with resilience in mind (RESBy method (16,17)—the Environmentally Friendly Resilient Residential Buildings method – was applied to this case study). This selection was part of the methodological approach, but it is important to note that the system's validity could have been tested on other buildings as well.

## 6.2 Assessment of the case studies

All relevant documentation for each building was collected to conduct the building assessments and validate the Resilience Module. This included floor plans, technical specifications, and other materials, such as the SBToolCZ certification report or the building energy performance report. Each criterion from the Resilience Module was then analysed individually, using the available documentation to guide the assessment process (see Appendix A – Resilience Module Manual and Appendix B – Resilience Calculation Tool sheets). It is essential to highlight that the three critical hazards identified in the Site Risk Assessment criterion (PRE.SA) will be treated equally in the Robustness category. The 22.5% weight assigned to the Robustness category is based on the average results provided by a panel of experts. This ensures that the assessment of site-specific risks is balanced and consistent within the overall framework.

### 6.2.1 Case study 1 – X-LOFT multi-residential building

X-LOFT is a multi-residential building accounting for 48 residential units located in the Northern area of the city of Prague. Table 29 is listing the primary information about the building. Figure 38, Figure 39, Figure 40, Figure 41, and Figure 42 show a floor plan and photos of the building.

The project adheres to aesthetic, fire safety, and energy efficiency standards, incorporating triple glazing, solar collectors, rainwater retention, and potential air recovery. Gas boilers and solar collectors provide heating, while individual units offer the option of a residential recuperation system. The glazed areas feature wooden windows, and solid surfaces are insulated with high-performance mineral wool. The installation of a rainwater retention tank supports ecological garden watering.

The assessment of this building was partially derived from the conference paper of Felicioni et al. titled *Implementing Resilience in Sustainable Building Design: Testing Selected Resilience Criteria in a Case Study* (accepted for publication on 13/09/2024) (19), available in Appendix C – Appended articles.

*Table 29 Primary information of the building case study.*

| **Criterion** | **Category** |
|---|---|
| Location | U Libeňského pivovaru, 180 00 Prague, Czechia |
| Year of construction | 2011-2013 |
| Residential unit | 48 |
| Floor | 2 underground floors + 4 double-height floors |
| Total internal usable floor area in heated zones | 4078 m$^2$ |
| Annual energy consumption | 81.2 kW/m2/y |
| SBToolCZ certification | 2013 - silver |
| Sustainability features | Solar collectors, reuse of harvested rainwater, accessibility to public transport, wooden windows with triple glazing. |

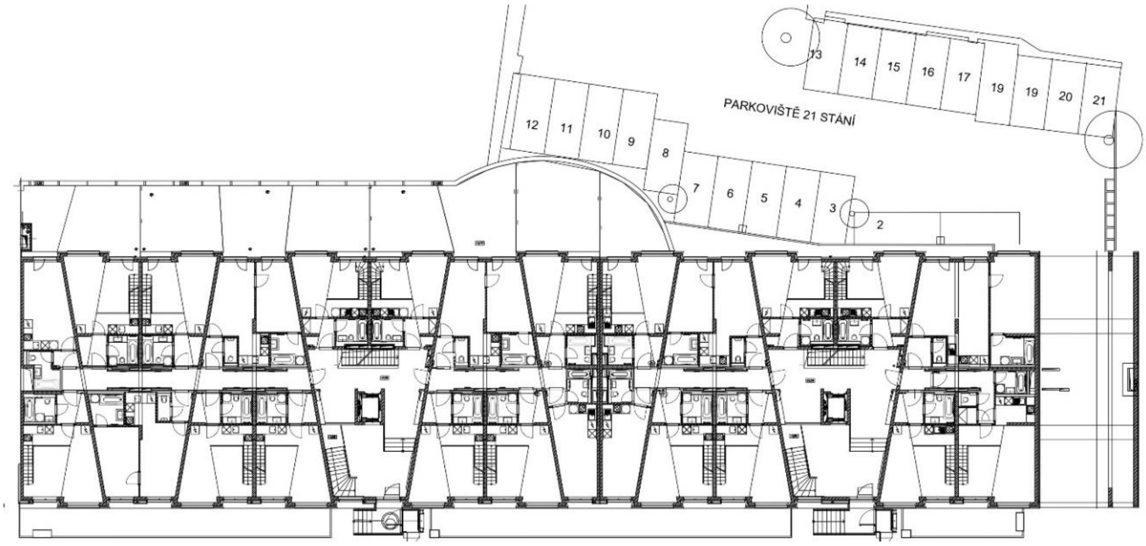



*Figure 38 X-LOFT's ground floor plan. Source of the plan: ECOTEN s.r.o.*

*Figure 39 View of the X-LOFT Eastern building façade (main entrance) from the U Libeňského pivovaru street.*

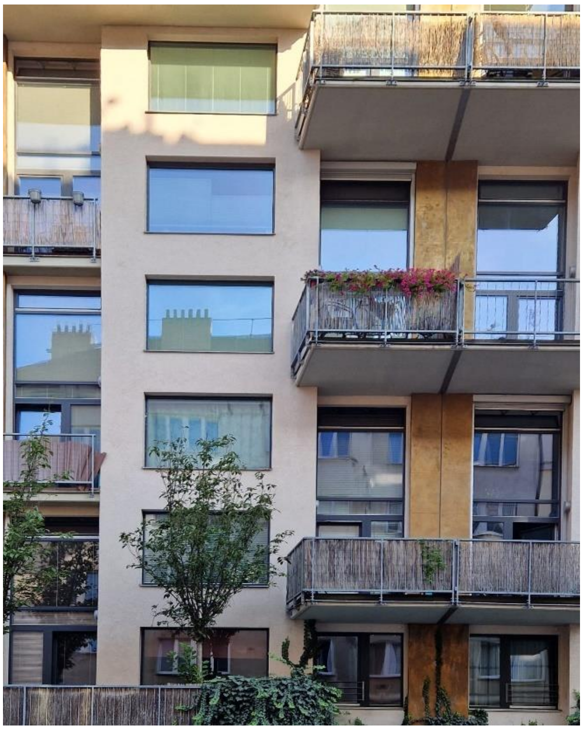


Figure 40 Detail of the windows and terraces of the X-LOFT building.

Figure 41 View of the Western façade from the internal parking of the X-LOFT building.


Figure 42 Street view of the X-LOFT building.

## PRE.WA Wayfinding and accessibility

Floor maps, cross-sections, photographs, and documentation have been reviewed to evaluate to which extent this criterion is met. For building accessibility, public transport options are conveniently located near the site, and parking spaces are available on the street, in the courtyard, and in the underground garage for residents.

The main building entrance features ramps to accommodate wheelchair users; however, there are no specific provisions for visually impaired individuals. Internally, the building has apartments facing the street, which presents stairs that may pose challenges for individuals with disabilities, such as reduced mobility or blindness.

While there is clear signage for emergency exits, it should be enhanced to address other potential hazards. Consequently, five out of the ten available points have been awarded for this criterion.

*Recommendations for enhancing the level of resilience*
*Improving accessibility for various users is crucial for both social resilience and the overall accessibility of the building. For instance, incorporating materials that assist visually impaired individuals in navigating the building, as well as implementing clear signage and illuminated wayfinding systems for hearing-impaired persons during emergencies, can enhance safety and ease of movement. These measures are closely linked to the criteria concerning emergency preparedness and warning systems, and if they are implemented, they could increase the score to eight points.*

## PRE.SA Site risk assessment

A comprehensive analysis of historical and projected data should be undertaken to assess this criterion and identify the most likely risks for the area in question. This process involves consulting location-specific databases and maps, focusing on past incidents like heatwaves, droughts, storms, subsidence and floods. The review included an examination of historical climate patterns and future projections under various scenarios. Hazard maps proved especially valuable in correlating climate data with areas vulnerable to these risks [19].

Given that the focus is on the Czech Republic, research extended beyond European databases to include sources specific to the Czech context. Notably, the Czech Extreme Weather Database (CZEXWED) [1] was consulted, cataloguing the 60 most severe weather events from 1961 to 2020. Although the full list is not yet available for download, a preview of the system's functionality is accessible through the provided source [2,3]. This database will be instrumental in identifying the most significant extreme weather events that have impacted Czechia.

*Extreme heat and droughts*

Maps related to Prague were thoroughly examined, including a satellite image taken by NASA's ECOSTRESS instrument in June 2022 [4], which recorded ground temperatures and identified the hottest areas (Figure 43). The image clearly illustrated the cooling effects provided by parks, vegetation, and water bodies. These findings are supported by the Urban Heat Island modelling from the European Environmental Agency's Urban Adaptation Map Viewer. Specifically, the X-LOFT building case study is located in an area where surface temperatures ranged between 42-44 degrees Celsius, emphasising the significant risk posed by extreme heat in that location and the necessity for adaptation measures.

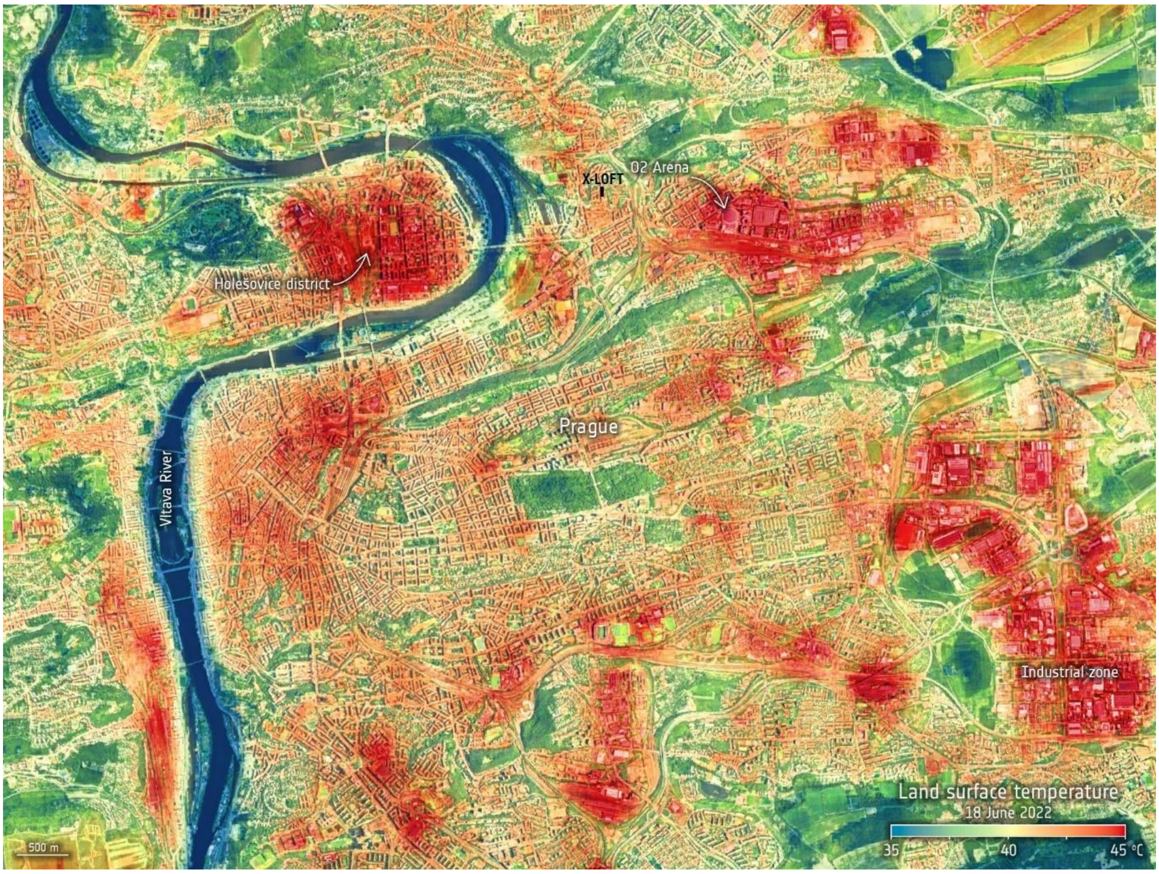



*Figure 43 Land surface temperature in Prague on 18 June 2022. Source:* [4]

Furthermore, the Urban Adaptation Map Viewer highlights Prague as a heat hotspot, with projections indicating that the number of extreme heatwaves between 2020 and 2052 could reach 1.71 [5]. The viewer also provides insight into the projected drought frequency for the RPC 8.5 emission scenario from 2041 to 2071. While Prague (with a value of -1 to 1) and, more broadly, the entire Czech Republic (value -2 to -1) appear less affected by drought hazards, the Standardised Precipitation Index (SPI-6) still indicates potential vulnerability, defined by months in a 30-year period where the SPI-6 falls below -2 [6].

*Flood*

Historically, the city has faced severe river flooding, most notably during the major flood of 2002, which necessitated over 5 million CZK in expenses for the installation of both fixed and mobile flood barriers. However, the X-LOFT area is not vulnerable to this hazard, as confirmed by images from Bezpecnost.praha.eu [7]. These images, illustrating the floodplain for a 100-year flood event, confirm that the X-LOFT vicinity remains outside the flood risk zone.

*Heavy precipitation and storm*

The analysis of maps related to pluvial flooding, which occurs when heavy rainfall exceeds the capacity of drainage systems due to a high percentage of impervious surfaces, shows that Prague has an impervious area covering 40% to 60% [5]. This raises a considerable risk of flooding from surface runoff.

Future projections under the RCP8.5 emissions scenario indicate a 25% to 35% increase in heavy winter precipitation and a 15% to 25% increase in summer by the end of the century, as reported by the European Severe Storms Laboratory [8]. Additionally, the frequency of severe storms, including hail, strong winds, and thunderstorms, is expected to rise significantly.

Large hail (≥ 2 cm) and winds over 25 m/s are projected to become 40% to 80% more likely in Central Europe, including Czechia, by the late 21st century [9].

*Subsidence*

Regarding geology and the risk of subsidence, the ground consists of shales, siltstones, sandstones, and basalt interlayers, as referenced by the Czech Geological Survey [10]. No risk of subsidence was identified, so this hazard is not considered one of the more significant impacts.

Consequently, as a risk assessment was not conducted during the building's design phase, points were not awarded for this criterion. However, the findings from this desk research were utilised to identify the three hazards to be addressed under the Robustness category.

*Recommendations for enhancing the level of resilience*

*A workshop involving stakeholders who are directly or indirectly impacted by a decision, strategy, treatment, or process could be highly beneficial in identifying critical hazards that require adaptation to reduce vulnerability. These workshops would focus on prioritising risks by considering factors such as exposure, sensitivity, and interdependencies. This would award the criterion with 5 points.*

**PRE.US Unsuitable sites**

This criterion is defined by two modules: avoiding flood-prone areas and adverse geology zones. The site is neither located on a floodplain nor susceptible to river flooding, which is also proven by the result of the Site risk assessment.

Regarding geology, the ground consists of shales, siltstones, sandstones, and basalt interlayers, as referenced by the Czech Geological Survey [10]. As a result, a maximum score of ten points was assigned to this criterion.

**PRE.VE Conserve and use appropriate vegetation**

The building was built on the site of the former Libeň brewery. While some of the existing vegetation was preserved, and additional single trees were planted along the street in front of the building, the available documentation lacked specific details about the original vegetation, making it impossible to identify them. Although project documentation includes drawings of the overall vegetation, only three out of a possible ten points were awarded for this criterion.

*Recommendations for enhancing the level of resilience*

*Select and plant species that are specifically tolerant to extreme heat, given that heat stress is a relevant hazard in these areas – this would add three additional points to the score. Document the selection process and illustrate the planting sites on maps.*

**RED.PS Passive survivability**

This criterion consists of four modules, each carefully evaluated.

For passive heating, the building performs well with triple-glazed windows that effectively reduce heat loss and sound transmission. Additionally, a 14-cm thick layer of mineral wool insulation enhances energy efficiency.

Regarding passive cooling, the building benefits from dual exposure, which facilitates cross ventilation and helps lower indoor temperatures. External and internal blinds can shade the large windows, mitigating excessive heat. Additionally, 2% of the building's façade is covered with greenery, slightly improving thermal efficiency.

Regarding passive lighting, the building's favourable east-west orientation minimises exposure to intense southern sunlight. Floor-to-ceiling windows allow ample natural light, ensuring well-lit spaces.

The fourth module assesses the maximum daily indoor air temperature in the hottest habitable room according to ISO 7730:2005 standards. As the building is SBToolCZ-certified, information on this module was obtained from certification reports. Architectural drawings and on-site inspections were crucial for meeting the requirements of the remaining modules. Eight out of ten possible points were awarded for this criterion.

**RED. AP Alternative power sources**

*The documentation of the building's energy performance has resulted in the hot water production being covered by solar panels placed on the roof.* As a result, two points out of a possible eleven were allocated to this criterion.

*Recommendations for enhancing the level of resilience*

*Enhancing resilience could involve increasing the capacity of the existing solar photovoltaic system or adding more panels that would cover other operations. For example, if renewable energy sources would cover between 5% to 15% of the needs, the score would be increased by two points. Additionally, connecting the building to district heating may provide a more sustainable and resilient alternative to relying on gas, meeting daily energy demand for heating in winter – this would add two additional points to the score.*

**ROB.HR Heavy precipitation-resistant building envelope and structure**

According to the Site Risk Assessment, the building and its surroundings are at risk from heavy precipitation. Based on available documentation and drawings, an examination of the building design shows that a few measures have been implemented to reduce the vulnerability to this hazard. The building does not present flat surfaces and also a minor portion of green façade. The rainwater is collected in a tank and reused for irrigation.

Consequently, three out of a possible ten points were awarded for this criterion.

*Recommendations for enhancing the level of resilience*

*Introducing sustainable urban drainage systems in the courtyard or in front of the building would help reduce water runoff and prevent sewer overload during heavy rainfall. Additionally, backflow prevention devices should be installed in the apartments. Installing hail nets to protect fragile elements on the roof, as well as covering potential urban gardening areas that could be placed there (as outlined in the COM.UG Urban Gardening criterion), would also enhance resilience, and would results n two additional points.*

**ROB.SR Storm-resistant building envelope and structure**

According to the Site Risk Assessment, the building and its surroundings are at risk from heavy precipitation. Based on available documentation and drawings, an examination of the building design shows that a few measures have been implemented to reduce the vulnerability to this hazard. The building is elevated above street level, with only garages located underground. Triple-glazed, impact-resistant windows are installed on the facades, and most of the windows are sliding, eliminating the need to secure them with hooks. However, no additional measures have been implemented to fully meet this criterion, resulting in a score of two out of ten.

*Recommendations for enhancing the level of resilience*

*Introducing backup generators and dense hedges or shrubs around the building could help reduce vulnerability to potential blackouts during magnetic storms or strong winds – these implementations would add two additional points to the score. Other measures could be implemented, but they are more complex and costly.*

**ROB. HW Heat wave-resistant building envelope and structure**

According to the Site Risk Assessment, the building and its surroundings are at risk from potential heatwave impacts. Based on available documentation and drawings, an examination of the building design shows that adequate measures have been implemented to address extreme summer heat, some of which were discussed earlier in the passive cooling section.

The orientation of the building is optimal, East-West. The street-facing and courtyard-facing glazed areas have triple-glazed wooden windows that are solar-shaded by blinds. Additionally, the building features a rainwater tank that collects water from an underground reservoir for reuse, which helps reduce the need for irrigation water during the summer. The opaque white surfaces are insulated with 14 cm of high-performance mineral wool. Consequently, six out of a possible ten points were awarded for this criterion.

*Recommendations for enhancing the level of resilience*

*Increasing the density of vegetation on the west side of the building would help moderate the outdoor climate, making the area more comfortable for occupants. Additionally, blinds and shutters could be automated to adjust based on the sun's position throughout the day. This adjustment would add an extra point to the score.*

### CAP.SS Safe equipped space

The criterion requires evidence of installing first aid kits and communication devices that remain functional during emergencies. These items are not standard equipment for buildings but rather specific measures, and there is no documentation in the project files confirming their presence or that of a safe room. Consequently, no points were awarded for this criterion.

*Recommendations for enhancing the level of resilience*

*It is important to designate a safe room for emergencies. In mid-rise buildings, the ideal refuge areas are typically located on the lower floors and central sections of the building. Stairwells with reinforced concrete walls often provide the most secure options. Restrooms are usually the next best alternative if these cannot accommodate everyone. If such a room is implemented in the design, the criterion will be awarded two points.*

*Also, the city of Prague, particularly the municipalities, has designated specific areas as shelters. For instance, a shelter managed by Prague 8 municipality, with a capacity to host 55 people, is available near X-LOFT. Other shelters in the neighbourhood can accommodate up to 150 people [7].*

### CAP. PS Emergency power supply

Two 90 kW gas boilers manage heating and hot water, with additional hot water support from roof solar collectors during summer. Each residential unit has a recuperation unit that reduces energy losses through ventilation and maintains carbon dioxide levels below the 1200 ppm limit (classified as "C" according to ČSN EN 1752). This unit also ensures optimal relative humidity between 35% and 42% during both heating and transitional periods.

However, the lack of a backup power source limits the assessment of this criterion. As a result, no points were awarded for this criterion.

*Recommendations for enhancing the level of resilience*

*Measures such as installing generators for water pumps, operational cable modems and wireless routers for internet access, or emergency escape lighting would be beneficial during disruptions and would add at least five points to the criterion.*

**CAP. WS Emergency water supply**

This criterion is partially met because while a water tank for collecting rainwater is available and used for irrigation purposes, there is no indication that this water is utilised for other building operations, such as flushing toilets. Consequently, two out of ten points were assigned to this criterion.

*Recommendations for enhancing the level of resilience*

*Rainwater usage can extend beyond irrigation and support other operations to reduce dependence on municipal water supplies. Additionally, a groundwater well tapping into aquifers can provide a primary source of freshwater, mainly for drinking purposes – proper water quality assessment must be performed beforehand [11,12]. Implementing a system to recycle and reuse greywater in a closed-loop system can minimise waste and promote sustainable water use.*

*Standby or emergency pumps are essential for maintaining water supply projects in case of breakdowns. By understanding all the relevant details about the pump, appropriate renewable energy sources like solar or wind can be utilised to power the water system [13]. Implementing all these measures, although potentially costly, would result in a score of 8 points for the criterion.*

**COM.SS Access to useful shared spaces**

This criterion is only partially met in the specific building case study. The building includes common parking areas, bike storage, and essential connecting halls between apartments but lacks additional shared spaces.

The decision not to include these shared spaces is partly due to the proximity of external amenities, such as sports facilities, which are within a 5-minute walk. Residents also have access to a shared courtyard and pergola outdoors. Information for this assessment was derived from a review of the building's drawings, resulting in two out of ten points for this criterion.

*Recommendations for enhancing the level of resilience*

*The building could have benefited from the design and addition of several common areas to foster social interaction among residents. Given the high number of units and occupants, incorporating shared amenities such as a gym, laundry room, or multipurpose space (e.g., coworking area) would have been particularly advantageous, especially since 40 out of the 48 apartments are under 50m², making them more suitable for individuals or young couples. By including at least three dedicated shared spaces or areas for the building's residents, the criterion could earn an additional two points.*

### COM.UG Urban gardening

The building presents a water tank where the rainwater is collected and stored for irrigation purposes. The information to meet this criterion arose from a review of the drawings and led to 2 out of the 10 available points.

*Recommendations for enhancing the level of resilience*

*Activities like growing vegetables, fruits, or edible plants can allow residents to connect, share ideas, and engage in communal activities. These efforts offer numerous benefits, including food production, ornamental gardening, nature education, and various environmental advantages such as air purification, noise reduction, and improved surface water drainage. Dedicating spaces for these activities, whether on the rooftop or in the internal courtyard, could promote greater interaction with nature, fostering relaxation and a stronger sense of community and would increase the criterion's score to four points.*

### COM. EP Emergency preparedness

The building does not have a warning system, though it does include a fire alarm system as mandated by law. Furthermore, the blinds do not automatically adjust to block sunlight through sensors, contributing to heat buildup inside the apartments. However, the city of Prague has installed an electronic siren near the building to provide warnings in case of major emergencies to the residents of that neighbourhood [7]. As a result, this criterion is not met under the current conditions of the building.

*Recommendations for enhancing the level of resilience*

*Sensors and warning systems, including both visual and audio signals to accommodate all building occupants, including those with disabilities, could be installed not only for fire alarms but also for flood risks and, specifically in this case, heat stress. These systems would help inform residents that a disruptive event may be ongoing. By installing these systems, at least three points could be awarded to the criterion. Additionally, annual meetings and training sessions with residents should be conducted to educate them on the appropriate measures to take during emergencies and how to react effectively.*

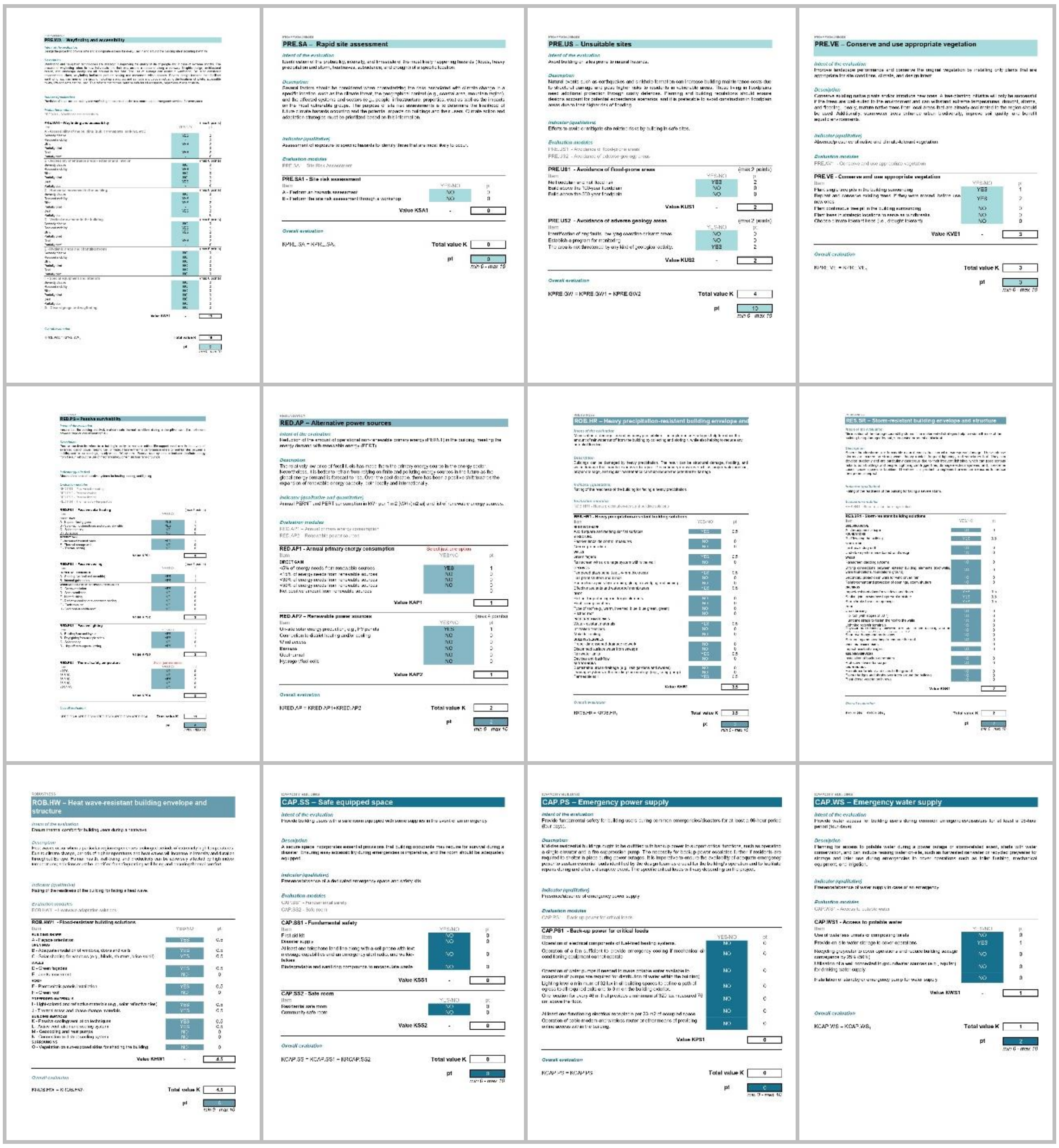
Finally, Figure 44 presents the assessment results, with the X-LOFT building receiving a final score of 3.42. This score was determined by normalising the points based on the average weights the panel of experts provided.

| X-LOFT | PT | WEIGHT | NORMALIZED WEIGHT | NORMALIZED SCORE | |
|---|---|---|---|---|---|
| **PREPAREDNESS- R.PRE** | **18.0** | | **24%** | **1.13** | |
| PRE.WA – Wayfinding and accessibility | 5 | 16% | 3.8% | 0.19 | PRE.WA |
| PRE.SA – Site risk assessment | 0 | 26% | 6.2% | 0.00 | PRE.SA |
| PRE.US – Unsuitable sites | 10 | 32% | 7.5% | 0.75 | PRE.US |
| PRE.VE – Conserve and use appropriate vegetation | 3 | 26% | 6.0% | 0.18 | PRE.VE |
| **REDUNDANCY – R.RED** | **9.7** | | **22%** | **1.19** | |
| RED.PS – Passive survivability | 8 | 58% | 13.0% | 1.02 | RED.PS |
| RED.PS – Alternative power sources | 2 | 42% | 9.2% | 0.17 | RED.AP |
| **ROBUSTNESS – R.ROB** | **11.1** | | **23%** | **0.83** | |
| ~~RES.FR – Flood-resistant building envelope and structure~~ | ~~0~~ | ~~0%~~ | 0.0% | 0.00 | ~~ROB.FR~~ |
| RES.HR – Heavy precipitation-resistant building envelope and structure | 3 | 33% | 7.5% | 0.23 | ROB.HR |
| RES.SR – Storm-resistant building envelope and structure | 2 | 33% | 7.5% | 0.12 | ROB.SR |
| ~~RES.SU – Subsidence-resilient building envelope and structure~~ | ~~0~~ | ~~0%~~ | 0.0% | 0.00 | ~~ROB.SU~~ |
| ~~RES.DR – Drought-resistant building envelope and structure~~ | ~~0~~ | ~~0%~~ | 0.0% | 0.00 | ~~ROB.DR~~ |
| RES.HW – Heat wave-resistant building envelope and structure | 6 | 33% | 7.5% | 0.48 | ROB.HW |
| **RESPONSE CAPABILITY - R.CAP** | **2.0** | | **19%** | **0.13** | |
| CAP.SS – Safe equipped space | 0 | 30% | 5.6% | 0.00 | CAP.SS |
| CAP.PS – Emergency power supply | 0 | 35% | 6.4% | 0.00 | CAP.PS |
| CAP.WS – Emergency water supply | 2 | 35% | 6.4% | 0.13 | CAP.WS |
| **COMMUNITY COHESION - R.COM** | **3.5** | | **13%** | **0.14** | |
| COM.SS – Access to useful shared spaces | 2 | 35% | 4.4% | 0.07 | COM.SS |
| COM.UG – Urban gardening | 2 | 29% | 3.7% | 0.07 | COM.UG |
| COM.EP – Emergency preparadness | 0 | 36% | 4.6% | 0.00 | COM.EP |
| | | | | **3.42** | |

*Figure 44 Overview of X-LOFT's score criterion by criterion.*

Considering that the highest possible score using the Resilience Module as a stand-alone system is 10, a score of 3.42 is below the sufficiency. This can be attributed to the building being constructed between 2011 and 2013 without accounting for potential future hazards and focusing primarily on sustainability principles to gain the SBToolCZ certification. These sustainability features, while beneficial, were not designed with resilience in mind.

The analysis suggests that the building could be enhanced by implementing resilience solutions, such as installing a backup power generator or adding sensors for a heat warning system, given that the site risk assessment identified extreme heat as the most significant hazard for the building location. Additionally, other resilience measures could be integrated during any future renovations to ensure the building is better equipped to withstand and adapt to changing climate conditions. Finally, it is important to observe that if the recommendations provided for each criterion are adhered to and implemented, the resulting score would increase by at least 5.86 points. This represents a substantial improvement over the current status, achievable through measures that are not overly complex. Figure 45 provides an excerpt from the Resilience Calculation Tool sheets (see Appendix B).



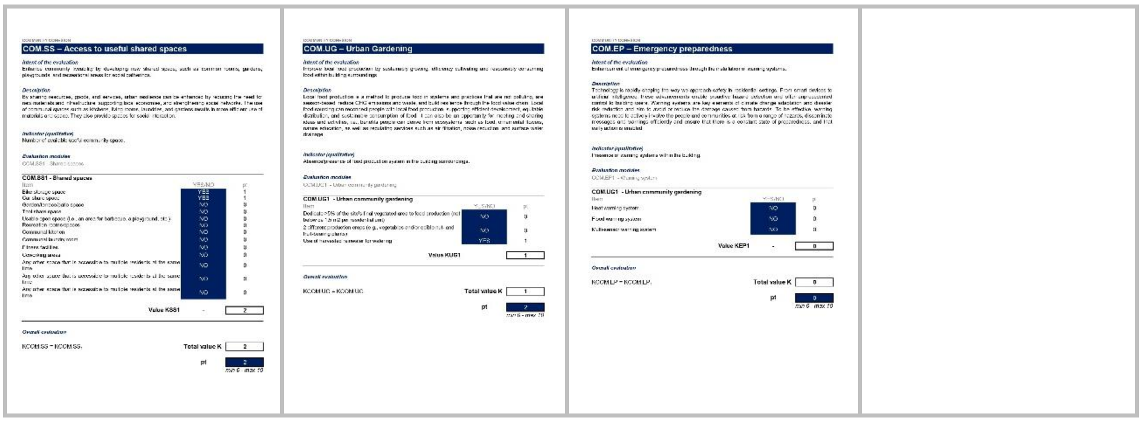



*Figure 45 X-LOFT assessment - Excerpt from the Calculation tool (see Appendix B).*

### 6.2.2 Case study 2 – Bohemian Court (Šumavský Dvůr) multi-residential building

The building is a four-storey, two-winged apartment complex with a gabled roof and one underground level, as detailed in Table 30. The glazed areas are primarily oriented towards the south-east and south-west. Constructed mainly from wood and featuring mineral wool thermal insulation, the building's primary load-bearing elements are reinforced concrete. The roof is supported by a wooden truss with thermal insulation (PUR) placed above the rafters. The ceilings are reinforced concrete slabs.

The ground-floor heating spaces are equipped with a layer of polystyrene thermal insulation. Two gas-condensing boilers provide heating, each with a nominal output of 100 kW. There are two indirect storage tanks with capacities of 1000 and 500 litres for hot water. The heating of the rooms is managed by steel plate and steel tube heaters. The plate heaters are installed in the living rooms, particularly in the cooler areas like under or near windows and will be floor-mounted with thermostatic heads. Rainwater from the roofs is managed by a soakage facility adjacent to the main building.

The complex includes two residential buildings and an existing hotel, with a ski slope nearby. Figure 46, Figure 47, Figure 48 show details of the floor map and building facades from multiple angles.

*Table 30 Primary information of the building case study.*

| **Criterion** | **Category** |
|---|---|
| Location | Železná Ruda 193, 340 04 Železná Ruda, Czechia |
| Year of construction | 2010-2012 |
| Residential unit | 23 (70 residents) |
| Floor | 1 underground floor + 4 aboveground floors |

| | |
|---|---|
| Total internal usable floor area in heated zones | 3000 m$^2$ |
| SBToolCZ certification | 2012 - silver |
| Sustainability features | Housing with natural character, renewable construction materials. rainwater harvesting |

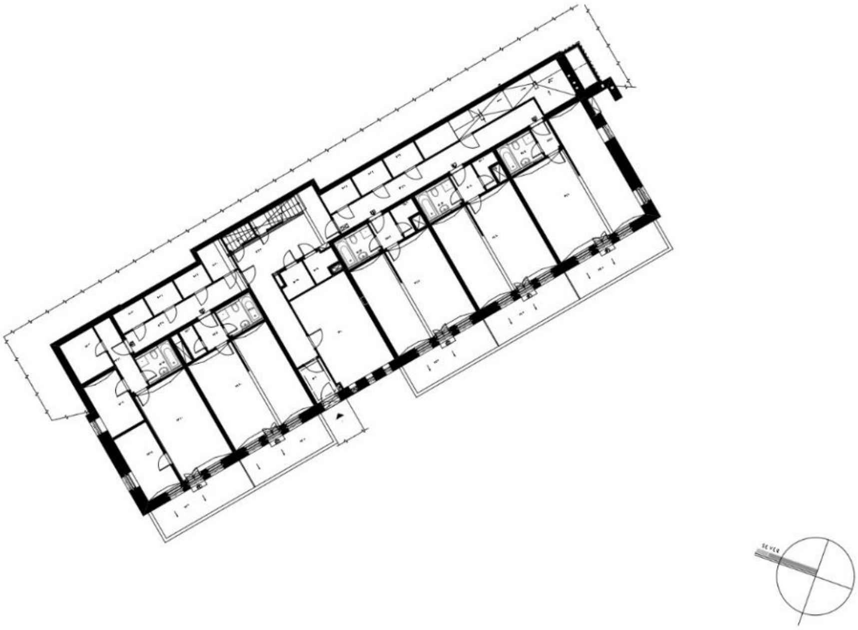


*Figure 46 Šumavský Dvůr's first floor map. Source of the map: ECOTEN s.r.o.*

*Figure 47 Details of the northwest façade. Photo credits: Ing. Jiří Tencar, Ph.D.*

*Figure 48 Šumavský dvůr from the main street "Železná Ruda". Credits: Ing. Jiří Tencar, Ph.D.*

**PRE.WA Wayfinding and accessibility**

Floor maps, cross-sections, photographs, and documentation have been reviewed to evaluate to which extent this criterion is met. For building accessibility, public transport options are conveniently located near the site (less than 1 km away), and parking spaces are available on the building site property.

As presented in the SBToolCZ report of the building, the main building entrance does not feature ramps to accommodate wheelchair users. While there is clear signage for emergency exits, it should be enhanced to address other potential hazards. Consequently, five out of the ten available points have been awarded for this criterion.

*Recommendations for enhancing the level of resilience*
*Improving accessibility for various users, including those with reduced mobility, is crucial for both social resilience and the overall accessibility of the building. For instance, incorporating materials that assist visually impaired individuals in navigating the building, as well as implementing clear signage and illuminated wayfinding systems for hearing-impaired persons during emergencies, can enhance safety and ease of movement. These measures are closely linked to the emergency preparedness and warning system criterion. This implementation would add an extra three points to this criterion.*

## PRE.SA Site risk assessment

A comprehensive historical and projected data analysis should be undertaken to assess this criterion and identify the most likely risks for the area in question. This process involves consulting location-specific databases and maps, focusing on past incidents like heatwaves, droughts, storms, subsidence and floods. The review included an examination of historical climate patterns and future projections under various scenarios. Hazard maps proved especially valuable in correlating climate data with areas vulnerable to these risks.

*Flood*

Upon consulting the Flood Warning and Forecasting Service provided by the Czech Hydrometeorological Institute [14], it was determined that the building site is located in an area where the risk of flash floods could be considerably high. This heightened risk is primarily due to the region's moderate retention capacity, which indicates that the soil and surrounding landscape may not be able to adequately absorb and retain heavy rainfall, leading to potential overflow and rapid water accumulation. The saturation level of the land, combined with the area's natural drainage characteristics, suggests a vulnerability to sudden and intense flooding events, necessitating further protective measures for the site.

*Heavy precipitation and storm*

Future projections under the RCP8.5 emissions scenario suggest a 5% to 15% increase in heavy winter precipitation, according to findings from the European Severe Storms Laboratory [8]. Furthermore, the frequency of severe storms—including hail, strong winds, and thunderstorms—is anticipated to rise considerably. These changes underscore the growing need for enhanced resilience and adaptive strategies in building design and urban planning to mitigate the potential impacts of these increasingly severe weather events.

*Subsidence*

Regarding geology and the risk of subsidence, the ground consists of low-pressure cordierite gneisses and cordierite migmatites, as referenced by the Czech Geological Survey [10]. No risk of subsidence was really identified, as well as consulting the Czech Historical Landslide Database [15]. However, since the building site is in a mountain area surrounded by forests, the risk of subsidence due to heavy rain may be become more frequent since Large volumes of water running through the ground under the property can wash away the soil and leave the structure with uneven support.

Consequently, as a risk assessment was not conducted during the building's design phase, no points were awarded for this criterion. However, the findings from this desk research were utilised to identify the three hazards to be addressed under the Robustness category.

*Recommendations for enhancing the level of resilience*

*A workshop involving stakeholders who are directly or indirectly impacted by a decision, strategy, treatment, or process could be highly beneficial in identifying critical hazards that require adaptation to reduce vulnerability. These kinds of workshops would focus on prioritising risks by considering factors such as exposure, sensitivity, and interdependencies – this would award the criterion with five points.*

**PRE.US Unsuitable sites**

The site is neither located on a floodplain nor susceptible to river flooding, which is also proven by the result of the Site risk assessment.

Regarding geology, the ground consists of shales, siltstones, sandstones, and basalt interlayers, as referenced by the Czech Geological Survey [10]. However, UNESCO declared this area a biological reserve as early as 1990. As a result, a maximum score of ten points was assigned to this criterion.

**PRE.VE Conserve and use appropriate vegetation**

The building was built in the natural landscape in proximity to sky facilities. The existing trees were conserved, but no additional ones were planted. Thus, only two out of a possible ten points were awarded for this criterion.

*Recommendations for enhancing the level of resilience*

*Select plant species that are specifically tolerant to the specific climate, and that could be potentially used as a windbreaker – this would award the criterion with two extra points. Document the selection process and illustrate the planting sites on maps.*

### RED.PS Passive survivability

The building features a thick layer of mineral wool insulation for passive heating and increased thermal mass. The glazed areas are mainly oriented towards the southeast and southwest, optimising sun exposure and heat gain.

However, no measures have been implemented for passive cooling, and the building lacks an active cooling system altogether.

In terms of passive lighting, the building benefits from its favourable orientation, which maximises exposure to strong southern sunlight. However, natural daylight is not available from multiple sides.

The fourth module evaluates the maximum daily indoor air temperature in the hottest habitable room according to ISO 7730:2005 standards. As the building is SBToolCZ-certified, data for this module was sourced from certification reports, showing a maximum recorded temperature of approximately 26.5 degrees Celsius in the hottest room. Architectural drawings were essential for fulfilling the module's requirements.

Ultimately, the building received only four out of ten possible points for this criterion.

*Recommendations for enhancing the level of resilience*

*In this case, there are no passive cooling and ventilation measures currently in place. It is recommended that stack ventilation be implemented using the existing windows (Figure 49), particularly on the second floor and in the attic, where the apartments are on two levels. Moreover, adding a solar chimney could improve both lighting and solar heating. By implementing this strategies, two extra points may be awarded to the criterion.*

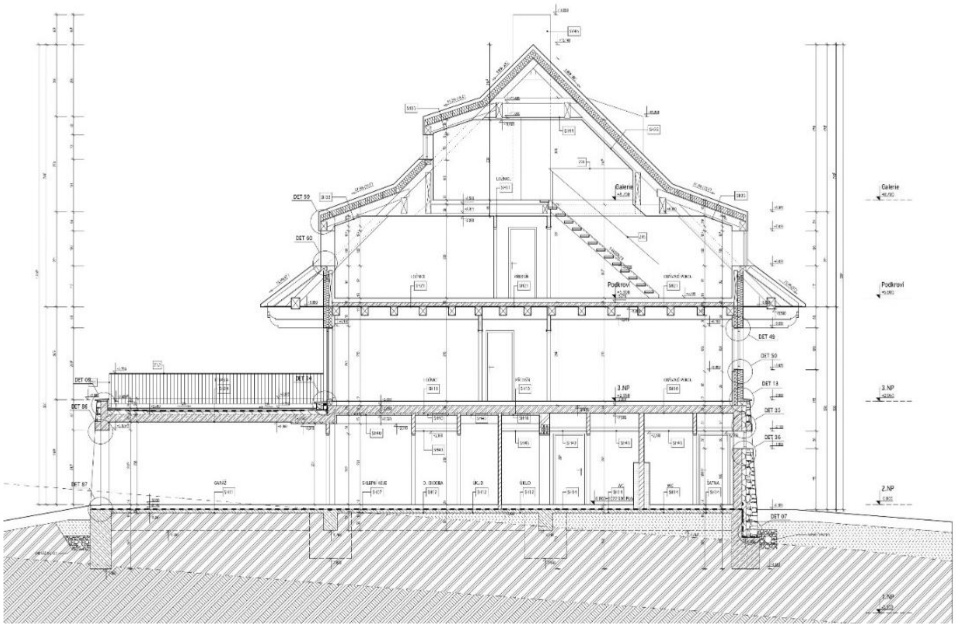


*Figure 49 Cross section of the Šumavský Dvůr building. Source of the section: ECOTEN s.r.o.*

## RED. AP Alternative power sources

The documentation reveals no evidence of renewable energy sources being used on the site. Consequently, no points were awarded for this criterion.

*Recommendations for enhancing the level of resilience*

*Onsite energy production could be an excellent solution for meeting electricity demands or generating hot water. However, the performance of photovoltaics at higher altitudes often falls short, as confirmed by existing literature. Therefore, utilising hydropower could serve as a viable alternative for renewable energy production. This implementation would award the criterion with 3 points.*

## ROB.FL Flood-resistant building envelope and structure

Given the risk of flash floods from heavy rains, the buildings should be designed to withstand such conditions. To address this, the foundations have been constructed with waterproofing measures, and effective sealants and proper insulation materials have been utilised. Additionally, the basement hosts non-essential functions. This approach results in a rating of 5 out of 10 for this criterion.

*Recommendations for enhancing the level of resilience*

*Introducing a water sump pump, along with a properly dimensioned drainage network, would help reduce water runoff and prevent sewer overload during heavy rainfall. Additionally, backflow prevention devices should be installed in the apartments. This adjustment would add an extra point to the criterion.*

**ROB.HR Heavy precipitation-resistant building envelope and structure**

According to the Site Risk Assessment, the building and its surroundings may be at risk from heavy precipitation since the trend tends to grow in the future. Based on available documentation and drawings, an examination of the building design shows that a few measures have been implemented to reduce the vulnerability to this hazard.

The building features irregular surfaces and a pitched roof designed to withstand heavy snowfall in winter. Rainwater is collected in a tank and reused for irrigation, fully meeting the water demand throughout the year. The surrounding soil is left permeable, with impermeable surfaces limited to the building footprint and an access road. The materials used in construction are water-resistant, ensuring durability against both rain and snow. However, there is no information on managing excess water on-site, such as through a sustainable drainage system or sump pump.

As a result, only three out of ten possible points were awarded for this criterion.

*Recommendations for enhancing the level of resilience*

*The recommendations for flood prevention and mitigation are equally relevant in this case – an extra point could be awarded by installing a water pump. Moreover, by installing anti-hail measures, an additional point could be achieved.*

**ROB.SU Subsidence-resistant building envelope and structure**

Due to the possibility of heavy rains, soil moisture levels and composition can be affected, potentially leading to subsidence and soil movement. This criterion consists of two modules. The first module focuses on implementing adaptation solutions for the building, and in this case, trees have been planted at a safe distance to prevent their roots from threatening the foundations.

The second module addresses the construction process and soil movement. Given that the area is protected, soil movement has been minimised as much as possible. The project was divided into sections, and slope protection measures were implemented.

As a result, a total of five out of ten points were awarded for this criterion.

*Recommendations for enhancing the level of resilience*

*Strengthening the foundation would be beneficial, incorporating deep foundation systems such as piles or caissons could provide greater stability. Implementing proper drainage systems around the foundation to manage excess water and reduce soil saturation would also help mitigate the risk. Regular monitoring of soil conditions and foundation stability could further enhance the building's resilience over time. This adjustment would add two additional points; however, it is challenging to implement and would be costly.*

### CAP.SS Safe equipped space

The criterion requires evidence of installing first aid kits and communication devices that remain functional during emergencies. These items are not standard equipment for buildings but rather specific measures, and there is no documentation in the project files confirming their presence or that of a safe room. Consequently, no points were awarded for this criterion.

*Recommendations for enhancing the level of resilience*

*It is important to designate a safe room for emergencies. In mid-rise buildings, the ideal refuge areas are typically located on the lower floors and central sections of the building. Stairwells with reinforced concrete walls often provide the most secure options. Restrooms are usually the next best alternative if these cannot accommodate everyone. If this room is added to the layout, two points will be awarded.*

### CAP. PS Emergency power supply

Heating and hot water preparation is provided by gas condensing boilers and two indirect heating tanks with a volume of 500 l and 1000 l. The operation of the heating system is guaranteed with the stored emergency fuel. However, the lack of a backup power source or water pump system limits the achievement of this criterion. As a result, only two points were awarded for this criterion.

*Recommendations for enhancing the level of resilience*

*Measures such as generators for water pumps for potable water, operational cable modems and wireless routers for internet access, or using a common room for emergency supply storage could enhance resilience during blackouts or other disruptions. These implementations would add three points to the score.*

**CAP. WS Emergency water supply**

This criterion is partially met because while a water tank for collecting rainwater is available and used for irrigation purposes, there is no indication that this water is utilised for other building operations, such as flushing toilets. Consequently, two out of ten points were assigned to this criterion.

*Recommendations for enhancing the level of resilience*

*Rainwater usage can extend beyond irrigation; it can also support other operations to reduce dependence on municipal water supplies. Additionally, a groundwater well tapping into aquifers can provide a primary source of freshwater, mainly for drinking purposes – proper water quality assessment must be performed beforehand [11,12]. By implementing these measures, four extra points will be added to the score. Standby or emergency pumps are essential for maintaining water supply projects in case of breakdowns. By understanding all the relevant details about the pump, appropriate renewable energy sources like solar or wind can be utilised to power the water system [13].*

*Finally, implementing a system to recycle and reuse greywater in a closed-loop system can minimise waste and promote sustainable water use – this implementation would add two extra points to the score.*

**COM.SS Access to useful shared spaces**

This criterion is only partially met in the specific building case study. The building includes common parking areas, bike storage, and essential connecting halls between apartments but lacks additional shared spaces.

Residents also have access to a shared terrace and outdoor playground. Information for this assessment was derived from a review of the building's drawings, resulting in three out of ten points for this criterion.

*Recommendations for enhancing the level of resilience*

*The building could have benefited from the design and addition of several common areas to foster social interaction among residents. Given the high number of units and occupants, incorporating shared amenities such as a gym, laundry room, or multipurpose space (e.g., coworking area) –adjustments to the layout would add two points to the score.*

**COM.UG Urban gardening**

The building presents a water tank where the rainwater is collected and stored for irrigation. The information to meet this criterion arose from a review of the drawings and led to 2 out of the 10 available points.

*Recommendations for enhancing the level of resilience*

*Activities like growing vegetables, fruits, or edible plants can allow residents to connect, share ideas, and engage in communal activities. Dedicating spaces for these activities, for example, in the building surrounding installing a small greenhouse, could promote greater interaction with nature, fostering relaxation and a stronger sense of community – this would add two points to the score.*

**COM. EP Emergency preparedness**

The building does not have a warning system, though it does include a fire alarm system as mandated by law. Furthermore, the blinds do not automatically adjust to allow/block sunlight through sensors. As a result, this criterion is not met under the current conditions of the building.

*Recommendations for enhancing the level of resilience*

*Sensors and warning systems, including both visual and audio signals to accommodate all building users, including those with disabilities, could be installed not only for fire alarms but also for flood risks and, specifically in this case, subsidence hazards. These systems would help inform residents that a disruptive event may be ongoing – the installation of such systems will award 7 points to the score. Additionally, annual meetings and training sessions with residents should be conducted to educate them on the appropriate measures to take during emergencies and how to react effectively.*

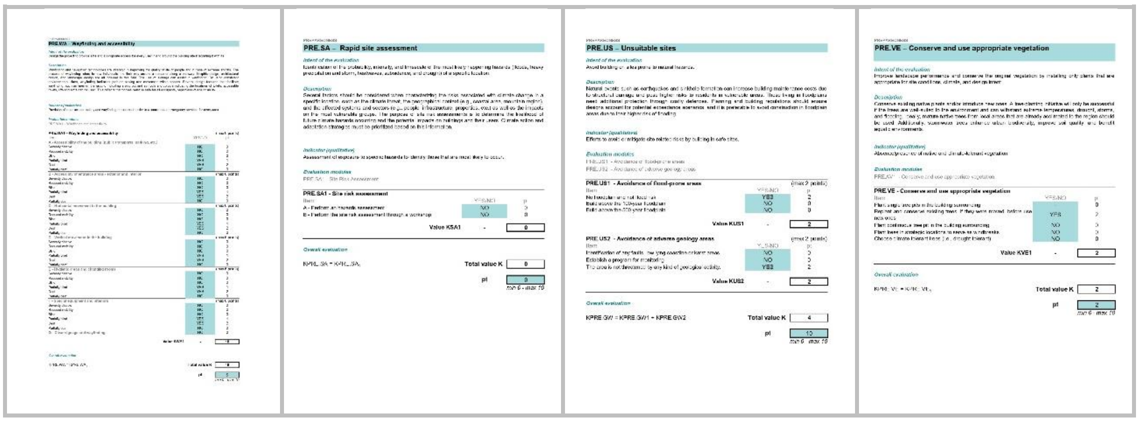
Finally, Figure 50 presents the assessment results, with the Šumavský Dvůr building receiving a final score of 3 out of 10 possible points. This score was determined by normalising the points based on the average weights the panel of experts provided – see Section 5.5.4.

However, if the recommendations for each criterion are followed, at least 5.7 points could be achieved. These recommendations are based on solutions and strategies that are relatively easy to implement, even at this building stage.

| Šumavský Dvůr | PT | WEIGHT | NORMALIZED WEIGHT | NORMALIZED SCORE | |
|---|---|---|---|---|---|
| **PREPAREDNESS- R.PRE** | **16.7** | | **24%** | **1.05** | |
| PRE.WA – Wayfinding and accessibility | 5 | 16% | 3.8% | 0.18 | PRE.WA |
| PRE.SA – Site risk assessment | 0 | 26% | 6.2% | 0.00 | PRE.SA |
| PRE.US – Unsuitable sites | 10 | 32% | 7.5% | 0.75 | PRE.US |
| PRE.VE – Conserve and use appropriate vegetation | 2 | 26% | 6.0% | 0.12 | PRE.VE |
| **REDUNDANCY – R.RED** | **3.9** | | **22%** | **0.51** | |
| RED.PS – Passive survivability | 4 | 58% | 13.0% | 0.51 | RED.PS |
| RED.PS – Alternative power sources | 0 | 42% | 9.2% | 0.00 | RED.AP |
| **ROBUSTNESS – R.ROB** | **13.9** | | **23%** | **1.04** | |
| RES.FR – Flood-resistant building envelope and structure | 5 | 33% | 7.5% | 0.37 | ROB.FR |
| RES.HR – Heavy precipitation-resistant building envelope and structure | 3 | 33% | 7.5% | 0.26 | ROB.HR |
| ~~RES.SR – Storm-resistant building envelope and structure~~ | ~~0~~ | ~~0%~~ | 0.0% | 0.00 | ~~ROB.SR~~ |
| RES.SU – Subsidence-resilient building envelope and structure | 5 | 33% | 7.5% | 0.40 | ROB.SU |
| ~~RES.DR – Drought-resistant building envelope and structure~~ | ~~0~~ | ~~0%~~ | 0.0% | 0.00 | ~~ROB.DR~~ |
| ~~RES.HW – Heat wave-resistant building envelope and structure~~ | ~~0~~ | ~~0%~~ | 0.0% | 0.00 | ~~ROB.HW~~ |
| **RESPONSE CAPABILITY - R.CAP** | **3.7** | | **19%** | **0.24** | |
| CAP.SS – Safe equipped space | 0 | 30% | 5.6% | 0.00 | CAP.SS |
| CAP.PS – Emergency power supply | 2 | 35% | 6.4% | 0.11 | CAP.PS |
| CAP.WS – Emergency water supply | 2 | 35% | 6.4% | 0.13 | CAP.WS |
| **COMMUNITY COHESION - R.COM** | **5.1** | | **13%** | **0.21** | |
| COM.SS – Access to useful shared spaces | 3 | 35% | 4.4% | 0.14 | COM.SS |
| COM.UG – Urban gardening | 2 | 29% | 3.7% | 0.07 | COM.UG |
| COM.EP – Emergency preparadness | 0 | 36% | 4.6% | 0.00 | COM.EP |
| | | | | **3.0** | |

*Figure 50 Overview of the score of the Šumavský Dvůr building criterion by criterion.*

Figure 51 provides an excerpt from the Resilience Calculation Tool sheets; standard size sheets are available in Appendix B.



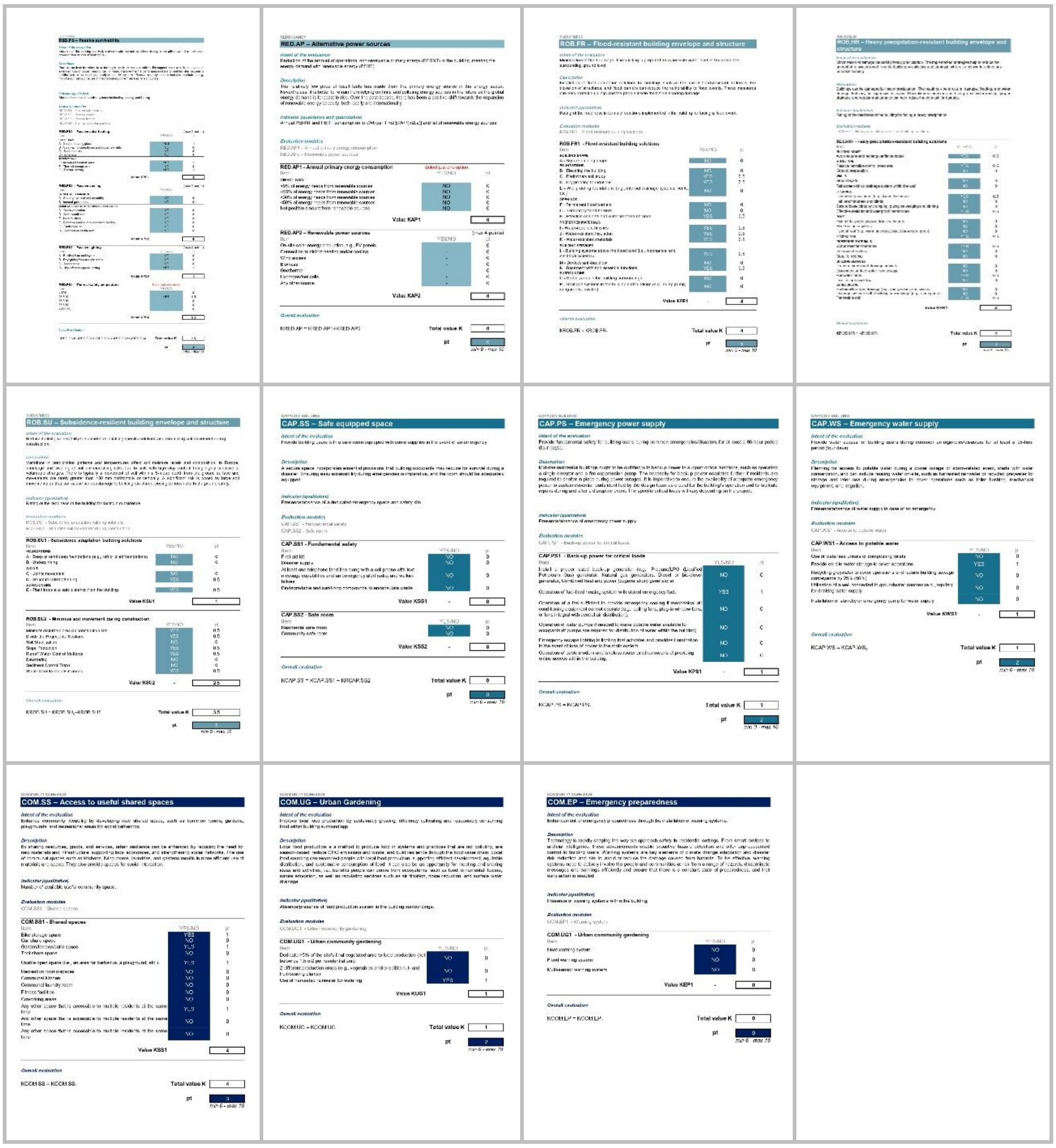


*Figure 51 Šumavský Dvůr assessment - Excerpt from the Calculation tool (see Appendix B).*

### 6.2.3 Case study 3 – RESBy resilient multi-residential building

This multi-residential building in the South Moravian region features a simple, axially symmetrical design with a pitched roof and a playful arrangement of window openings complemented by suspended balconies. This seemingly random placement of windows and balconies is closely tied to the functionality and layout of the individual residential units, allowing for flexibility in design and prefabricated construction. The main information about the building is available in Table 31.

*Table 31 Primary information of the building case study.*

| Criterion | Category |
|---|---|
| Location | Vomáčkova 164/8, 619 00 Brno - Dolní Heršpice, Czech Republic |
| Year of construction | n/a |
| Residential unit | 11 (27 users) |
| Floor | 4 above-ground floors |
| Total internal usable floor area in heated zones | 870 $m^2$ |
| Sustainability features | Solar chimney, green roof, light-coloured materials |

Initially, the building was a case study to test the RESBy methodology (16,17); the Environmentally Friendly Resilient Residential Buildings (RESBy) project was developed in 2017 by the University Centre for Energy Efficient Buildings (UCEEB) at the Czech Technical University in Prague, financed by the Technological Agency of the Czech Republic (Epsilon program). The original design of this case study was modified into two variants: Variant A, which features a green roof (Figure 52), and Variant B, which includes photovoltaic panels on the roof. Both variants were developed to align with the RESBy methodology's standards, aiming to retain the original concept while enhancing resilience for apartment buildings in the Czech Republic. Variant A was selected to test the Resilience Module as a stand-alone system.

The ground floor is allocated for garages and bike storage (Figure 53), while the upper floors are reserved for residential use (Figure 54). Four types of residential units are designed to accommodate various social compositions, and the apartments can be reconfigured according to predefined layouts throughout the building's life. The building's structural system uses a prefabricated approach, combining a reinforced concrete skeleton on the first floor with a prefabricated reinforcing wall core around the staircase and a longitudinal wall system on the upper floors. The floors are made of wood-concrete composite ceilings, and counter wooden nailed trusses support the roof.

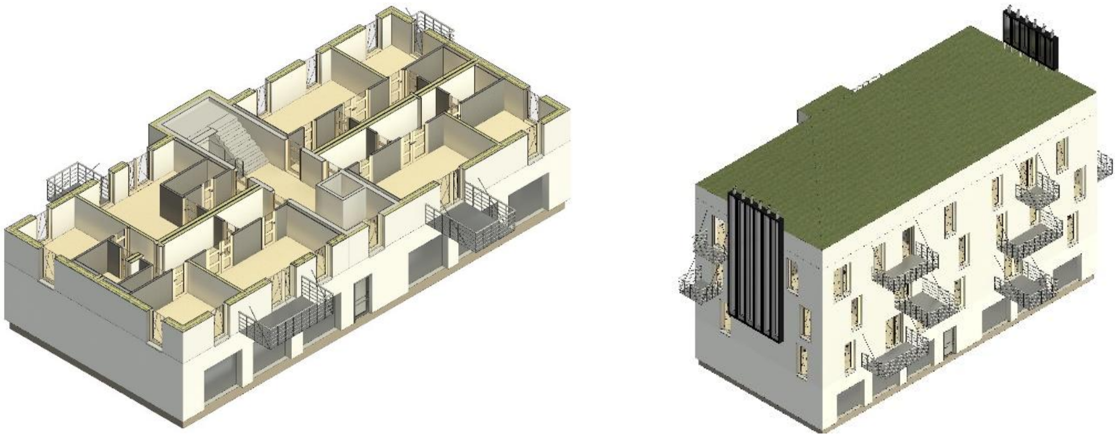


*Figure 52 Axonometric views of the RESBy building model. Source: (17)*

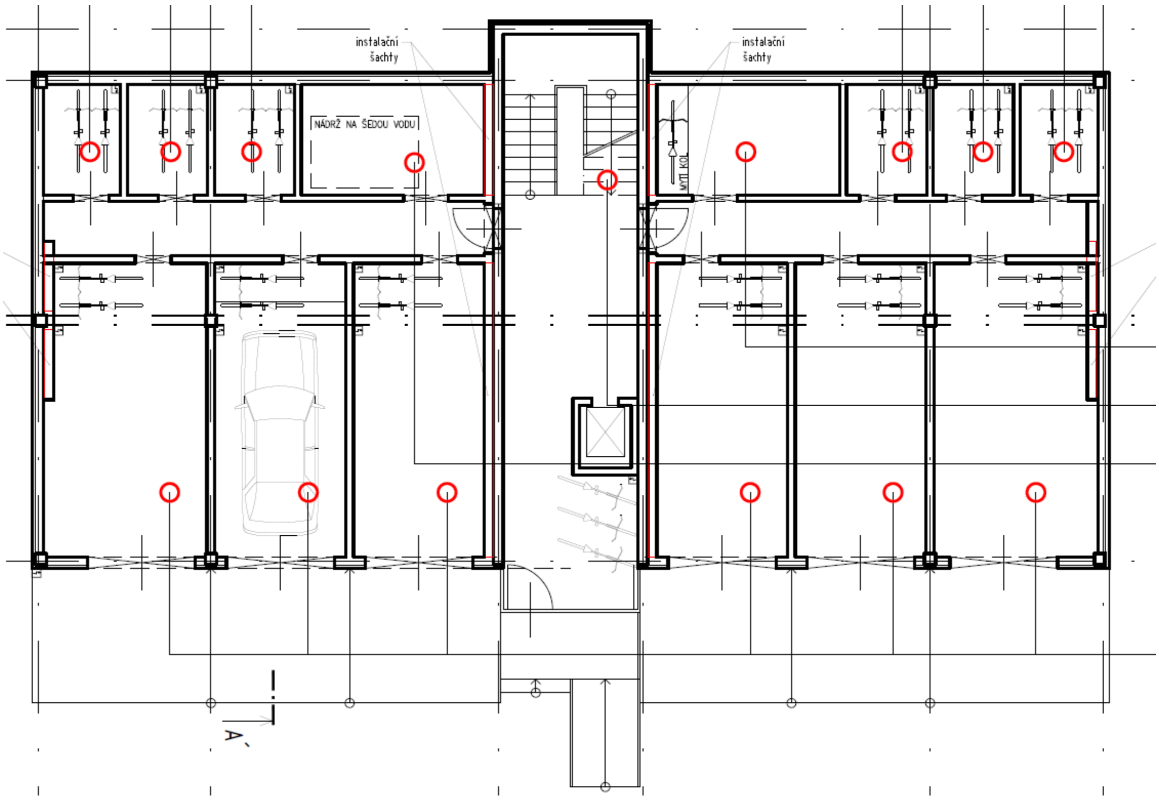



*Figure 53 RESBy residential building's ground floor. Source: (17).*

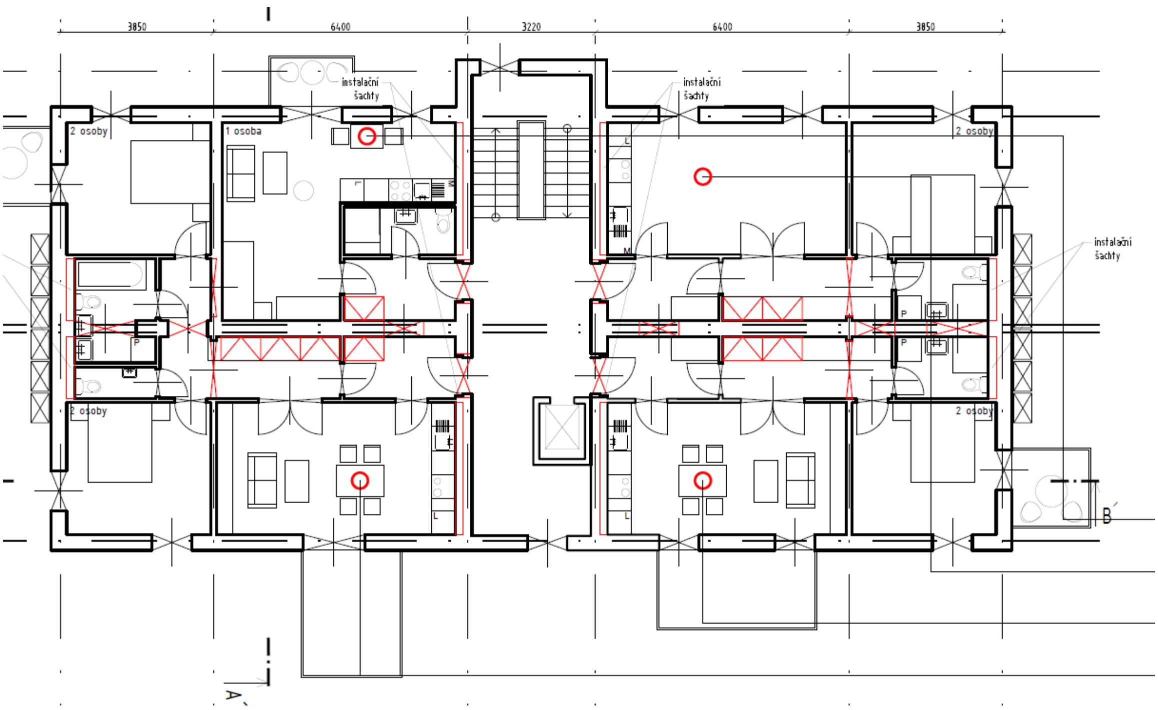



*Figure 54 RESBy residential building's second floor. Source: (17).*

## PRE.WA Wayfinding and accessibility

The building is designed to be barrier-free, with the first floor raised 300 mm above the adjusted ground level and accessible via a ramp and a levelling staircase. The central stairwell is spacious enough to accommodate a lift. There is also the option of creating an "adaptable flat," meaning a dwelling that could serve people with reduced mobility and orientation without additional structural changes, according to specific regulations. However, the current layout does not allow for wheelchair access without modifications. Possible adjustments include replacing a bathtub with a shower, implementing threshold-free flooring, installing extra handrails and a shower seat, adding a trapeze over the bed, ensuring 90 cm wide door frames for wheelchair access or positioning beds, and installing a ceiling rail system between the bedroom and bathroom.

Additionally, ageing/visual imparity issues can be addressed with assistive technologies—tools, devices, software, or systems that enhance the quality of life, independence, and self-sufficiency for people with special needs. The installation of assistive technologies, such as intelligent sockets, fire sensors, window and water sensors, air quality monitoring, remote control systems for blinds and lighting, motion sensors, fall detection systems, surveillance systems, and video communication setups, is possible but not currently available.

The criterion scores 8 out of 10 points because these measures still need to be fully implemented, and the design needs modification.

**PRE.SA Site risk assessment**

As part of the RESBy methodology adaptation process, experts conducted a site risk assessment for the building location, analysing past events and future forecasts. The evaluation identified flooding, heavy rainfall, and extreme temperatures as the most probable risks for the area. During heavy rain, 15-minute precipitation intensities with different recurrence times for Brno were examined. Given that a risk assessment has been carried out, this criterion scores 5 out of 10 points.

*Recommendations for enhancing the level of resilience*

*Engaging stakeholders in a workshop to conduct the site risk assessment would not only add 5 points to the building's score but also be crucial for raising awareness about the potential hazards that buildings in that location may face in the future.*

**PRE.US Unsuitable sites**

The site is not located in a floodplain or an area threatened by geological activity, resulting in a maximum score of 10 points for this criterion.

**PRE.VE Conserve and use appropriate vegetation**

Existing vegetation has been preserved, and the building utilises utility water for irrigation, with drought-resistant plants used in landscaping. This criterion is rated 5 points.

*Recommendations for enhancing the level of resilience*

*Using vegetation as natural shading can help mitigate extreme heat. More plants and trees could be planted on the western façade to reduce sun exposure. This would give an additional 3 points to this criterion.*

**RED.PS Passive survivability**

The building's design, materials, and technological solutions aim to ensure functionality during crises such as blackouts, floods, and temperature extremes while maximising passive energy-saving measures during normal operations. A solar chimney supports natural ventilation, and the building's west-east orientation is ideal for daylighting. Operable shutters and balconies allow for solar gain control. The warmest living room in the building reaches a maximum daily air temperature of 24.3 degrees Celsius. This criterion scores 8 out of 10 points.

**RED. AP Alternative power sources**

Variant A of the building selected for evaluation does not incorporate alternative power sources, unlike Variant B, which includes rooftop photovoltaics. Two cascaded central pellet boilers provide heating and hot water with an accumulation tank, and a two-pipe heating system with plate radiators in living rooms and ladder radiators in bathrooms that allow for natural water circulation. Due to the lack of alternative energy sources, this criterion scores 0 points.

*Recommendations for enhancing the level of resilience*

*For example, installing solar panels on the building façade could add 1 point to this criterion, and if less than 5% of the energy needs are met through renewable sources, it would provide an additional point. In fact, the more energy need is covered by renewable sources, the more points will be awarded. Furthermore, connecting the building to the district heating system would earn another point.*

**ROB.FL Flood-resistant building envelope and structure**

The first floor is elevated 300 mm above the landscaped ground level, and HVAC equipment is installed at least 1.0 m above the first floor to mitigate flooding risks. Waterproof building materials are used up to 1 m above the ground floor, along with washable surfaces, anti-backflow devices, and pumps for stormwater management. This criterion scores 6 out of 10 points.

*Recommendations for enhancing the level of resilience*

*Installing temporary/permanent flood barriers could help control pluvial flooding and would increase the score to 8 out of 10 points.*

**ROB.HR Heavy precipitation-resistant building envelope and structure**

A green roof helps reduce water runoff due to its absorption capacity, and a water tank is installed to collect water. However, the site's seepage coefficient, a key factor, is unknown, and an indicative value was used, which could differ from the actual value. If the site proves unsuitable for seepage, the building would score 0 points. Therefore, this criterion is awarded 4 out of 10 points.

*Recommendations for enhancing the level of resilience*

*Installing backflow prevention devices and hail-proof blinds and nets to protect fragile elements would award the building with additional points, for example.*

**ROB.HW Heatwave-resistant building envelope and structure**

The flat roof is designed as a green roof with high storage capacity to prevent summer overheating and retain water. Solar shading for windows and balconies helps reduce solar gain, and the west-east orientation allows proper daylighting for each apartment. Passive ventilation techniques, such as a solar chimney, are also implemented. This criterion scores 5 out of 10 points.

*Recommendations for enhancing the level of resilience*

*Planting vegetation for solar shading on the western side of the building or installing photovoltaic panels on the façade could improve energy efficiency and reduce heating and cooling loads by utilising renewable energy. This would add an extra point to the score, with an additional point possible if a heat pump is installed.*

**CAP.SS Safe equipped space**

The criterion requires evidence of installing first aid kits and communication devices that remain functional during emergencies. These items are not standard equipment for buildings but rather specific measures. However, emergency lighting is provided by flashlight for five days. Consequently, 2 points out of 10 were awarded for this criterion.

*Recommendations for enhancing the level of resilience*

*In mid-rise buildings, the ideal refuge areas are typically located on lower floors and in the central sections. Stairwells with reinforced concrete walls often provide the most secure options. If these cannot accommodate everyone, restrooms are usually the next best alternative. An additional point would be awarded to this criterion if such a room is allocated for the building users.*

**CAP. PS Emergency power supply**

The building's energy solution meets passive standards, but mechanical ventilation with heat recovery is not proposed. The façade includes active shading elements. A solar chimney provides ventilation with an auxiliary fan; in case of failure, the solar chimney function will still be maintained. The building has a sufficient supply of pellets for heating, and hot water can be heated by a backup pump. For these reasons, this criterion scores 7 points.

*Recommendations for enhancing the level of resilience*

*The installation of a backup generator for critical loads would add an additional point to the score.*

### CAP. WS Emergency water supply

A greywater purification plant provides utility water, primarily for flushing. There is a marked tap on the first floor for utility water use, such as irrigation, bike, and car washing. A cistern supplies drinking water. This criterion scores 6 points.

*Recommendations for enhancing the level of resilience*

*Since emergency water is provided, installing waterless urinals or composting toilets might not be necessary but could be considered for common areas on the ground floor. This would be an easy solution and would give an additional point to the score.*

### COM.SS Access to useful shared spaces

The ground floor contains operational and technical areas. The technical area also has a utility room and laundry room with washers and dryers, including washing bikes. The apartments have six garage spaces for charging electric cars and storing bicycles, along with brick cellars for storing and charging electric bicycles. This criterion scores 5 out of 10 points.

*Recommendations for enhancing the level of resilience*

*It would be advantageous to create a barbecue or relaxation area at the back of the building, where the space is more private and away from the street. Additionally, a fitness room for residents could be included if the ground floor layout is adjusted. These changes could add 2 points to the score. Further points could be earned with more substantial modifications to the building design.*

### COM.UG Urban gardening

The building has a water tap for irrigation, but there are no dedicated food production areas, resulting in a score of 2 out of 10 points.

*Recommendations for enhancing the level of resilience*

*Activities such as growing vegetables, fruits, or edible plants can encourage community engagement and provide relaxation. Allocating space for urban gardening on the green roof or in the courtyard at the back of the building could strengthen the sense of community and connection with nature. This would add two points to the total score. If more than 5% of the vegetated area is dedicated to such activities, a maximum score of 10 out of 10 could be achieved.*

**COM. EP Emergency preparedness**

The active solar shading system in the project design contributes to this criterion scoring 3 out of 10 points.

*Recommendations for enhancing the level of resilience*

*Installing additional sensor systems for heat stress or flooding would be highly beneficial for the building's residents, especially for those with reduced mobility or special needs who may require extra support during disruptions. This would add four extra points to the score.*

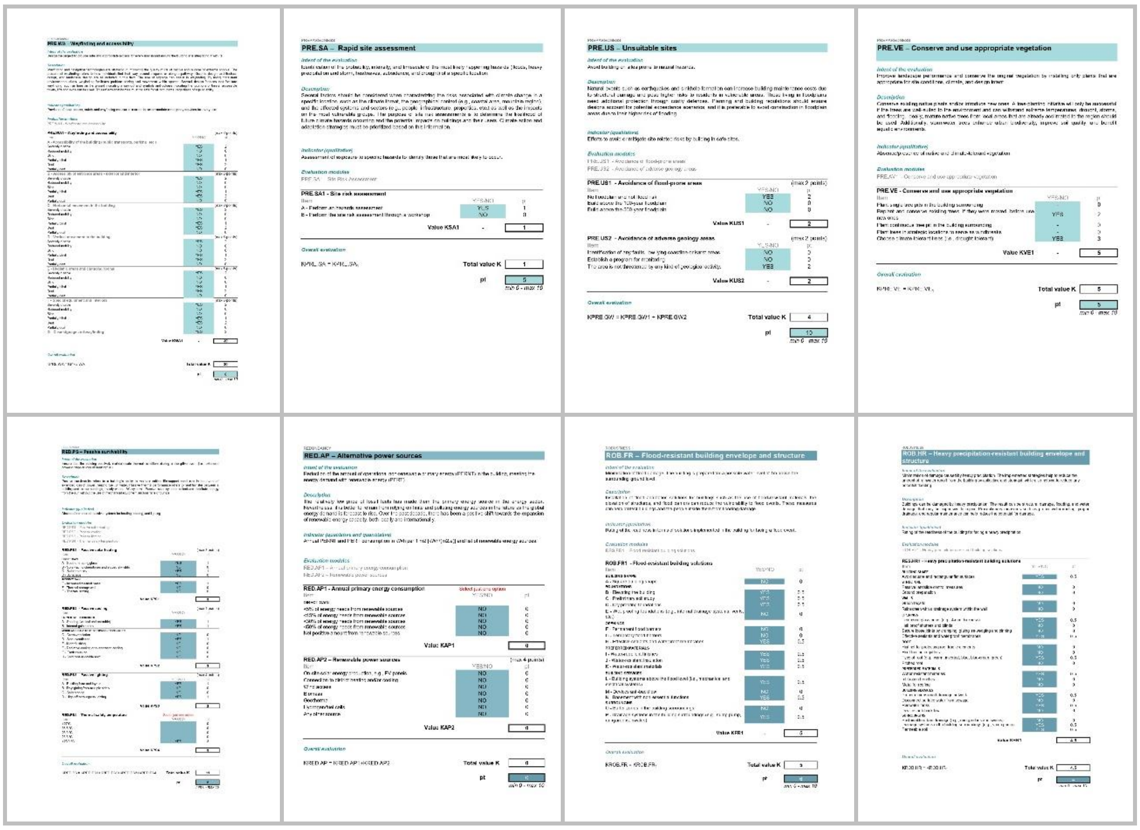
Finally, Figure 55 presents the assessment results, with the RESBy building receiving a final score of 5.2 out of 10 possible points. This score was determined by normalising the points based on the average weights the panel of experts provided.

The score may seem surprising, given that the building was designed according to the resilience principles of the RESBy method. However, that system uses criteria and indicators different from those of this Resilience Module. As a result, the final score appears to be average because the design of the multi-residential building was originally intended to comply with the RESBy principles. For this specific scope, the assessment is conducted without altering the design; had modifications been made, the results would have been significantly higher. This is supported by the recommendations below the criteria, which show how many more points the building could have gained with certain adjustments. If the recommendations were implemented, the building could have achieved at least 7.1 points with only minor adjustments to its design, showing that a higher score is possible with some design changes or the incorporation of specific technologies.

| RESBy residential building - variant A | PT | WEIGHT | NORMALIZED WEIGHT | NORMALIZED SCORE | |
|---|---|---|---|---|---|
| PREPAREDNESS- R.PRE | 27.9 | | 24% | 1.67 | |
| PRE.WA – Wayfinding and accessibility | 8 | 16% | 3.8% | 0.30 | PRE.WA |
| PRE.SA – Site risk assessment | 5 | 26% | 6.2% | 0.31 | PRE.SA |
| PRE.US – Unsuitable sites | 10 | 32% | 7.5% | 0.75 | PRE.US |
| PRE.VE – Conserve and use appropriate vegetation | 5 | 26% | 6.0% | 0.30 | PRE.VE |
| REDUNDANCY – R.RED | 7.9 | | 22% | 1.02 | |
| RED.PS – Passive survivability | 8 | 58% | 13.0% | 1.02 | RED.PS |
| RED.PS – Alternative power sources | 0 | 42% | 9.2% | 0.00 | RED.AP |
| ROBUSTNESS – R.ROB | 15.2 | | 23% | 1.14 | |
| RES.FR – Flood-resistant building envelope and structure | 6 | 33% | 7.5% | 0.47 | ROB.FR |
| RES.HR – Heavy precipitation-resistant building envelope and structure | 4 | 33% | 7.5% | 0.29 | ROB.HR |
| ~~RES.SR – Storm-resistant building envelope and structure~~ | 0 | ~~0%~~ | 0.0% | 0.00 | ~~ROB.SR~~ |
| ~~RES.SU – Subsidence-resilient building envelope and structure~~ | 0 | ~~0%~~ | 0.0% | 0.00 | ~~ROB.SU~~ |
| ~~RES.DR – Drought-resistant building envelope and structure~~ | ~~0~~ | ~~0%~~ | 0.0% | 0.00 | ~~ROB.DR~~ |
| RES.HW – Heat wave-resistant building envelope and structure | 5 | 33% | 7.5% | 0.37 | ROB.HW |
| RESPONSE CAPABILITY - R.CAP | 14.3 | | 19% | 0.91 | |
| CAP.SS – Safe equipped space | 2 | 30% | 5.6% | 0.09 | CAP.SS |
| CAP.PS – Emergency power supply | 7 | 35% | 6.4% | 0.43 | CAP.PS |
| CAP.WS – Emergency water supply | 6 | 35% | 6.4% | 0.38 | CAP.WS |
| COMMUNITY COHESION - R.COM | 9.9 | | 13% | 0.43 | |
| COM.SS – Access to useful shared spaces | 5 | 35% | 4.4% | 0.20 | COM.SS |
| COM.UG – Urban gardening | 2 | 29% | 3.7% | 0.07 | COM.UG |
| COM.EP – Emergency preparedness | 3 | 36% | 4.6% | 0.15 | COM.EP |
| | | | | 5.2 | |

*Figure 55 Overview of the score of the RESBy building criterion by criterion.*

Figure 56 provides an excerpt from the Resilience Calculation Tool sheets; standard size sheets are available in Appendix B.



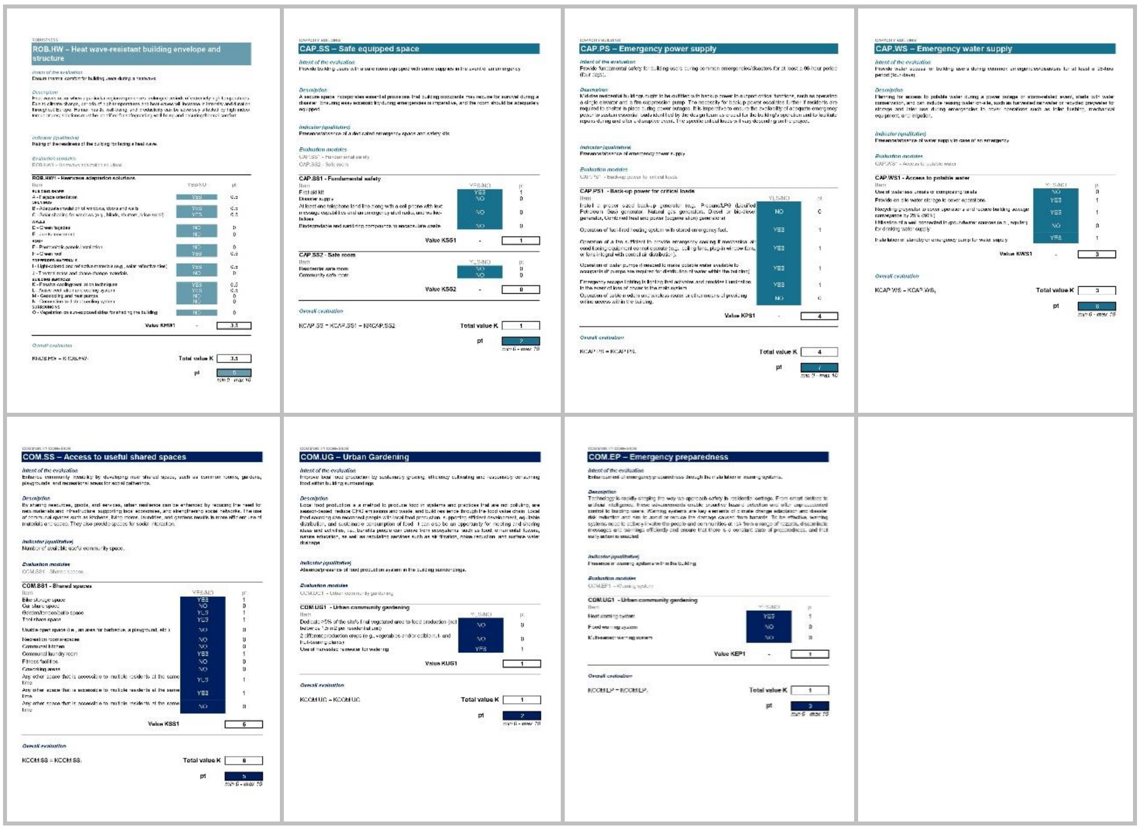



*Figure 56 RESBy building assessment - Excerpt from the Calculation tool (see Appendix B).*

## 6.3 Adjustment of the criteria based on the testing experience

During the testing phase, it became clear that early-stage information regarding specific emergency equipment is often unavailable in project documentation, also considering that the buildings being tested are existing ones. For example, only one case study—the RESBy building—mentioned an emergency lighting system with flashlights, while other solutions, like first aid kits, were not included. Given that the "CAP.SS – Safe equipped space" criterion requires very specific details that designers do not always provide, these items have been removed from the criteria list but will be included as recommendations.

Another key finding from the testing phase involved the "PRE.SA – Site risk assessment" criterion. Analysing the three buildings showed that this criterion is the most time-consuming because it requires consulting various sources and maps to determine the relevant hazards for the Robustness category. However, this detailed process aligns with other risk assessment methodologies, such as the C40 Rapid Site Assessment (18), and depends on data availability for a specific location. Thus, no modifications to this criterion were made.

Additionally, the "PRE.WA – Wayfinding and Accessibility" criterion, which is closely associated with the "COM.EP – Emergency Preparedness" criterion, has been updated to incorporate provisions for installing assistive technologies for older people and individuals with special needs. This includes the option to convert a dwelling unit into an "adaptable flat"—a unit designed to accommodate persons with reduced mobility without requiring further structural modifications—as well as the installation of specialised sensors. These assistive technologies are not related to health monitoring but are intended to facilitate daily activities. For example, installing smart home technologies can enhance the accessibility of existing home features, such as light switches, doors, and TVs, through smartphone apps or voice, thereby improving usability for individuals with disabilities. For this reason, the “PRE.WA – Wayfinding and Accessibility” has been renamed “PRE.AR - Accessibility and Readiness”. As a result, the criteria have been updated, and the final details are available in the Module manual in Appendix A.

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# 7. Resilience Module: Integration into SBToolCZ

*This chapter focuses on the integration of the Resilience Module into an established sustainability rating system. The design of this Module has been strategically developed to ensure seamless implementation and adaptation into existing sustainability rating frameworks, particularly those belonging to the SBTool family of ratings. In this context, SBToolCZ, the Czech Republic's national rating system, was chosen as a case study tool. Consequently, the Module was incorporated into the Czech system to assess its impact on the overall system with the support of the SBToolCZ research and development team. The newly adjusted SBToolCZ system was then tested using a building case study to show the difference in the overall assessment and final score.*

## 7.1 Current status

The significance of resilience in the built environment cannot be overstated. The rise in both the frequency and severity of extreme weather events, such as storms, floods, and heat waves, has the potential to disrupt critical infrastructure, jeopardise lives, and inflict property damage. To mitigate these risks, buildings must be designed, built and operated with resilience at the forefront.

The Resilience Module, presented in Chapter 5, is conceptualised as an independent tool for assessing the resilience and, to a certain degree, the sustainability of multi-residential buildings. However, to strike a harmonious balance between sustainability and resilience in building structures, its potential incorporation into an existing sustainability rating system is deemed essential. This integration is crucial to substantiate the feasibility and effectiveness of the module in measuring and guiding the development of the next generation of sustainable and resilient buildings. In fact, by addressing climate resilience through the essential criteria, the green building community can actively embrace a proactive approach to adapting to the challenges posed by the evolving climate.

Since the Module functions as a green building rating system, its integration into an established framework can be achieved differently. To explore this, a case study tool, SBToolCZ (1), has been considered to systematically assess the feasibility of this integration and pinpoint any potential obstacles to its smooth implementation. Three primary approaches have emerged (Figure 57):

a) Treating the Resilience Module as a distinct category:
   This approach mirrors the treatment of the Location category within the current system, where it stands apart and carries no weight in the final scoring, thus not influencing the overall building quality assessment. Similarly, the resilience module would operate independently.
b) Incorporating the Resilience Module as a new category alongside existing ones.
   Under this approach, the Resilience Module would affect the final scores as the other categories. Adjustments to the weighting system would be necessary to ensure that the resilience category and possibly the Location category also contribute meaningfully to the overall score. This would involve convening another panel of experts to redefine criteria and category weights.
c) Distributing the Resilience Module across existing categories (i.e., environmental, social, economic and management, and location):

This approach involves integrating aspects of the resilience module into existing relevant criteria within these categories, either as new modules within the existing criteria or directly as new criteria themselves. This division would be based on thematic similarities between resilience topics and existing categories. Moreover, the weighting of each single criterion would undergone an adjustment.

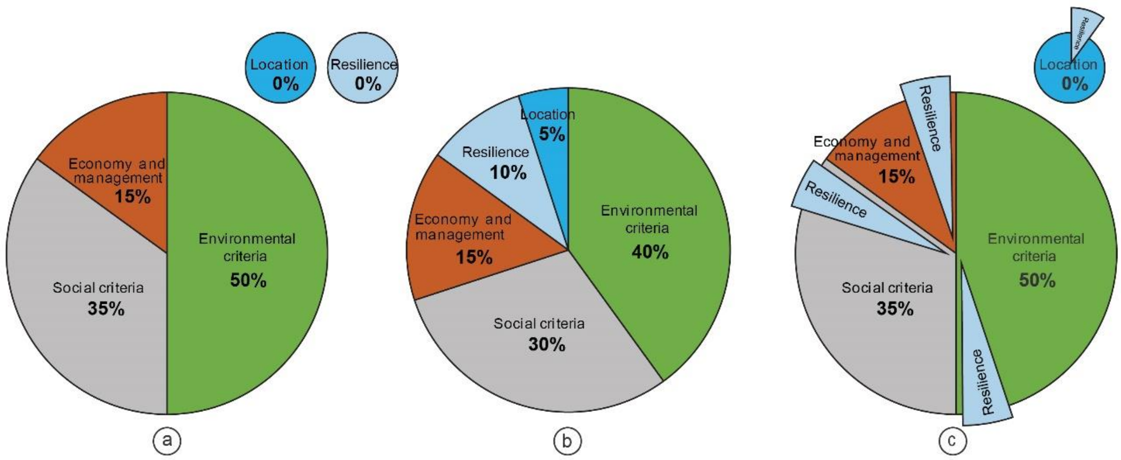


*Figure 57 Potential scenarios for integrating the new Resilience Module into SBToolCZ - The weights assigned to option B are calculated arbitrarily.*

The option to adopt was determined through a series of meetings with the SBToolCZ research and development team of the Czech Technical University in Prague (CZ) held between January and March 2024. The SBToolCZ team consists of five core members and 13 authorised individuals who can engage with SBToolCZ assessments (2). Currently, the team is dedicated to aligning the SBToolCZ system with the EU Taxonomy (3).

Throughout these meetings, the primary focus was on understanding how the Module could be effectively implemented and whether the resilience of the entire building should predominantly fall under the Location category rather than other categories. Finally, Option C was chosen to test the integration.

Insights from the SBToolCZ team were instrumental in refining and exploring alternative approaches to this integration. A significant step in this process involved understanding how each criterion could be categorised within the existing SBToolCZ methodology for multi-residential buildings.

### 7.1.1 RESBy - Environmentally friendly resilient apartment buildings

The SBTool research and development team has previously tried to design a framework for building resilience principles. Indeed, the Environmentally Friendly Resilient Residential

Buildings (RESBy) project was developed in 2017 by the University Centre for Energy Efficient Buildings (UCEEB) at the Czech Technical University in Prague, financed by the Technological Agency of the Czech Republic (Epsilon program). One of its main objectives was to develop a methodology to assess new residential buildings during the planning phase, focussing on resilience, climate change mitigation, and adaptation, particularly tailored to Central European residential structures (4). Within this project, sample solutions for low-carbon resilient apartment buildings were crafted in two variants to meet the following criteria:

- Minimisation of carbon footprint,
- Preparedness for global climate change,
- Rapid, high-quality, and efficient construction with significant industrialisation and the utilisation of local natural materials.

RESBy is based on an assessment method to assess potential threats to residential buildings. This method includes descriptions of indicators, procedures for the calculation of values, and benchmarks for scoring each criterion (5). This method focuses on local flash flood mitigation, minimising damage from regular floods, resilience to extreme weather events, and protection against wildfires. Additionally, it evaluates the level of preparedness for building operations in the event of infrastructure failures resulting from disasters (6). Table 32 displays a list of criteria that are all equally important.

*Table 32 Set of RESBy criteria for assessing the resilience of multifamily residential buildings in Central Europe. Source: (5).*

| Category | Threat |
|---|---|
| Climatic and atmospheric threats | Torrential rains Floods |
| | Extreme summer and winter temperatures |
| | Longer periods of drought |
| | Heat islands |
| | Dust particles in outdoor air |
| Fire | Effects of external fire |
| | Effects of indoor fire |
| Noise | Noise from transportation |
| | Noise from external technological sources |
| Social threats | Ageing population |
| | Low architectural and operating quality, low variability |
| | Energy poverty |
| | Disorderly conduct, Social riots and Crime |
| Infrastructural failures | Interruptions of electricity supply for more than several hours |

| | |
|---|---|
| | interruptions of the supply of heat or gas for heating for more than several hours |
| | Interruptions of freshwater supply for more days |
| | Interruptions of fuel supplies for more weeks |
| Risk of failures of building services | Unreliability or over-complexity of building services |

Despite these efforts, this system was never formally integrated into the SBToolCZ assessment methodology or used as a stand-alone system and was eventually set aside. The team's prior experience with resilience assessment has informed the current approach, allowing for a more comprehensive and refined integration of resilience principles into the SBTool framework.

## 7.2 Compatibility of the Resilience Module criteria and SBToolCZ

Given the primary aim of comprehensively integrating the Resilience Module into the SBToolCZ multi-residential building system, an exhaustive analysis of the Module’s criteria and similarities with the SBToolCZ version has been undertaken. This involved categorising each Resilience Module’s criterion into one of the existing categories (namely Environmental, Social, Economic and Management, and Location criteria) and finding potential similar existing criteria - Table 33. This step was crucial to determine whether similar criteria already exist in the selected version of SBToolCZ or if they could potentially be incorporated as a module within an existing criterion.

*Table 33 Resilience Module criteria in relation to SBToolCZ categories and existing comparable criteria.*

| Criterion | SBToolCZ Category | SBToolCZ Criteria |
|---|---|---|
| **PREPAREDNESS - R.PRE** | | |
| **PRE.WA – Wayfinding and accessibility**<br>PRE.WA1 – Wayfinding and accessibility | Social | S.EXT Use of the exterior of the building<br>S.BRR Barrier-free design |
| **PRE.SA – Rapid site assessment**<br>PRE.SA1 – Rapid site assessment | Location | L.RIZ Site risks |
| **PRE.US – Unsuitable sites**<br>PRE.US1 - Avoidance of flood-prone areas<br>• PRE.US2 - Avoidance of adverse geology areas | Location | L. Site risks |
| **PRE.VE – Conserve and use appropriate vegetation**<br>PRE.VE1 – Conserve and use appropriate vegetation | Location/Environment | E.ZEL Greenery on the building and land<br>E.ZSV Retention of rainwater<br>E.PUD Land use |
| **REDUNDANCY – R.RED** | | |
| **RED.PS – Passive survivability**<br>RED.PS1 – Passive solar heating<br>RED.PS2 – Passive cooling<br>RED.PS3 – Passive lighting<br>RED.PS4 – Thermal safety temperatures | Social | S.KOM User comfort<br>S.TLK Thermal comfort in summer<br>S.TKZ Thermal comfort in winter |
| **RED.AP – Alternative power sources**<br>RED.AP1 – Annual primary energy consumption<br>RED.AP2 – Renewable power sources | Environment | E.PEE Primary energy from non-renewable sources<br>E.OZE Renewable energy sources |

| ROBUSTNESS – R.ROB | | |
|---|---|---|
| **ROB.FR – Flood-resistant building envelope and structure**<br>ROB.FR1 – Flooding adaptation solutions | Location | L.RIZ Location risks |
| **ROB.HR – Heavy precipitation-resistant building envelope and structure**<br>ROB.BR1 – Heavy precipitation adaptation solutions | Location | L.RIZ Location risks |
| **ROB.SR – Storm-resistant building envelope and structure**<br>ROB.SR1 – Storm adaptation solutions | Location | L.RIZ Location risks |
| **ROB.SU – Subsidence-resilient building envelope and structure**<br>ROB.SU1 – Balanced earthquake<br>ROB.SU2 – Subsidence adaptation solutions | Location | L.RIZ Location risks |
| **ROB.DR – Drought-resistant building envelope and structure**<br>ROB.DR1 – Drought adaptation solutions | Location | L.RIZ Location risks |
| **ROB.HW – Heat wave-resistant building envelope and structure**<br>ROB.HW1 – Heat wave adaptation solutions | Location | L.RIZ Location risks |
| **RESPONSE CAPABILITY - R.CAP** | | |
| **CAP.SS – Safe equipped space**<br>CAP.SS1 - Fundamental safety<br>CAP.SS2 - Safe room | Economics and management | - |
| **CAP. PS – Emergency power supply**<br>CAP.PS1 - Back-up power | Economics and management | - |
| **CAP.WS – Emergency water supply**<br>CAP.WS1 - Access to water | Economics and management | E.ZSV Retention of rainwater |
| **COMMUNITY COHESION - R.COM** | | |
| **COM.SS – Access to useful shared spaces**<br>COM.SS1 - Shared spaces | Social/Location | L.DVM Availability of public places for relaxation<br>S.EXT Use of the exterior of the building<br>S.KOM User comfort |
| **COM.UG – Urban gardening**<br>COM.UG1 – Urban community gardening | Social/Environment | L.DVM Availability of public places for relaxation<br>E.ZEL Greenery on the building and land |
| **COM.EP – Emergency preparedness**<br>COM-EP1 – Warning system | Economics and management | - |

Subsequently, the analysis proceeded to assess the congruence in terms of objectives and indicators between each resilience criterion and the already established SBToolCZ criteria - Table 34. Any disparities were meticulously identified to ascertain whether the inclusion of resilience criteria could introduce novel elements to the overall system, provided that they are effectively implemented.

The findings of this analysis underscore that the criteria aligned with the Economics and Management category (Table 33) predominantly concentrate on risk management rather than building management. Therefore, it is proposed to rename the SBToolCZ category to "Economics, Risk, and Management" to encompass those criteria intricately linked to risk and vulnerability mitigation.

Therefore, the following version of the SBToolCZ system includes resilience principles from the Resilience Module within the existing categories, either as brand-new criteria or as modules part of an existing criterion. This transition is outlined in Table 35 (Environmental criteria), Table 36 (Social criteria), Table 37 (Economics, risk and management criteria) and Table 38 (Location criteria), moving from the initial 45 criteria of the SBToolCZ multi-residential building version to 52 criteria, now encompassing resilience features. As mentioned, some previous Resilience Module criteria have been integrated as "modules" within existing criteria rather than being introduced as entirely new criteria, as they already align closely with the themes addressed in those specific criteria.

Table 34 Comparison of the indicators with SBToolCZ multi-residential building criteria indicators.

| Resilience Module criterion | Indicator | SBToolCZ similar Criterion | Indicator |
|---|---|---|---|
| **PREPAREDNESS- R.PRE** | | | |
| PRE.WA – Wayfinding and accessibility | Provide clear access, safety, and wayfinding measures for every user. | S.EXT Use of the exterior of the building | S.EXT - Availability of barrier-free solution |
| | | S.BRR Barrier-free design | S.BRR - m² of shared outdoor space |
| PRE.SA – Rapid site assessment | Assessment of exposure to specific hazards. | L.RIZ Site risks | Evaluation of the location of the building from the point of view of the risk of flood damage, technical seismicity, and the associated risks. |
| PRE.US – Unsuitable sites | Evaluation of the location of the building from the point of view of site-related risks. | L. Site risks | Evaluation of the location of the building from the point of view of the risk of flood damage, technical seismicity, and the associated risks. |
| PRE.VE – Conserve and use appropriate vegetation | Availability of native and climate-tolerant vegetation. | E.ZEL Greenery on the building and land | E.ZEL - Percentage of greening of the facade, roof, and adjacent land, as well as the existence of a plan for development care and subsequent maintenance. |
| | | E.ZSV Retention of rainwater | E.ZSV - Average runoff coefficient and measures supporting the prevention of stormwater runoff from the property. |
| | | E.PUD Land use | E.PUD - Assessment based on land management. |
| **REDUNDANCY – R.RED** | | | |
| RED.PS – Passive survivability | Availability of passive systems and fulfilment of requirements in the field of thermal comfort in summer. | S.KOM User comfort | S.KOM – Availability of areas focused on individual aspects of user comfort. |
| | | S.TLK Thermal comfort in summer | S.TLK - Fulfilment of requirements in the field of thermal comfort in summer. |
| | | S.TKZ Thermal comfort in winter | S.TKZ – Fulfilment of requirements for thermal stability in winter. |
| RED.AP – Alternative power sources | Percentage of renewable energy sourced used in the building. | E.PEE Primary energy from non-renewable sources | E.PEE - Annual consumption of primary energy from non-renewable sources in MJ per 1 m² of total floor area. |
| | | E.OZE Renewable energy sources | E.OZE – Percentage of locally produced renewable energy. |
| **ROBUSTNESS – R.ROB** | | | |
| ROB.FL – Flood-resistant building envelope and structure | Rating of readiness in terms of building solutions for facing flood events. | L.RIZ Location risks | Evaluation of the location of the building from the point of view of the risk of flood damage, technical seismicity, and the associated risks. |
| ROB.HR – Heavy precipitation-resistant building envelope and structure | Rating of readiness in terms of building solutions for facing heavy precipitations. | L.RIZ Location risks | Evaluation of the location of the building from the point of view of the risk of flood damage, technical seismicity, and the associated risks. |
| ROB.SR – Storm-resistant building envelope and structure | Rating of readiness in terms of building solutions for facing severe storms. | L.RIZ Location risks | Evaluation of the location of the building from the point of view of the risk of flood damage, technical seismicity, and the associated risks. |
| ROB.SU – Subsidence-resilient building envelope and structure | Rating of readiness in terms of building solutions for facing subsidence of the soil. | L.RIZ Location risks | Evaluation of the location of the building from the point of view of the risk of flood damage, technical seismicity, and the associated risks. |
| ROB.DR – Drought-resistant building envelope and structure | Rating of readiness in terms of building solutions for facing droughts. | L.RIZ Location risks | Evaluation of the location of the building from the point of view of the risk of flood damage, technical seismicity, and the associated risks. |
| ROB.HW – Heat wave-resistant building envelope and structure | Rating of readiness in terms of building solutions for facing heat waves. | L.RIZ Location risks | Evaluation of the location of the building from the point of view of the risk of flood damage, technical seismicity, and the associated risks. |
| **RESPONSE CAPABILITY - R.CAP** | | | |
| CAP.SS – Safe equipped space | Availability of safe areas and equipment. | n/a | n/a |
| CAP. PS – Emergency power supply | Availability of emergency power supply in case of emergency. | C.MAR Measurement of energy and water consumption | The ability of residents of individual housing units to have a detailed overview of energy and water consumption and to easily change and control the parameters of the internal environment. |
| CAP.WA – Emergency water supply | Availability of water supply in case of emergence. | E.ZSV Retention of rainwater | E.ZSV - Average runoff coefficient and measures supporting the prevention of stormwater runoff from the property. |
| | | C.MAR Measurement of energy and water consumption | C.MAR - Residents of individual housing units have the ability to have a detailed overview of energy and water consumption and easily change and control the parameters of the internal environment. |
| **COMMUNITY COHESION - R.COM** | | | |
| COM.SS – Access to useful shared spaces | Availability of different types of useful community places within the building premises. | L.DVM Availability of public places for relaxation | L.DVM - Availability of different types of public places for relaxation in the surroundings. |
| | | S.EXT Use of the exterior of the building | S.EXT - m² of shared outdoor space |
| | | S.KOM User comfort | S.KOM – Availability of areas focused on individual aspects of user comfort |
| COM.UG – Urban gardening | Availability of a food production system within the building premise or its surroundings | L.DVM Availability of public places for relaxation | L.DVM - Availability of different types of public places for relaxation in the surroundings. |
| | | E.ZEL Greenery on the building and land | E.ZEL - Percentage of greening of the facade, roof, and adjacent land, as well as the existence of a plan for development care and subsequent maintenance. |
| COM.EP – Emergency preparedness | Availability of warning system for different types of hazards. | n/a | n/a |

An important modification that has been made to the former system is the creation of a criterion, namely “Site Risk Assessment”, within the Social criteria category, which is strictly connected to the S.ROB criterion.

This adjustment was made because, although the Location category does not contribute to the overall score, every aspect of resilience to climate change is closely tied to regional factors and specific site conditions. Assessing site risks is vital for devising effective solutions and prompt responses. Thus, including this criterion in the overall evaluation remains essential even without impacting the final score.

*Table 35 Integration of resilience features into Environmental category criteria.*

| **E – Environmental criteria** |
|---|
| **E.ACP Environmental acidification potential** |
| ACP.PE - Specific annual production of operational SO2 emissions, eq. |
| ACP.SE - Specific annual bound production of SO2 emissions, eq. |
| **E.BIO Biodiversity** |
| BIO.BP - Biological research |
| BIO.PF - Support of biodiversity of local fauna and flora |
| BIO.VP - Impact of building operation on the surrounding nature |
| BIO.ZF - Preservation of original fauna and flora |
| **E.CEM Certified products and materials** |
| CEM.EP - Products with an environmental certificate |
| CEM.ND - Wood-based furniture with FSC and/or PEFC certification |
| CEM.VD - Wood-based products and materials with FSC and/or PEFC certificate |
| **E.CIR Circularity of structures and materials** |
| CIR.CI - Circularity of elements and structures |
| CIR.KP - Project quality in terms of circularity |
| CIR.OR - Renewable and recycled products and materials |
| CIR.RG - Regionally produced products and materials |
| **E.DOP Support for gentle individual non-automotive transport** |
| DOP.BK - Collision-free transport solutions |
| DOP.DP - Storage of means of transport |
| **E.EUP Environmental eutrophication potential** |
| EUP.PE - Specific annual operating emissions PO43-eq. |
| EUP.SE - Specific annual bound emissions PO43-eq. |
| **E.GWP Global Warming Potential** |
| GWP.PE - Specific annual production of operational CO2 emissions, eq. |
| GWP.SE - Specific annual production of embodied CO2 emissions, eq. |

| | |
|---|---|
| **E.ODP Ozone depletion potential** |
| ODP.PE - Specific annual production of operational emissions of CFC 11, equiv.<br>ODP.SE - Specific annual production of bound CFC 11 emissions, eq. |
| **E.OZE Renewable energy sources** |
| OZE.OE - Share of renewable energy |
| **E.PAR Traffic at ease** |
| PAR.PA - Parking<br>PAR.PP - Land for transport in peace |
| **E.PEE Primary energy from non-renewable sources** |
| PEE.PR - Relative annual consumption of operating primary energy<br>PEE.SV - Specific annual consumption of bound primary energy |
| **E.POC Ground-level ozone generation potential** |
| POC.PE - Specific annual production of operational emissions C2H4, equiv.<br>POC.SE - Specific annual production of bound C2H4 emissions, equiv. |
| **E.PUD Land use** |
| PUD.NP - Land management<br>PUD.PP - Transportation of soil |
| **E.SOD Construction waste** |
| SOD.KS - Checklist<br>SOD.NS - Construction and demolition waste stored in a landfill<br>SOD.RC - Construction and demolition waste for recycling<br>SOD.TR - Sorting on the construction site |
| **E.UPV Drinking water savings** |
| UPV.RT - Use of rainwater<br>UPV.SP - Use of gray sewage water |
| **E.ZEL Greenery on the building and land** |
| ZEL.PO - Shading translucent surfaces using deciduous climbing plants<br>ZEL.PR - Plan for development care and subsequent maintenance of greenery<br>ZEL.ST - Trees creating shade on the facade<br>ZEL.ZF - Green facades<br>ZEL.ZP - Greenery and water on the property<br>ZEL.ZS - Green roofs<br>ZEL.VE – Conserve and use appropriate vegetation |
| **E.ZSV Retention of rainwater** |
| ZSV.OP - Measures supporting retention of rainwater on the property<br>ZSV.OS - Runoff coefficient of building and land surfaces |

*Blue-coloured text denotes modified or added criteria or modules.*

It has been recognised that the former criterion, “Wayfinding and Accessibility” (PRE.WA), was already somewhat present in the SBToolCZ version for multi-residential buildings under the S.BBR Barrier-free solution. Therefore, the criterion has been adjusted to align with the existing one. Similarly, the COM.SHA criterion, which partially falls under the User comfort criterion, is important because it stresses community cohesion, as well as the Urban gardening criterion, which, however, has been considered a brand-new criterion.

The criterion “Robustness of the structure and envelope” (ROB.STR) has been identified as a new addition to the Social criteria category. To some extent, this criterion could be combined with the Flexibility of the structure criterion. In the future, these two criteria might be merged to create a more challenging criterion to meet.

*Table 36 Integration of resilience features into Social category criteria.*

| **S – Social criteria** |
|---|
| **S.AKU Acoustic comfort** |
| AKU.OB - Noise protection |
| AKU.PB - Spatial acoustics |
| AKU.ZI - Sound insulation |
| **S.ARC Architectural quality** |
| ARC.VZ - Selection of processor and the resulting solution |
| **S.BBR Barrier-free solution** |
| BBR.DO - Entrance to the building |
| BBR.KR - Access to the building |
| BBR.PA - Disabled parking |
| BBR.UB - Movement and storage of strollers and aids facilitating movement |
| BBR.VB - Movement of people in apartment buildings |
| BBR.WA - Wayfinding in case of emergency |
| **S.EXT Use of the exterior of the building** |
| EXT.MB - Places designated for common use in apartment buildings |
| EXT.PR - Additional elements that improve the quality of the place |
| **S.FLX Flexibility of the construction, layout and operational solution of the building** |
| FLX.AB - Adaptation of an apartment building |
| FLX.DK - Character of internal dividing structures |
| FLX.PB - The diversity of the composition of residential units in an apartment building |
| FLX.SB - Structural system of apartment buildings |
| **S.ROB Robustness of structure and envelope** |
| ROB.FA1 – Flooding adaptation solutions |
| ROB.HA1 – Heavy precipitation adaptation solutions |

| |
|---|
| ROB.TA1 – Storm adaptation solutions<br>ROB.SA2 – Subsidence adaptation solutions<br>ROB.DA1 – Drought adaptation solutions<br>ROB.WA1 – Heat wave adaptation solutions |
| **S.INT Indoor air quality** |
| INT.FI - Use of filters<br>INT.HG - Ventilation of sanitary facilities<br>INT.RE - Regulation of the ventilation system<br>INT.UD - Maintenance<br>INT.VV - Amount of outdoor air |
| **S.KOM User comfort** |
| KOM.PS - Positive stimulation in the interior of the building<br>KOM.RB - Relaxation areas shared and in the exclusive use of the apartment unit<br>KOM.UB - Storage spaces shared and in the exclusive use of the apartment unit<br>KOM.SS – Access to other useful shared spaces |
| **S.PEF Spatial efficiency** |
| PEF.DE - Disposition space efficiency of housing units<br>PEF.KE - Structural spatial efficiency factor |
| **S.RAD Protection against radon** |
| RAD.IV - Design intensity of ventilation<br>RAD.KR - Radon concentration<br>RAD.PO - Anti-radon measures<br>RAD.RE - Character of reconstruction<br>RAD.RF - Occurrence of risk factors<br>RAD.UO - Effectiveness of anti-radon measures<br>RAD.UP - Location of residential or residence spaces<br>RAD.VM - Measurement results |
| **S.TKL Thermal comfort in summer** |
| TKL.ST - Necessity of a construction solution to meet the requirement for the highest daily air temperature<br>TKL.TE - Highest daily air temperature |
| **S.TKZ Thermal comfort in winter** |
| TKZ.DT - Drop in floor touch temperature<br>TKZ.TS - Thermal stability of the room |
| **S.PAS Passive survivability** |
| PAS.ME – Passive measures for heating, cooling, and lighting |
| **S.VIS Visual comfort** |
| VIZ.CB - Daylight factor<br>VIZ.PR - Sunlight |

| |
|---|
| VIZ.VY - View |
| **S.UGA Urban gardening** |
| UGA.FO Shared spaces for food production |
| **S.VPR Connection to public space** |
| VPR.EP - Making exterior areas accessible to the public<br>VPR.MB - Multifunctional use of an apartment building<br>VPR.ZP - Making the building's facilities available to the public |
| **S.ZAB Security against intrusion** |
| ZAB.TO - Resistance classes |
| **S.ZNM Health safety of materials** |
| ZNM.IP - Creation of an information guide<br>ZNM.SM - Building materials and products used in the interior of the building |

*Blue-coloured text denotes modified or added criteria or modules.*

The newly added criterion, PRE-SA Rapid Site Assessment, has been placed at the top of the existing criteria in the Economics, Risk, and Management category (Table 37). This decision, made in agreement with the SBToolCZ research and development team, highlights its significance as potentially the most crucial criterion. It has the capacity to influence various aspects of the building, not only regarding resilience features but also sustainability. Additionally, it serves as the baseline from which all resilience principles fundamentally originate.

*Table 37 Integration of resilience features into Economics, Risk and Management category criteria.*

| **C – Economics, Risk and Management** |
|---|
| **PRE.SA – Rapid site assessment** |
| PRE.SA1 – Rapid site assessment |
| **C.DOK Implementation and operational documentation** |
| DOK.DK - Quality and content of submitted documentation<br>DOK.DZ - Presence of copyright supervision and technical supervision of the builder<br>DOK.UL - Implementation of a storage place for documents<br>DOK.UP - User manuals |
| **C.FMG Facility management** |
| FMG.FM - Facility Management<br>FMG.MR - Measurement and regulation systems |
| **C.LCC Life Cycle Costs** |
| LCC.AN - Detail of life cycle cost analysis performed |
| **C.MAR Measurement of energy and water consumption** |
| MAR.DB - Additional functions of end devices displaying energy consumption |

| |
|---|
| MAR.PM - Number of fed media with a detailed overview of consumption |
| **C.MTO Management of sorted waste** |
| MTO.OB - Waste management in the building<br>MTO.PB - Number of sorted commodities<br>MTO.SB - Construction of collection points<br>MTO.KN - Capacity of collection containers |
| **C.PMG Project management and participation** |
| PMG.BD - Degree of involvement of target groups within the apartment building project<br>PMG.TM - Composition of the project team |
| **C.SES – Safe equipped space** |
| CAP.FS1 - Fundamental safety<br>CAP.FS2 - Safe room |
| **C.EPS – Emergency power supply** |
| CAP.BU1 – Emergency power supply<br>CAP.WA2 – Emergency water supply |
| **C.EPR – Emergency preparedness** |
| EPR.WS – Warning system |

*Blue-coloured text denotes modified or added criteria or modules.*

Within the Location criteria (Table 38), only PRE.CM Unsuitable site has been added. It must be recalled that this whole category in the system is not weighted; thus, it will not influence the final score. Thus, even if the decision of the building site is fundamental, it has been chosen that the measures to adapt to the location be taken following other criteria that may influence the results, such as Rapid risk assessment. In fact, it can be noticed that the former criterion L.RIZ Locality risk is no longer present in the list of criteria because it has been merged in objectives with Rapid risk assessment and moved to the Economics category where it could really influence the results.

*Table 38 Integration of resilience features into Location category criteria.*

| **L – Location criteria** |
|---|
| **L.AIR Local air quality** |
| AIR.PM - Average annual concentration of PM10 |
| **L.DOS Availability of services** |
| DOS.VZ - Distance to basic services<br>DOS.ZB - Classification of basic services for residential buildings |
| **L.DVM Availability of public places for relaxation** |
| DVM.TB - Classification of places for relaxation<br>DVM.VZ - Distance places for relaxation |

| |
|---|
| **L.EKO Ecological value of the place** |
| EKO.PC - Naturally valuable places<br>EKO.VB - Use of brownfield |
| **L.KRI Prevention of crime** |
| KRI.RK - Crime risk assessment |
| **L.USI – Unsuitable sites** |
| PRE.US1 - Avoidance of flood-prone areas<br>PRE.US2 - Avoidance of adverse geology areas |
| **L.VHD Availability of public transport** |
| VHD.FB - Frequency of public transport connections<br>VHD.KO - Quality of pedestrian roads<br>VHD.PD - Walking distance to public transport stops from the building<br>VHD.ZS - Number of public transport stops |

*Blue-colored text denotes modified or added criteria or modules.*

## 7.3 Adjusted weighting system

As happened for the Resilience Module in Chapter 5 – Weighting system, the updated version of SBToolCZ has been subjected to a new weighting system. This involved assembling a panel of experts to evaluate each criterion individually. In this instance, experts were selected from the SBToolCZ development team, employing the same pairwise comparison method used for the Resilience Module as a stand-alone system to determine the significance of each criterion but applying it to the 52 criteria of the SBToolCZ integrated version. The provided table (Figure 58) required completion: a score of 1 indicated that the criterion in the row was more relevant than the one in the column, 0 indicated lesser importance, and 0.5 indicated equal importance.

Five experts from the SBToolCZ development team provided responses to these matrices, and the average percentage for each criterion obtained by their matrices was utilised to determine the final percentage value – Figure 58. This value was subsequently normalised by the predetermined weight assigned to the entire category. The weightings of the categories remained unchanged (i.e., Environmental criteria 50%, Social criteria 35%, Economics, Risk and Management criteria 15% and Location criteria 0%). Indeed, the Location criteria category retains zero weight in the overall system. In contrast, compliance with the Site Risk Assessment criterion in the economics, Risk and Management category is mandatory for obtaining the certification (either Silver or Gold).

| E – Environmental criteria | E.ACP | E.BIO | E.CEM | E.CIR | E.DOP | E.EUP | E.GWP | E.ODP | E.OZE | E.PAR | E.PEE | E.POC | E.PUD | E.SOD | E.UPV | **E.ZEL** | E.ZSV |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| E.ACP Environmental acidification potential | | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| E.BIO Biodiversity | | | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| E.CEM Certified products and materials | | | | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| E.CIR Circularity of structures and materials | | | | | - | - | - | - | - | - | - | - | - | - | - | - | - |
| E.DOP Support for gentle individual non-automotive transport | | | | | | - | - | - | - | - | - | - | - | - | - | - | - |
| E.EUP Environmental eutrophication potential | | | | | | | - | - | - | - | - | - | - | - | - | - | - |
| E.GWP Global Warming Potential | | | | | | | | - | - | - | - | - | - | - | - | - | - |
| E.ODP Ozone depletion potential | | | | | | | | | - | - | - | - | - | - | - | - | - |
| E.OZE Renewable energy sources | | | | | | | | | | - | - | - | - | - | - | - | - |
| E.PAR Traffic at ease | | | | | | | | | | | - | - | - | - | - | - | - |
| E.PEE Primary energy from non-renewable sources | | | | | | | | | | | | - | - | - | - | - | - |
| E.POC Ground-level ozone generation potential | | | | | | | | | | | | | - | - | - | - | - |
| E.PUD Land use | | | | | | | | | | | | | | - | - | - | - |
| E.SOD Construction waste | | | | | | | | | | | | | | | - | - | - |
| E.UPV Drinking water savings | | | | | | | | | | | | | | | | - | - |
| **E.ZEL Greenery on the building and land** | | | | | | | | | | | | | | | | | - |
| E.ZSV Retention of rainwater | | | | | | | | | | | | | | | | | |

| S – Social criteria | S.AKU | S.ARC | **S.BBR** | S.EXT | S.FLX | **S.ROB** | S.INT | **S.KOM** | S.PEF | S.RAD | S.TKL | S.TKZ | **S.PAS** | S.VIS | **S.GAR** | S.VPR | S.ZAB | S.ZNM |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| S.AKU Acoustic comfort | | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| S.ARC Architectural quality | | | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| **S.BBR Barrier-free solution** | | | | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| S.EXT Use of the exterior of the building | | | | | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| S.FLX Flexibility of the construction, layout and operational solution of the building | | | | | | - | - | - | - | - | - | - | - | - | - | - | - | - |
| **S.ROB Robustness of structure and envelope** | | | | | | | - | - | - | - | - | - | - | - | - | - | - | - |
| S.INT Indoor air quality | | | | | | | | - | - | - | - | - | - | - | - | - | - | - |
| **S.KOM User comfort** | | | | | | | | | - | - | - | - | - | - | - | - | - | - |
| S.PEF Spatial efficiency | | | | | | | | | | - | - | - | - | - | - | - | - | - |
| S.RAD Protection against radon | | | | | | | | | | | - | - | - | - | - | - | - | - |
| S.TKL Thermal comfort in summer | | | | | | | | | | | | - | - | - | - | - | - | - |
| S.TKZ Thermal comfort in winter | | | | | | | | | | | | | - | - | - | - | - | - |
| **S.PAS Passive survivability** | | | | | | | | | | | | | | - | - | - | - | - |
| S.VIS Visual comfort | | | | | | | | | | | | | | | - | - | - | - |
| **S.GAR Urban gardening** | | | | | | | | | | | | | | | | - | - | - |
| S.VPR Connection to public space | | | | | | | | | | | | | | | | | - | - |
| S.ZAB Security against intrusion | | | | | | | | | | | | | | | | | | - |
| S.ZNM Health safety of materials | | | | | | | | | | | | | | | | | | |

| C – Economics, Risk and Management criteria | **C.RSA** | C.DOK | C.FMG | C.LCC | C.MAR | C.MTO | C.PMG | **C.EQU** | **C.SUP** | **C.PRE** |
|---|---|---|---|---|---|---|---|---|---|---|
| **C.RSA – Rapid site assessment** | | - | - | - | - | - | - | - | - | - |
| C.DOK Implementation and operational documentation | | | - | - | - | - | - | - | - | - |
| C.FMG Facility management | | | | - | - | - | - | - | - | - |
| C.LCC Life Cycle Costs | | | | | - | - | - | - | - | - |
| C.MAR Measurement of energy and water consumption | | | | | | - | - | - | - | - |
| C.MTO Management of sorted waste | | | | | | | - | - | - | - |
| C.PMG Project management and participation | | | | | | | | - | - | - |
| **C.EQU – Safe equipped space** | | | | | | | | | 0 | - |
| **C.SUP – Emergency supply** | | | | | | | | 1 | | - |
| **C.PRE – Emergency preparedness** | | | | | | | | | | |

| L – Location criteria | L.AIR | L.DOS | L.DVM | L.EKO | L.KRI | **L.UNS** | L.VHD |
|---|---|---|---|---|---|---|---|
| L.AIR Local air quality | | - | - | - | - | - | - |
| L.DOS Availability of services | | | - | - | - | - | - |
| L.DVM Availability of public places for relaxation | | | | - | - | - | - |
| L.EKO Ecological value of the place | | | | | - | - | - |
| L.KRI Prevention of crime | | | | | | - | - |
| **L.UNS – Unsuitable sites** | | | | | | | - |
| L.VHD Availability of public transport | | | | | | | |

*Red text denotes modified criteria, and yellow text denotes added criteria.*

*Figure 58 Matrices that experts were requested to provide ratings (a 0, 0.5, 1 value in the yellow-coloured cells) for pairwise comparisons.*

Finally, Table 39 presents the criteria weightings based on the average values provided by five experts. These average values are then multiplied by the overall category weight—for instance, 50% for the Environmental criteria category—to obtain normalized weights. These normalized weights are then applied to the point scores of each criterion, resulting in the normalized score for each. The sum of all normalized scores provides the final result of the assessment.

*Table 39 Overview of SBToolCZ framework weightings implemented with resilience criteria.*

| **E – Environmental criteria** | **AVG** | **Normalized [%]** |
|---|---|---|
| E.ACP Environmental acidification potential | **7.1%** | 3.5% |
| E.BIO Biodiversity | **6.6%** | 3.3% |
| E.CEM Certified products and materials | **3.7%** | 1.8% |
| E.CIR Circularity of structures and materials | **6.6%** | 3.3% |
| E.DOP Support for gentle individual non-automotive transport | **1.8%** | 0.9% |
| E.EUP Environmental eutrophication potential | **7.0%** | 3.5% |
| E.GWP Global Warming Potential | **10.3%** | 5.2% |
| E.ODP Ozone depletion potential | **7.1%** | 3.6% |
| E.OZE Renewable energy sources | **7.4%** | 3.7% |
| E.PAR Traffic at ease | **1.5%** | 0.7% |
| E.PEE Primary energy from non-renewable sources | **8.1%** | 4.1% |
| E.POC Ground-level ozone generation potential | **5.9%** | 3.0% |
| E.PUD Land use | **5.1%** | 2.5% |
| E.SOD Construction waste | **1.9%** | 0.9% |
| E.UPV Drinking water savings | **7.9%** | 3.9% |
| E.ZEL Greenery on the building and land | **4.9%** | 2.5% |
| E.ZSV Retention of rainwater | **7.1%** | 3.5% |
| | **100%** | 50% |
| **S – Social criteria** | | |
| S.AKU Acoustic comfort | **7.2%** | 2.5% |
| S.ARC Architectural quality | **4.3%** | 1.5% |
| S.BBR Barrier-free solution | **7.0%** | 2.4% |
| S.EXT Use of the exterior of the building | **4.3%** | 1.5% |
| S.FLX Flexibility of the construction, layout and operational solution of the building | **4.8%** | 1.7% |
| S.ROB Robustness of structure and envelope | **5.5%** | 1.9% |
| S.INT Indoor air quality | **8.6%** | 3.0% |
| S.KOM User comfort | **6.5%** | 2.3% |
| S.PEF Spatial efficiency | **3.0%** | 1.1% |
| S.RAD Protection against radon | **3.5%** | 1.2% |
| S.TKL Thermal comfort in summer | **9.0%** | 3.2% |
| S.TKZ Thermal comfort in winter | **8.4%** | 3.0% |
| S.PAS Passive survivability | **7.5%** | 2.6% |
| S.VIS Visual comfort | **5.1%** | 1.8% |
| S.GAR Urban gardening | **1.8%** | 0.6% |
| S.VPR Connection to public space | **2.2%** | 0.8% |
| S.ZAB Security against intrusion | **3.2%** | 1.1% |
| S.ZNM Health safety of materials | **8.1%** | 2.8% |
| | **100%** | 35% |
| **Economic, Risk and Management criteria** | | |
| C.RSA – Rapid site assessment | **14.5%** | 2.2% |
| C.DOK Implementation and operational documentation | **8.6%** | 1.3% |

| | | |
|---|---|---|
| C.FMG Facility management | **8.4%** | 1.3% |
| C.LCC Life Cycle Costs | **13.2%** | 2.0% |
| C.MAR Measurement of energy and water consumption | **9.5%** | 1.4% |
| C.MTO Management of sorted waste | **5.5%** | 0.8% |
| C.PMG Project management and participation | **5.5%** | 0.8% |
| C.EQU – Safe equipped space | **12.5%** | 1.9% |
| C.SUP – Emergency supply | **13.4%** | 2.0% |
| C.PRE – Emergency preparedness | **8.9%** | 1.3% |
| | **100%** | **15%** |
| **Location criteria** | | |
| L.AIR Local air quality | 16% | 0% |
| L.DOS Availability of services | 10% | 0% |
| L.DVM Availability of public places for relaxation | 13% | 0% |
| L.EKO Ecological value of the place | 13% | 0% |
| L.KRI Prevention of crime | 15% | 0% |
| L.USI – Unsuitable sites | 18% | 0% |
| L.VHD Availability of public transport | 14% | 0% |
| | **100%** | **0%** |

Green-coloured text denotes modified criteria and blue-coloured text denotes newly added criteria.

## 7.4 Testing and validation of a case study

The updated weighting system and overall framework were applied to a case study to prove the effectiveness of the integration. For convenience, the same building used to test the Resilience Module in Chapter 6 was also used for this purpose – X-LOFT multi-residential building. The building was originally certified under SBToolCZ in 2013, achieving Silver certification. However, since the Resilience Module has now been integrated into the 2022 version of SBToolCZ, with the weighting system recalculated based on expert input, a direct comparison between the 2013 and 2022 results is not feasible. Even if the Resilience Module had been integrated into the earlier SBToolCZ 2013 version, differences in the number and weighting of criteria between the two versions would have made alignment difficult.

Thus, the X-LOFT building was reassessed using the SBToolCZ 2022 version for multi-residential buildings based on available documentation from the 2013 certification and documentation and the most recent SBToolCZ 2022 benchmarks and metrics. A comparison was then made between this version and the one integrated with resilience criteria. A few key considerations were made before analysing the results:

- Only three criteria—ZEL.VE (Vegetation Conservation), S.BBR (Barrier-Free Solutions), and S.KOM (User Comfort)—were updated with additional resilience modules, as it is shown in Table 35 and Table 36. The calculations were performed by applying resilience and sustainability modules according to the SBToolCZ structure, where multiple modules are often summed due to their equal significance.

- The final score (X points out of 10) may not be entirely accurate, as the X-LOFT building's documentation is over ten years old. The final result, which may show the building at a different certification level than in 2013, is less relevant than demonstrating that the difference between systems with and without resilience criteria is minor, proving its feasibility for standard integration.
- For convenience, the Location category was not recalculated, as its weight was zero and would not impact the final score.

Figure 59 illustrates the differences in weighting for each criterion between the integrated resilience version (light blue) and the standard version (dark blue). The most significant changes are seen in the Economic and Management criteria category, where four new criteria were introduced.

The results are presented in Figure 60, showing the scores divided by categories. The Environmental category remained largely unaffected between the two versions, with only the E.ZEL criterion adjusted. In the Social category, the integrated version scored 1.65 points, compared to 1.53 points for the standard version, mainly due to the inclusion of the S.ROB criterion, which accounts for 5.5% of the weighting in the resilience version.

The most notable difference occurred in the Economic and Management category, where the score increased from 0.18 points in the standard version to 0.32 points in the integrated version, effectively doubling the score due to the addition of four criteria. While this category does not heavily influence the overall system (only 15% of weight over 100%), the final score is still impacted—4.67 points for the standard version versus 5.11 points for the integrated version. This demonstrates that the integrated version balances sustainability and resilience for some extent.

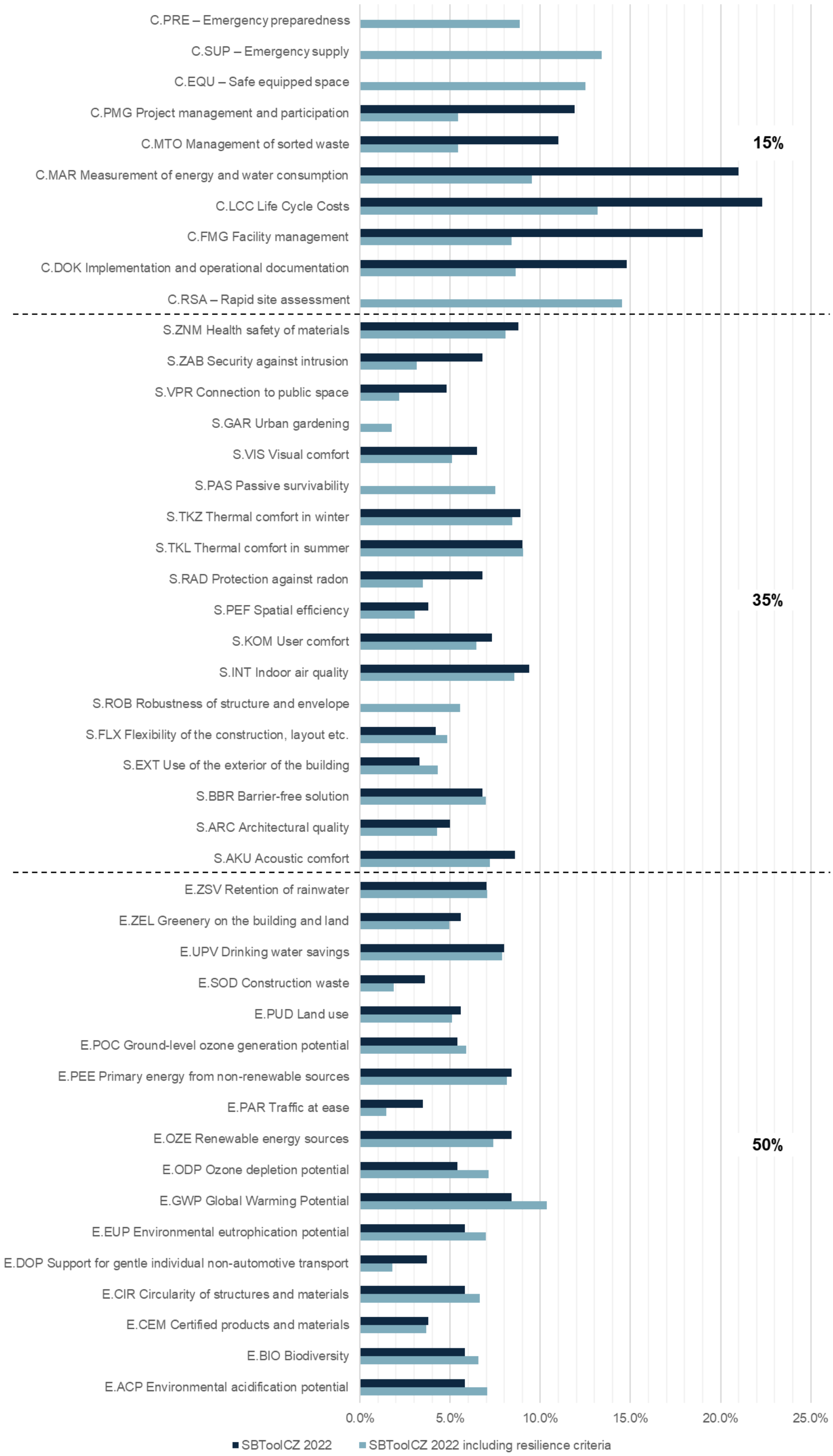


*Figure 59 Difference of weightings between the two version of SBToolCZ.*

It should be noted that the final score of the X-LOFT building under the SBToolCZ 2022 version is lower than the 2013 version (4.67 points vs. 6.34 points), which is expected given the stricter benchmarks and criteria in the updated system. However, the focus here is rather on the final scores of the standard 2022 and integrated resilience versions, highlighting that integrating resilience into sustainability frameworks is feasible, offering a more comprehensive approach to building design. It is important to note that the scores are not directly comparable, as the 2022 version used a different weighting system. This system could not be applied to the integrated version due to the introduction of new criteria, which required the development of a new weighting system, but the comparison was mainly to prove the effectiveness of the integrated version on an already certified building.

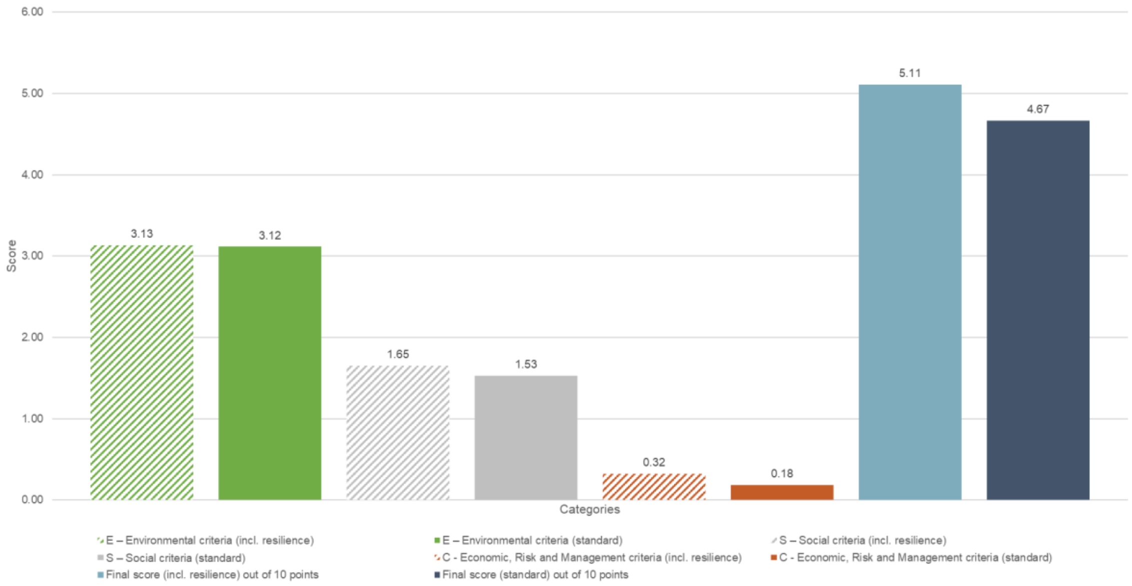


*Figure 60 Comparison of scores between the standard SBToolCZ 2022 version and the integrated version with resilience criteria.*

### 7.5 References


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# 8. Conclusions

*This chapter underscores how the research met its objectives, showing the outcomes and the related publications. The findings point to several directions for future progress, such as continued collaboration with SBToolCZ experts and piloting the Resilience Module. This work has the potential to shape sustainable building practices, urban planning, and environmental resilience across Europe thanks to its replicability and scalability, driving new industry standards and improving building design strategies.*

In recent years, the growing impacts of climate change have brought resilience to the forefront of building design, highlighting the necessity for structures to not only meet sustainability standards but also adapt to evolving climate-related challenges. This thesis has demonstrated that while resilience principles are not yet systematically integrated into green building rating systems, these frameworks can be enhanced by incorporating resilience criteria. The research explored integrating resilience principles into an existing rating system, specifically the SBToolCZ, through a thorough analysis of sustainability and resilience literature and assessment tools. This investigation revealed that integrating resilience into sustainability assessments is feasible and beneficial for buildings, thereby enriching the current understanding of both domains.

*Fulfilment of the objectives*

The primary objectives of this thesis were to: (1) define the core elements of sustainability and resilience, along with their commonalities, to facilitate seamless integration into the design process; (2) develop a standalone Resilience Module for assessing the resilience of multi-residential buildings, which also serves as a guideline for architects and designers; and (3) effectively integrate this module into the SBToolCZ rating system, used as a case study tool.

The first objective was achieved through an extensive literature review and an analysis of the assessment tools available in the market, conducted at the early stages of the PhD research. The outcome of this work was the identification of common clusters between the domains of sustainability and resilience at the building level. These findings are detailed in Chapter 3 and have been disseminated in a conference paper titled *Sustainability and Resilience in Building Design: Discussion on Two Case Studies* and a research article titled *Exploring the Common Ground of Sustainability and Resilience in the Building Sector: A Systematic Literature Review and Analysis of Building Rating Systems*—both of which are included in Appendix C.

The second objective was met after defining the key principles of resilience, drawn from literature, existing assessment tools, and best practices in building design. This objective was further validated through a panel of experts who reviewed the Resilience Module during the weighting process. The resulting Resilience Module can serve both as an independent assessment tool and as guidelines for integrating resilience principles into building design. It was developed following a structure similar to that of green building rating systems, particularly those associated with SBTool, to enable smoother integration. These results are discussed in Chapters 5 and 6, and are presented in a conference paper titled *Implementing Resilience in Sustainable Building Design: Testing Selected Resilience Criteria in a Case Study* (accepted for publication on 13/09/2024), which is reported in Appendix C. The paper details the testing of selected resilience criteria from the module in a building case study.

The final main objective was achieved in the latter stages of the PhD, following several meetings with the SBToolCZ research and development team, and after the successful completion of the second objective. The outcome was the design of an integrated framework for SBToolCZ—a comprehensive proposal for incorporating resilience criteria into an existing framework. This integration is partially presented in Chapters 4 and 7. A related publication, titled *Environmental, Social, and Economic Resilience in Multi-Residential Buildings: Assessing SBToolCZ Rating System*, has also been published and is included in Appendix C.

*Originality of the thesis and contribution to existing knowledge*

This research makes a significant and original contribution to the field of building design by integrating resilience principles into an existing sustainability rating system, setting a precedent for similar future initiatives. The PhD work demonstrates that it is feasible to incorporate resilience principles early in the design phase by adapting an established rating system already used for assessing the quality of buildings. The feasibility of this approach was confirmed through validation in three case studies for the stand-alone module and one building case study for the integrated version of SBToolCZ. Additionally, the resilience criteria developed can be applied in assessing existing buildings and providing recommendations to enhance their resilience against specific hazards. This work enriches the body of knowledge by practically demonstrating that resilience principles can be effectively integrated into existing frameworks, thus advancing both theoretical understanding and application in building design.

*Exploitation of results in the Czech Republic*

The application of the Resilience Module within the Czech national tool for sustainability and quality assessment underscores its potential impact. The findings can be used to advocate for the integration of resilience principles in future versions of SBToolCZ and could serve as guidelines for Czech architects and designers to enhance building resilience. This has the potential to positively influence national building practices and improve the resilience of the building stock.

*Scalability and application in other contexts*

The Resilience Module, particularly as integrated into SBToolCZ, is applicable beyond the Czech Republic. Its methodologies and findings can be adapted to other sustainability rating systems, provided they follow a similar structure to facilitate integration and stakeholder acceptance. The module's flexibility allows it to be used as a stand-alone system in various contexts without extensive modifications or to be integrated into existing rating systems, making it valuable for addressing local, national, and European challenges about resilience enhancement, including those outlined in the EU taxonomy.

*Future directions for building resilience integration*

This PhD study primarily focused on the technical aspects of enhancing building resilience, but future research could explore integrating these aspects with economic considerations. In particular, combining cost-benefit analysis existing methods with various resilience enhancement scenarios could help stakeholders better understand the financial benefits of investing in such improvements to their building assets.

Additionally, the Resilience Module could be further refined through expert collaboration and pilot implementation to gather real-world feedback.

These efforts would ensure that the research continues to advance building resilience while contributing to ongoing discussions in academia and industry on the urgent need to address the impacts of climate change.

# Table of Figures

*References are listed at the end of each chapter, with the numbering starting anew in each chapter. To locate the appropriate reference for a figure, please consult the reference list of the corresponding chapter.*

# Table of Tables

*References are listed at the end of each chapter, with the numbering starting anew in each chapter. To locate the appropriate reference for a table, please consult the reference list of the corresponding chapter.*

# Appendix A – Resilience Module for Multi-Residential Buildings Manual

*This appendix provides the Manual for the Resilience Module, detailing each criterion, including its intent, description, indicators, evaluation methods, overall assessment, documentation guidance, specific limitations, and relevant literature. The Manual was then converted into an MS Excel calculation tool to streamline the process and make it more user-friendly. It is designed for the stand-alone version of the Resilience Module, not the integrated SBToolCZ 202 system. However, the criteria incorporated into SBToolCZ 2022 rely on these guidelines for proper implementation and assessment of the building performance in terms of resilience.*

## Criteria structure

The Resilience Module is organized into five distinct categories (Preparedness, Redundancy, Robustness, Response Capability and Community Cohesion), each encompassing a minimum of two criteria. Each criterion within the Resilience Module is comprised of at least one evaluation module, ensuring a structured and systematic approach to assessing resilience. These criteria are comprehensively detailed in the following sections:

- Intent of the criterion: Outlines the purpose and goals of the criterion.
- Description: Provides a detailed explanation of the criterion's scope and relevance.
- SBToolCZ-related Criteria: Connects the criterion to related criteria within the SBToolCZ framework.
- Indicator: Specifies the metrics or indicators used to assess the criterion.
- Evaluation modules: Lists the specific modules used for assessing the criterion.
- Overall evaluation of the criterion: Summarizes the results and effectiveness of the criterion based on the evaluation.
- Documentation guidance: Provides instructions on the necessary documentation for addressing the criterion.
- Specific criterion limits: Defines the specific benchmarks associated with the criterion.
- Literature: Includes references and further reading related to the criterion.

## Preparedness - R.PRE

*This category refers to the adoption of resilience strategies that reduce risk exposure. Design strategies such as a good wayfinding system, site risk assessment at an early stage and avoiding floodplains are examples of preparedness measures.*

## PRE.AR - Accessibility and Readiness

### Intent of the criterion

Design the project to provide safe and appropriate access for every user in the building site while guaranteeing readiness of assistive technology installation.

### Scale

### Description

Wayfinding and navigation technologies are strategic in improving the quality of life of people and in case of extreme shocks. The process of wayfinding refers to how individuals find their way around a space or along a pathway. Graphic design, architectural design, and landscape design are all included in this field. The use of signage can assist in wayfinding. Several design features that facilitate wayfinding, such as lines on the ground indicating a way out and symbols and colours indicating the locations of toilets, accessible toilets, lifts and exits, can be used. This reflects that homes must be safe for all occupants, regardless of age or ability; moreover, they should be guaranteed the adaptability of the apartment to assistive technologies.

### Hazards

### SBToolCZ-related criteria

S.EXT Use of the exterior of the building

S.BRR Barrier-free design

### Indicator (qualitative)

Provision of clear access, safety and wayfinding measures in order to accommodate emergency services for every user.

### Evaluation modules

- $PRE.AA_1$ - Accessibility
- $PRE.AA_2$ - Technology readiness

### Overall evaluation of the criterion

The final criterion rating is calculated according to the following equation:

$$K_{PRE.AA} = K_{PRE.AA1} + K_{PRE.AA2}$$

**PRE.AA1 | ACCESSIBILITY**

| *Item* | *Description* | *Points* $K_{PRE.WA1}$ |
|---|---|---|
| A | Accessibility of the building (public transport, parking, etc.) | (max+6) |
| | Severely disable | +2 |
| | Reduced mobility | +1 |
| | Blind | +2 |
| | Partially blind | +1 |
| | Deaf | +2 |
| | Partially deaf | +1 |
| B | Accessibly of entrance areas - exterior and interior | (max+6) |
| | Severely disable | +2 |
| | Reduced mobility Blind | +1 |
| | | +2 |
| | Partially blind | +1 |
| | Deaf | +2 |
| | Partially deaf | +1 |
| C | Horizontal movement in the building | (max+6) |
| | Severely disable | +2 |
| | Reduced mobility | +1 |
| | Blind | +2 |
| | Partially blind | +1 |
| | Deaf | +2 |
| | Partially deaf | +1 |
| D | Vertical movement in the building | (max+6) |
| | Severely disable | +2 |
| | Reduced mobility | +1 |
| | Blind | +2 |
| | Partially blind | +1 |
| | Deaf | +2 |
| | Partially deaf | +1 |
| E | Common hygienic areas and changing rooms (if present) | (max+6) |
| | Severely disable | +2 |
| | Reduced mobility | +1 |
| | Blind | +2 |
| | Partially blind | +1 |
| | Deaf | +2 |
| | Partially deaf | +1 |
| F | Special equipment and interiors | (max+6) |
| | Severely disable | +2 |
| | Reduced mobility | +1 |
| | Blind | +2 |
| | Partially blind | +1 |
| | Deaf | +2 |
| | Partially deaf | +1 |
| G | Clear signage and wayfinding<br>Implement visual cues are valuable wayfinding milestones during severe weather emergencies | +2 |

**PRE.AA2 | TECHNOLOGY READINESS**

| *Item* | *Description* | *Points $K_{PRE.WA1}$* |
|---|---|---|
| A | Assistive technology installation for users with special needs<br>*Guarantee individual's independence and function* | +2 |
| B | Adaptability of apartment design for people with special needs<br>*Readiness of apartment's layout to be modified to accommodate the needs of individuals with disabilities or other special requirements* | +2 |

**Documentation guidance**

- Design document showing plans for access and egress paths for users and occupants.
- Report describing how the solutions implemented benefit users affected by different levels of disability.
- Documentation (photos) that clear signage and wayfinding techniques are used to integrate the project into the surroundings.

**Specific criterion limits**

The final criterion score is calculated according to the following table for linear interpolation:

| *Points* $K_{PRE.WA}$ | *Points* |
|---|---|
| 0 | 0 |
| 42 | 10 |

**Literature**


Alabbad, Y. et al. (2020) 'Wayfinding and Accessibility Analysis for Critical Amenities in Iowa During Flood Events'. Available at: http://dx.doi.org/10.31223/osf.io/2yha5.

ARUP (no date) Accessible and inclusive environments. Available at: https://www.arup.com/services/buildings/accessible-environments (Accessed: 20 March 2023).

Institute for Sustainable Infrastructure (2018) Envision Sustainable Infrastructure Framework version 3. Washigtion, DC.

Meuser, P., Pogade, D. and Tobolla, J. (2018) Accessibility and Wayfinding: Construction and Design Manual. DOM Publishers.

Prandi, C. et al. (2021) 'Accessible wayfinding and navigation: a systematic mapping study', Universal Access in the Information Society. Springer Berlin Heidelberg, 22(1), pp. 185–212. doi: 10.1007/s10209-021-00843-x.

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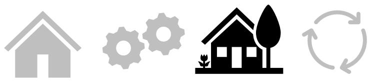
## PRE.SA – Site risk assessment

**Intent of the criterion**

Identification of the most likely hazards (floods, heavy precipitation and storms, heatwaves, subsidence, and drought) of a specific location.

**Scale**



**Description**

Several factors should be considered when characterising the risks associated with climate change in a specific location, such as the climate threat, the geographical context (e.g., coastal area, mountain region), and the affected systems and sectors (e.g., people, infrastructure, properties, etc.) as well as the impacts on the most vulnerable groups. The purpose of site risk assessments is to determine the likelihood of future climate hazards occurring and the potential impacts on buildings and their users. Climate action and adaptation strategies must be prioritised based on this information.

**Hazards**

**SBToolCZ-related criteria**

L.RIZ Site risks

**Indicator (qualitative)**

Assessment of exposure to specific hazards to identify those that are most likely to occur.

**Evaluation modules**

• PRE.SA1 – Site risk assessment

**PRE.SA1 | SITE RISK ASSESSMENT**

This assessment seeks to understand the likelihood of hazards and their potential impacts on cities, their inhabitants, the environment and the economy. It includes two components:

| *Item* | *Description* | *Points* $K_{PRE.SA1}$ |
|---|---|---|
| A | Perform the site risk assessment<br>*Gather information on past disasters and future hazard projections based on desk work* | +1 |
| B | Involvement of stakeholders from the professional and academic fields throughout the assessment process<br>*Involve the main stakeholder in a workshop to define the most likely hazards* | +1 |

*This criterion is directly linked to the Robustness category. Upon completing the relevant sheet in the Calculation tool, the criteria for the module concerning the most significant hazards for the location will be automatically activated.*

**Key data sources:**

Consider historical extreme weather events in the area and consult any available risk maps under national Geographic Information Systems, like the national flood risk hazard map, the Flood Risk Management Plan, the relevant drought management plan (if available) and River Basin Management Plans.

- Climate data and climate scenarios (e.g. European Climate Data Explorer, Copernicus Climate Change Service, IPCC Interactive Atlas, Urban Adaptation Map Viewer)
- Satellite imaging;
- Event databases and socio-economic data (e.g., DRMKC Risk Data Hub);
- Climate change impacts projections (e.g. PESETA IV and other relevant European or global research projects);
- Global assessments of climate hazards and risks (e.g., IPCC AR6).

For the specific site, consider:

- Exposure to high wind speeds.
- Excessive solar gain and urban heat island effects.
- Proximity of mountainous regions.
- Proximity of steeply sloped land masses.
- Proximity to the sea or watercourses (both in vertical and horizontal axes).

Consult public reports, weather databases, climate change projections, and experts as needed. Insurance analysts can also provide valuable assistance.

**Documentation guidance**

- Compile your findings into a report that includes the following:
    - A base map: a topographic map of the area under investigation.
    - A hazard record map: indicating the locations of events based on geological and scientific evidence, as well as historical data.
    - A hazard forecast map: depicting the location, severity, and likelihood of future hazardous events.

**Overall evaluation of the criterion**

The final criterion rating is calculated according to the following equation:

$$K_{PRE.SA} = K_{PRE.SA1}$$

**Specific criterion limits**

The final criterion score is calculated according to the following table for linear interpolation:

| *Points* $K_{PRE.WA}$ | *Points* |
|---|---|
| 0 | 0 |
| 2 | 10 |

**Literature**

C40 Knowledge (2018) Climate Change Risk Assessment Guidance and Screening Template. Available at: https://www.c40knowledgehub.org/s/article/Climate-Change-Risk-Assessment-Guidance?language=en_US

C40 Knowledge (2021) Rapid Climate Change Risk Assessment Module. Available at: https://www.c40knowledgehub.org/s/article/Rapid-Climate-Change-Risk-Assessment-Module?language=en_US

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Institute for Sustainable Infrastructure (2018) Envision Sustainable Infrastructure Framework version 3. Washington, DC.

Iturbide, M. et al. (2021) Repository supporting the implementation of FAIR principles in the IPCC-WG1 Atlas. doi: 10.5281/zenodo.3691645.

The World Bank (no date) Climate and Disaster Risk Screening Tools. Available at: https://climatescreeningtools.worldbank.org/rapid-assessment-tool

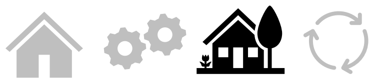
Urban adaptation map viewer (no date) Available at: https://climate-adapt.eea.europa.eu/en/knowledge/tools/urban-adaptation

## PRE.US – Unsuitable sites

### Intent of the criterion

Avoid building on sites prone to natural hazards.

### Scale



### Description

Natural events such as earthquakes and sinkhole formation can increase building maintenance costs due to structural damage and pose higher risks to residents in vulnerable areas. Those living in floodplains need additional protection through costly defences. Planning and building regulations should ensure designs account for potential exceedance scenarios, and it is preferable to avoid construction in floodplain areas due to their higher risk of flooding.

### Hazards

### SBToolCZ-related criteria

L. Site risks

### Indicator (quantitative)

Efforts to avoid or mitigate site-related risks.

### Evaluation modules

- $PRE.US_1$ - Avoidance of flood-prone areas
- $PRE.US_2$ - Avoidance of adverse geology areas

### Overall evaluation of the criterion

The final criterion rating is calculated according to the following equation:

$$K_{PRE.US} = K_{PRE.US1} + K_{PRE.US2}$$

### PRE.US1 | Avoidance of flood-prone areas

Avoid areas within 100- and 500-year floodplain. Statistically, these floodplains have been found vulnerable to extreme events.

| *Item* | *Description* | *Points $K_{PRE.US1}$ (max 2 points)* |
|---|---|---|
| A | No floodplain and no flood risk | +2 |
| B | Build above the 100-year floodplain<br>*Need to consult a flood-risk map.* | +1 |
| C | Build above the 500-year floodplain<br>*Need to consult a flood-risk map.* | +2 |

**PRE.US2 | Avoidance of adverse geology areas**

| *Item* | *Description* | *Points $K_{PRE.US2}$ (max 2 points)* |
|---|---|---|
| A | Identification of any faults, low-lying coastline or karst areas | 1 |
| B | Establish a program for monitoring<br>*Follow local regulations regarding building in identified earthquake-prone areas and over karst formations.* | 1 |
| C | The area is not threatened by any kind of geological activity | 2 |

**Documentation guidance**

- Documentation of identified site hazards along with documentation identifying strategies and controls implemented to reduce risk, e.g., monitoring and response plans or mitigation measures implemented to reduce the project's impact.

**Specific criterion limits**

The final criterion score is calculated according to the following table for linear interpolation:

| *Points* $K_{PRE.GW}$ | *Points* |
|---|---|
| 0 | 0 |
| 4 | 10 |

**Literature**


Dottori, F. et al. (2022) 'A new dataset of river flood hazard maps for Europe and the Mediterranean Basin', 81, pp. 1549–1569.

European Environment Agency (2020) Floodplain statistics viewer. Available at: https://www.eea.europa.eu/data-and-maps/data/data-viewers/floodplain-areas (Accessed: 3 October 2023).

European Environment Agency (2023) EEA potential flood-prone area extent. Available at: https://www.eea.europa.eu/en/datahub/datahubitem-view/254a8583-e34f-4324-bbdf-1fbda7a3d222 (Accessed: 3 October 2023).

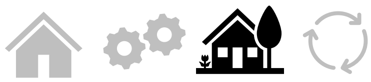
Paprotny, D. et al. (1870) 'Trends in flood losses in Europe over the past 150 years', Nature Communications. Springer US, (2018). doi: 10.1038/s41467-018-04253-1.

## PRE.VE – Conserve and use appropriate vegetation

### Intent of the criterion

Improve landscape performance and conservation of original vegetation by planting only appropriate plants for site conditions, climate, and design intent.

### Scale



### Description

A tree-planting initiative will only be successful if the trees are well-suited to the environment and can withstand extreme temperatures, drought, storms, and flooding. Ideally, mature native trees from local areas that are already acclimated to the region should be used. Additionally, stormwater trees enhance urban biodiversity, improve soil quality, and benefit aquatic environments.

### Hazards

### SBToolCZ-related criteria

E.ZEL Greenery on the building and land

E.ZSV Retention of rainwater

E.PUD Land use

### Indicator (qualitative)

Absence/presence of native and climate-tolerant vegetation.

### Evaluation modules

- $PRE.VE_1$ - Conserve and use appropriate vegetation

### Overall evaluation of the criterion

The final criterion rating is calculated according to the following equation:

$$K_{PRE.VE} = K_{PRE.VE1}$$

### $PRE.VE_1$ | CONSERVE AND USE APPROPRIATE VEGETATION

| *Item* | *Description* | *Points* $K_{RED.VE1}$ |
|---|---|---|
| A | Plant single tree pits in the building surrounding<br>*Ensure an adequate volume of high-quality rooting zone.* | +1 |
| B | Replant and conserve existing trees, if they were moved, before using new ones | +2 |
| C | Plant continuous tree pits in the building surrounding<br>*Continuous planting pit with a minimum area of 30 m² for managing rainwater* | +2 |
| D | Plant trees in strategic locations to serve as windbreaks | +2 |

| | | |
|---|---|---|
| | *Windbreaks consist of rows of trees placed perpendicular to prevailing winds. A strategic location of trees can reduce home energy use.* | |
| E | Choose climate-tolerant trees (i.e., drought-tolerant)<br>*Consulting with an arborist can help in selecting the most appropriate species.* | +3 |

**Documentation guidance**

- Provide documents indicating both the existing vegetated area and the new vegetated area, specifying which plants are native species.
- Provide documents demonstrating how the newly planted vegetation functions as windbreakers.
- Provide a report on the climate-change tolerance of the newly planted vegetation.

**Specific criterion limits**

The final criterion score is calculated according to the following table for linear interpolation:

| *Points* $K_{RED.PS}$ | *Points* |
|---|---|
| 0 | 0 |
| 10 | 10 |

**Literature**


Barwise, Y. and Kumar, P. (2020) 'Designing vegetation barriers for urban air pollution abatement: a practical review for appropriate plant species selection', *Climate and Atmospheric Science*. Springer US, 3(1), pp. 1–19. doi: 10.1038/s41612-020-0115-3.

Nature Portfolio. n.d. "The Biologists Mapping out Climate-Resilient Trees for Our Cities." Accessed May 28, 2024. https://www.nature.com/articles/d42473-023-00237-y.

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**Redundancy - R.RED**

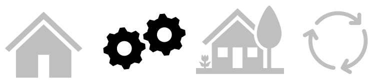
*This category refers to the ability of a building to maintain critical life-support conditions for occupants without relying on external power or other resources. The strategies in this category include cooling load reduction, natural ventilation capabilities, highly efficient thermal envelopes, passive solar gain, and natural daylighting or even backup generators. All strategies that support the building's main functions with minimal external input if the primary system is disrupted.*

## RED.PS – Passive survivability

### Intent of the criterion

Ensure that the building maintains safe thermal conditions thanks to passive solutions.

### Scale



### Description

Passive survivability refers to a building’s ability to maintain critical life-support conditions in the event of extended loss of power, heating fuel, or water. Passive thermal performance refers to heat transfer between a building and its surroundings, mainly without AC systems. Passive solar systems collect and distribute energy from the sun without the use of mechanical equipment such as fans or pumps.

### Hazards

### SBToolCZ-related criteria

S.KOM User comfort

S.TLK Thermal comfort in summer

S.TKZ Thermal comfort in winter

### Indicator (qualitative)

Absence/presence of passive systems for heating, cooling, and lighting.

### Evaluation modules

- RED.$PS_1$ - Passive solar heating
- RED.$PS_2$ - Passive cooling
- RED.$PS_3$ - Passive lighting
- RED.$PS_4$ - Thermal safety temperature

### Overall evaluation of the criterion

The final criterion rating is calculated according to the following equation:

$$K_{RED.PS} = (K_{RED.PS1}+K_{RED.PS2}+K_{RED.PS3}) + 2 \times K_{RED.PS4}$$

**RED.PS$_1$ | PASSIVE HEATING**

| *Item* | *Description* | *Points $K_{RED.PS1}$* (max 3 points) |
|---|---|---|
| **Direct gain** | | |
| A | Southern facing glass<br>*Glazing on the southern-facing side of the building absorbs the sun's heat energy and warms the building during the winter.* | +1 |
| B | Solar-facing clerestories and sloped skylights<br>*This approach is appropriate for increased privacy, shading of the solar façade, heating deep spaces and spaces located along other facades, avoiding direct sunlight on people and furniture, and avoiding glare.* | +1 |
| C | Solar chimney<br>*Natural ventilation systems that use solar radiation to produce convective airflows.* | +1 |
| D | Sunspace<br>*This solution is heated by direct sunlight, with heat transferred to adjacent spaces through a common mass wall. It must be designed according to the climate.* | +1 |
| **Indirect gain** | | |
| E | Increased thermal mass<br>*Improving the ability of a material to absorb, store and release heat* | +1 |
| F | Thermal storage wall<br>*This solution absorbs sunlight (heat) in winter, conducting heat through the wall and releasing it into an adjacent space at night.* | +1 |
| G | Thermal zoning<br>*Distribution of thermally various zones according to the orientation* | +1 |

**RED.PS$_2$ | PASSIVE COOLING**

| *Item* | *Description* | *Points $K_{RED.PS1}$* (max 4 points) |
|---|---|---|
| **Preventive techniques** | | |
| A | Shading (vertical and operable)<br>*This solution would intercept sunlight before it reaches the walls and glazing of a building.* | +1 |
| B | Internal gain control | +1 |
| **Modulation and heat dissipation techniques** | | |
| C | Cross ventilation<br>*Locate outlet openings on the opposite side of inlet openings, and make them equal to, or greater in size than, the inlet openings.* | +1 |
| D | Stack ventilation<br>*Openings are located low and high and are on opposite sides of a space.* | +1 |
| E | Night flushing<br>*Using the natural drop in temperature after sunset to remove accumulated heat within a building's thermal mass* | +1 |
| F | Radiative cooling or evaporation cooling | +1 |

| | | |
|---|---|---|
| | *Process of removing heat from a surface due to the evaporation of water* | |
| G | Earth coupling<br>*This solution protects and buffers a building from extreme outdoor temperature, precipitation, wind, and humidity.* | +1 |
| H | Cold roof or double roof<br>*This roof solution has surfaces that reflect sunlight and emit heat efficiently.* | +1 |

**RED.PS$_3$ | PASSIVE LIGHTING**

| *Item* | *Description* | *Points $K_{RED.PS3}$* |
|---|---|---|
| A | Building form and layout | +1 |
| B | Daylighting from multiple sides<br>*Daylighting spaces from multiple sides provides more even lighting and produces less glare around people and objects.* | +1 |
| C | Solar zoning<br>*Direct, diffused or reflected sunlight to provide supplemental lighting for building interiors* | +1 |
| D | High-efficacy egress lighting<br>*Energy-efficient lighting, including fluorescent lighting and LED lighting, lasts longer in exit signage and requires fewer amp-hours to run from a battery in the event of a power outage.* | +1 |

**RED.PS$_4$ | THERMAL SAFETY TEMPERATURE**

Determination of the maximum daily calculated indoor air temperature in the hottest habitable room of the building/apartment. The calculation follows the ISO 7730:2005 - Ergonomics of the thermal environment.

| *Item* | *Description*<br>*Maximum daily calculated air temperature in the warmest habitable room (one item only)* | *Points $K_{RED.PS4}$* |
|---|---|---|
| A | >27°C | +1 |
| B | 26.5 °C | +1.5 |
| C | 26.0 °C | +2 |
| D | 25.5 °C | +2.5 |
| E | <25.0 °C | +3 |

**Documentation guidance**

- Report detailing the passive solutions integrated into the design.
- Design documentation illustrating technical cross-sections and floor maps showcasing the implemented solutions.
- Specifications of habitable room geometry, including air volumes, floor areas, building structure and opening surfaces, and other geometric parameters.
- Thermal-technical characteristics of building structures and openings.

**Specific criterion limits**

The final criterion score is calculated according to the following table for linear interpolation:

| *Points* $K_{RED.PS}$ | *Points* |
|---|---|
| 0 | 0 |
| 14 | 10 |

**Literature**


Architecture 2030 (no date) 2030 PALETTE - A database of sustainable design principles, strategies, and tools. Available at: http://2030palette.org/.

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Enright, P. (2017) Passive Cooling Measures for Multi-Unit Residential Buildings. Vancouver, CA. Available at: https://vancouver.ca/files/cov/passive-cooling-measures-for-murbs.pdf.

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World Building Design Council (2016a) Daylighting. Available at: https://www.wbdg.org/resources/daylighting.

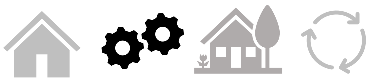
World Building Design Council (2016b) Passive Solar Heating. Available at: https://www.wbdg.org/resources/passive-solar-heating.

## RED.AP – Alternative power sources

### Intent of the criterion

Reduction of the amount of operational non-renewable primary energy (PERNT) in the building, meeting the energy demand with renewable energy (PERT).

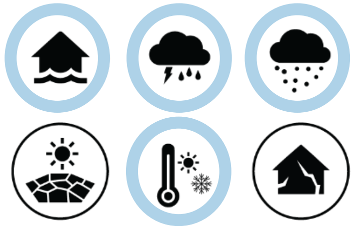
### Scale



### Description

The dominant position of fossil fuels as the primary energy source in the energy sector is largely due to their relatively low price. However, considering the projected increase in global energy demand, it is advisable to move away from relying on finite and polluting energy sources in the future. Over the past decade, there has been a noticeable positive shift towards expanding renewable energy capacity, both on local and international scales. The reliance on alternative sources helps reduce emissions of greenhouse gases and other pollutants.

### Hazards



### SBToolCZ-related criteria

E.PEE Primary energy from non-renewable sources

E.OZE Renewable energy sources

### Indicator (quantitative)

Extent to which renewable energy sources are incorporated.

### Evaluation modules

- RED.AP1 - Annual primary energy consumption
- RED.AP2 – Renewable power sources

### Overall evaluation of the criterion

The final criterion rating is calculated according to the following equation:

$$K_{RED.PS} = K_{RED.AP1} + K_{RED.AP2}$$

**RED.AP1 - ANNUAL PRIMARY ENERGY CONSUMPTION**

Calculate the annual PERNT and PERT baseline consumption in kWh per 1 $m^2$ [kWh/($m^2$.a)], i.e. kilowatt hours of energy per square metre of building per year, to finally determine the percentage of PERT over the total, considering loads coming from heating, cooling, hot water preparation, mechanical ventilation, lighting, auxiliary energies.

| *Item* | *Description (select one item only)* | *Points $K_{RED.AP1}$ (only one item)* |
|---|---|---|
| A | <5% of energy needs from renewable sources | +1 |
| B | <15% of energy needs from renewable sources | +2 |
| C | <30% of energy needs from renewable sources | +3 |
| D | <50% of energy needs from renewable sources | +4 |
| E | Net positive amount from renewable sources | +5 |

By way of explanation:

$$Annual\ energy\ consmption\ [kWh/(m2.a)] = \frac{(A\ [kWh/a]) + (B\ [kWh/a])}{(C\ [m2])}$$

(A) = Annual consumption of imported (grid) energy
kWh energy consumption figures (A) can be taken directly from gas and electricity utility bills or BMS reports or as the difference between manual meter readings taken one year apart (or monthly over a year).

(B) = Annual consumption of on-site renewable energy
If on-site renewables (such as PV panels) are present, the renewable energy in kWh (B) that is used directly on-site, i.e., not sold back to the grid, must be calculated.

The sum of (A) and (B) will provide the annual operational energy consumption of the property.

Lastly, the building's gross internal floor area (GFA) needs to be obtained in square metres. This can be taken from building plans. All floor levels must be included (C).

**RED.AP2 – RENEWABLE POWER SOURCES**

| *Item* | *Description* | *Points $K_{RED.AP2}$ (max 2 points)* |
|---|---|---|
| A | On-site solar energy production, e.g., PV panels | +1 |
| B | Connection to district heating and/or cooling | +1 |
| C | Wind access | +1 |
| D | Biomass | +1 |
| E | Geothermal | +1 |
| F | Hydrogen/fuel cells | +1 |
| G | Any other kind of renewable source | +1 |

**Documentation guidance**

- Documentation reporting the analysis performed to calculate the annual energy consumption.

- Report listing the breakdown of renewable energy sources by type. Renewable energy may include solar energy (thermal heating, both active and passive, and photovoltaic); wind (electricity generation); water (hydro or tidal for electricity generation); biomass (electricity generation or as fuels); geothermal (electricity generation or heating and cooling); and hydrogen/fuel cells (used as a fuel).

**Specific criterion limits**

The final criterion score is calculated according to the following table for linear interpolation:

| *Points* $K_{RED.AP}$ | *Points* |
|---|---|
| 0 | 0 |
| 7 | 10 |

**Literature**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## Robustness - R.ROB

*This category raises the ability of a building to absorb and adapt to disruptions and changes provided by different hazards. As part of this category, it is important to use materials that are resistant to natural disasters, use strong-in-depth construction techniques, and utilise traditional building forms that have been in use in the region for centuries and have proven to be resilient over the years (vernacular architecture principles).*

## ROB.FR – Flood-resistant building structure and envelope

**Intent of the evaluation**

Minimisation of flood damage. The building is prepared for a possible water level of 1m above the surrounding ground level.

**Scale**

**Description**

Installation of flood adaptation solutions for buildings, such as the use of flood-resistant materials, the elevation of structures, and flood barriers, can reduce the vulnerability to flood events. These measures can help protect buildings and the people inside them from flooding damage.

**Hazards**

**SBToolCZ-related criteria**

L.RIZ Location risks

**Indicator (qualitative)**

Rating of readiness in terms of solutions implemented in the building to face a flood event.

**Evaluation modules**

- ROB.FR$_1$ - Flood-resistant building solutions

**ROB.FR$_1$ | FLOOD-RESISTANT BUILDING SOLUTIONS**

Consider this module if flood risk has been identified as high in the PRE.SA - Rapid site assessment.

| *Item* | *Description* | *Points $K_{ROB.FR1}$* | *Impact on other risks* |
|---|---|---|---|
| **Building shape** | | | |
| A | Square building shape<br>*Square-shaped houses are preferred as they are generally stronger in flood conditions. Long and narrow building shapes intercepting the direction of flow should be avoided.* | +0.5 | *Storms<br>*Heavy rain |
| **Foundations** | | | |
| B | Elevating the building<br>*Structure should be built above the flood level to minimize damage when a flood occurs. Elevating a building on columns or stilts or raising the foundation could be a solution.* | +0.5 | +Subsidence |
| C | Preliminary soil study<br>*Soil permeability could affect water infiltration on the site, leading to potential damage to the safety of the foundations or basement structure. A preliminary soil study to detect all risks of ground movement should be made.* | +0.5 | +Heavy rain |

| | | | |
|---|---|---|---|
| D | Dry proofing foundations<br>*Dry floodproofing aims to make a building watertight below the flood level.* | +0.5 | +Heavy rain<br>+Storm |
| E | Wetproofing foundations (e.g., internal drainage systems, vents, etc.)<br>*These allow for temporary flooding of the lower parts of the building using openings or breakaway walls. This method can include stilts or a sacrificial basement (uninhabitable spaces such as car parks).* | +0.5 | +Heavy rain<br>+Storm |
| **Openings** | | | |
| F | Permanent flood-barriers<br>*These can be appropriate for windows and doors that are below a floodplain and are the first to flood in the case of high water, e.g., flood walls, automatic barriers, and retractable barriers.* | +0.5 | +Drought<br>+Storms |
| G | Temporary flood barriers<br>*These can be installed in preparation for potential flooding, or after a flood warning is issued, e.g., flood shields, sandbags, deployable barriers. Flood shields are typically made of aluminium, stainless steel, or plastic and use neoprene rubber or similar materials to seal the barrier.* | +0.5 | +Drought<br>+Storms |
| H | Effective sealants and waterproof membranes<br>*Effective in sealing a wall, reducing or preventing the penetration of flood water through the wall.* | +0.5 | +Heavy rain<br>+Storm |
| **Preferred materials** | | | |
| I | Water-repellent finishes<br>*Choose paints and plasters that offer increased water resistance and cannot be permanently damaged by water.* | +0.5 | +Heavy rain<br>+Storm<br>*Heat waves |
| J | Water-resistant insulation<br>*Materials such as expanded polystyrene (EPS) and extruded polystyrene (XPS) rigid foam panels that can withstand water for at least 72 hours without significant damage.* | +0.5 | +Heavy rain<br>+Storm<br>+Heat waves |
| K | Water-resistant materials<br>*The walls of the building that are at greatest risk from flooding are in the lower part of the building and, therefore, part of the foundation and basement. To preserve the interior spaces and particularly the lower floors, select this kind of material, e.g., plasterboard coating or water-repellent mortars, that can withstand water for at least 72 hours without significant damage.* | +0.5 | *Storms<br>*Heavy rain |
| **Building services** | | | |
| L | Building systems above the flood level (i.e., mechanical and electrical systems)<br>*When designed for submerged installations, the buried portions of underground electrical utilities are also generally resistant to flood damage, but above-ground components of underground electrical utilities, such as below-grade electrical vaults, pad-mounted* | +0.5 | +Heavy rain<br>+Storm |

| | | | |
|---|---|---|---|
| | *transformers, pad-mounted switchgear, and electrical substations, can be damaged by floods when located below the flood level* | | |
| M | Devices anti-backflow<br>*Inside the building, devices to prevent backflow can be installed on sewage pipes to prevent contaminated water from flowing back into a building through the plumbing due to flood-induced sewage overflow.* | +0.5 | +Heavy rain |
| N | Basement with non-essential functions<br>*If the building is designed to be resistant to short-duration flooding, intend the basement to be used for non-essential functions only (such as parking or storage), and the outer walls and floors can be lined with water-resistant concrete to improve flood resilience.* | +0.5 | +Heavy rain |
| **Surroundings** | | | |
| O | Buffer zones in the building surroundings<br>*To combat hydrostatic and buoyancy forces, these zones should be installed with a setback distance from the edge of the flood hazard area. The fill soil should be homogeneous and of a low permeability.* | +0.5 | +Heavy rain<br>+Storm |
| P | Drainage systems in the building surroundings (e.g., sump pump, rain gardens, swales)<br>*Sump pumps can be installed to compensate for leakages inside basements.* | +0.5 | +Heavy rain<br>+Storm |

* Negative effect on another hazard, + Positive effect on another hazard

**Documentation guidance**

- Include cross sections of the building with terrain markings.
- Provide maps indicating the location of electrical equipment.
- Flood protection measures typically aren't included in standard project documentation; thus, they should be explicitly specified in the project documentation for resilience assessment purposes.

**Overall evaluation of the criterion**

The final criterion rating is calculated according to the following equation:

$$K_{ROB.FR} = K_{ROB.FR1}$$

**Specific criterion limits**

The final criterion score is calculated according to the following table for linear interpolation directly in the Excel tool:

| *Points* $K_{ROB.FR}$ | *Points* |
|---|---|
| 0 | 0 |
| 8 | 10 |

**Literature**


BREEAM (2015) *POL 03 - Flood Risk Management and Reducing Surface Water Run-off*. Available at: https://kb.breeam.com/wp-content/plugins/breeamkb-pdf/pdf/?c=797 (Accessed: 1 July 2023).

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Flood Guidance. (n.d.). Flood resistance measures (types). Retrieved May 28, 2024, from https://www.floodguidance.co.uk/flood-guidance/flood-resistance-measures/

Kandel, S., & Frantzeskaki, N. (2024). Nature-based solutions and buildings: A review of the literature and an agenda for renaturing our cities one building at a time. Nature-Based Solutions, 5, 100106. https://doi.org/10.1016/J.NBSJ.2023.100106

## ROB.HR – Heavy precipitation-resistant building envelope and structure

**Intent of the criterion**

Minimisation of damage caused by heavy precipitation. The implemented strategies help to reduce the amount of rainwater runoff from the building by collecting and storing it while also helping to reduce any potential flooding.

**Scale**

**Description**

Buildings can be damaged by heavy precipitation. The result can be structural damage, flooding, and water damage that may be expensive to repair. Precautionary measures such as proper waterproofing, proper drainage, and regular maintenance can help reduce the potential for damage.

**Hazards**

**SBToolCZ-related criteria**

L.RIZ Location risks

**Indicator (qualitative)**

Rating of the readiness of the building for facing heavy precipitation.

**Evaluation modules**

• ROB.HR$_1$ - Heavy precipitation-resistant building solutions

**RED.HE$_1$ | HEAVY PRECIPITATION-RESISTANT BUILDING SOLUTIONS**

Consider this module if heavy precipitation risk has been identified as high in the PRE.SA - Rapid site assessment.

| *Item* | *Description* | *Points* $K_{ROB.HR1}$ | *Impact on other risks* |
|---|---|---|---|
| **Building shape** | | | |
| A | Avoid square and rectangular flat surfaces perpendicular to the wind<br>*Triangular-shaped buildings with edges to the wind have a breaking effect on horizontal rainfall intensity* | +0.5 | *Storms<br>*Heavy rain |
| **Structure** | | | |
| B | Passive landslide control measures | +0.5 | +Storms<br>+Landslides<br>*Floods |
| C | Ground preparation | +0.5 | +Drought |

| | | | |
|---|---|---|---|
| | *Necessary to ensure foundations do not become displaced and improve groundwater drainage* | | +Storm<br>+Heatwave |
| **Walls** | | | |
| D | Green façade<br>*Acts as a rain screen and helps decrease air and surface temperatures by canopy evapotranspiration and shading* | +0.5 | +Heatwave |
| E | Rainscreen with a drainage system within the wall | +0.5 | +Storms |
| **Openings** | | | |
| F | Tempered glass panel (e.g., 4-mm thickness)<br>*Windows will not be damaged by hail* | +0.5 | +Storms |
| G | Hail-proof shutters and blinds | +0.5 | +Storms |
| H | Secure loose joints by cramping, glueing, re-wedging, and pinning | +0.5 | +Storms<br>+Floods |
| I | Effective sealants and waterproof membranes | +0.5 | +Storms<br>+Floods |
| **Preferred materials** | | | |
| J | Water-resistant materials<br>*The walls that are at greatest risk from flooding are in the lower part of the building and, therefore, part of the foundation and basement. To preserve the interior spaces and particularly the lower floors, select this kind of material, e.g., plasterboard coating or water-repellent mortars, that can withstand water for at least 72 hours without significant damage.* | +0.5 | +Storms<br>*Floods |
| K | Infiltration trenches<br>*Increased infiltration rate reduces risk from pluvial flooding* | +0.5 | +Storms<br>*Floods |
| L | Metal for roofing<br>*Provides protection against hailstones and storm debris* | +0.5 | +Storms<br>*Floods |
| **Roof** | | | |
| M | Hail net for protecting roof fragile elements<br>*Fragile elements of the envelope can be protected* | +0.5 | |
| N | Heat tracing in gutters<br>*Prevention of ice forming and the consequential blocking of gutters* | +0.5 | |
| O | Type of roof (e.g., warm, inverted, blue, blue-green, green)<br>*They can be used for water storage and mitigate pluvial and fluvial flooding* | +0.5 | |
| P | Pitched roof<br>*It offers protection from water pooling and infiltration* | +0.5 | |
| **Building services** | | | |
| Q | Proper dimensioned drainage network<br>*Increased capacity of the network reduces the risk of overflow or flooding* | +0.5 | +Floods<br>+Storms |
| R | Disconnect surface water from sewage<br>*Reduces the risk of flooding from backflow or overflows of sewage system* | +0.5 | +Drought<br>+Storms<br>+Floods |

| | | | |
|---|---|---|---|
| S | Rainwater tanks<br>*Proper dimensioned tank for rainwater collection and reuse* | +0.5 | +Drought<br>+Storm<br>+Heatwave |
| T | Devices anti-backflow<br>*Inside the building, devices to prevent backflow can be installed on sewage pipes to prevent contaminated water from flowing back into a building through the plumbing due to flood-induced sewage overflow.* | +0.5 | +Drought<br>+Storms<br>+Heatwave |
| **Surroundings** | | | |
| U | Sustainable urban drainage (e.g., rain gardens and swales)<br>*Engineered as part of a landscaping strategy and placed at an appropriate distance from the building* | +0.5 | +Drought<br>+Storms<br>+Heatwave |
| V | Drainage systems in the building surroundings (e.g., sump pump)<br>*Sump pumps can be installed to compensate for leakages inside basements.* | +0.5 | +Heavy rain<br>+Storms |
| W | Permeable soil<br>*Reduction of run off* | +0.5 | +Drought<br>+Storms<br>+Heatwave<br>*Subsidence |

* Negative effect on another hazard, + Positive effect on another hazard

**Documentation guidance**

- Including cross sections of the building with terrain markings.
- Providing maps indicating the locations of electrical equipment.
- Heavy rain protection measures are typically not included in standard project documentation, so they must be specified in the project documentation, particularly for resilience assessment.

**Overall evaluation of the criterion**

The final criterion rating is calculated according to the following equation:

$$K_{ROB.Hr} = K_{ROB.HR\ 1}$$

**Specific criterion limits**

The final criterion score is calculated according to the following table for linear interpolation directly in the Excel tool:

| *Points* $K_{ROB.HR}$ | *Points* |
|---|---|
| 0 | 0 |
| 11.5 | 10 |

**Literature**

Dodd, N., Donatello, S. and Cordella, M. (2021) Level(s) indicator 5.2: Increased risk of extreme weather events.

European Commission (2021a) *EU-level technical guidance on adapting buildings to climate change*. Available at: https://c.ramboll.com/adapting-buildings.

European Commission (2021b) *EU-level technical guidance on adapting buildings to climate change - Best Practice Guidance*. Available at: https://c.ramboll.com/adapting-buildings.

Ministry of the Environment (2021) S*trategy for adapting to climate change in the conditions of the Czech Republic*. Available at: https://www.mzp.cz/cz/zmena_klimatu_adaptacni_strategie (Accessed: 1 July 2023).

## ROB.ST – Storm-resistant building envelope and structure

**Intent of the criterion**

Minimisation of the damage caused by storms. The implemented strategies help to reduce the risk of the building being damaged by hail, strong wind or potential blackout.

**Scale**

**Description**

Severe thunderstorms are formidable natural events that can inflict widespread damage. These intense storms are marked by strong winds, heavy rainfall, frequent lightning, and sometimes hail. They can develop suddenly and are particularly dangerous due to their frequent lightning, which can pose serious risks to both buildings and people. Lightning can trigger fires, damage electrical systems, and, in extreme cases, cause injuries or fatalities. Therefore, it is prudent to implement preventive measures to reduce their potential impact.

**Hazards**

**SBToolCZ-related criteria**

L.RIZ Location risks

**Indicator (qualitative)**

Rating of the readiness of the building for facing a severe storm.

**Evaluation modules**

- $ROB.SR_1$ - Storm-resistant building solutions

**$ROB.SR_1$ | STORM-RESISTANT BUILDING SOLUTIONS**

Consider this module if storm risk has been identified as high in the PRE.SA - Rapid site assessment.

| *Item* | *Description* | *Points* $K_{ROB.SR1}$ | *Impact on other risks* |
|---|---|---|---|
| **Building shape** | | | |
| A | Aerodynamic shape<br>*Reduces wind resistance on the building structure* | +0.5 | - |
| **Foundations** | | | |
| B | Elevating the building<br>*The lowest habitable floor is elevated above the ground level.* | +0.5 | +Flood |

| | | | |
|---|---|---|---|
| **Structure** | | | |
| C | Limit peak story drift | +0.5 | |
| D | Undertake performance-based wind design | +0.5 | |
| **Walls** | | | |
| E | Rainscreen cladding systems<br>*Prevents deterioration of outside walls* | +0.5 | |
| F | Strong connections between exterior building elements (roof-walls, walls-foundations, foundations-ground) | +0.5 | |
| G | Additional protection in walls for wind driven rain<br>*This can be done by installing a vapour barrier* | +0.5 | +Heavy precipitation |
| H | Reinforcement and protection of openings, storm shutters<br>*Prevents high winds and airborne debris from entering the building and creating wind pressure inside* | +0.5 | +Heatwave<br>+Subsidence |
| **Preferred materials** | | | |
| I | Impact-resistant shingles<br>*Minimise roof damages* | +0.5 | - |
| **Openings** | | | |
| J | Impact-resistant glass for windows and doors<br>*Minimize damages* | +0.5 | +Heatwave<br>+Subsidence |
| K | Sealant joint in windows to prevent moisture<br>*This prevents moisture and water from entering the building* | +0.5 | +Heavy precipitation |
| L | Storm hooks to secure openings<br>*Protects doors and windows from bending inwards in strong gusts of wind* | +0.5 | - |
| **Roof** | | | |
| M | Cross-bracing<br>*This can allow some wind to flow into the building* | +0.5 | |
| N | Hip-roof (with slopes of 30°)<br>*Good performance in resisting strong winds and helping shed snow* | +0.5 | +Heavy precipitation |
| O | Hurricane straps to fasten the roof to the walls<br>*The linkage between the roof and the walls should be reinforced to prevent uplift* | +0.5 | |
| P | Lightning rods/air terminals<br>*This can redirect electrical currents from lightning to the ground* | +0.5 | |
| Q | Physical non-continuity between the roof of the building and an extension (covered terrace, veranda, patio)<br>*Minimise roof damages* | +0.5 | |
| R | Short overhangs and protrusions | +0.5 | *Heatwave |
| S | Sub-roofing and sheathing to reinforce the roof | +0.5 | +Subsidence |
| **Building services** | | | |
| T | Installation of backup generators | +0.5 | |
| U | Protective device for surges | +0.5 | |

| | | | |
|---|---|---|---|
| | *Prevent power surges (caused by lightning) causing damage to electronic devices* | | |
| **Surroundings** | | | |
| V | Fix outdoor furniture and slabs to the ground<br>*Prevents uplift and damage to furniture, slabs, terraces and people* | +0.5 | - |
| X | Favour hedges and shrubs around the building<br>*They can act as windbreaks, offering some level of protection in the event of storms.* | +0.5 | |
| Y | Plant dense vegetation in rows<br>*They can act as windbreaks. Trees should be placed at a safe distance from the building (they may fall)* | +0.5 | |

* Negative effect on another hazard, + Positive effect on another hazard

**Documentation guidance**

- Storm protection measures are not usually part of the standard project documentation. Therefore, they need to be specified in the project documentation with regard to resilience assessment.

**Overall evaluation of the criterion**

The final criterion rating is calculated according to the following equation:

$$K_{ROB.SR} = K_{ROB.SR1}$$

**Specific criterion limits**

The final criterion score is calculated according to the following table for linear interpolation directly in the Excel tool:

| *Points* $K_{ROB.SR}$ | *Points* |
|---|---|
| 0 | 0 |
| 12 | 10 |

**Literature**

Dodd, N., Donatello, S. and Cordella, M. (2021) Level(s) indicator 5.2: Increased risk of extreme weather events.

European Commission (2021a) *EU-level technical guidance on adapting buildings to climate change*. Available at: https://c.ramboll.com/adapting-buildings.

European Commission (2021b) *EU-level technical guidance on adapting buildings to climate change - Best Practice Guidance*. Available at: https://c.ramboll.com/adapting-buildings.

Ministry of the Environment (2021) S*trategy for adapting to climate change in the conditions of the Czech Republic*. Available at: https://www.mzp.cz/cz/zmena_klimatu_adaptacni_strategie (Accessed: 1 July 2023).

## ROB.SU – Subsidence-resilient building envelope and structure

**Intent of the criterion**

Reduction of building vulnerability to subsidence through adaptation solutions.

**Scale**

**Description**

Variations in precipitation patterns and temperatures affect soil moisture levels and composition. In Europe, shrinkage and swelling of soil are increasing risks due to soils with high clay content being highly sensitive to volumetric changes. There is typically a movement of soil within a 5-metre depth from the ground surface, and movements are rarely greater than 150 mm horizontally or vertically. Large soil movements can cause serious damage to building structures and pose serious risks to people's safety.

**Hazards**

**SBToolCZ-related criteria**

L.RIZ Location risks

**Indicator (qualitative)**

Rating of the readiness of the building for facing subsidence.

**Evaluation modules**

- ROB.$SU_1$ - Subsidence adaptation building solutions
- ROB.$SU_2$ - Minimize soil movement during construction

**ROB.$SU_1$ | SUBSIDENCE ADAPTATION BUILDING SOLUTIONS**

Consider this module if subsidence risk has been identified as high in the PRE.SA - Rapid site assessment.

| *Item* | *Description* | *Points $K_{ROB.SU1}$* | *Impact on other risks* |
|---|---|---|---|
| **Foundations** | | | |
| A | Deep or semi-deep foundations (e.g., raft or piled foundations)<br>*As foundations reach more stable ground, the effects of shrinkage and swelling on a structure will be reduced to a greater extent. Soil subsidence susceptibility determines the recommended depth.* | +0.5 | +Storms<br>+Drought |
| B | Underpinning | +0.5 | - |

| | | | |
|---|---|---|---|
| | *Buildings can be raised, releveled, and re-supported by adding an additional foundation level. Traditional underpinning techniques are mass concrete underpinning, beam and base underpinning, and micro piles.* | | |
| **Walls** | | | |
| C | Joints movement<br>*Building frames and walls should be designed to be adaptable to soil movements by installing movement joints, which enable them to move and adjust independently, enhancing the flexibility and durability of the building.* | +0.5 | *Heat wave |
| D | Structural strengthening<br>*By implementing solutions to strengthen the structure, additional stability can be achieved.* | +0.5 | - |
| **Surroundings** | | | |
| E | Plant trees at a safe distance from the building<br>*A tree should either be removed or not be placed within 1.5 to 2 times the height of the tree from the building. Depending on the species of tree, a particular distance may be recommended. Roots can be reduced by cutting them or digging a trench between it and the property.* | +0.5 | +Storms<br>+Drought<br>*Heat wave<br>*Heavy precipitation<br>*Flooding |

* Negative effect on another hazard, + Positive effect on another hazard

**ROB.SU$_2$ | MINIMIZE SOIL MOVEMENT DURING CONSTRUCTION**

Consider this module if subsidence risk has been identified as high in the PRE.SA - Rapid site assessment.

| *Item* | *Description* | *Points* $K_{ROB.SU2}$ |
|---|---|---|
| A | Minimize disturbed areas on the construction site<br>*Disturb only the area required for the project. The rest of the area should be left undisturbed to conserve the natural vegetation and the topsoil.* | +0.5 |
| B | Divide the project into sections<br>*Divide the working land into different sections to control erosion and sedimentation in a phased manner.* | +0.5 |
| C | Soil stabilisation<br>*It can be done either temporarily or permanently. The use of mulch, blankets, and wood binders can act as a temporary measure. The permanent methods include planting, seeding, green buffer, and channel stabilisation.* | +0.5 |
| D | Slope protection<br>*This can be achieved through different methods, such as geotextiles, turf blankets, etc.* | +0.5 |
| E | Runoff water control methods<br>*This can be achieved through different methods, such as geotextiles, ditches, sediment traps, etc.* | +0.5 |
| F | Dewatering<br>*This solution facilitates the remotion of groundwater or accumulated rainwater on the building’s site.* | +0.5 |

| | | |
|---|---|---|
| G | Sediment control traps<br>*Runoff water on construction sites can be reduced by employing sediment control traps or basins.* | +0.5 |
| H | Stable Construction Entrances<br>*Stabilised construction entrances mainly made of crushed stone help reduce the number of sediments that get carried away.* | +0.5 |

**Documentation guidance**

- Subsidence protection measures are not usually part of the standard project documentation; therefore, they need to be specified in the project documentation.
- Drawing proof of a site plan or floor plan with the topographic profile of the existing and planned situation.

**Overall evaluation of the criterion**

The final criterion rating is calculated according to the following equation:

$$K_{ROB.SU} = K_{ROB.SU1} + K_{ROB.SU2}$$

**Specific criterion limits**

The final criterion score is calculated according to the following table for linear interpolation directly in the Excel tool:

| *Points* $K_{ROB.SU}$ | *Points* |
|---|---|
| 0 | 0 |
| 6.5 | 10 |

**Literature**

Dodd, N., Donatello, S. and Cordella, M. (2021) *Level(s) indicator 5.2: Increased risk of extreme weather events.*

Ministry of the Environment (2021) S*trategy for adapting to climate change in the conditions of the Czech Republic*. Available at: https://www.mzp.cz/cz/zmena_klimatu_adaptacni_strategie (Accessed: 1 July 2023).

Observatoire de l'immobilier Durable (2020) Taloen. Available at: https://www.taloen.fr/bat-adapt (Accessed: 25 June 2023).

## ROB.HW – Heat wave-resistant building envelope and structure

**Intent of the criterion**

Ensure thermal comfort for building users during a heatwave.

**Scale**

**Description**

Heat waves occur when a particular region experiences prolonged periods of extremely high temperatures. Due to climate change, periods of high temperatures and heat waves will increase in intensity and duration throughout Europe. Human health, well-being, and productivity can be adversely affected by high indoor temperatures; solutions must be identified to safeguard well-being and ensure thermal comfort.

**Hazards**

**SBToolCZ-related criteria**

L.RIZ Location risks

**Indicator (qualitative)**

Rating of the readiness of the building for facing a heat wave.

**Evaluation modules**

• ROB.HW1 – Heatwave adaptation solutions

**ROB.HW$_1$ | HEAT WAVE ADAPTATION SOLUTIONS**

Consider this module if heatwave risk has been identified as high in the Rapid site assessment.

| *Item* | *Description* | *Points $K_{ROB.HW1}$* | *Impact on other risks* |
|---|---|---|---|
| **Building shape** | | | |
| A | Façade orientation<br>*Orientation of the main façades in strategical position, away from direct sunlight from southwest. This will reduce exposure to solar heat gain.* | +0.5 | - |
| **Openings** | | | |
| B | Adequate insulation of windows, doors and walls<br>*Delay heat gain of the building.* | +0.5 | *Flooding<br>*Heavy precipitation |
| C | Solar shading for windows (e.g., blinds, shutters, brise-soleil)<br>*Either manual or automatic system for reducing the amount of heat or light entering the building.* | +0.5 | *Storms |

| | | | |
|---|---|---|---|
| **Walls** | | | |
| D | Green façades<br>*High capacity of heat storage. Plants can grow directly on the façade or from the bottom of the building and climbing up the wall.* | +0.5 | +Heavy precipitation |
| E | Joints movement<br>*During high temperatures, materials tend to dilate, so it is important to maintain a degree of flexibility.* | +0.5 | *Subsidence |
| **Roof** | | | |
| F | Photovoltaic panels installation<br>*Installed to produce renewable energy while shading and cooling the building.* | +0.5 | *Storms |
| H | Green roof<br>*High capacity of heat storage.* | +0.5 | +Heavy precipitation |
| **Preferred materials** | | | |
| I | Light-colored and reflective materials (e.g., solar reflective tiles)<br>*Increasing the reflection of incoming light and preventing the building from overheating while reducing the urban heat island.* | +0.5 | - |
| J | Thermal mass and phase-change materials<br>*By absorbing and releasing the heat gradually, these materials regulate temperatures and keep the building cool during the day and warm at night.* | +0.5 | - |
| **Building services** | | | |
| K | Passive cooling/ventilation techniques<br>*Adopt passive solutions and avoid energy consumption (e.g., natural ventilation, cross or stack ventilation, solar chimney, etc.)* | +0.5 | - |
| L | Active ventilation and cooling system<br>*During peak heat times, this solution reduces indoor air temperature and improves thermal comfort. Priority is given to the use of renewable energy sources.* | +0.5 | *Storms<br>*Heavy precipitation<br>*Flood |
| M | Geocooling and heat pumps<br>*Ground-source heat pumps will absorb heat from indoor air and dissipate it outdoors.* | +0.5 | - |
| N | Connection to district cooling system<br>*A modern, efficient way to air condition a network of buildings.* | +0.5 | - |
| **Surroundings** | | | |
| O | Vegetation on sun-exposed sides for shading the building<br>*Sunlight is shaded from direct sunlight by the trees and vegetation surrounding the building.* | +0.5 | +Heavy rain<br>+Flooding<br>*Storm<br>*Subsidence |

* Negative effect on another hazard, + Positive effect on another hazard

**Documentation guidance**

- There is usually standard project documentation that includes heatwave adaptation measures as solutions usually implemented in buildings, such as insulation or PV panels; however, redact a report in which these measures are clearly specified.

**Overall evaluation of the criterion**

The final criterion rating is calculated according to the following equation:

$$K_{ROB.HW} = K_{ROB.HW1}$$

**Specific criterion limits**

The final criterion score is calculated according to the following table for linear interpolation directly in the Excel tool:

| *Points* $K_{ROB.HW}$ | *Points* |
|---|---|
| 0 | 0 |
| 7 | 10 |

**Literature**

Dodd, N., Donatello, S. and Cordella, M. (2021) Level(s) indicator 5.2: Increased risk of extreme weather events.

European Commission (2021a) EU-level technical guidance on adapting buildings to climate change. Available at: https://c.ramboll.com/adapting-buildings.

European Commission (2021b) EU-level technical guidance on adapting buildings to climate change - Best Practice Guidance. Available at: https://c.ramboll.com/adapting-buildings

European Environment Agency. (2022). Europe’s heatwaves: How to keep buildings cool sustainably? https://www.eea.europa.eu/en/newsroom/news/europes-heatwaves-buildings-cool-sustainably

Ministry of the Environment (2021) S*trategy for adapting to climate change in the conditions of the Czech Republic*. Available at: https://www.mzp.cz/cz/zmena_klimatu_adaptacni_strategie (Accessed: 1 July 2023).

United Nations Environment Programme (2021) A Practical Guide to Climate-resilient Buildings & Communities.

UNDRR (2022) Technical Guidance on Comprehensive Risk Assessment and Planning in the Context of Climate Change. Available at: https://www.undrr.org/publication/technical-guidance-comprehensive-risk-assessment-and-planning-context-climate-change.

**ROB.DR – Drought-resistant building envelope and structure**

**Intent of the criterion**

Ensure thermal comfort and water access for building users during a drought.

**Scale**

**Description**

As temperatures rise, precipitation patterns change, and water resources are overexploited, droughts will become more frequent and severe throughout Europe. Build adaptation measures focus on reducing water consumption, harvesting rainwater, and recycling grey water.

**Hazards**

**SBToolCZ-related criteria**

L.RIZ Location risks

**Indicator (qualitative)**

Rating of the readiness of the building for facing dry periods.

**Evaluation modules**

• ROB.DR1 – Drought adaptation solutions

**RED.HW$_1$ | DROUGHT ADAPTATION SOLUTIONS**

Consider this module if the drought risk has been identified as high in the Rapid site assessment.

| *Item* | *Description* | *Points $K_{ROB.DR1}$* | *Impact on other risks* |
|---|---|---|---|
| **Building services** | | | |
| A | Installation of water-efficiency fixtures and fittings<br>*Helpful in reducing household water consumption and leaks.* | +0.5 | +Heat wave |
| B | Grey water recycling system (water from showers, bathtubs, etc.)<br>*It can be considered as an alternative water supply source for irrigation.* | +0.5 | - |
| C | Air-handling unit condensate capture and reuse<br>*Water collected can be reduced in the building.* | +0.5 | |
| D | Onsite water supply (e.g., water storage or wells that can supply fresh water for 3/4 days)<br>*Decrease vulnerability to water shortage. The storage must be placed on a solid foundation and protected from direct sunlight.* | +0.5 | +Heat wave<br>+Storms |

| | | | |
|---|---|---|---|
| E | Passive cooling and ventilation techniques<br>*Adopt passive solutions and avoid energy consumption (e.g., natural ventilation, cross or stack ventilation, solar chimney, etc.)* | +0.5 | +Heat wave |
| F | Installation of a water tank<br>*Storing rainwater for irrigation purposes or flushing toilets to save water consumption* | +0.5 | +Heat wave |
| **Surroundings** | | | |
| E | Installation of nature-based solutions (e.g., green roofs, green facades, drought-tolerant trees)<br>*Vegetation that is resistant to drought and does not require additional irrigation.* | +0.5 | +Heat wave |

* Negative effect on another hazard, + Positive effect on another hazard

**Documentation guidance**

- There is usually standard project documentation which includes drought adaptation measures as solutions usually implemented in buildings, such as installing water-efficient fixtures; however, redact a report in which these measures are clearly specified.

**Overall evaluation of the criterion**

The final criterion rating is calculated according to the following equation:

$$K_{ROB.DR} = K_{ROB.DR1}$$

**Specific criterion limits**

The final criterion score is calculated according to the following table for linear interpolation directly in the Excel tool:

| *Points* $K_{ROB.DR}$ | *Points* |
|---|---|
| 0 | 0 |
| 3 | 10 |

**Literature**


Dodd, N., Donatello, S. and Cordella, M. (2021) Level(s) indicator 5.2: Increased risk of extreme weather events.

European Commission (2021a) EU-level technical guidance on adapting buildings to climate change. Available at: https://c.ramboll.com/adapting-buildings.

European Commission (2021b) EU-level technical guidance on adapting buildings to climate change - Best Practice Guidance. Available at: https://c.ramboll.com/adapting-buildings.

European Commission (no date) *European Drought Observatory*. Available at: https://edo.jrc.ec.europa.eu/edov2/php/index.php?id=1000 (Accessed: 1 July 2023).

Ministry of the Environment (2021) S*trategy for adapting to climate change in the conditions of the Czech Republic*. Available at: https://www.mzp.cz/cz/zmena_klimatu_adaptacni_strategie (Accessed: 1 July 2023).

United Nations Environment Programme (2021) A Practical Guide to Climate-resilient Buildings & Communities.

UNDRR (2022) Technical Guidance on Comprehensive Risk Assessment and Planning in the Context of Climate Change. Available at: https://www.undrr.org/publication/technical-guidance-comprehensive-risk-assessment-and-planning-context-climate-change.

## Response Capability - R.CAP

*This category encompasses actions and strategies to minimise damage and save lives after disruptions. The strategies presented in the criteria should be applied after an emergency has passed, and they should include activities for resuming normal building systems activity, such as repairing the damages and restoring essential services.*

## CAP.SS – Safe equipped space

### Intent of the criterion

Provide building users with a safe room equipped with some supplies in the event of an emergency.

### Scale

### Description

A secure space incorporates essential provisions that building occupants may require for survival during a disaster. Ensuring easy accessibility during emergencies is imperative, and the room should be adequately equipped.

### Hazards

### SBToolCZ-related criteria

n/a

### Indicator (qualitative)

Presence/absence of a dedicated emergency space and safety kits.

### Evaluation modules

- CAP.SS1 - Fundamental safety
- CAP.SS2 - Safe room

### Overall evaluation of the criterion

The final criterion rating is calculated according to the following equation:

$$K_{CAP.SS} = K_{CAP.SS1} + K_{CAP.SS2}$$

### CAP.SS$_1$ | FUNDAMENTAL SAFETY

Provide these items in a safe Kit Storage Location within the building or within the safe room.

| *Item* | *Description* | *Points* $K_{CAP.SS1}$ |
|---|---|---|
| A | Emergency lighting stored in the common areas of the building<br>*Provide space where flashlights can be stored and used in case of blackout* | +1 |
| B | Biodegradable and sanitising compounds to encapsulate waste<br>*There must be a safe waste container to avoid disease spread.* | +1 |

**$CAP.SS_2$ | SAFE ROOM**

| Item | Description | Points $K_{CAP.SS2}$ |
|---|---|---|
| A | Residential safe room<br>*A safe room is serving occupants of dwelling units and having a designed occupant capacity of at least 3.5 m2/person per floor. Safe rooms should be in areas at low risk of flooding.* | +2 |
| B | Community safe room<br>*Any safe room that is not defined as a residential safe room. This includes safe rooms intended for use by the general public, by building occupants, or a combination of both providing life-safety protection. Safe rooms should be in areas at low risk of flooding.* | +1 |

*For mid-rise buildings, the optimal refuge areas are typically situated on the lower floors and in the central sections of the building. Stairwells, especially those with reinforced concrete walls, generally offer the most suitable refuge options. If the stairwells cannot accommodate the occupant load adequately, restrooms typically serve as the next best refuge areas.*

**Documentation guidance**

- Present a plan illustrating how a safe room could function as storage for emergency items.
- Offer a floor plan delineating the locations of safe rooms.
- Include maps indicating travel routes to the community safe room from outside the building, specifying the path to the safe room.

**Recommendations**

The building manager should host and facilitate a yearly no-cost or very low-cost education event open to the building users covering safety and climate-resilience topics. Presentations should be provided by knowledgeable persons and organizations to train building users on how to identify what types of disasters are most likely to happen in the area and learn about how to prepare for each. Practice the plan regularly (every six months). Stored food and water should be replaced every three months.

In the case of users with special needs, it is important to establish a support network in advance and keep all the necessary equipment (e.g., extra wheelchair batteries, oxygen, catheters, medications, etc.) on hand.

**Specific criterion limits**

The final criterion score is calculated according to the following table for linear interpolation:

| *Points* $K_{CAP.SS}$ | *Points* |
|---|---|
| 0 | 0 |
| 5 | 10 |

**Literature**

Federal Emergency Management Agency (FEMA) (2021) Fact Sheet Flood Hazard Siting and Elevation Criteria for Residential Safe Rooms.

Federal Emergency Management Agency (FEMA) (2020) How to Build a Kit for Emergencies. Available at: https://www.fema.gov/press-release/20210318/how-build-kit-emergencies (Accessed: 2 May 2023).

Habitat for Humanity (no date) Disabilities and special needs. Available at: https://www.habitat.org/our-work/disaster-response/disaster-preparedness-homeowners/disabilities-special-needs (Accessed: 6 May 2023).

Habitat for Humanity (no date) Disaster preparedness for homeowners. Available at: https://www.habitat.org/our-work/disaster-response/disaster-preparedness-homeowners (Accessed: 6 May 2023).

Habitat for Humanity (no date) Disaster supply kit. Available at: https://www.habitat.org/our-work/disaster-response/disaster-preparedness-homeowners/disaster-supply-kit (Accessed: 6 May 2023).

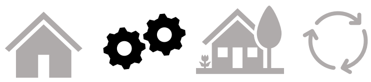
Ready.gov (2023) Build A Kit. Available at: https://www.ready.gov/kit (Accessed: 4 May 2023).

## CAP.PS – Emergency power supply

### Intent of the criterion

Provide power supply for building users during common emergencies/disasters for at least a 96-hour period (four days).

### Scale



### Description

Mid-rise residential buildings should be outfitted with backup power to support critical functions, such as operating a single elevator and a fire suppression pump. The necessity for backup power escalates further if residents must shelter in place during power outages. It is imperative to ensure the availability of adequate emergency power to sustain essential loads identified by the design team as crucial for the building's operation and to facilitate repairs during and after a disruptive event. The specific critical loads will vary depending on the project.

### Hazards

### SBToolCZ-related criteria

C.MAR Measurement of energy and water consumption

### Indicator (qualitative)

Presence/absence of emergency power supply.

### Evaluation modules

• CAP.PS1 - Back-up power for critical loads

### Overall evaluation of the criterion

The final criterion rating is calculated according to the following equation:

$$K_{CAP.PS} = K_{CAP.PS1}$$

### CAP.PS$_1$ | BACK-UP POWER FOR CRITICAL LOADS

Provide power source for at least 3 power demands for 4 consecutive days, 24 hours daily. The backup power generator should be located above the flood levels.

| *Item* | *Description* | *Points* $K_{CAP.PS1}$ |
|---|---|---|
| A | Install a proper-sized back-up generator (e.g., Propane/LPG (Liquified Petroleum Gas) generator, Natural gas generator, Diesel or bio-diesel generator, Combined heat and power (cogeneration) generators)<br>*Consider what systems will be connected to the generator's emergency circuit. The higher the power needs, the more complex and costly the system must be.* | +1 |
| B | Operation of fuel-fired heating system with stored emergency fuel. | +1 |
| C | Operation of a fan sufficient to provide emergency cooling if mechanical air conditioning equipment cannot operate (e.g., ceiling fans, plug-in window fans, or fans integral with central air distribution). | +1 |
| D | Operation of water pumps if needed to make potable water available to occupants (if pumps are required for the distribution of water within the building). | +1 |
| E | Place a non-maintained lighting type to define a path of egress to all required exits and in the escape route.<br>*Emergency escape lighting is lighting that activates and provides illumination when the lighting system fails in an emergency/power loss.* | +1 |
| F | Operation of cable modem and wireless router or other means of providing online access within the building. | +1 |

**Documentation guidance**

- Furnish a roster detailing the critical loads supported by the backup power system, accompanied by calculations for kWh electricity demand derived from the duration of service.
- Supply technical drawings depicting backup power equipment, along with product data sheets clearly delineating their power production capacity.

**Recommendations**

Create a maintenance schedule that includes regular generator testing and periodic rotation of stored liquid fuel to ensure its availability and freshness when required.

**Specific criterion limits**

The final criterion score is calculated according to the following table for linear interpolation:

| *Points* $K_{CAP.PS}$ | *Points* |
|---|---|
| 0 | 0 |
| 6 | 10 |

**Literature**


FEMA. (2012). Engineering: Principles and Practices for Retrofitting Flood-Prone Residential Structures (Issue January).

Hachem-Vermette, C., & Yadav, S. (2023). Impact of Power Interruption on Buildings and Neighborhoods and Potential Technical and Design Adaptation Methods. Sustainability, 15(21), 15299. https://doi.org/10.3390/SU152115299

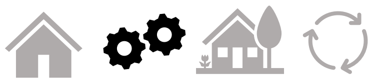
Schmitz, W. I., Schmitz, M., Canha, L. N., & Garcia, V. J. (2020). Proactive home energy storage management system to severe weather scenarios. Applied Energy, 279, 115797. https://doi.org/10.1016/J.APENERGY.2020.115797

## CAP.WS – Emergency water supply

**Intent of the criterion**

Provide water access for building users during common emergencies/disasters for at least a 96-hour period (four days).

**Scale**



**Description**

Planning for access to water during a power outage or storm-related event starts with water conservation and can include reusing water on-site, such as harvested rainwater or recycled greywater for storage and later use during emergencies to cover operations such as toilet flushing, mechanical equipment, and irrigation.

**Hazards**

**SBToolCZ-related criteria**

E.ZSV Retention of rainwater

C.MAR Measurement of energy and water consumption

**Indicator (qualitative)**

Presence/absence of water supply in case of an emergency.

**Evaluation modules**

• CAP.WS1 - Access to potable water

**Overall evaluation of the criterion**

The final criterion rating is calculated according to the following equation:

$$K_{CAP.WS} = K_{CAP.WS1}$$

**CAP.WS$_1$ | ACCESS TO POTABLE WATER**

Guarantee water supply for a period of at least 96 hours in case of an emergency.

| *Item* | *Description* | *Points* *$K_{CAP.WS1}$* |
|---|---|---|
| A | Use of waterless urinals or composting toilets | +1 |
| B | Provide on-site water storage to cover operations<br>*Each square meter of roof area captures 7.37 litres of rainwater for one centimetre of rainfall. Sizing the system: storage tank capacity (litres) = water catchment area (m2) x rainfall (cm) x 7.37, where rainfall = peak monthly average.* | +1 |
| C | Recycling greywater to cover operations and reduce building sewage conveyance by 25% or more | +1 |

| | | |
|---|---|---|
| | *Install a greywater treatment system.* | |
| D | Utilisation of a well connected to groundwater sources (e.g., aquifer) for drinking water supply<br>*The installation of the well must be in a location as far as possible from potential sources of pollution. The groundwater is subject to prior safety analysis* | +1 |
| E | Installation of standby or emergency pump for water supply<br>*An engineer will calculate the pump power and then determine the most suitable energy source, ideally opting for renewable energy.* | +1 |

**Documentation guidance**

- Supply floor maps indicating the installation of the equipment, such as waterless toilets in bathrooms or the filtration system, accompanied by technical details and a factsheet.
- Submit a report detailing and describing calculations for water storage and/or water treatment functions, along with using the filtered water.
- Submit a report detailing the calculation for the pump and the operation data.

**Specific criterion limits**

The final criterion score is calculated according to the following table for linear interpolation:

| *Points* $K_{CAP.WS}$ | *Points* |
|---|---|
| 0 | 0 |
| 5 | 10 |

**Literature**


Kubba, S. (2017). Water Efficiency and Sanitary Waste. Handbook of Green Building Design and Construction, 413–441. https://doi.org/10.1016/B978-0-12-810433-0.00008-3

Olanrewaju, O. (2015). Assessment of a Waterless Toilet. Journal of Scientific Research and Reports, 8(3), 1–10. https://doi.org/10.9734/JSRR/2015/18461

Peirce, J. J., Weiner, R. F., & Vesilind, P. A. (1998). Wastewater Treatment. Environmental Pollution and Control, 105–123. https://doi.org/10.1016/B978-075069899-3/50009-2

Ministry of the Environment (n.d) Groundwater. https://www.mzp.cz/cz/podzemni_vody

Czech Hydrometeorological Institute (n.d.). Monthly State of Groundwater. https://www.chmi.cz/aktualni-situace/hydrologicka-situace/podzemni-vody/stav-podzemnich-vod/mesicni-stav

Mohammad, T. (2021) Chapter Seventeen - Water desalination, purification, irrigation, and wastewater treatment, 393-433, in Empowering a Sustainable, Competitive, and Secure Twenty-First Century. https://doi.org/10.1016/B978-0-12-821605-7.00004-0

## Community Cohesion - R.COM

*This category presents criteria established to improve the net quality of life of the residents. This means that efforts are being made to ensure that people are safe, secure, and productive by providing access to resources such as transportation and services and educating them on responding to unexpected events.*

## COM.SS – Access to useful shared spaces

### Intent of the criterion

Enhance community interaction by developing new shared spaces, such as common rooms, gardens, playgrounds, and recreational facilities for social gatherings.

### Scale

### Description

By sharing resources, goods, and services, urban resilience can be enhanced by reducing the need for new materials and infrastructure, supporting local economies, and strengthening social networks. Using communal spaces such as kitchens, living rooms, laundries, and gardens results in more efficient use of materials and space. They also provide spaces for social interaction.

### Hazards

### SBToolCZ-related criteria

L.DVM Availability of public places for relaxation

S.EXT Use of the exterior of the building

S.KOM User comfort

### Indicator (quantitative)

Number of available useful community spaces.

### Evaluation modules

• COM.SS$_1$ - Shared spaces

### Overall evaluation of the criterion

The final criterion rating is calculated according to the following equation:

$$K_{COM.SS} = K_{COM.SS1}$$

### COM.SS$_1$ | SHARED SPACES

| *Item* | *Description* | *Points $K_{COM.SS1}$* |
|---|---|---|
| A | Bike storage space | +1 |
| B | Car share space | +1 |
| C | Garden/terrace/patio space | +1 |
| D | Tool share space | +1 |
| E | Usable open space (i.e., an area for barbecue, a playground, etc.) | +1 |
| F | Recreation rooms/spaces | +1 |

| | | |
|---|---|---|
| G | Communal kitchen | +1 |
| H | Communal laundry room | +1 |
| I | Fitness facilities | +1 |
| J | Coworking areas | +1 |
| K | Any other space that is accessible to multiple residents at the same time | +1 (each – max 3) |

**Documentation guidance**

- Drawing proof showing floor/site plans with shared spaces highlighted and described.

**Specific criterion limits**

The final criterion score is calculated according to the following table for linear interpolation:

| *Points* $K_{COM.SS}$ | *Points* |
|---|---|
| 0 | 0 |
| 13 | 10 |

**Literature**


Castaño-Rosa, R. et al. (2022) 'Resilience in the built environment: Key characteristics for solutions to multiple crises', Sustainable Cities and Society, 87(October). doi: 10.1016/j.scs.2022.104259.

Neykova, L. (2022). Design of communal housing spaces to stimulate social interaction and promote social cohesion among (older) tenants. Technische Universiteit Eindhoven.

Wynne, L. and Riedy, C. (2018) 'Precinct-scale Innovation and the Sharing Paradigm', in Building Urban Resilience through Change of Use, pp. 21–37. doi: 10.1002/9781119231455.ch2.

Devmini Bandara W.H.M.S. et al. (2020) 'An investigation on community spaces in condominiums and their impact on social interactions among apartment dwellers concerning the city of Colombo', Social Sciences & Humanities Open, Volume 2, Issue 1, 100043, ISSN 2590-2911, https://doi.org/10.1016/j.ssaho.2020.100043.

He, X. (2018) 'Study of Interior Public Spaces for the Promotion of Social Interaction in High-rise Residential Buildings'. Rochester Institute of Technology. https://repository.rit.edu/theses/9974

## COM.UG – Urban gardening

**Intent of the criterion**

Production of local food by sustainably growing, efficiently cultivating, and responsibly consuming food within building surroundings.

**Scale**

**Description**

Local food production is a method to produce food in systems and practices that are not polluting, are season-based, reduce GHG emissions and waste, and build resilience through the food value chain.

Local food sourcing can reconnect people with local food production, supporting efficient development, equitable distribution, and sustainable food consumption. It can also be an opportunity for meeting and sharing ideas and activities, i.e., benefits people can derive from ecosystems, such as food, ornamental flowers, nature education, and regulating services such as air filtration, noise reduction, and surface water drainage.

**Hazards**

**SBToolCZ-related criteria**

L.DVM Availability of public places for relaxation

E.ZEL Greenery on the building and land

**Indicator (qualitative)**

Absence/presence of food production system in the building surroundings.

**Evaluation modules**

• COM.UG$_1$ - Urban gardening

**Overall evaluation of the criterion**

The final criterion rating is calculated according to the following equation:

$$K_{COM.UG} = K_{COM.UG1}$$

**COM.UG$_1$ | URBAN GARDENING**

The building users manage urban community gardens, who also enjoy these spaces for health promotion, social interaction, and recreation. Provide a dedicated portion of the site for onsite food production: gardens or planters with vegetables and/or edible nut- and fruit-bearing plants appropriate to the site. Roofs, if suitable, can be considered as part of the vegetated area.

| *Item* | *Description* | *Points* $K_{COM.UG1}$ |
|---|---|---|
| A | Dedicate >5% of the site's final vegetated area to food production (not below ca 1.5 m$^2$ per residential unit) | +3 |
| B | 2 different production crops (e.g., vegetables and/or edible nut- and fruit-bearing plants) | +1 |
| C | Use of harvested rainwater for watering | +1 |

**Documentation guidance**

- Drawing proof illustrating food production locations and species on the site, in greenhouses, and/or on roofs with dimensions that demonstrate the amount of space reserved for food production.
- Calculations demonstrate that the area for food production meets the prescribed thresholds (square meters per residential unit).
- Documentation describing how the area will be distributed to all users or homeowners. Ensure that the section of the site assessment describing the site conditions is complete and accurate.
- Supplemental documentation confirming permanent infrastructure (if any).
- Supplemental documentation about distributing/selling food produced to the community (e.g., farmers' market, local food sources, restaurants, schools, hospitals, and community-supported agriculture) - if planned.
- A signed letter from the building/tenant space owner confirming the commitment to the food distribution program over a three-year period.

**Recommendations**

- Consider using organic waste generated on-site as a substitute for traditional fertiliser (e.g., grass clippings or compost)
- Food crops may be adversely affected by contaminated soils. Sites need to be evaluated for their suitability for food production (e.g., be aware of sites that have previously been developed for nut or fruit production, as well as brownfield sites that may contain contaminated soils). It is recommended that only a qualified environmental professional determine the site's suitability for food production.
- Provide alternative spaces for food production and reduce risk by using different gardening methods (e.g., greenhouses, raised beds, container gardens) when contaminated soils are present.
- Utilize rainwater harvesting to minimise the usage of potable water.

**Specific criterion limits**

The final criterion score is calculated according to the following table for linear interpolation:

| *Points* $K_{COM.UG}$ | *Points* |
|---|---|
| 0 | 0 |
| 5 | 10 |

**Literature**

Green Business Certification (2014) *SITES v2 Rating System For Sustainable Land Design and Development*.

McEldowney, J. (2017) *Urban agriculture in Europe Patterns, challenges and policies*, *European Parliamentary Research Service*. doi: 10.2861/413185.

Ramaswami, A. *et al.* (2020) 'A hybrid method to quantify household urban agriculture gardening : Implications for sustainable and equitable food action planning', *Frontiers in Sustainable Food System*, 6. doi: 10.3389/fsufs.2022.997081.

Sany, E. *et al.* (2018) 'Eco-Efficiency Assessment and Food Security Potential of Home Gardening : A Case Study in Padua, Italy', *Sustainability*, 10(2124). doi: 10.3390/su10072124.

Spilkova, J. (2015) 'New urban gardening trends in Prague: community and ecosystem services on stage', in *Agriculture in an Urbanizing Society: Reconnecting Agriculture and food chains to Societal Needs*. Rome, Italy, pp. 237–238.

UN Food and Agriculture Organization (2020) *COVID-19 and the role of local food production in building more resilient local food systems*. doi: 10.4060/cb1020en.

## COM.EP – Emergency preparedness

### Intent of the criterion

Enhancement of emergency preparedness through the installation of warning systems and smart technology for people with special needs.

### Scale

### Description

Technology is rapidly shaping the way we approach safety in residential settings. From smart devices to artificial intelligence, these advancements enable proactive hazard detection and offer unprecedented control to building users. Warning systems are key elements of climate change adaptation and disaster risk reduction and aim to avoid or reduce the damage caused by hazards. To be effective, warning systems need to actively involve the people and communities at risk from a range of hazards, disseminate messages and warnings efficiently and ensure that there is a constant state of preparedness, and that early action is enabled.

### Hazards

### SBToolCZ-related criteria

n/a

### Indicator (qualitative)

Presence of warning systems within the building.

### Evaluation modules

- COM.EP$_1$ - Warning system

### Overall evaluation of the criterion

The final criterion rating is calculated according to the following equation:

$$K_{COM.EP1} = K_{COM.EP1}$$

**COM.EP$_1$ | WARNING SYSTEM**

| *Item* | *Description* | *Points* $K_{COM.EP1}$ |
|---|---|---|
| A | Heat warning system<br>*Have fixed-temperature elements and respond to the temperature of the fire gases near the heat alarm.* | +1 |
| B | Flood warning system<br>*Senses the presence of water and can provide early warning of leaks if placed near the floor in basements and drain areas.* | +1 |
| C | Multi-sensor warning system<br>*Detect more than one phenomenon, for example, optical and heat detection.* | +1 |
| D | Guarantee that the installed systems are adequate also for people with special needs | +1 |

**Documentation guidance**

- Provide drawings to show where these systems are located and a report that describes how the technology works.

**Specific criterion limits**

The final criterion score is calculated according to the following table for linear interpolation:

| *Points* $K_{COM.EP}$ | *Points* |
|---|---|
| 0 | 0 |
| 3 | 10 |

**Recommendations**

Building owners and managers should provide emergency preparedness information in alignment with the schedule for the fire and emergency preparedness guide mandated by the Fire Department, including at the time of lease signing. It is also advisable to conduct emergency preparedness training periodically within the building.

**Literature**

Bae Y. et al. (2021), 'Sensor impacts on building and HVAC controls: A critical review for building energy performance', *Advances in Applied Energy*, Volume 4, 100068, ISSN 2666-7924, https://doi.org/10.1016/j.adapen.2021.100068.

Sufri S. et al. (2020), 'A systematic review of Community Engagement (CE) in Disaster Early Warning Systems (EWSs)', *Progress in Disaster Science*, Volume 5, 100058, ISSN 2590-0617,

https://doi.org/10.1016/j.pdisas.2019.100058.

Sharifi A. et al. (2021), 'A systematic review of the health co-benefits of urban climate change adaptation', *Sustainable Cities and Society*, Volume 74, 103190, ISSN 2210-6707, https://doi.org/10.1016/j.scs.2021.103190.

Šakić Trogrlić, R. et al. (2022), ‘Early Warning Systems and Their Role in Disaster Risk Reduction’ In: Golding, B. (eds) *Towards the “Perfect” Weather Warning*. Springer, Cham. https://doi.org/10.1007/978-3-030-98989-7_2

# Appendix B – Exctracts from the Calculation tool

*This appendix provides a comprehensive collection of screenshots from the Resilience Module calculation tool, organized criterion by criterion, for three distinct building case studies. The screenshots illustrate the step-by-step assessment and scoring process for each criterion of the Resilience Module, allowing for a clear comparison and understanding of the resilience performance across the different case studies. It also serves as a visual reference to validate the data and results discussed in the main body of the thesis.*

## Case study 1 – X-LOFT multi-residential building

PREPAREDNESS

### PRE.WA – Wayfinding and accessibility

*Intent of the evaluation*

Design the project to provide safe and appropriate access for every user in and around the building site integrating it with its

*Description*

Wayfinding and navigation technologies are strategic in improving the quality of life of people and in case of extreme shocks. The process of wayfinding refers to how individuals find their way around a space or along a pathway. Graphic design, architectural design, and landscape design are all included in this field. The use of signage can assist in wayfinding. By using consistent environmental clues, wayfinding facilitates problem-solving and movement within spaces. Several design features that facilitate wayfinding, such as lines on the ground indicating a way out and symbols and colours indicating the locations of toilets, accessible toilets, lifts and exits can be used. This reflects that homes must be safe for all occupants, regardless of age or ability.

*Indicator (qualitative)*

Provision of clear access, safety and wayfinding measures in order to accommodate emergency services for every user.

*Evaluation modules*

PRE.WA1 – Wayfinding and accessibility

| PRE.WA1 – Wayfinding and accessibility | | (max 6 points) |
|---|---|---|
| Item | YES/NO | pt |
| A - Accessibility of the building (public transports, parking, etc.) | | |
| Severely disable | YES | 2 |
| Reduced mobility | - | 0 |
| Blind | YES | 2 |
| Partially blind | - | 0 |
| Deaf | YES | 2 |
| Partially deaf | - | 0 |
| B - Accessibly of entrance areas - exterior and interior | | (max 6 points) |
| Severely disable | NO | 0 |
| Reduced mobility | YES | 1 |
| Blind | NO | 0 |
| Partially blind | NO | 0 |
| Deaf | YES | 2 |
| Partially deaf | - | 0 |
| C - Horizontal movement in the building | | (max 6 points) |
| Severely disable | NO | 0 |
| Reduced mobility | YES | 1 |
| Blind | YES | 2 |
| Partially blind | - | 0 |
| Deaf | YES | 2 |
| Partially deaf | - | 0 |
| D - Vertical movement in the building | | (max 6 points) |
| Severely disable | NO | 0 |
| Reduced mobility | YES | 1 |
| Blind | YES | 2 |
| Partially blind | - | 0 |
| Deaf | YES | 2 |
| Partially deaf | - | 0 |
| E - Hygienic areas and changing rooms | | (max 6 points) |
| Severely disable | NO | 0 |
| Reduced mobility | NO | 0 |
| Blind | NO | 0 |
| Partially blind | NO | 0 |
| Deaf | NO | 0 |
| Partially deaf | NO | 0 |
| F - Special equipment and interiors | | (max 6 points) |
| Severely disable | NO | 0 |
| Reduced mobility | NO | 0 |
| Blind | NO | 0 |
| Partially blind | NO | 0 |
| Deaf | NO | 0 |
| Partially deaf | NO | 0 |
| G - Clear signage and wayfinding | NO | 0 |
| **Value KWA1** | - | 19 |

*Overall evaluation*

KPRE.WA = KPRE.WA$_1$

**Total value K** 19

**pt** 5

*min 0 - max 10*

PREPAREDNESS

### PRE.SA – Rapid site assessment

*Intent of the evaluation*

Identification of the probability, intensity, and timescale of the most likely happening hazards (floods, heavy precipitation and storm, heatwaves, subsidence, and drought) of a specific location.

*Description*

Several factors should be considered when characterizing the risks associated with climate change in a specific location, such as the climate threat, the geographical context (e.g., coastal area, mountain region), and the affected systems and sectors (e.g., people, infrastructure, properties, etc.) as well as the impacts on the most vulnerable groups. The purpose of site risk assessments is to determine the likelihood of future climate hazards occurring and the potential impacts on buildings and their users. Climate action and adaptation strategies must be prioritized based on this information.

*Indicator (qualitative)*

Assessment of exposure to specific hazards to identify those that are most likely to occur.

*Evaluation modules*

PRE.SA1 - Site Risk Assessment

| PRE.SA1 - Site risk assessment | | |
|---|---|---|
| Item | YES/NO | pt |
| A - Perform an hazards assessment | NO | 0 |
| B - Perform the site risk assessment through a workshop | NO | 0 |
| **Value KSA1** | - | 0 |

*Overall evaluation*

KPRE.SA = KPRE.SA$_1$

**Total value K** 0

**pt** 0

*min 0 - max 10*

PREPAREDNESS

## PRE.US – Unsuitable sites

***Intent of the evaluation***

Avoid building on sites prone to natural hazards.

***Description***

Natural events such as earthquakes and sinkhole formation can increase building maintenance costs due to structural damage and pose higher risks to residents in vulnerable areas. Those living in floodplains need additional protection through costly defences. Planning and building regulations should ensure designs account for potential exceedance scenarios, and it is preferable to avoid construction in floodplain areas due to their higher risk of flooding.

***Indicator (qualitative)***

Efforts to avoid or mitigate site-related risks by building in safe sites.

***Evaluation modules***

PRE.US1 - Avoidance of flood-prone areas
PRE.US2 - Avoidance of adverse geology areas

| **PRE.US1 - Avoidance of flood-prone areas** | | (max 2 points) |
|---|---|---|
| Item | YES/NO | pt |
| No floodplain and not flood risk | YES | 2 |
| Build above the 100-year floodplain | NO | 0 |
| Build above the 500-year floodplain | NO | 0 |
| **Value KUS1** | - | **2** |

| **PRE.US2 - Avoidance of adverse geology areas** | | (max 2 points) |
|---|---|---|
| Item | YES/NO | pt |
| Identification of any faults, low lying coastline or karst areas | NO | 0 |
| Establish a program for monitoring | NO | 0 |
| The area is not threatened by any kind of geological activity. | YES | 2 |
| **Value KUS2** | - | **2** |

***Overall evaluation***

| | | |
|---|---|---|
| KPRE.GW = KPRE.GW1 + KPRE.GW2 | **Total value K** | **4** |
| | **pt** | 10 |
| | | *min 0 - max 10* |

REDUNDANCY

## RED.PS – Passive survivability

*Intent of the evaluation*

Ensure that the building passively maintain safe thermal conditions during a disruptive event (i.e., extended power outage or loss of heating fuel).

*Description*

Passive survivability refers to a building's ability to maintain critical life-support conditions in the event of extended loss of power, heating fuel, or water. Passive thermal performance refers to heat transfer between a building and its surroundings, mainly without AC systems. Passive solar systems collect and distribute energy from the sun without the use of mechanical equipment such as fans or pumps.

*Indicator (qualitative)*

Absence/presence of passive systems for heating, cooling, and lighting.

*Evaluation modules*

RED.PS1 - Passive solar heating
RED.PS2 - Passive cooling
RED.PS3 - Passive lighting
RED.PS4 - Thermal safety temperature

| RED.PS1 - Passive solar heating | | (max 3 points) |
|---|---|---|
| Item | YES/NO | pt |
| DIRECT GAIN | | |
| A - Equator-facing glass | YES | 1 |
| B - Solar-facing clerestories and sloped skylights | YES | 1 |
| C - Solar chimney | NO | 0 |
| D - Sunspace | NO | 0 |
| INDIRECT GAIN | | |
| E - Increased thermal mass | YES | 1 |
| F - Thermal storage wall | NO | 0 |
| G - Thermal zoning | NO | 0 |
| **Value KPS1** | | 3 |

| RED.PS2 - Passive cooling | | (max 4 points) |
|---|---|---|
| Item | YES/NO | pt |
| PREVENTIVE TECHNIQUES | | |
| A - Shading (vertical and operable) | YES | 1 |
| B - Internal gain control | YES | 1 |
| MODULATION AND HEAT DISSIPATION TECHNIQUES | | |
| C - Cross ventilation | YES | 1 |
| D - Stack ventilation | NO | 0 |
| E - Night flushing | NO | 0 |
| F - Radiative cooling or evaporation cooling | NO | 0 |
| G - Earth coupling | NO | 0 |
| H - Cold roof or double roof | NO | 0 |
| **Value KPS2** | | 3 |

| RED.PS3 - Passive lighting | | |
|---|---|---|
| Item | YES/NO | pt |
| A - Building form and layout | YES | 1 |
| B - Daylighting from multiple sides | YES | 1 |
| C - Solar zoning | NO | 0 |
| D - High efficacy egress lighting | YES | 1 |
| **Value KPS3** | | 3 |

| RED.PS4 - Thermal safety temperature | Select just one option | |
|---|---|---|
| Item | YES/NO | pt |
| >27°C | NO | 0 |
| 26.5 °C | NO | 0 |
| 26.0 °C | YES | 2 |
| 25.5 °C | NO | 0 |
| <25.0 °C | NO | 0 |
| **Value KPS4** | | 2 |

*Overall evaluation*

KRED.PS = KRED.PS1+KRED.PS2+KRED.PS3+KRED.PS4 **Total value K** 11

**pt** 8

*min 0 - max 10*

PREPAREDNESS

## PRE.VE – Conserve and use appropriate vegetation

*Intent of the evaluation*

Improve landscape performance and conserve the original vegetation by installing only plants that are appropriate for site conditions, climate, and design intent.

*Description*

Conserve existing native plants and/or introduce new ones. A tree-planting initiative will only be successful if the trees are well-suited to the environment and can withstand extreme temperatures, drought, storms, and flooding. Ideally, mature native trees from local areas that are already acclimated to the region should be used. Additionally, stormwater trees enhance urban biodiversity, improve soil quality, and benefit aquatic environments.

*Indicator (qualitative)*

Absence/presence of native and climate-tolerant vegetation.

*Evaluation modules*

PRE.AV1 - Conserve and use appropriate vegetation

| PRE.VE - Conserve and use appropriate vegetation | | |
|---|---|---|
| Item | YES/NO | pt |
| Plant single tree pits in the building surrounding | YES | 1 |
| Replant and conserve existing trees, if they were moved, before use new ones | YES | 2 |
| Plant continuous tree pit in the building surrounding | NO | 0 |
| Plant trees in strategic locations to serve as windbreaks | NO | 0 |
| Choose climate-tolerant trees (i.e., drought-tolerant) | NO | 0 |
| **Value KVE1** | - | 3 |

*Overall evaluation*

$KPRE.VE = KPRE.VE_1$ **Total value K** 3

**pt** 3

*min 0 - max 10*

ROBUSTNESS

## ROB.HR – Heavy precipitation-resistant building envelope and

*Intent of the evaluation*

Minimization of damage caused by heavy precipitation. The implemented strategies help to reduce the amount of rainwater runoff from the building by collecting and storing it, while also helping to reduce any potential flooding.

*Description*

Buildings can be damaged by heavy precipitation. The result can be structural damage, flooding, and water damage that may be expensive to repair. Precautionary measures such as proper waterproofing, proper drainage, and regular maintenance can help reduce the potential for damage.

*Indicator (qualitative)*

Rating of the readiness of the building for facing a heavy precipitation.

*Evaluation modules*

ROB.HR1 - Heavy precipitation-resistant building solutions

**RES.HR1 - Heavy precipitation-resistant building solutions**

| Item | YES/NO | pt |
|---|---|---|
| **BUILDING SHAPE** | | |
| Avoid square and rectangular flat surfaces | YES | 0.5 |
| **STRUCTURE** | | |
| Passive landslide control measures | NO | 0 |
| Ground preparation | NO | 0 |
| **WALLS** | | |
| Green façade | YES | 0.5 |
| Rainscreen with a drainage system within the wall | NO | 0 |
| **OPENINGS** | | |
| Tempered glass panel (e.g., 4-mm thickness) | YES | 0.5 |
| Hail-proof shutters and blinds | NO | 0 |
| Secure loose joints by cramping, gluing, re-wedging and pinning | NO | 0 |
| Effective sealants and waterproof membranes | YES | 0.5 |
| **ROOF** | | |
| Hail net for protecting roof fragile elements | NO | 0 |
| Heat tracing in gutters | NO | 0 |
| Type of roof (e.g., warm, inverted, blue, blue-green, green) | NO | 0 |
| Pitched roof | NO | 0 |
| **PREFERRED MATERIALS** | | |
| Water-resistant materials | YES | 0.5 |
| Infiltration trenches | NO | 0 |
| Metal for roofing | NO | 0 |
| **BUILDING SERVICES** | | |
| Proper dimensioned drainage network | NO | 0 |
| Disconnect surface water from sewage | NO | 0 |
| Rainwater tanks | YES | 0.5 |
| Devices anti-backflow | NO | 0 |
| **SURROUNGINS** | | |
| Sustainable urban drainage (e.g., rain gardens and swales) | NO | 0 |
| Drainage systems in the building surroundings (e.g., sump pump) | NO | 0 |
| Permeable soil | YES | 0.5 |
| | **Value KHR1** | 3.5 |

*Overall evaluation*

KROB.HR = $KROB.HR_1$

**Total value K** 3.5

**pt** 3

*min 0 - max 10*

REDUNDANCY

## RED.AP – Alternative power sources

*Intent of the evaluation*

Reduction of the amount of operational non-renewable primary energy (PERNT) in the building, meeting the energy demand with renewable energy (PERT).

*Description*

The relatively low price of fossil fuels has made them the primary energy source in the energy sector. Nevertheless, it is better to refrain from relying on finite and polluting energy sources in the future as the global energy demand is forecast to rise. Over the past decade, there has been a positive shift towards the expansion of renewable energy capacity, both locally and internationally.

*Indicator (qualitative and quantitative)*

Annual PERNT and PERT consumption in kWh per 1 m2 [kWh/(m2.a)] and list of renewable energy sources.

*Evaluation modules*

RED.AP1 – Annual primary energy consumption

RED.AP2 – Renewable power sources

**RED.AP1 - Annual primary energy consumption** — Select just one option

| Item | YES/NO | pt |
|---|---|---|
| **DIRECT GAIN** | | |
| <5% of energy needs from renewable sources | YES | 1 |
| <15% of energy needs from renewable sources | NO | 0 |
| <30% of energy needs from renewable sources | NO | 0 |
| <50% of energy needs from renewable sources | NO | 0 |
| Net positive amount from renewable sources | - | 0 |
| | **Value KAP1** | 1 |

**RED.AP2 – Renewable power sources** (max 4 points)

| Item | YES/NO | pt |
|---|---|---|
| On-site solar energy production, e.g., PV panels | YES | 1 |
| Connection to district heating and/or cooling | NO | 0 |
| Wind access | NO | 0 |
| Biomass | NO | 0 |
| Geothermal | NO | 0 |
| Hydrogen/fuel cells | NO | 0 |
| | **Value KAP2** | 1 |

*Overall evaluation*

KRED.AP = KRED.AP1+KRED.AP2

**Total value K** 2

**pt** 2

*min 0 - max 10*

## ROB.HW – Heat wave-resistant building envelope and structure

*Intent of the evaluation*

Ensure thermal comfort for building users during a heatwave.

*Description*

Heat waves occur when a particular region experiences prolonged periods of extremely high temperatures. Due to climate change, periods of high temperatures and heat waves will increase in intensity and duration throughout Europe. Human health, well-being, and productivity can be adversely affected by high indoor temperatures; solutions must be identified for safeguarding well-being and ensuring thermal comfort.

*Indicator (qualitative)*

Rating of the readiness of the building for facing a heat wave.

*Evaluation modules*

ROB.HW1 – Heatwave adaptation solutions

**ROB.HW1 - Flood-resistant building solutions**

| Item | YES/NO | pt |
|---|---|---|
| **BUILDING SHAPE** | | |
| A - Façade orientation | YES | 0.5 |
| **OPENINGS** | | |
| B - Adequate insulation of windows, doors and walls | YES | 0.5 |
| C - Solar shading for windows (e.g., blinds, shutters, brise-soleil) | YES | 0.5 |
| **WALLS** | | |
| D - Green façades | YES | 0.5 |
| E - Joints movement | NO | 0 |
| **ROOF** | | |
| F - Photovoltaic panels installation | YES | 0.5 |
| H - Green roof | NO | 0 |
| **PREFERRED MATERIALS** | | |
| I - Light-colored and reflective materials (e.g., solar reflective tiles) | YES | 0.5 |
| J - Thermal mass and phase-change materials | YES | 0.5 |
| **BUILDING SERVICES** | | |
| K - Passive cooling/ventilation techniques | YES | 0.5 |
| L - Active ventilation and cooling system | YES | 0.5 |
| M - Geocooling and heat pumps | NO | 0 |
| N - Connection to district cooling system | NO | 0 |
| **SURROUNGINS** | | |
| O - Vegetation on sun-exposed sides for shading the building | NO | 0 |
| **Value KHW1** | - | **4.5** |

*Overall evaluation*

KROB.HW = KROB.$HW_1$

**Total value K** 4.5

**pt** 6

*min 0 - max 10*



## RES.SR – Storm-resistant building envelope and structure

*Intent of the evaluation*

Minimisation of the damage caused by storms. The implemented strategies help to reduce the risk of the building being damaged by hail, strong wind or potential blackout.

*Description*

Severe thunderstorms are formidable natural events that can inflict widespread damage. These intense storms are marked by strong winds, heavy rainfall, frequent lightning, and sometimes hail. They can develop suddenly and are particularly dangerous due to their frequent lightning, which can pose serious risks to both buildings and people. Lightning can trigger fires, damage electrical systems, and, in extreme cases, cause injuries or fatalities. Therefore, it is prudent to implement preventive measures to reduce their potential impact.

*Indicator (qualitative)*

Rating of the readiness of the building for facing a severe storm.

*Evaluation modules*

RES.SR1 - Storm-resistant building solutions

**RES.SR1 - Storm-resistant building solutions**

| Item | YES/NO | pt |
|---|---|---|
| **BUILDING SHAPE** | | |
| A - Aerodynamic shape | NO | 0 |
| **FOUNDATIONS** | | |
| B - Elevating the building | YES | 0.5 |
| **STRUCTURE** | | |
| Limit peak story drift | NO | 0 |
| Undertake performance-based wind design | NO | 0 |
| **WALLS** | | |
| Rainscreen cladding systems | NO | 0 |
| Strong connections between exterior building elements (roof-walls, walls-foundations, foundations-ground) | NO | 0 |
| Secondary protection in walls for wind driven rain | NO | 0 |
| Reinforcement and protection of openings, storm shutters | NO | 0 |
| **OPENINGS** | | |
| Impact-resistant glass for windows and doors | YES | 0.5 |
| Sealant joint in windows to prevent moisture | YES | 0.5 |
| Storm hooks to secure openings | YES | 0.5 |
| **ROOF** | | |
| Cross-bracing | NO | 0 |
| Hip-roof (with slopes of 30 °) | NO | 0 |
| Hurricane straps to fasten the roof to the walls | NO | 0 |
| Lightning rods/air terminals | NO | 0 |
| Physical non-continuity between the roof of the building and an extension (covered terrace, veranda, patio) | NO | 0 |
| Short overhangs and protrusions | NO | 0 |
| Sub-roofing and sheathing to reinforce the roof | NO | 0 |
| **PREFERRED MATERIALS** | | 0 |
| Impact-resistant shingles | NO | 0 |
| **BUILDING SERVICES** | | |
| Installation of backup generators | NO | 0 |
| Protective device for surges | NO | 0 |
| **SURROUNGINS** | | |
| Fix outdoor furniture and slabs to the ground | NO | 0 |
| Favour hedges and shrubs over trees around the building | NO | 0 |
| Plant dense vegetation in rows | NO | 0 |
| **Value KSR1** | | **2** |

*Overall evaluation*

KROB.SR = KROB.$SR_1$

**Total value K** 2

**pt** 2

*min 0 - max 10*

CAPACITY BUILDING

## CAP.PS – Emergency power supply

***Intent of the evaluation***

Provide fundamental safety for building users during common emergencies/disasters for at least a 96-hour period (four days).

***Description***

Mid-rise residential buildings ought to be outfitted with backup power to support critical functions, such as operating a single elevator and a fire-suppression pump. The necessity for backup power escalates further if residents are required to shelter in place during power outages. It is imperative to ensure the availability of adequate emergency power to sustain essential loads identified by the design team as crucial for the building's operation and to facilitate repairs during and after a disruptive event. The specific critical loads will vary depending on the project.

***Indicator (qualitative)***

Presence/absence of emergency power supply.

***Evaluation modules***

CAP.PS1 - Back-up power for critical loads

**CAP.PS1 - Back-up power for critical loads**

| Item | YES/NO | pt |
|---|---|---|
| Operation of electrical components of fuel-fired heating systems. | NO | 0 |
| Operation of a fan sufficient to provide emergency cooling if mechanical air conditioning equipment cannot operate | NO | 0 |
| Operation of water pumps if needed to make potable water available to occupants (if pumps are required for distribution of water within the building). | NO | 0 |
| Lighting level a minimum of 32 lux in all building spaces to define a path of egress to all required exits and to 3 m on the building exterior. | NO | 0 |
| One location for every 46 m that provides a minimum of 320 lux measured 76 cm above the floor. | NO | 0 |
| At least one functioning electrical receptacle per 23 m2 of occupied space. | NO | 0 |
| Operation of cable modem and wireless router or other means of providing online access within the building. | NO | 0 |
| **Value KPS1** | - | **0** |

***Overall evaluation***

KCAP.PS = $KCAP.PS_1$

**Total value K** 0

**pt** 0

*min 0 - max 10*

CAPACITY BUILDING

## CAP.SS – Safe equipped space

***Intent of the evaluation***

Provide building users with a safe room equipped with some supplies in the event of an emergency.

***Description***

A secure space incorporates essential provisions that building occupants may require for survival during a disaster. Ensuring easy accessibility during emergencies is imperative, and the room should be adequately equipped.

***Indicator (qualitative)***

Presence/absence of a dedicated emergency space and safety kits.

***Evaluation modules***

CAP.SS1 - Fundamental safety

CAP.SS2 - Safe room

**CAP.SS1 - Fundamental safety**

| Item | YES/NO | pt |
|---|---|---|
| First aid kit | NO | 0 |
| Disaster supply | NO | 0 |
| At least one telephone land-line along with a cell phone with text message capabilities and an emergency alert radio, and walkie-talkies. | NO | 0 |
| Biodegradable and sanitizing compounds to encapsulate waste | NO | 0 |
| **Value KSS1** | - | **0** |

**CAP.SS2 - Safe room**

| Item | YES/NO | pt |
|---|---|---|
| Residential safe room | NO | 0 |
| Community safe room | NO | 0 |
| **Value KSS2** | - | **0** |

***Overall evaluation***

KCAP.SS = KCAP.SS1 + KRCAP.SS2

**Total value K** 0

**pt** 0

*min 0 - max 10*

CAPACITY BUILDING

## CAP.PS – Emergency power supply

***Intent of the evaluation***

Provide fundamental safety for building users during common emergencies/disasters for at least a 96-hour period (four days).

***Description***

Mid-rise residential buildings ought to be outfitted with backup power to support critical functions, such as operating a single elevator and a fire-suppression pump. The necessity for backup power escalates further if residents are required to shelter in place during power outages. It is imperative to ensure the availability of adequate emergency power to sustain essential loads identified by the design team as crucial for the building's operation and to facilitate repairs during and after a disruptive event. The specific critical loads will vary depending on the project.

***Indicator (qualitative)***

Presence/absence of emergency power supply.

***Evaluation modules***

CAP.PS1 - Back-up power for critical loads

**CAP.PS1 - Back-up power for critical loads**

| Item | YES/NO | pt |
|---|---|---|
| Operation of electrical components of fuel-fired heating systems. | NO | 0 |
| Operation of a fan sufficient to provide emergency cooling if mechanical air conditioning equipment cannot operate | NO | 0 |
| Operation of water pumps if needed to make potable water available to occupants (if pumps are required for distribution of water within the building). | NO | 0 |
| Lighting level a minimum of 32 lux in all building spaces to define a path of egress to all required exits and to 3 m on the building exterior. | NO | 0 |
| One location for every 46 m that provides a minimum of 320 lux measured 76 cm above the floor. | NO | 0 |
| At least one functioning electrical receptacle per 23 m2 of occupied space. | NO | 0 |
| Operation of cable modem and wireless router or other means of providing online access within the building. | NO | 0 |
| **Value KPS1** | - | **0** |

***Overall evaluation***

$KCAP.PS = KCAP.PS_1$

**Total value K** **0**

**pt** 0

*min 0 - max 10*

CAPACITY BUILDING

## CAP.WS – Emergency water supply

***Intent of the evaluation***

Provide water access for building users during common emergencies/disasters for at least a 96-hour period (four days).

***Description***

Planning for access to potable water during a power outage or storm-related event, starts with water conservation, and can include reusing water on-site, such as harvested rainwater or recycled greywater for storage and later use during emergencies to cover operations such as toilet flushing, mechanical equipment, and irrigation.

***Indicator (qualitative)***

Presence/absence of water supply in case of an emergency.

***Evaluation modules***

CAP.WS1 - Access to potable water

**CAP.WS1 - Access to potable water**

| Item | YES/NO | pt |
|---|---|---|
| Use of waterless urinals or composting toilets | NO | 0 |
| Provide on-site water storage to cover operations | YES | 1 |
| Recycling greywater to cover operations and reduce building sewage conveyance by 25% (50%) | NO | 0 |
| Utilisation of a well connected to groundwater sources (e.g., aquifer) for drinking water supply | NO | 0 |
| Installation of standby or emergency pump for water supply | NO | 0 |
| **Value KWS1** | - | **1** |

***Overall evaluation***

$KCAP.WS = KCAP.WS_1$

**Total value K** **1**

**pt** 2

*min 0 - max 10*

COMMUNITY COHESION

## COM.SS – Access to useful shared spaces

***Intent of the evaluation***
Enhance community liveability by developing new shared space, such as common rooms, gardens, playgrounds, and recreational areas for social gatherings.

***Description***
By sharing resources, goods, and services, urban resilience can be enhanced by reducing the need for new materials and infrastructure, supporting local economies, and strengthening social networks. The use of communal spaces such as kitchens, living rooms, laundries, and gardens results in more efficient use of materials and space. They also provide spaces for social interaction.

***Indicator (qualitative)***
Number of available useful community space.

***Evaluation modules***
COM.SS1 - Shared spaces

**COM.SS1 - Shared spaces**

| Item | YES/NO | pt |
|---|---|---|
| Bike storage space | YES | 1 |
| Car share space | YES | 1 |
| Garden/terrace/patio space | NO | 0 |
| Tool share space | NO | 0 |
| Usable open space (i.e., an area for barbecue, a playground, etc.) | NO | 0 |
| Recreation rooms/spaces | NO | 0 |
| Communal kitchen | NO | 0 |
| Communal laundry room | NO | 0 |
| Fitness facilities | NO | 0 |
| Coworking areas | NO | 0 |
| Any other space that is accessible to multiple residents at the same time | NO | 0 |
| Any other space that is accessible to multiple residents at the same time | NO | 0 |
| Any other space that is accessible to multiple residents at the same time | NO | 0 |
| **Value KSS1** | - | **2** |

***Overall evaluation***

$KCOM.SS = KCOM.SS_1$

**Total value K** 2

**pt** 2
*min 0 - max 10*

CAPACITY BUILDING

## CAP.WS – Emergency water supply

***Intent of the evaluation***
Provide water access for building users during common emergencies/disasters for at least a 96-hour period (four days).

***Description***
Planning for access to potable water during a power outage or storm-related event, starts with water conservation, and can include reusing water on-site, such as harvested rainwater or recycled greywater for storage and later use during emergencies to cover operations such as toilet flushing, mechanical equipment, and irrigation.

***Indicator (qualitative)***
Presence/absence of water supply in case of an emergency.

***Evaluation modules***
CAP.WS1 - Access to potable water

**CAP.WS1 - Access to potable water**

| Item | YES/NO | pt |
|---|---|---|
| Use of waterless urinals or composting toilets | NO | 0 |
| Provide on-site water storage to cover operations | YES | 1 |
| Recycling greywater to cover operations and reduce building sewage conveyance by 25% (50%) | NO | 0 |
| Utilisation of a well connected to groundwater sources (e.g., aquifer) for drinking water supply | NO | 0 |
| Installation of standby or emergency pump for water supply | NO | 0 |
| **Value KWS1** | - | **1** |

***Overall evaluation***

$KCAP.WS = KCAP.WS_1$

**Total value K** 1

**pt** 2
*min 0 - max 10*

## COM.EP – Emergency preparedness

***Intent of the evaluation***

Enhancement of emergency preparedness through the installation of warning systems.

***Description***

Technology is rapidly shaping the way we approach safety in residential settings. From smart devices to artificial intelligence, these advancements enable proactive hazard detection and offer unprecedented control to building users. Warning systems are key elements of climate change adaptation and disaster risk reduction and aim to avoid or reduce the damage caused from hazards. To be effective, warning systems need to actively involve the people and communities at risk from a range of hazards, disseminate messages and warnings efficiently and ensure that there is a constant state of preparedness, and that early action is enabled.

***Indicator (qualitative)***

Presence of warning systems within the building.

***Evaluation modules***

COM.EP1 - Warning system

**COM.UG1 - Urban community gardening**

| Item | YES/NO | pt |
|---|---|---|
| Heat warning system | NO | 0 |
| Flood warning system | NO | 0 |
| Multi-sensor warning system | NO | 0 |
| **Value KEP1** | - | **0** |

***Overall evaluation***

$KCOM.EP = KCOM.EP_1$

| | |
|---|---|
| **Total value K** | **0** |
| **pt** | 0 |
| | *min 0 - max 10* |



## COM.UG – Urban Gardening

***Intent of the evaluation***

Improve local food production by sustainably growing, efficiency cultivating and responsibly consuming food within building surroundings.

***Description***

Local food production is a method to produce food in systems and practices that are not polluting, are season-based, reduce GHG emissions and waste, and build resilience through the food value chain. Local food sourcing can reconnect people with local food production, supporting efficient development, equitable distribution, and sustainable consumption of food. It can also be an opportunity for meeting and sharing ideas and activities, i.e., benefits people can derive from ecosystems, such as food, ornamental flowers, nature education, as well as regulating services such as air filtration, noise reduction, and surface water drainage.

***Indicator (qualitative)***

Absence/presence of food production system in the building surroundings.

***Evaluation modules***

COM.UG1 - Urban community gardening

**COM.UG1 - Urban community gardening**

| Item | YES/NO | pt |
|---|---|---|
| Dedicate >5% of the site's final vegetated area to food production (not below ca 1.5 m2 per residential unit) | NO | 0 |
| 2 different production crops (e.g., vegetables and/or edible nut- and fruit-bearing plants) | NO | 0 |
| Use of harvested rainwater for watering | YES | 1 |
| **Value KUG1** | - | **1** |

***Overall evaluation***

$KCOM.UG = KCOM.UG_1$

| | |
|---|---|
| **Total value K** | **1** |
| **pt** | 2 |
| | *min 0 - max 10* |

## Case study 2 – Bohemian Court (Šumavský Dvůr) multi-residential building

PREPAREDNESS

### PRE.WA – Wayfinding and accessibility

*Intent of the evaluation*

Design the project to provide safe and appropriate access for every user in and around the building site integrating it with its

*Description*

Wayfinding and navigation technologies are strategic in improving the quality of life of people and in case of extreme shocks. The process of wayfinding refers to how individuals find their way around a space or along a pathway. Graphic design, architectural design, and landscape design are all included in this field. The use of signage can assist in wayfinding. By using consistent environmental clues, wayfinding facilitates problem-solving and movement within spaces. Several design features that facilitate wayfinding, such as lines on the ground indicating a way out and symbols and colours indicating the locations of toilets, accessible toilets, lifts and exits can be used. This reflects that homes must be safe for all occupants, regardless of age or ability.

*Indicator (qualitative)*

Provision of clear access, safety and wayfinding measures in order to accommodate emergency services for every user.

*Evaluation modules*

PRE.WA1 – Wayfinding and accessibility

| **PRE.WA1 – Wayfinding and accessibility** | | (max 6 points) |
|---|---|---|
| Item | YES/NO | pt |
| A - Accessibility of the building (public transports, parking, etc.) | | |
| Severely disable | NO | 0 |
| Reduced mobility | NO | 0 |
| Blind | NO | 0 |
| Partially blind | YES | 1 |
| Deaf | YES | 2 |
| Partially deaf | NO | 0 |
| B - Accessibly of entrance areas - exterior and interior | | (max 6 points) |
| Severely disable | NO | 0 |
| Reduced mobility | NO | 0 |
| Blind | NO | 0 |
| Partially blind | YES | 1 |
| Deaf | YES | 2 |
| Partially deaf | NO | 0 |
| C - Horizontal movement in the building | | (max 6 points) |
| Severely disable | NO | 0 |
| Reduced mobility | NO | 0 |
| Blind | NO | 0 |
| Partially blind | YES | 1 |
| Deaf | YES | 2 |
| Partially deaf | NO | 0 |
| D - Vertical movement in the building | | (max 6 points) |
| Severely disable | NO | 0 |
| Reduced mobility | NO | 0 |
| Blind | NO | 0 |
| Partially blind | YES | 1 |
| Deaf | YES | 2 |
| Partially deaf | NO | 0 |
| E - Hygienic areas and changing rooms | | (max 6 points) |
| Severely disable | NO | 0 |
| Reduced mobility | NO | 0 |
| Blind | NO | 0 |
| Partially blind | YES | 1 |
| Deaf | YES | 2 |
| Partially deaf | NO | 0 |
| F - Special equipment and interiors | | (max 6 points) |
| Severely disable | NO | 0 |
| Reduced mobility | NO | 0 |
| Blind | NO | 0 |
| Partially blind | YES | 1 |
| Deaf | YES | 2 |
| Partially deaf | NO | 0 |
| G - Clear signage and wayfinding | NO | 0 |
| **Value KWA1** | - | **18** |

*Overall evaluation*

KPRE.WA = $KPRE.WA_1$

**Total value K** 18

**pt** 5

*min 0 - max 10*

PREPAREDNESS

### PRE.SA – Rapid site assessment

*Intent of the evaluation*

Identification of the probability, intensity, and timescale of the most likely happening hazards (floods, heavy precipitation and storm, heatwaves, subsidence, and drought) of a specific location.

*Description*

Several factors should be considered when characterizing the risks associated with climate change in a specific location, such as the climate threat, the geographical context (e.g., coastal area, mountain region), and the affected systems and sectors (e.g., people, infrastructure, properties, etc.) as well as the impacts on the most vulnerable groups. The purpose of site risk assessments is to determine the likelihood of future climate hazards occurring and the potential impacts on buildings and their users. Climate action and adaptation strategies must be prioritized based on this information.

*Indicator (qualitative)*

Assessment of exposure to specific hazards to identify those that are most likely to occur.

*Evaluation modules*

PRE.SA1 - Site Risk Assessment

| **PRE.SA1 - Site risk assessment** | | |
|---|---|---|
| Item | YES/NO | pt |
| A - Perform an hazards assessment | NO | 0 |
| B - Perform the site risk assessment through a workshop | NO | 0 |
| **Value KSA1** | - | **0** |

*Overall evaluation*

KPRE.SA = $KPRE.SA_1$

**Total value K** **0**

**pt** 0

*min 0 - max 10*

## PRE.VE – Conserve and use appropriate vegetation

*Intent of the evaluation*
Improve landscape performance and conserve the original vegetation by installing only plants that are appropriate for site conditions, climate, and design intent.

*Description*
Conserve existing native plants and/or introduce new ones. A tree-planting initiative will only be successful if the trees are well-suited to the environment and can withstand extreme temperatures, drought, storms, and flooding. Ideally, mature native trees from local areas that are already acclimated to the region should be used. Additionally, stormwater trees enhance urban biodiversity, improve soil quality, and benefit aquatic environments.

*Indicator (qualitative)*
Absence/presence of native and climate-tolerant vegetation.

*Evaluation modules*
PRE.AV1 - Conserve and use appropriate vegetation

**PRE.VE - Conserve and use appropriate vegetation**

| Item | YES/NO | pt |
|---|---|---|
| Plant single tree pits in the building surrounding | - | 0 |
| Replant and conserve existing trees, if they were moved, before use new ones | YES | 2 |
| Plant continuous tree pit in the building surrounding | NO | 0 |
| Plant trees in strategic locations to serve as windbreaks | NO | 0 |
| Choose climate-tolerant trees (i.e., drought-tolerant) | NO | 0 |
| **Value KVE1** | - | **2** |

*Overall evaluation*

$KPRE.VE = KPRE.VE_1$

| | |
|---|---|
| **Total value K** | **2** |
| **pt** | 2 |
| | *min 0 - max 10* |



## PRE.US – Unsuitable sites

*Intent of the evaluation*
Avoid building on sites prone to natural hazards.

*Description*
Natural events such as earthquakes and sinkhole formation can increase building maintenance costs due to structural damage and pose higher risks to residents in vulnerable areas. Those living in floodplains need additional protection through costly defences. Planning and building regulations should ensure designs account for potential exceedance scenarios, and it is preferable to avoid construction in floodplain areas due to their higher risk of flooding.

*Indicator (qualitative)*
Efforts to avoid or mitigate site-related risks by building in safe sites.

*Evaluation modules*
PRE.US1 - Avoidance of flood-prone areas
PRE.US2 - Avoidance of adverse geology areas

**PRE.US1 - Avoidance of flood-prone areas** (max 2 points)

| Item | YES/NO | pt |
|---|---|---|
| No floodplain and not flood risk | YES | 2 |
| Build above the 100-year floodplain | NO | 0 |
| Build above the 500-year floodplain | NO | 0 |
| **Value KUS1** | - | **2** |

**PRE.US2 - Avoidance of adverse geology areas** (max 2 points)

| Item | YES/NO | pt |
|---|---|---|
| Identification of any faults, low lying coastline or karst areas | NO | 0 |
| Establish a program for monitoring | NO | 0 |
| The area is not threatened by any kind of geological activity. | YES | 2 |
| **Value KUS2** | - | **2** |

*Overall evaluation*

KPRE.GW = KPRE.GW1 + KPRE.GW2

| | |
|---|---|
| **Total value K** | **4** |
| **pt** | 10 |
| | *min 0 - max 10* |

## RED.AP – Alternative power sources

*Intent of the evaluation*
Reduction of the amount of operational non-renewable primary energy (PERNT) in the building, meeting the energy demand with renewable energy (PERT).

*Description*
The relatively low price of fossil fuels has made them the primary energy source in the energy sector. Nevertheless, it is better to refrain from relying on finite and polluting energy sources in the future as the global energy demand is forecast to rise. Over the past decade, there has been a positive shift towards the expansion of renewable energy capacity, both locally and internationally.

*Indicator (qualitative and quantitative)*
Annual PERNT and PERT consumption in kWh per 1 m2 [kWh/(m2.a)] and list of renewable energy sources.

*Evaluation modules*
RED.AP1 – Annual primary energy consumption
RED.AP2 – Renewable power sources

| RED.AP1 - Annual primary energy consumption | Select just one option | |
|---|---|---|
| Item | YES/NO | pt |
| DIRECT GAIN | | |
| <5% of energy needs from renewable sources | NO | 0 |
| <15% of energy needs from renewable sources | NO | 0 |
| <30% of energy needs from renewable sources | NO | 0 |
| <50% of energy needs from renewable sources | NO | 0 |
| Net positive amount from renewable sources | NO | 0 |
| **Value KAP1** | | **0** |

| RED.AP2 – Renewable power sources | | (max 4 points) |
|---|---|---|
| Item | YES/NO | pt |
| On-site solar energy production, e.g., PV panels | - | 0 |
| Connection to district heating and/or cooling | - | 0 |
| Wind access | - | 0 |
| Biomass | - | 0 |
| Geothermal | - | 0 |
| Hydrogen/fuel cells | - | 0 |
| Any other source | - | 0 |
| **Value KAP2** | | **0** |

*Overall evaluation*

| | | |
|---|---|---|
| KRED.AP = KRED.AP1+KRED.AP2 | **Total value K** | 0 |
| | **pt** | 0 |
| | | *min 0 - max 10* |



## RED.PS – Passive survivability

*Intent of the evaluation*
Ensure that the building passively maintain safe thermal conditions during a disruptive event (i.e., extended power outage or loss of heating fuel).

*Description*
Passive survivability refers to a building's ability to maintain critical life-support conditions in the event of extended loss of power, heating fuel, or water. Passive thermal performance refers to heat transfer between a building and its surroundings, mainly without AC systems. Passive solar systems collect and distribute energy from the sun without the use of mechanical equipment such as fans or pumps.

*Indicator (qualitative)*
Absence/presence of passive systems for heating, cooling, and lighting.

*Evaluation modules*
RED.PS1 - Passive solar heating
RED.PS2 - Passive cooling
RED.PS3 - Passive lighting
RED.PS4 - Thermal safety temperature

| RED.PS1 - Passive solar heating | | (max 3 points) |
|---|---|---|
| Item | YES/NO | pt |
| DIRECT GAIN | | |
| A - Southern facing glass | YES | 1 |
| B - Solar-facing clerestories and sloped skylights | NO | 0 |
| C - Solar chimney | NO | 0 |
| D - Sunspace | NO | 0 |
| INDIRECT GAIN | | |
| E - Increased thermal mass | YES | 1 |
| F - Thermal storage wall | NO | 0 |
| G - Thermal zoning | YES | 1 |
| **Value KPS1** | | **3** |

| RED.PS2 - Passive cooling | | (max 4 points) |
|---|---|---|
| Item | YES/NO | pt |
| PREVENTIVE TECHNIQUES | | |
| A - Shading (vertical and operable) | NO | 0 |
| B - Internal gain control | NO | 0 |
| MODULATION AND HEAT DISSIPATION TECHNIQUES | | |
| C - Cross ventilation | NO | 0 |
| D - Stack ventilation | NO | 0 |
| E - Night flushing | NO | 0 |
| F - Radiative cooling or evaporation cooling | NO | 0 |
| G - Earth coupling | NO | 0 |
| H - Cold roof or double roof | NO | 0 |
| **Value KPS2** | | **0** |

| RED.PS3 - Passive lighting | | (max 4 points) |
|---|---|---|
| Item | YES/NO | pt |
| A - Building form and layout | NO | 0 |
| B - Daylighting from multiple sides | NO | 0 |
| C - Solar zoning | NO | 0 |
| D - High efficacy egress lighting | YES | 1 |
| **Value KPS3** | | **1** |

| RED.PS4 - Thermal safety temperature | Select just one option | |
|---|---|---|
| Item | YES/NO | pt |
| >27°C | - | 0 |
| 26.5 °C | YES | 1.5 |
| 26.0 °C | - | 0 |
| 25.5 °C | - | 0 |
| <25.0 °C | - | 0 |
| **Value KPS4** | | **1.5** |

*Overall evaluation*

| | | |
|---|---|---|
| KRED.PS = KRED.PS1+KRED.PS2+KRED.PS3+KRED.PS4 | **Total value K** | 5.5 |
| | **pt** | 4 |
| | | *min 0 - max 10* |

## ROB.HR – Heavy precipitation-resistant building envelope and structure

*Intent of the evaluation*

Minimization of damage caused by heavy precipitation. The implemented strategies help to reduce the amount of rainwater runoff from the building by collecting and storing it, while also helping to reduce any potential flooding.

*Description*

Buildings can be damaged by heavy precipitation. The result can be structural damage, flooding, and water damage that may be expensive to repair. Precautionary measures such as proper waterproofing, proper drainage, and regular maintenance can help reduce the potential for damage.

*Indicator (qualitative)*

Rating of the readiness of the building for facing a heavy precipitation.

*Evaluation modules*

ROB.HR1 - Heavy precipitation-resistant building solutions

**RES.HR1 - Heavy precipitation-resistant building solutions**

| Item | YES/NO | pt |
|---|---|---|
| **BUILDING SHAPE** | | |
| Avoid square and rectangular flat surfaces | YES | 0.5 |
| **STRUCTURE** | | |
| Passive landslide control measures | YES | 0.5 |
| Ground preparation | NO | 0 |
| **WALLS** | | |
| Green façade | NO | 0 |
| Rainscreen with a drainage system within the wall | NO | 0 |
| **OPENINGS** | | |
| Tempered glass panel (e.g., 4-mm thickness) | YES | 0.5 |
| Hail-proof shutters and blinds | NO | 0 |
| Secure loose joints by cramping, gluing, re-wedging and pinning | NO | 0 |
| Effective sealants and waterproof membranes | YES | 0.5 |
| **ROOF** | | |
| Hail net for protecting roof fragile elements | NO | 0 |
| Heat tracing in gutters | NO | 0 |
| Type of roof (e.g., warm, inverted, blue, blue-green, green) | NO | 0 |
| Pitched roof | YES | 0.5 |
| **PREFERRED MATERIALS** | | |
| Water-resistant materials | YES | 0.5 |
| Infiltration trenches | NO | 0 |
| Metal for roofing | NO | 0 |
| **BUILDING SERVICES** | | |
| Proper dimensioned drainage network | NO | 0 |
| Disconnect surface water from sewage | NO | 0 |
| Rainwater tanks | YES | 0.5 |
| Devices anti-backflow | NO | 0 |
| **SURROUNGINS** | | |
| Sustainable urban drainage (e.g., rain gardens and swales) | NO | 0 |
| Drainage systems in the building surroundings (e.g., sump pump) | NO | 0 |
| Permeable soil | YES | 0.5 |
| **Value KHR1** | | 4 |

*Overall evaluation*

$KROB.HR = KROB.HR_1$

| | |
|---|---|
| **Total value K** | 4 |
| **pt** | 3 |
| | *min 0 - max 10* |

ROBUSTNESS

## ROB.FR – Flood-resistant building envelope and structure

*Intent of the evaluation*

Minimization of flood damage. The building is prepared for a possible water level of 1m above the surrounding ground level.

*Description*

Installation of flood adaptation solutions for buildings such as the use of flood-resistant materials, the elevation of structures, and flood barriers can reduce the vulnerability to flood events. These measures can help protect buildings and the people inside them from flooding damage.

*Indicator (qualitative)*

Rating of the readiness in terms of solutions implemented in the building for facing a flood event.

*Evaluation modules*

RES.FR1 - Flood-resistant building solutions

**ROB.FR1 - Flood-resistant building solutions**

| Item | YES/NO | pt |
|---|---|---|
| **BUILDING SHAPE** | | |
| A - Square building shape | NO | 0 |
| **FOUNDATIONS** | | |
| B - Elevating the building | NO | 0 |
| C - Preliminary soil study | YES | 0.5 |
| D - Dry proofing foundations | YES | 0.5 |
| E - Wet proofing foundations (e.g., internal drainage systems, vents, etc.) | NO | 0 |
| **OPENINGS** | | |
| F - Permanent flood barriers | NO | 0 |
| G - Temporary flood barriers | NO | 0 |
| H - Effective sealants and waterproof membranes | YES | 0.5 |
| **PREFERRED MATERIALS** | | |
| I - Water-repellent finishes | YES | 0.5 |
| J - Water-resistant insulation | YES | 0.5 |
| K - Water-resistant materials | YES | 0.5 |
| **BUILDING SERVICES** | | |
| L - Building systems above the flood level (i.e., mechanical and electrical systems) | YES | 0.5 |
| M - Devices anti-backflow | NO | 0 |
| N - Basement with non-essential functions | YES | 0.5 |
| **SURROUNGINS** | | |
| O - Buffer zones in the building surroundings | NO | 0 |
| P - Drainage systems in the building surroundings (e.g., sump pump, raingardens, swales) | NO | 0 |
| **Value KFR1** | - | 4 |

*Overall evaluation*

$KROB.FR = KROB.FR_1$

| | |
|---|---|
| **Total value K** | 4 |
| **pt** | 5 |
| | *min 0 - max 10* |

## ROB.SU – Subsidence-resilient building envelope and structure

*Intent of the evaluation*

Reduce building vulnerability to subsidence installing specific solutions and minimizing soil movement during construction.

*Description*

Variations in precipitation patterns and temperatures affect soil moisture levels and composition. In Europe, shrinkage and swelling of soil are increasing risks due to soils with high clay content being highly sensitive to volumetric changes. There is typically a movement of soil within a 5-metre depth from the ground surface and movements are rarely greater than 150 mm horizontally or vertically. A significant risk is posed by large soil movements as they can cause serious damage to building structures, posing serious risks to the people safety.

*Indicator (qualitative)*

Rating of the readiness of the building for facing a subsidence.

*Evaluation modules*

ROB.SU1 - Subsidence adaptation building solutions
ROB.SU2 - Minimize soil movement during construction

**ROB.SU1 - Subsidence adaptation building solutions**

| Item | YES/NO | pt |
|---|---|---|
| **FOUNDATIONS** | | |
| A - Deep or semi-deep foundations (e.g., raft or piled foundations) | NO | 0 |
| B - Underpinning | NO | 0 |
| **WALLS** | | |
| C - Joints movement | NO | 0 |
| D - Structural strengthening | YES | 0.5 |
| **SURROUNGINS** | | |
| E - Plant trees at a safe distance from the building | YES | 0.5 |
| **Value KSU1** | - | **1** |

**ROB.SU2 - Minimize soil movement during construction**

| Item | YES/NO | pt |
|---|---|---|
| Minimize disturbed area on construction site | YES | 0.5 |
| Divide the Project into Sections | YES | 0.5 |
| Soil Stabilization | NO | 0 |
| Slope Protection | YES | 0.5 |
| Runoff Water Control Methods | YES | 0.5 |
| Dewatering | NO | 0 |
| Sediment Control Traps | NO | 0 |
| Stable Construction Entrances | YES | 0.5 |
| **Value KSU2** | - | **2.5** |

*Overall evaluation*

KROB.SU = KROB.$SU_1$+KROB.SU2

| | |
|---|---|
| **Total value K** | **3.5** |
| **pt** | 5 |
| | *min 0 - max 10* |

CAPACITY BUILDING

## CAP.PS – Emergency power supply

***Intent of the evaluation***
Provide fundamental safety for building users during common emergencies/disasters for at least a 96-hour period (four days).

***Description***
Mid-rise residential buildings ought to be outfitted with backup power to support critical functions, such as operating a single elevator and a fire-suppression pump. The necessity for backup power escalates further if residents are required to shelter in place during power outages. It is imperative to ensure the availability of adequate emergency power to sustain essential loads identified by the design team as crucial for the building's operation and to facilitate repairs during and after a disruptive event. The specific critical loads will vary depending on the project.

***Indicator (qualitative)***
Presence/absence of emergency power supply.

***Evaluation modules***
CAP.PS1 - Back-up power for critical loads

**CAP.PS1 - Back-up power for critical loads**

| Item | YES/NO | pt |
|---|---|---|
| Install a proper sized back-up generator (e.g., Propane/LPG (Liquified Petroleum Gas) generator, Natural gas generators, Diesel or bio-diesel generator, Combined heat and power (cogeneration) generators). | NO | 0 |
| Operation of fuel-fired heating system with stored emergency fuel. | YES | 1 |
| Operation of a fan sufficient to provide emergency cooling if mechanical air conditioning equipment cannot operate (e.g., ceiling fans, plug-in window fans, or fans integral with central air distribution). | NO | 0 |
| Operation of water pumps if needed to make potable water available to occupants (if pumps are required for distribution of water within the building). | NO | 0 |
| Emergency escape lighting is lighting that activates and provides illumination in the event of loss of power to the main system. | NO | 0 |
| Operation of cable modem and wireless router or other means of providing online access within the building. | NO | 0 |
| **Value KPS1** | - | **1** |

***Overall evaluation***

KCAP.PS = $KCAP.PS_1$

| | |
|---|---|
| **Total value K** | 1 |
| **pt** | 2 |
| | *min 0 - max 10* |

CAPACITY BUILDING

## CAP.SS – Safe equipped space

***Intent of the evaluation***
Provide building users with a safe room equipped with some supplies in the event of an emergency.

***Description***
A secure space incorporates essential provisions that building occupants may require for survival during a disaster. Ensuring easy accessibility during emergencies is imperative, and the room should be adequately equipped.

***Indicator (qualitative)***
Presence/absence of a dedicated emergency space and safety kits.

***Evaluation modules***
CAP.SS1 - Fundamental safety
CAP.SS2 - Safe room

**CAP.SS1 - Fundamental safety**

| Item | YES/NO | pt |
|---|---|---|
| First aid kit | NO | 0 |
| Disaster supply | NO | 0 |
| At least one telephone land-line along with a cell phone with text message capabilities and an emergency alert radio, and walkie-talkies. | NO | 0 |
| Biodegradable and sanitizing compounds to encapsulate waste | NO | 0 |
| **Value KSS1** | - | **0** |

**CAP.SS2 - Safe room**

| Item | YES/NO | pt |
|---|---|---|
| Residential safe room | NO | 0 |
| Community safe room | NO | 0 |
| **Value KSS2** | - | **0** |

***Overall evaluation***

KCAP.SS = KCAP.SS1 + KRCAP.SS2

| | |
|---|---|
| **Total value K** | 0 |
| **pt** | 0 |
| | *min 0 - max 10* |

COMMUNITY COHESION

## COM.SS – Access to useful shared spaces

***Intent of the evaluation***
Enhance community liveability by developing new shared space, such as common rooms, gardens, playgrounds, and recreational areas for social gatherings.

***Description***
By sharing resources, goods, and services, urban resilience can be enhanced by reducing the need for new materials and infrastructure, supporting local economies, and strengthening social networks. The use of communal spaces such as kitchens, living rooms, laundries, and gardens results in more efficient use of materials and space. They also provide spaces for social interaction.

***Indicator (qualitative)***
Number of available useful community space.

***Evaluation modules***
COM.SS1 - Shared spaces

**COM.SS1 - Shared spaces**

| Item | YES/NO | pt |
|---|---|---|
| Bike storage space | YES | 1 |
| Car share space | NO | 0 |
| Garden/terrace/patio space | YES | 1 |
| Tool share space | NO | 0 |
| Usable open space (i.e., an area for barbecue, a playground, etc.) | YES | 1 |
| Recreation rooms/spaces | NO | 0 |
| Communal kitchen | NO | 0 |
| Communal laundry room | NO | 0 |
| Fitness facilities | NO | 0 |
| Coworking areas | NO | 0 |
| Any other space that is accessible to multiple residents at the same time | YES | 1 |
| Any other space that is accessible to multiple residents at the same time | NO | 0 |
| Any other space that is accessible to multiple residents at the same time | NO | 0 |
| **Value KSS1** | - | 4 |

***Overall evaluation***

KCOM.SS = $KCOM.SS_1$

| | |
|---|---|
| **Total value K** | 4 |
| **pt** | 3 |
| | *min 0 - max 10* |

CAPACITY BUILDING

## CAP.WS – Emergency water supply

***Intent of the evaluation***
Provide water access for building users during common emergencies/disasters for at least a 96-hour period (four days).

***Description***
Planning for access to potable water during a power outage or storm-related event, starts with water conservation, and can include reusing water on-site, such as harvested rainwater or recycled greywater for storage and later use during emergencies to cover operations such as toilet flushing, mechanical equipment, and irrigation.

***Indicator (qualitative)***
Presence/absence of water supply in case of an emergency.

***Evaluation modules***
CAP.WS1 - Access to potable water

**CAP.WS1 - Access to potable water**

| Item | YES/NO | pt |
|---|---|---|
| Use of waterless urinals or composting toilets | NO | 0 |
| Provide on-site water storage to cover operations | YES | 1 |
| Recycling greywater to cover operations and reduce building sewage conveyance by 25% (50%) | NO | 0 |
| Utilisation of a well connected to groundwater sources (e.g., aquifer) for drinking water supply | NO | 0 |
| Installation of standby or emergency pump for water supply | NO | 0 |
| **Value KWS1** | - | 1 |

***Overall evaluation***

KCAP.WS = $KCAP.WS_1$

| | |
|---|---|
| **Total value K** | 1 |
| **pt** | 2 |
| | *min 0 - max 10* |

## COM.EP – Emergency preparedness

***Intent of the evaluation***
Enhancement of emergency preparedness through the installation of warning systems.

***Description***
Technology is rapidly shaping the way we approach safety in residential settings. From smart devices to artificial intelligence, these advancements enable proactive hazard detection and offer unprecedented control to building users. Warning systems are key elements of climate change adaptation and disaster risk reduction and aim to avoid or reduce the damage caused from hazards. To be effective, warning systems need to actively involve the people and communities at risk from a range of hazards, disseminate messages and warnings efficiently and ensure that there is a constant state of preparedness, and that early action is enabled.

***Indicator (qualitative)***
Presence of warning systems within the building.

***Evaluation modules***
COM.EP1 - Warning system

**COM.UG1 - Urban community gardening**

| Item | YES/NO | pt |
|---|---|---|
| Heat warning system | NO | 0 |
| Flood warning system | NO | 0 |
| Multi-sensor warning system | NO | 0 |
| **Value KEP1** | - | **0** |

***Overall evaluation***

KCOM.EP = $KCOM.EP_1$

| | |
|---|---|
| **Total value K** | **0** |
| **pt** | 0 |
| | *min 0 - max 10* |

COMMUNITY COHESION

## COM.UG – Urban Gardening

***Intent of the evaluation***
Improve local food production by sustainably growing, efficiency cultivating and responsibly consuming food within building surroundings.

***Description***
Local food production is a method to produce food in systems and practices that are not polluting, are season-based, reduce GHG emissions and waste, and build resilience through the food value chain. Local food sourcing can reconnect people with local food production, supporting efficient development, equitable distribution, and sustainable consumption of food. It can also be an opportunity for meeting and sharing ideas and activities, i.e., benefits people can derive from ecosystems, such as food, ornamental flowers, nature education, as well as regulating services such as air filtration, noise reduction, and surface water drainage.

***Indicator (qualitative)***
Absence/presence of food production system in the building surroundings.

***Evaluation modules***
COM.UG1 - Urban community gardening

**COM.UG1 - Urban community gardening**

| Item | YES/NO | pt |
|---|---|---|
| Dedicate >5% of the site's final vegetated area to food production (not below ca 1.5 m2 per residential unit) | NO | 0 |
| 2 different production crops (e.g., vegetables and/or edible nut- and fruit-bearing plants) | NO | 0 |
| Use of harvested rainwater for watering | YES | 1 |
| **Value KUG1** | - | **1** |

***Overall evaluation***

KCOM.UG = $KCOM.UG_1$

| | |
|---|---|
| **Total value K** | **1** |
| **pt** | 2 |
| | *min 0 - max 10* |

## Case study 3 – RESBy resilient multi-residential building

PREPAREDNESS

### PRE.SA – Rapid site assessment

***Intent of the evaluation***

Identification of the probability, intensity, and timescale of the most likely happening hazards (floods, heavy precipitation and storm, heatwaves, subsidence, and drought) of a specific location.

***Description***

Several factors should be considered when characterizing the risks associated with climate change in a specific location, such as the climate threat, the geographical context (e.g., coastal area, mountain region), and the affected systems and sectors (e.g., people, infrastructure, properties, etc.) as well as the impacts on the most vulnerable groups. The purpose of site risk assessments is to determine the likelihood of future climate hazards occurring and the potential impacts on buildings and their users. Climate action and adaptation strategies must be prioritized based on this information.

***Indicator (qualitative)***

Assessment of exposure to specific hazards to identify those that are most likely to occur.

***Evaluation modules***

PRE.SA1 - Site Risk Assessment

| **PRE.SA1 - Site risk assessment** | | |
|---|---|---|
| Item | YES/NO | pt |
| A - Perform an hazards assessment | YES | 1 |
| B - Perform the site risk assessment through a workshop | NO | 0 |
| **Value KSA1** | - | **1** |

***Overall evaluation***

KPRE.SA = $KPRE.SA_1$

| | |
|---|---|
| **Total value K** | **1** |
| **pt** | 5 |
| | *min 0 - max 10* |

PREPAREDNESS

### PRE.WA – Wayfinding and accessibility

***Intent of the evaluation***

Design the project to provide safe and appropriate access for every user in and around the building site integrating it with its

***Description***

Wayfinding and navigation technologies are strategic in improving the quality of life of people and in case of extreme shocks. The process of wayfinding refers to how individuals find their way around a space or along a pathway. Graphic design, architectural design, and landscape design are all included in this field. The use of signage can assist in wayfinding. By using consistent environmental clues, wayfinding facilitates problem-solving and movement within spaces. Several design features that facilitate wayfinding, such as lines on the ground indicating a way out and symbols and colours indicating the locations of toilets, accessible toilets, lifts and exits can be used. This reflects that homes must be safe for all occupants, regardless of age or ability.

***Indicator (qualitative)***

Provision of clear access, safety and wayfinding measures in order to accommodate emergency services for every user.

***Evaluation modules***

PRE.WA1 – Wayfinding and accessibility

| **PRE.WA1 – Wayfinding and accessibility** | | (max 6 points) |
|---|---|---|
| Item | YES/NO | pt |
| A - Accessibility of the building (public transports, parking, etc.) | | |
| Severely disable | YES | 2 |
| Reduced mobility | NO | 0 |
| Blind | NO | 0 |
| Partially blind | YES | 1 |
| Deaf | YES | 2 |
| Partially deaf | NO | 0 |
| B - Accessibly of entrance areas - exterior and interior | | (max 6 points) |
| Severely disable | YES | 2 |
| Reduced mobility | NO | 0 |
| Blind | NO | 0 |
| Partially blind | YES | 1 |
| Deaf | YES | 2 |
| Partially deaf | NO | 0 |
| C - Horizontal movement in the building | | (max 6 points) |
| Severely disable | YES | 2 |
| Reduced mobility | NO | 0 |
| Blind | NO | 0 |
| Partially blind | YES | 1 |
| Deaf | YES | 2 |
| Partially deaf | NO | 0 |
| D - Vertical movement in the building | | (max 6 points) |
| Severely disable | YES | 2 |
| Reduced mobility | NO | 0 |
| Blind | NO | 0 |
| Partially blind | YES | 1 |
| Deaf | YES | 2 |
| Partially deaf | NO | 0 |
| E - Hygienic areas and changing rooms | | (max 6 points) |
| Severely disable | YES | 2 |
| Reduced mobility | NO | 0 |
| Blind | NO | 0 |
| Partially blind | YES | 1 |
| Deaf | YES | 2 |
| Partially deaf | NO | 0 |
| F - Special equipment and interiors | | (max 6 points) |
| Severely disable | YES | 2 |
| Reduced mobility | NO | 0 |
| Blind | NO | 0 |
| Partially blind | YES | 1 |
| Deaf | YES | 2 |
| Partially deaf | NO | 0 |
| G - Clear signage and wayfinding | YES | 2 |
| **Value KWA1** | - | **30** |

***Overall evaluation***

KPRE.WA = $KPRE.WA_1$

| | |
|---|---|
| **Total value K** | **30** |
| **pt** | 8 |
| | *min 0 - max 10* |

PREPAREDNESS

## PRE.VE – Conserve and use appropriate vegetation

*Intent of the evaluation*

Improve landscape performance and conserve the original vegetation by installing only plants that are appropriate for site conditions, climate, and design intent.

*Description*

Conserve existing native plants and/or introduce new ones. A tree-planting initiative will only be successful if the trees are well-suited to the environment and can withstand extreme temperatures, drought, storms, and flooding. Ideally, mature native trees from local areas that are already acclimated to the region should be used. Additionally, stormwater trees enhance urban biodiversity, improve soil quality, and benefit aquatic environments.

*Indicator (qualitative)*

Absence/presence of native and climate-tolerant vegetation.

*Evaluation modules*

PRE.AV1 - Conserve and use appropriate vegetation

**PRE.VE - Conserve and use appropriate vegetation**

| Item | YES/NO | pt |
|---|---|---|
| Plant single tree pits in the building surrounding | - | 0 |
| Replant and conserve existing trees, if they were moved, before use new ones | YES | 2 |
| Plant continuous tree pit in the building surrounding | - | 0 |
| Plant trees in strategic locations to serve as windbreaks | - | 0 |
| Choose climate-tolerant trees (i.e., drought-tolerant) | YES | 3 |
| **Value KVE1** | - | **5** |

*Overall evaluation*

$KPRE.VE = KPRE.VE_1$

**Total value K** 5

**pt** 5

*min 0 - max 10*

PREPAREDNESS

## PRE.US – Unsuitable sites

*Intent of the evaluation*

Avoid building on sites prone to natural hazards.

*Description*

Natural events such as earthquakes and sinkhole formation can increase building maintenance costs due to structural damage and pose higher risks to residents in vulnerable areas. Those living in floodplains need additional protection through costly defences. Planning and building regulations should ensure designs account for potential exceedance scenarios, and it is preferable to avoid construction in floodplain areas due to their higher risk of flooding.

*Indicator (qualitative)*

Efforts to avoid or mitigate site-related risks by building in safe sites.

*Evaluation modules*

PRE.US1 - Avoidance of flood-prone areas

PRE.US2 - Avoidance of adverse geology areas

**PRE.US1 - Avoidance of flood-prone areas** (max 2 points)

| Item | YES/NO | pt |
|---|---|---|
| No floodplain and not flood risk | YES | 2 |
| Build above the 100-year floodplain | NO | 0 |
| Build above the 500-year floodplain | NO | 0 |
| **Value KUS1** | - | **2** |

**PRE.US2 - Avoidance of adverse geology areas** (max 2 points)

| Item | YES/NO | pt |
|---|---|---|
| Identification of any faults, low lying coastline or karst areas | NO | 0 |
| Establish a program for monitoring | NO | 0 |
| The area is not threatened by any kind of geological activity. | YES | 2 |
| **Value KUS2** | - | **2** |

*Overall evaluation*

KPRE.GW = KPRE.GW1 + KPRE.GW2

**Total value K** 4

**pt** 10

*min 0 - max 10*

REDUNDANCY

## RED.AP – Alternative power sources

*Intent of the evaluation*

Reduction of the amount of operational non-renewable primary energy (PERNT) in the building, meeting the energy demand with renewable energy (PERT).

*Description*

The relatively low price of fossil fuels has made them the primary energy source in the energy sector. Nevertheless, it is better to refrain from relying on finite and polluting energy sources in the future as the global energy demand is forecast to rise. Over the past decade, there has been a positive shift towards the expansion of renewable energy capacity, both locally and internationally.

*Indicator (qualitative and quantitative)*

Annual PERNT and PERT consumption in kWh per 1 m2 [kWh/(m2.a)] and list of renewable energy sources.

*Evaluation modules*

RED.AP1 – Annual primary energy consumption
RED.AP2 – Renewable power sources

| **RED.AP1 - Annual primary energy consumption** | Select just one option | |
|---|---|---|
| Item | YES/NO | pt |
| **DIRECT GAIN** | | |
| <5% of energy needs from renewable sources | NO | 0 |
| <15% of energy needs from renewable sources | NO | 0 |
| <30% of energy needs from renewable sources | NO | 0 |
| <50% of energy needs from renewable sources | NO | 0 |
| Net positive amount from renewable sources | NO | 0 |
| **Value KAP1** | | 0 |

| **RED.AP2 – Renewable power sources** | | (max 4 points) |
|---|---|---|
| Item | YES/NO | pt |
| On-site solar energy production, e.g., PV panels | NO | 0 |
| Connection to district heating and/or cooling | NO | 0 |
| Wind access | NO | 0 |
| Biomass | NO | 0 |
| Geothermal | NO | 0 |
| Hydrogen/fuel cells | NO | 0 |
| Any other source | NO | 0 |
| **Value KAP2** | | 0 |

*Overall evaluation*

| | | |
|---|---|---|
| KRED.AP = KRED.AP1+KRED.AP2 | **Total value K** | 0 |
| | **pt** | 0 |
| | | *min 0 - max 10* |

REDUNDANCY

## RED.PS – Passive survivability

*Intent of the evaluation*

Ensure that the building passively maintain safe thermal conditions during a disruptive event (i.e., extended power outage or loss of heating fuel).

*Description*

Passive survivability refers to a building's ability to maintain critical life-support conditions in the event of extended loss of power, heating fuel, or water. Passive thermal performance refers to heat transfer between a building and its surroundings, mainly without AC systems. Passive solar systems collect and distribute energy from the sun without the use of mechanical equipment such as fans or pumps.

*Indicator (qualitative)*

Absence/presence of passive systems for heating, cooling, and lighting.

*Evaluation modules*

RED.PS1 - Passive solar heating
RED.PS2 - Passive cooling
RED.PS3 - Passive lighting
RED.PS4 - Thermal safety temperature

| **RED.PS1 - Passive solar heating** | | (max 3 points) |
|---|---|---|
| Item | YES/NO | pt |
| **DIRECT GAIN** | | |
| A - Southern facing glass | YES | 1 |
| B - Solar-facing clerestories and sloped skylights | NO | 0 |
| C - Solar chimney | YES | 1 |
| D - Sunspace | NO | 0 |
| **INDIRECT GAIN** | | |
| E - Increased thermal mass | YES | 1 |
| F - Thermal storage wall | NO | 0 |
| G - Thermal zoning | NO | 0 |
| **Value KPS1** | | 3 |

| **RED.PS2 - Passive cooling** | | (max 4 points) |
|---|---|---|
| Item | YES/NO | pt |
| **PREVENTIVE TECHNIQUES** | | |
| A - Shading (vertical and operable) | YES | 1 |
| B - Internal gain control | YES | 1 |
| **MODULATION AND HEAT DISSIPATION TECHNIQUES** | | |
| C - Cross ventilation | NO | 0 |
| D - Stack ventilation | YES | 1 |
| E - Night flushing | NO | 0 |
| F - Radiative cooling or evaporation cooling | NO | 0 |
| G - Earth coupling | NO | 0 |
| H - Cold roof or double roof | NO | 0 |
| **Value KPS2** | | 3 |

| **RED.PS3 - Passive lighting** | | (max 4 points) |
|---|---|---|
| Item | YES/NO | pt |
| A - Building form and layout | YES | 1 |
| B - Daylighting from multiple sides | NO | 0 |
| C - Solar zoning | NO | 0 |
| D - High efficacy egress lighting | YES | 1 |
| **Value KPS3** | | 2 |

| **RED.PS4 - Thermal safety temperature** | Select just one option | |
|---|---|---|
| Item | YES/NO | pt |
| >27°C | - | 0 |
| 26.5 °C | - | 0 |
| 26.0 °C | - | 0 |
| 25.5 °C | - | 0 |
| <25.0 °C | YES | 3 |
| **Value KPS4** | | 3 |

*Overall evaluation*

| | | |
|---|---|---|
| KRED.PS = KRED.PS1+KRED.PS2+KRED.PS3+KRED.PS4 | **Total value K** | 11 |
| | **pt** | 8 |
| | | *min 0 - max 10* |

## ROB.HR – Heavy precipitation-resistant building envelope and structure

*Intent of the evaluation*

Minimization of damage caused by heavy precipitation. The implemented strategies help to reduce the amount of rainwater runoff from the building by collecting and storing it, while also helping to reduce any potential flooding.

*Description*

Buildings can be damaged by heavy precipitation. The result can be structural damage, flooding, and water damage that may be expensive to repair. Precautionary measures such as proper waterproofing, proper drainage, and regular maintenance can help reduce the potential for damage.

*Indicator (qualitative)*

Rating of the readiness of the building for facing a heavy precipitation.

*Evaluation modules*

ROB.HR1 - Heavy precipitation-resistant building solutions

**RES.HR1 - Heavy precipitation-resistant building solutions**

| Item | YES/NO | pt |
|---|---|---|
| **BUILDING SHAPE** | | |
| Avoid square and rectangular flat surfaces | YES | 0.5 |
| **STRUCTURE** | | |
| Passive landslide control measures | NO | 0 |
| Ground preparation | NO | 0 |
| **WALLS** | | |
| Green façade | NO | 0 |
| Rainscreen with a drainage system within the wall | NO | 0 |
| **OPENINGS** | | |
| Tempered glass panel (e.g., 4-mm thickness) | YES | 0.5 |
| Hail-proof shutters and blinds | NO | 0 |
| Secure loose joints by cramping, gluing, re-wedging and pinning | NO | 0 |
| Effective sealants and waterproof membranes | YES | 0.5 |
| **ROOF** | | |
| Hail net for protecting roof fragile elements | NO | 0 |
| Heat tracing in gutters | NO | 0 |
| Type of roof (e.g., warm, inverted, blue, blue-green, green) | YES | 0.5 |
| Pitched roof | NO | 0 |
| **PREFERRED MATERIALS** | | |
| Water-resistant materials | YES | 0.5 |
| Infiltration trenches | NO | 0 |
| Metal for roofing | NO | 0 |
| **BUILDING SERVICES** | | |
| Proper dimensioned drainage network | YES | 0.5 |
| Disconnect surface water from sewage | NO | 0 |
| Rainwater tanks | YES | 0.5 |
| Devices anti-backflow | NO | 0 |
| **SURROUNGINS** | | |
| Sustainable urban drainage (e.g., rain gardens and swales) | NO | 0 |
| Drainage systems in the building surroundings (e.g., sump pump) | YES | 0.5 |
| Permeable soil | YES | 0.5 |
| **Value KHR1** | | **4.5** |

*Overall evaluation*

KROB.HR = KROB.HR$_1$

| | |
|---|---|
| **Total value K** | **4.5** |
| **pt** | 4 |
| | *min 0 - max 10* |



## ROB.FR – Flood-resistant building envelope and structure

*Intent of the evaluation*

Minimization of flood damage. The building is prepared for a possible water level of 1m above the surrounding ground level.

*Description*

Installation of flood adaptation solutions for buildings such as the use of flood-resistant materials, the elevation of structures, and flood barriers can reduce the vulnerability to flood events. These measures can help protect buildings and the people inside them from flooding damage.

*Indicator (qualitative)*

Rating of the readiness in terms of solutions implemented in the building for facing a flood event.

*Evaluation modules*

RES.FR1 - Flood-resistant building solutions

**ROB.FR1 - Flood-resistant building solutions**

| Item | YES/NO | pt |
|---|---|---|
| **BUILDING SHAPE** | | |
| A - Square building shape | NO | 0 |
| **FOUNDATIONS** | | |
| B - Elevating the building | YES | 0.5 |
| C - Preliminary soil study | YES | 0.5 |
| D - Dry proofing foundations | YES | 0.5 |
| E - Wet proofing foundations (e.g., internal drainage systems, vents, etc.) | NO | 0 |
| **OPENINGS** | | |
| F - Permanent flood barriers | NO | 0 |
| G - Temporary flood barriers | NO | 0 |
| H - Effective sealants and waterproof membranes | YES | 0.5 |
| **PREFERRED MATERIALS** | | |
| I - Water-repellent finishes | YES | 0.5 |
| J - Water-resistant insulation | YES | 0.5 |
| K - Water-resistant materials | YES | 0.5 |
| **BUILDING SERVICES** | | |
| L - Building systems above the flood level (i.e., mechanical and electrical systems) | YES | 0.5 |
| M - Devices anti-backflow | NO | 0 |
| N - Basement with non-essential functions | YES | 0.5 |
| **SURROUNGINS** | | |
| O - Buffer zones in the building surroundings | NO | 0 |
| P - Drainage systems in the building surroundings (e.g., sump pump, raingardens, swales) | YES | 0.5 |
| **Value KFR1** | - | 5 |

*Overall evaluation*

KROB.FR = KROB.FR$_1$

| | |
|---|---|
| **Total value K** | 5 |
| **pt** | 6 |
| | *min 0 - max 10* |

CAPACITY BUILDING

## CAP.SS – Safe equipped space

***Intent of the evaluation***

Provide building users with a safe room equipped with some supplies in the event of an emergency.

***Description***

A secure space incorporates essential provisions that building occupants may require for survival during a disaster. Ensuring easy accessibility during emergencies is imperative, and the room should be adequately equipped.

***Indicator (qualitative)***

Presence/absence of a dedicated emergency space and safety kits.

***Evaluation modules***

CAP.SS1 - Fundamental safety
CAP.SS2 - Safe room

**CAP.SS1 - Fundamental safety**

| Item | YES/NO | pt |
|---|---|---|
| First aid kit | YES | 1 |
| Disaster supply | NO | 0 |
| At least one telephone land-line along with a cell phone with text message capabilities and an emergency alert radio, and walkie-talkies. | NO | 0 |
| Biodegradable and sanitizing compounds to encapsulate waste | NO | 0 |
| **Value KSS1** | - | **1** |

**CAP.SS2 - Safe room**

| Item | YES/NO | pt |
|---|---|---|
| Residential safe room | NO | 0 |
| Community safe room | NO | 0 |
| **Value KSS2** | - | **0** |

***Overall evaluation***

KCAP.SS = KCAP.SS1 + KRCAP.SS2

| | |
|---|---|
| **Total value K** | 1 |
| **pt** | 2 |
| | *min 0 - max 10* |

ROBUSTNESS

## ROB.HW – Heat wave-resistant building envelope and structure

***Intent of the evaluation***

Ensure thermal comfort for building users during a heatwave.

***Description***

Heat waves occur when a particular region experiences prolonged periods of extremely high temperatures. Due to climate change, periods of high temperatures and heat waves will increase in intensity and duration throughout Europe. Human health, well-being, and productivity can be adversely affected by high indoor temperatures; solutions must be identified for safeguarding well-being and ensuring thermal comfort.

***Indicator (qualitative)***

Rating of the readiness of the building for facing a heat wave.

***Evaluation modules***

ROB.HW1 – Heatwave adaptation solutions

**ROB.HW1 - Heatwave adaptation solutions**

| Item | YES/NO | pt |
|---|---|---|
| **BUILDING SHAPE** | | |
| A - Façade orientation | YES | 0.5 |
| **OPENINGS** | | |
| B - Adequate insulation of windows, doors and walls | YES | 0.5 |
| C - Solar shading for windows (e.g., blinds, shutters, brise-soleil) | YES | 0.5 |
| **WALLS** | | |
| D - Green façades | NO | 0 |
| E - Joints movement | NO | 0 |
| **ROOF** | | |
| F - Photovoltaic panels installation | NO | 0 |
| H - Green roof | YES | 0.5 |
| **PREFERRED MATERIALS** | | |
| I - Light-colored and reflective materials (e.g., solar reflective tiles) | YES | 0.5 |
| J - Thermal mass and phase-change materials | NO | 0 |
| **BUILDING SERVICES** | | |
| K - Passive cooling/ventilation techniques | YES | 0.5 |
| L - Active ventilation and cooling system | YES | 0.5 |
| M - Geocooling and heat pumps | NO | 0 |
| N - Connection to district cooling system | NO | 0 |
| **SURROUNGINS** | | |
| O - Vegetation on sun-exposed sides for shading the building | NO | 0 |
| **Value KHW1** | - | **3.5** |

***Overall evaluation***

KROB.HW = $KROB.HW_1$

| | |
|---|---|
| **Total value K** | 3.5 |
| **pt** | 5 |
| | *min 0 - max 10* |

CAPACITY BUILDING

## CAP.WS – Emergency water supply

***Intent of the evaluation***
Provide water access for building users during common emergencies/disasters for at least a 96-hour period (four days).

***Description***
Planning for access to potable water during a power outage or storm-related event, starts with water conservation, and can include reusing water on-site, such as harvested rainwater or recycled greywater for storage and later use during emergencies to cover operations such as toilet flushing, mechanical equipment, and irrigation.

***Indicator (qualitative)***
Presence/absence of water supply in case of an emergency.

***Evaluation modules***
CAP.WS1 - Access to potable water

**CAP.WS1 - Access to potable water**

| Item | YES/NO | pt |
|---|---|---|
| Use of waterless urinals or composting toilets | NO | 0 |
| Provide on-site water storage to cover operations | YES | 1 |
| Recycling greywater to cover operations and reduce building sewage conveyance by 25% (50%) | YES | 1 |
| Utilisation of a well connected to groundwater sources (e.g., aquifer) for drinking water supply | NO | 0 |
| Installation of standby or emergency pump for water supply | YES | 1 |
| **Value KWS1** | - | **3** |

***Overall evaluation***

$KCAP.WS = KCAP.WS_1$

| | |
|---|---|
| **Total value K** | **3** |
| **pt** | 6 |
| | *min 0 - max 10* |

CAPACITY BUILDING

## CAP.PS – Emergency power supply

***Intent of the evaluation***
Provide fundamental safety for building users during common emergencies/disasters for at least a 96-hour period (four days).

***Description***
Mid-rise residential buildings ought to be outfitted with backup power to support critical functions, such as operating a single elevator and a fire-suppression pump. The necessity for backup power escalates further if residents are required to shelter in place during power outages. It is imperative to ensure the availability of adequate emergency power to sustain essential loads identified by the design team as crucial for the building's operation and to facilitate repairs during and after a disruptive event. The specific critical loads will vary depending on the project.

***Indicator (qualitative)***
Presence/absence of emergency power supply.

***Evaluation modules***
CAP.PS1 - Back-up power for critical loads

**CAP.PS1 - Back-up power for critical loads**

| Item | YES/NO | pt |
|---|---|---|
| Install a proper sized back-up generator (e.g., Propane/LPG (Liquified Petroleum Gas) generator, Natural gas generators, Diesel or bio-diesel generator, Combined heat and power (cogeneration) generators). | NO | 0 |
| Operation of fuel-fired heating system with stored emergency fuel. | YES | 1 |
| Operation of a fan sufficient to provide emergency cooling if mechanical air conditioning equipment cannot operate (e.g., ceiling fans, plug-in window fans, or fans integral with central air distribution). | YES | 1 |
| Operation of water pumps if needed to make potable water available to occupants (if pumps are required for distribution of water within the building). | YES | 1 |
| Emergency escape lighting is lighting that activates and provides illumination in the event of loss of power to the main system. | YES | 1 |
| Operation of cable modem and wireless router or other means of providing online access within the building. | NO | 0 |
| **Value KPS1** | - | **4** |

***Overall evaluation***

$KCAP.PS = KCAP.PS_1$

| | |
|---|---|
| **Total value K** | **4** |
| **pt** | 7 |
| | *min 0 - max 10* |

## COM.UG – Urban Gardening

***Intent of the evaluation***
Improve local food production by sustainably growing, efficiency cultivating and responsibly consuming food within building surroundings.

***Description***
Local food production is a method to produce food in systems and practices that are not polluting, are season-based, reduce GHG emissions and waste, and build resilience through the food value chain. Local food sourcing can reconnect people with local food production, supporting efficient development, equitable distribution, and sustainable consumption of food. It can also be an opportunity for meeting and sharing ideas and activities, i.e., benefits people can derive from ecosystems, such as food, ornamental flowers, nature education, as well as regulating services such as air filtration, noise reduction, and surface water drainage.

***Indicator (qualitative)***
Absence/presence of food production system in the building surroundings.

***Evaluation modules***
COM.UG1 - Urban community gardening

**COM.UG1 - Urban community gardening**

| Item | YES/NO | pt |
|---|---|---|
| Dedicate >5% of the site's final vegetated area to food production (not below ca 1.5 m2 per residential unit) | NO | 0 |
| 2 different production crops (e.g., vegetables and/or edible nut- and fruit-bearing plants) | NO | 0 |
| Use of harvested rainwater for watering | YES | 1 |
| **Value KUG1** | - | **1** |

***Overall evaluation***

KCOM.UG = $KCOM.UG_1$

| | |
|---|---|
| **Total value K** | **1** |
| **pt** | 2 |
| | *min 0 - max 10* |

COMMUNITY COHESION

## COM.SS – Access to useful shared spaces

***Intent of the evaluation***
Enhance community liveability by developing new shared space, such as common rooms, gardens, playgrounds, and recreational areas for social gatherings.

***Description***
By sharing resources, goods, and services, urban resilience can be enhanced by reducing the need for new materials and infrastructure, supporting local economies, and strengthening social networks. The use of communal spaces such as kitchens, living rooms, laundries, and gardens results in more efficient use of materials and space. They also provide spaces for social interaction.

***Indicator (qualitative)***
Number of available useful community space.

***Evaluation modules***
COM.SS1 - Shared spaces

**COM.SS1 - Shared spaces**

| Item | YES/NO | pt |
|---|---|---|
| Bike storage space | YES | 1 |
| Car share space | NO | 0 |
| Garden/terrace/patio space | YES | 1 |
| Tool share space | YES | 1 |
| Usable open space (i.e., an area for barbecue, a playground, etc.) | NO | 0 |
| Recreation rooms/spaces | NO | 0 |
| Communal kitchen | NO | 0 |
| Communal laundry room | YES | 1 |
| Fitness facilities | NO | 0 |
| Coworking areas | NO | 0 |
| Any other space that is accessible to multiple residents at the same time | YES | 1 |
| Any other space that is accessible to multiple residents at the same time | YES | 1 |
| Any other space that is accessible to multiple residents at the same time | NO | 0 |
| **Value KSS1** | - | **6** |

***Overall evaluation***

KCOM.SS = $KCOM.SS_1$

| | |
|---|---|
| **Total value K** | **6** |
| **pt** | 5 |
| | *min 0 - max 10* |

## COM.EP – Emergency preparedness

***Intent of the evaluation***
Enhancement of emergency preparedness through the installation of warning systems.

***Description***
Technology is rapidly shaping the way we approach safety in residential settings. From smart devices to artificial intelligence, these advancements enable proactive hazard detection and offer unprecedented control to building users. Warning systems are key elements of climate change adaptation and disaster risk reduction and aim to avoid or reduce the damage caused from hazards. To be effective, warning systems need to actively involve the people and communities at risk from a range of hazards, disseminate messages and warnings efficiently and ensure that there is a constant state of preparedness, and that early action is enabled.

***Indicator (qualitative)***
Presence of warning systems within the building.

***Evaluation modules***
COM.EP1 - Warning system

**COM.UG1 - Urban community gardening**

| Item | YES/NO | pt |
|---|---|---|
| Heat warning system | YES | 1 |
| Flood warning system | NO | 0 |
| Multi-sensor warning system | NO | 0 |
| **Value KEP1** | - | **1** |

***Overall evaluation***

KCOM.EP = $KCOM.EP_1$

| | |
|---|---|
| **Total value K** | **1** |
| **pt** | 3 |
| | *min 0 - max 10* |

# Appendix C – Appended articles with greater relevance to the thesis

*This Appendix includes the primary publications of the PhD candidate on the doctoral subject. Each publication was regarded as a milestone throughout the PhD journey, presenting the theoretical groundwork and empirical investigations, and they demonstrated significant advancements in the research to the scientific community. Finally, these papers collectively contribute to advancing the understanding and integration of sustainability and resilience in the building sector, laying a solid foundation for the research presented in this PhD thesis.*

## Conference paper I: Sustainability and Resilience in Building Design: Discussion on Two Case Studies

**Felicioni L.; Lupíšek A.; Gaspari J.; Antonini E.**

*Central Europe towards Sustainable Building **2022**, Acta Polytechnica CTU Proceedings 38:456–462*

This conference paper presents the work conducted during the initial phases of the PhD, focusing on whether sustainability and resilience at the building design level share common ground. Specifically, two buildings were analysed: one certified as sustainable by the LEED rating system, and another claimed to be flood-resistant. The analysis compared their performance based on key sustainability principles and resilience principles, derived from a literature review, information from green building rating systems, and resilience assessment tools. The main finding is that, to some extent, the sustainable building demonstrates resilience, and the flood-resistant building shows elements of sustainability. This suggests that the domains of sustainability and resilience overlap, and it is possible to integrate these principles within building projects.

### Authors' contributions

Licia Felicioni conducted a literature review on the common ground between sustainability and resilience in building design, revising publications and rating systems, highlighting the principles of sustainability and resilience and testing them on two case studies. Antonin Lupíšek, Jacopo Gaspari and Ernesto Antonini supervised throughout the process. Licia Felicioni led the drafting of the research paper while all authors were involved in reviewing and approving the final version.

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# SUSTAINABILITY AND RESILIENCE IN BUILDING DESIGN: DISCUSSION ON TWO CASE STUDIES

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ABSTRACT. Designing sustainable and, at the same moment, resilient buildings is a necessity to reach the UN Sustainable Development Goals by 2030. However, these two building design approaches – sustainability and resilience – are usually treated separately. Typically, resilience-improving strategies are placed only after a disruptive event and not at the design stage. It is clear that there is a substantial intersection between sustainability and resilience and this manuscript aims to determine more precisely the commonalities and contradictions seen in building design sustainable and resilient approaches as crucial elements for improving their cooperation in buildings. To accomplish this, the authors qualitatively analysed two case studies – respectively claiming to be sustainable and resilient – to understand if a sustainable building can also be considered resilient and vice versa. This paper is addressed to the private and public sectors that have a decisive role in building design and are determined to take tangible steps to influence decision-making and resilience-based solutions already at the design phase. In conclusion, once the commonalities of resilience and sustainability are highlighted, a building designed as sustainable or resilient will be in line with both long-term perspectives.

KEYWORDS: Building design, sustainable building, resilient building, synergies, contradictions, future threats.

## 1. INTRODUCTION

In the 6$^{th}$assessment report of the Intergovernmental Panel on Climate Change (IPCC) [1], it is highlighted that Earth is experiencing irreversible impacts and unprecedented warming, including more frequent and more extreme weather events; their consequences will continue to get more intensive for every bit of warming [2]. The frequency and severity of floods, wildfires, heat and cold waves, and droughts in the last decade was increasing, causing remarkable economic costs and life losses [3, 4]. The IPCC's report shows that emissions of greenhouse gases from human activities are responsible for approximately 1.1 °C of warming since 1850–1900 and significantly contributes to the alteration of the local climatic conditions in the built environment (i.e. urban heat islands) [2]. In Europe, buildings are the largest energy consumer, responsible for approximately 40 % of greenhouse gas emissions; indeed, the built environment represents a crucial sector in terms of saving potential and, at the same time, one of the most vulnerable and densely inhabited places affected by climate change effects.

### 1.1. SYNERGIES BETWEEN SUSTAINABILITY AND RESILIENCE

Developing the built environment sustainable and resilient to climate change is a pressing global need, as outlined by the 2015 Paris Agreement [5] and the recent 2021 IPCC assessment report [2]. Sustainability has been a trend since the '90s, when different protocols aimed at assessing sustainability in buildings were developed, such as Leadership in Energy and Environmental Design (LEED) [6] in the United States, Building Research Establishment Environmental Assessment Method (BREEAM) [7] in the United Kingdom, and Deutsche Gesellschaft für Nachhaltiges Bauen (DGNB) [8] in Germany. The current concept of resilience is instead less concrete and much more recent than sustainability. There is no fixed definition, but it is starting to experience a global increment in interest due to the climate change impacts [9]. However, the most accepted and common explanation defines resilience as the ability of a system to maintain or recover functionality in the event of disruption or disturbance [10, 11]. The need for effective strategies to face these interconnected challenges arises in the 2015 UN Sustainable Development Goals (SDGs), where adequate mitigation and adaptation measures are expected to be introduced by 2030 [12].

In particular, the targets of SDG 13 are aimed at increasing resilience from natural hazards, while others, such as SDG 7 or 11, are more focused on sustainability. However, SDGs always share benefits and synergies and are directly connected to sustainability and resilience for the built environment. Thus, it is highlighted that both resilience and sustainability can have commonalities at the building level and should be considered already at the design stage.

Accordingly, green buildings should be designed to be resilient to extreme events (loads connected to heavy rains, floods, or other hazards) to keep the occupants safe and reduce the environmental impacts associated with post-event adjustments [13].

### 1.2. Scope of the paper

Using two case studies, the paper aims to analyse sustainability and resilience in building design via a qualitative assessment. Qualitative analysis is suited to the initial phases of planning, object programming, and designing at every stage of the design process [14].

The first case study is a LEED-certified building ranked Platinum (LEED New Construction v3) among the very new generation of sustainable construction in the Czech Republic; the second is a resilient building completed in New York City following a new protocol developed as a response to the 2012 Sandy hurricane consequences. After preliminary identification of the distinctive criteria associated with sustainability and resilience, the buildings were assessed qualitatively to understand if the claimed as sustainable is also resilient and vice versa. Thus, the main scope is to understand the relationship between sustainability and resilience to design principles.

## 2. Materials and Methods

The adopted method includes a qualitative assessment for two case studies considering different criteria both for sustainability and resilience. The qualitative assessment approach is quite consolidated in the scientific literature as a source of universal methods for investigating whole objects and selected elements of the building [14].

In the case of sustainability, the criteria were selected analyzing the most known and worldwide sustainable protocols for New Construction: LEED v4.1 [6], BREEAM International 2016 [7] and DGNB 2020 [8]. Once the criteria and the benchmarks were picked, four levels of accomplishment (poor, sufficient, good and excellent) were selected to assess the specific criterion's level of achievement (Table 1).

A similar method has been considered in the case of resilience where RELi [15] and Envision v3 [16], two of the most known resilience assessment tools worldwide, have been chosen as reference tools for selecting the criteria (Table 2).

The benchmarks for the distribution of the grades were established using different methodologies aligned with benchmark values found in the literature that are explained case by case [7, 15, 17, 18]. Dependent on fulfilment of each criterion, points were given according to this scale: 2 points for "Poor", 5 points for "Sufficient", 8 points for "Good" and 10 points for "Excellent". It is assumed that buildings in which poor positive pro-environment or resilient measures were applied for the assessed criteria receive a satisfactory grade of 2. Consequently, the maximal value is set as 130 (respectively 70 for sustainability and 60 for resilience), which means that the building has a very excellent performance in terms of qualitative aspects.

For research purposes, we considered two case studies located in flood-prone areas:

- Main Point Karlin (Prague, Czechia) (Figure 1a) – LEED-certified office building (LEED v3); it was the first Platinum-certified building in Czechia and even Central Europe. It was built in 2012 in the Karlin neighborhood, an area really close to the Vltava river. It has been chosen because one of the first examples of a new generation of buildings in the Czech Republic – it achieved great results, particularly in the fields of energy utilization, indoor environmental quality and innovations.
- Dock 72 (Brooklyn, New York City) (Figure 1b) – Class A office building claimed to be flood-resistant. It was built in 2019 in the Brooklyn Navy Yard neighborhood, an area in front of the Navy Yard Bay. It has been chosen since it is a response building to the 2012 Sandy hurricane damages; the building hovers above the floodplain on V-shaped columns – it achieved great performance, particularly in the fields of energy back-up and passive systems.

Finally, a table with grades for every criterion gives a picture of the sustainability or resilience of both case studies.

### 2.1. Buildings descriptions

#### 2.1.1. Sustainable building case study

The building chosen as a case study for representing sustainability is the Main Point Karlin office building, located in Prague (Czechia) (Figure 1a), in the neighbourhood of Karlin, in front of the Vltava river. The building was awarded the title "Best Office Building in the World" at the MIPIM Awards 2012 and the first holder of the highest LEED Platinum certificate in Central Europe (certified under LEED New Construction 2009). Main Point Karlin is a technologically equipped 10-floors office building with a leasable area of 22 000 $m^2$. The distinctive facade panels have the function of sun breakers, ensuring optimal workplace lighting by direct and indirect components. The coloured material used in the facade is fiberC, which was considered one of the greenest concrete panels available in 2012 with low embodied environmental impacts (202 $MJ/m^2$ for primary energy and 14 kg $CO_2eq/m^2$ for global warming potential). Moreover, a 1 200 mm diameter flushing channel runs through the basement of the building and in

| Criteria | Poor | Sufficient | Good | Excellent |
|---|---|---|---|---|
| Connectivity and Transport | Public traffic connection > 1 km | Public traffic connection within 1 km | Public traffic connection within 800 m | Public traffic connection within 400 m |
| Land use and ecology | Using native vegetation | Green roof and native vegetation | Previous plus installed rainwater collection system | All the techniques before mentioned and other innovative solutions |
| Reduction of indoor water consumption | > 0 % | > 30 % | > 40 % | > 50 % |
| Improvement of energy performance (compared to the baseline building performance) | > 5 % | > 20 % | > 30 % | > 40 % |
| Resource-efficient and circular material life cycles | Surface area reused > 0 % | Surface area reused > 25 % | Surface area reused > 50 % | Surface area reused > 75 % |
| Renewable energy procurement | > 2 % (on-site) > 20 % (off-site) | > 5 % (on-site) > 30 % (off-site) | > 10 % (on-site) > 40 % (off-site) | > 20 % (on-site) > 50 % (off-site) |
| Daylight | < 55 % of occupied floor area | 55 % of occupied floor area | 75 % of occupied floor area | 90 % of occupied floor area |

Table 1. Compilation of criteria for the evaluation of qualitative aspects related to sustainability.

| Criteria | Poor | Sufficient | Good | Excellent |
|---|---|---|---|---|
| Building surroundings protection | Reduced run-off | Develop Nature-based Solutions that protect the surrounding | Plan system for 100-year floods for the building | Protect below ground system vents and entrance from floods and 100-year floods for the surrounding |
| Passive heating | Only active solutions | Direct gain via glazing | Direct gain via storage + glazing | All the strategies mentioned + indirect gain via sunspace |
| Passive cooling | Orientation | Orientation, cross ventilation | Solar shading, building facades | All the strategies mentioned |
| Passive lighting | Minimum daylight | Daylight from multiple sides | Intermediate light shelves and skylights | All the strategies mentioned |
| Water harvesting | None | < 50 % of the roof area | > 50 % of the roof area | > 50 % of the roof area and parking areas for reuse |
| Resilience to climate/natural hazards | None | Identification of regional hazards | Location hazards assessment + passive solutions | Location hazards assessment + passive solutions and resilience emergency plan |

Table 2. Compilation of criteria for the evaluation of qualitative aspects related to resilience.

(A). (B).

FIGURE 1. (A) Main Point Karlin, Prague (Czechia), designed by DAM Architeki. Details of the façade that works as sun shading. (B) Dock 72 at the Brooklyn Navy Yard (NYC), designed by S9 Architecture.

which the Vltava flows from the Těšnov weir to the Libeň docks. This technology is used to cool the building passively.

The quality of the building's indoor environment, corresponding to a higher standard, is ensured by ceiling induction units. The under-ceiling placement of the units is ideal in terms of natural airflow – the cooled air falls by its weight and does not "blow" on the workers from anywhere. However, even if it is located in proximity to the Vltava river, it does not consider any strategies against flood-related events since its ground floor, where restaurants, bars and even the main entrance are placed, is below the street level.

#### 2.1.2. Resilient building case study

The building chosen as a case study for representing resilience is the Dock 72 office complex, located in Brooklin (NYC) (Figure 1b), on the waterfront of the East River. The 62 700 $m^2$ structure, whose base uses steel frames and steel braced cores, has 16 floors looking out to Brooklyn and Manhattan, situated 0.3 m above the floodplain. The city of New York experienced the devastation of the hurricane Sandy in 2012 that led to a full collapse of the electric system and flooding all around the five neighbourhoods, mainly in Manhattan and Brooklyn. This Class-A office building is designed to withstand potential hazards, such as flood events and sea-level rise, with the 20 V-shaped columns allow water to flow under the building and sloping ramps that provide access to the elevated main floor. The building's mechanical systems are raised above the first level, ensuring that the building functional level can be preserved or reloaded easier in the recovery phase.

The Dock 72 indoor environment is characterized by open, flexible, and light-filled workspaces. The stepped massing and gridded, glazed façade maximizes the views on the Manhattan bay and allows a direct gain of sunlight.

## 3. Results and Discussion

### 3.1. Qualitative assessment of the two case studies

#### 3.1.1. Sustainability qualitative evaluation

As it was previously mentioned in Section 2, each case study was analysed to understand the general sustainability of the building. The qualitative sustainability evaluation considers seven main categories that are listed in Table 3.

Main Point Karlin presents great outcomes in the categories of Connectivity and Transport, since public transport services are very close to the building, and in Land Use and Ecology, since the building is placed on a former brownfield, successively redeveloped, and a rainwater collection system that allows to a 100 % reduction in potable landscape water use. In contrast, the category that presents the lower grade is Resource-efficient and circular material life cycles due to only 20 % recycled content building materials.

Dock 72 in Brooklyn showcases an excellent result in Connectivity and Transport since the proximity of various available transport services and good results in Energy performance and Daylight thanks to energy-saving measures that include increased roof and exposed floor insulation, reduced fan power and variable frequency drives, and high-performance building envelope and reduced lighting power centre. Quite the reverse, two of the seven selected sustainability categories are graded as "poor" because there are

| | Main Point Karlin | Dock 72 |
|---|---|---|
| Connectivity and Transport | Excellent | Excellent |
| Land use and ecology | Excellent | Sufficient |
| Reduce indoor water consumption | Good | Sufficient |
| Improvement of energy performance | Good | Good |
| Resource-efficient and circular material life cycles | Poor | Poor |
| Renewable energy procurement | Sufficient | Poor |
| Daylight | Good | Good |

TABLE 3. Qualitative assessment for sustainability criteria.

| | Main Point Karlin | Dock 72 |
|---|---|---|
| Building surroundings protection | Poor | Excellent |
| Passive heating | Sufficient | Excellent |
| Passive cooling | Excellent | Sufficient |
| Passive lighting | Excellent | Sufficient |
| Water harvesting | Good | Sufficient |
| Resilience to climate/natural hazards | Poor | Excellent |

TABLE 4. Qualitative assessment for resilient criteria.

no renewables on-site and no intentions of building material reuse.

#### 3.1.2. RESILIENCE QUALITATIVE EVALUATION

As it was previously mentioned in Section 2, each case study was analysed to understand the general resilience of the building. The qualitative resilience evaluation considers six main categories that are listed in Table 4.

Main Point Karlin presents, on one side, great outcomes in the categories of Passive Cooling thanks to the 1 200 mm pipe that runs through the entire building from the Vltava river, and in Passive Lighting, the orientation of the building and the characteristic coloured pillars that also work as sun breaker. On the other side, two categories present the lower grade: Transportation system protection and Resilience to climate/natural hazards.

Dock 72 was designed with a special focus on flood-resilient features to potentially face another catastrophic event like the 2012 hurricane. The ground floor was built 0.3 meters above the 100-year floodplain grade. A 1 500 kW emergency generator ensures that tenants, even in case of extreme events and consequent black-out, would not experience a lack of light or heating.

#### 3.1.3. COMPARISON

Figure 2 shows the two graphs related to the qualitative sustainability assessment (7 categories) and resilience (6 categories) of the two case studies.

As it was preannounced, the building claimed to be sustainable, Main Point Karlin, has greater results than the one claimed as resilient, Dock 72, because more categories are under the grades "Excellent" or "Good", such as Land use and Ecology and Reduce of indoor water consumption thanks to run-off reduction and rainwater harvesting system. However, Dock 72 presents the same great results for Connectivity and Transport as the Prague building, thanks to the closeness of different available public transportation (ferry, bus, metro, and bicycle lanes), while it lacks in reusing of building materials and recycling.

Focusing on the qualitative resilience assessment, Dock 72 presents excellent outcomes for three of the six categories, mostly due to its design thought to be flood-resistant. Indeed, placing the main entrance and the mechanical systems at higher levels allow the building's functional level to be preserved or reloaded easier in the recovery phase in the presence of heavy rain or other climate-related hazards.

In 2002, a 100-year flood event caused by over a week of continuous heavy rains ravaged Central Europe. Prague received significant damage; Karlin was one of the most severely affected capital city neighbourhoods, with a risk of building collapse. However, as shown in Figure 2, Main Point Karlin, built in 2012, precisely ten years after the catastrophic flood, does not present any strategy to face such a possible event that is even more potentially dangerous due to river proximity. However, it showcases great results for passive strategies for cooling, thanks to the tube of Vltava water that runs on the second-unground floor, and for lighting, due to the particular façade panels.

### 3.2. LIMIT OF THE STUDY

The limit of this study is related to the subjectivity of the adopted criteria used for assigning the grades. The list of indicators is limited and simplified but inclusive and clusters some sub-indicators that, otherwise, would expand the comparative process without focusing on the core point of finding a balance between sustainability and resilience. That allowed even

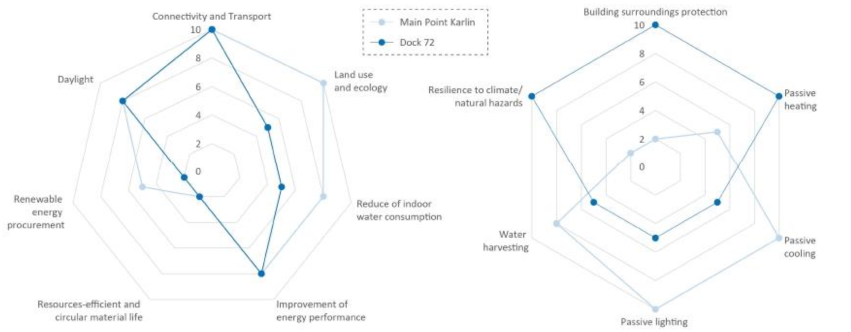


FIGURE 2. Analysis of the two case studies for sustainability (left) and resilience (right) according to the defined criteria.

to keep complexity manageable, as (1) other assessment frameworks (and even those that inspired the selection) consider other variables that could change the overall assessment result and (2) some of them are highly criticized "attribute-oriented" rather than "performance-oriented" criteria. However, these clusters address sustainability and mostly environmental resilience while not considering other aspects of resilience, such as economic or social. Still, these aspects will be studied in further studies.

## 4. CONCLUSION

The approach that has been adopted serves to identify common elements and distinctive attributes for sustainability and resilience so that these specific solutions can be exported or imported between the two domains to design a new generation of buildings.

As the results highlight, it is possible that if in a building only sustainability is considered, some resilience aspects may be neglected and/or when only principles of resilience are taken into consideration, some fundamental sustainability values may be ignored. The primary outcome of this work is that it is necessary to think about a new generation of buildings where both domains are considered to find a proper balance between them.

Finally, it is possible to conclude that some indicators must be identified and become irreplaceable in guiding the design so that a building, in addition to having minimal elements of sustainability, also contextually can give a minimal response to the concept of resilience since they share common roots. In practice, the final design will depend on the building objectives, which might include more or less severe resilience and/or sustainability requirements. This is in the logic of adapting the principles around which direct the construction sector, particularly the construction of new buildings, with respect to the tomorrow's challenges, so clearly evoked by the SDGs.

## ACKNOWLEDGEMENTS

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**Research Paper I: Exploring the Common Ground of Sustainability and Resilience in the Building Sector: A Systematic Literature Review and Analysis of Building Rating Systems**

**Felicioni L., Lupíšek A. and Gaspari J.**

*Sustainability*, **2023**, 15 (1), 844. DOI: 10.3390/su15010884

This paper represents a significant milestone in the first two years of the PhD study. It compiles a literature review of publications investigating the intersections between resilience and sustainability in building design. Additionally, it presents an approach for identifying these overlaps by analysing rating systems commonly used by architects and designers, particularly those focused on sustainability. The findings demonstrate shared clusters between sustainability and resilience, which can be applied to create building designs that are both sustainable and meet a basic level of resilience against specific hazards. The work carried out for this publication also contributed to subsequent phases of the PhD, such as populating a matrix with resilience principles, indicators, and metrics, ultimately leading to the development of the Resilience Module.

**Authors' contributions**

Licia Felicioni conducted a literature review on the common ground between sustainability and resilience in building design, revising publications and rating systems. Antonin Lupíšek and Jacopo Gaspari supervised throughout the process. Licia Felicioni led the drafting of the research paper while all authors were involved in reviewing and approving the final version.

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# Exploring the Common Ground of Sustainability and Resilience in the Building Sector: A Systematic Literature Review and Analysis of Building Rating Systems

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**Abstract:** Over the last ten years, due to the increase in frequency and severity of climate change effects, resilience in buildings has become a growing topic in the current global discussion on climate change adaptation. Designing both sustainable and resilient constructions would help to face such effects; however, sustainability and resilience in design have been mostly treated separately so far. Since sustainability has been considered more than resilience, paying deeper attention to the latter is indispensable to reducing building vulnerability. The purpose of this article is to examine the commonalities between the sustainability and resilience of buildings using two different approaches: (i) a systematic literature review, taking into consideration a 10-year period for selecting records, and (ii) an analysis of five green building rating systems and five resilience rating systems and guidelines selected according to their popularity and number of certified buildings. There is an overlap in some indicators between the two domains at the building level, as shown by the results from both paths. These aspects could assist in considering sustainability and resilience from the very beginning of the design process. This will ensure that buildings may be designed more effectively by considering and enhancing the synergies between the two domains. This paper targets potential stakeholders who may be interested in including such an integrated implementation in their designs.

**Keywords:** sustainability; resilience; buildings; rating systems; literature review; commonalities; building design; GBRSs; RRSs; clustering process



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## 1. Introduction

In the last decade, severe natural events, such as floods, wildfires, heat and cold waves, and droughts, resulting in significant loss of life and economic damage [1], have continued to occur at an increasing rate, demonstrating the intensity of climate change (CC) and its impact on the natural and built environment [2]. The 2021 report of the Intergovernmental Panel on Climate Change (IPCC) [3] shows that the emissions of greenhouse gases (GHG) from human activities are responsible for approximately 1.1 °C of warming from 1850 to 1900 and significantly contributed to the alteration of the local climatic conditions in the built environment (i.e., urban heat islands). In their report, IPCC experts have emphasised the irreversible consequences of temperature increase and urged action to reduce $CO_2$ emissions in the short term [4].

In addition to being responsible for 36% of emissions and 40% of energy consumption in the EU, the built environment represents a promising sector for massive savings, but at the same time, one of the most vulnerable to the impacts of CC [5].

Thus, defining effective, resilience-improving strategies to reduce vulnerability to disaster events, rather than working in just a reactive mode [6], represents a crucial issue for the near future. The international super-governmental bodies aim to address the possible causes by setting mitigation and adaptation measures for the medium and long term. Within these strategies, some specific indications for the building sector are embedded within the 2015 United Nations (UN) Sustainable Development Goals (SDGs) [7], where some principles of building design are linked to design for sustainability and resilience. The interrelationship of the two domains of sustainability and resilience needs to be studied to expedite the progress of building resilience at the local level towards achieving several international targets [8–10].

### 1.1. Sustainability and Resilience at Different Scales

According to [11–13], building sustainability refers to reducing the negative effects on the environment, while resilience refers to the way in which a building can adapt to changes imposed by CC.

Since the 1990s, different standards and certifications have been developed and used to ensure improved sustainability in buildings, such as Leadership in Energy and Environmental Design (LEED) [14] in the United States, Building Research Establishment Environmental Assessment Method (BREEAM) [15] in the United Kingdom, or Deutsche Gesellschaft für Nachhaltiges Bauen (DGNB) [16] in Germany. Currently, resilience is a big priority in the construction sector and often overlaps with the concept of sustainability, which has existed for a much longer time. As a consequence, a question arises as to whether resilience is a subset or something independent of sustainability [13]. Still, resilience to natural and manmade hazards is rarely included in green building rating systems (GBRSs) [17].

Although the precise meaning of building resilience is indeterminate, many organisations have tried to define this issue. For instance, the Rockefeller Center states that city resilience is the "overall capacity of a city (individuals, communities, institutions, businesses and systems) to survive, adapt and thrive no matter what kinds of chronic stresses or acute shocks they experience" [18]. Within this paper, resilience is assumed as the ability of a system, entity, community, or person to adapt to changing conditions, resist shocks while still preserving the essential functions, and recover all system features to a pre-disaster level. In the urban environment, improving building resilience has been associated with disaster risk reduction; moreover, when combined with urban resilience strategies, it can serve as a driving force for urban planning in the future [19].

The analysis of resilience is enhanced when a building is used as the unit of analysis, rather than a city or neighbourhood, as this allows a better understanding of how the building operators and managers (as key players within the building) deal with disruptions in the building system. This fact is especially significant because the most impacted user group from any resilience efforts (at any scale) are the end-users, who sometimes have limited control of the building system. Thus, since, in many cases, residential buildings are multifamily buildings, the owners and managers, having more power than building occupants, can influence and take purposeful actions in the building system to make it more resilient to ensure acceptable living conditions, including in case of extreme events [20]. Thus, the main idea behind this article is that two design processes, sustainability and resilience, are being discussed more and more by building and city experts and professionals, but there is little understanding of whether these are similar and could eventually be synergistic or whether there are contradictions [21]. To answer this question, a systematic literature review and analysis of building rating systems is needed. Identifying common clusters between the theoretical assumptions derived from the literature and the potential application within GBRSs/real construction processes can provide answers to the question of whether the two approaches overlap and how this is extended.

### 1.2. Scope and Objectives

This study reviews the commonalities of sustainability and resilience at the building level following two methods: a theoretical-based literature review and a rating-systems-based approach focused on investigating GBRSs and resilience rating systems (RRSs) and guidelines. Hence, the main objectives are (i) to identify the amount of research focused on both sustainability and resilience, and (ii) to define clusters and metrics of sustainability and resilience and to identify common clusters and synergies.

## 2. Materials and Methods

Since the main scope of this study is to point out the common ground between the domains of sustainability and resilience (Figure 1), the very first step of the process was to investigate their current notions and definitions within the scientific literature.

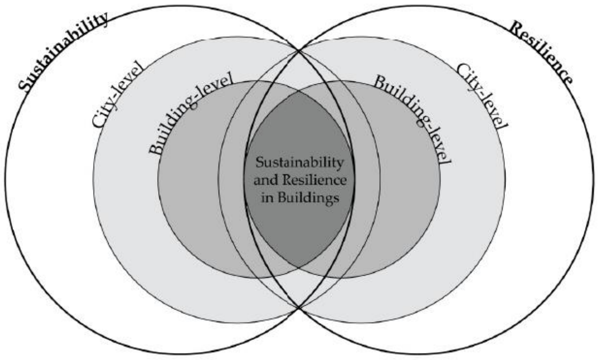


**Figure 1.** Venn diagram to identify the area of investigation.

A systemic review from electronic databases was therefore conducted. Figure 2 provides a conceptual workflow of the investigation process, which compares the outcomes of the literature review with the structure and consistency of the GBRSs and RRSs.

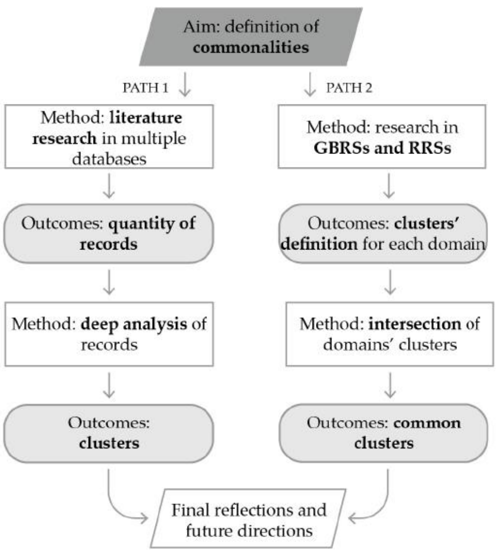


**Figure 2.** Overall research workflow.

Accordingly, a critical reflection addressed to the thematic cluster definition follows as a discussion regarding the two approaches and the future research trends in this sector.

*2.1. Theoretical Research*

The search was conducted in the Web of Science, Scopus, and Science Direct databases, which were chosen for their reputation in indexing high-quality and peer-reviewed papers and since they are managed by third parties. To control the quality and uniformity of data, the document types were limited to "reviews", "articles", "conference papers", and "books/book chapters", and the selected language was "English". The timespan set for this investigation was from 2002 to 2022, which is assumed as the "maturation period" of both the domains in which the larger scientific production was registered. The title, keywords, and abstracts of the papers were identified according to the following strings in each database:

- Sustainable building OR sustainable design OR sustainable construction OR sustainable built environment;
- Resilient building OR resilient design OR resilient construction OR resilient built environment.

Due to the fact that this study aims to identify the common ground between sustainability and resilience, additional narrowed research was conducted in the electronic databases to select records pertaining to sustainability in buildings which consider resilience aspects and vice versa. Moreover, since resilience is a more recent and less established concept, only the last ten years (2012–2022) were finally considered.

Figure 3 shows the PRISMA diagram [22] that illustrates the second-phase reviewing process. Once the data search was completed (1659 records identified), 7 additional records were identified through hand-searching, 744 duplicate records were removed, and a total of 922 records were selected for the screening process. For identifying patterns and trends, the VOSviewer tool (open-source software) [23,24] was used because it provides some analysis of recurrence of keywords that are useful to direct the search and immediately gain insights on emerging aspects. Titles and abstracts were then screened, and irrelevant results were excluded because the resilience aspect was only marginally considered. Hence, 86 full-text records were selected for the eligibility check. After reading the full-text records, a total of 47 records were included in this study.

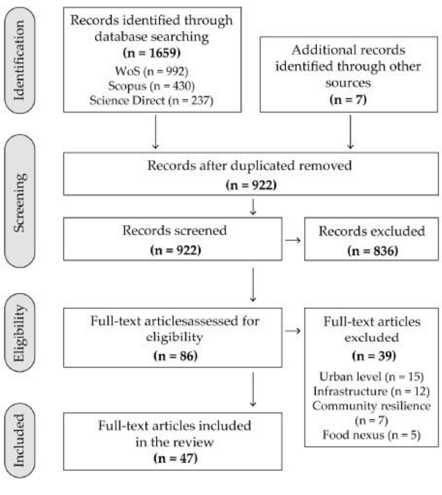


**Figure 3.** Literature review search strategy based on the PRISMA workflow.

### 2.2. Rating-Systems-Based Approach

GBRSs and RRSs can also be used for identifying the clusters for sustainability and resilience at the building level. Among the several available GBRSs [25], Table 1 shows key facts about the diffusion and application of the three most recurring ones at the European level, according to [26].

**Table 1.** Global statistics on the most prevalent GBRSs in Europe.

| GBRS | Country | N. Certified Buildings | Source |
|---|---|---|---|
| LEED | US | 79,418 | [27] |
| BREEAM | UK | 594,011 | [28] |
| DGNB | DE | 8700 | [29] |

Thus, the New Construction version of BREEAM [15], DGNB [16], and LEED [14] were carefully selected for this paper, assuming that these protocols have an essential role in setting directions for further sustainable strategies. Moreover, the new European sustainable framework Level(s) [29]—which was specifically developed to provide a common language among the rating systems—was also considered. Additionally, the RIBA design process [30], a well-known industry-standard planning method, particularly the RIBA Sustainable Outcomes [31], was included in the sustainable design domain.

After a screening among the currently available RRSs, Table 2 shows the five tools and guidelines that were chosen.

**Table 2.** Overview of chosen RRSs.

| RRS | Acronym | Country | Typology | Source |
|---|---|---|---|---|
| Resilience Action List and Credit Catalog | RELi | US | tool | [32] |
| Resilience-based Earthquake Design Initiative | REDi | US | tool | [33] |
| B-Ready | - | NO | tool | [34] |
| Performance Excellence in Electricity Renewal | PEER | US | tool | [35] |
| United States Green Building Council (USGBC) Green Building and Climate Resilience guidelines | USGBC | US | guidelines | [36] |

RELi was selected as being directly designed for LEED-certified buildings. REDi, also mentioned in RELi, is specifically designed to improve buildings' seismic response capacity. B-Ready was included as being one of the few protocols developed outside the US context. PEER is focused on energy efficiency and the environment. USGBC is the leading solution promoted by the United States Green Building Council.

Each selected GBRS and RRS has been carefully analysed to summarise (a) the key objectives; (b) the data to be collected; and (c) the metrics used to generate the rating scheme. Then, the tools were compared to assess their commonalities (including meaningful metrics) (Figure 4).

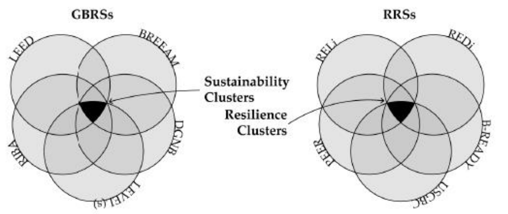


**Figure 4.** Clusters definition strategy—sustainability clusters on the left and resilience clusters on the right.

Following a thorough analysis of these rating systems (RSs) (criterion-by-criterion approach), several criteria were grouped into clusters. Based on this analysis, common clusters were recognised, taking into account the indicators and main effects of the strategies.

## 3. Results

### 3.1. Theoretical Research: Systematic Literature Review

The literature research was conducted between July and November 2022. The first search round produced 8437 results for the sustainability domain and 1130 results for the resilience domain, whose combined distribution over the 20-year range is reported in Figure 5. Not surprisingly, while sustainability has been extensively explored during the past 20 years, resilience is a relatively more recent field of study.

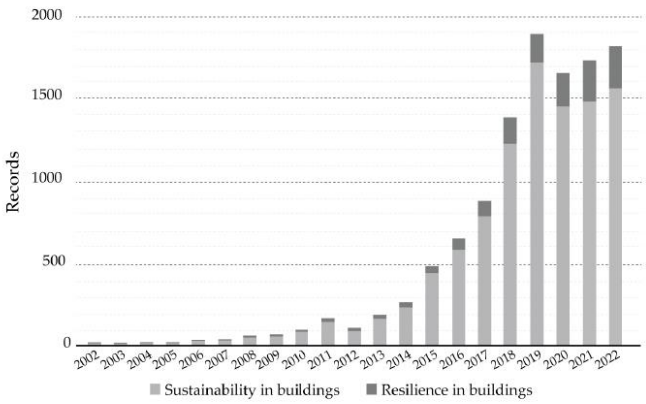


**Figure 5.** Records from the electronic databases (including duplicates).

In the second research round, only the last 10 years, from 2012 to 2022, were considered (Figure 6) to refine the process within a more balanced background knowledge, given that the detection of the common ground between the two domains was the main scope of this study.

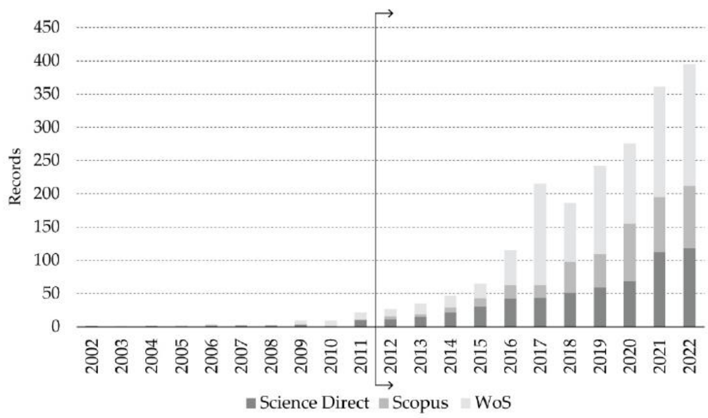


**Figure 6.** Records from the electronic databases (including duplicates).

After this analysis, the papers were entered into VOSviewer software, selecting the analysis of words co-occurrence both in titles and abstracts and keywords (Figure 7). Binary counting was then selected, and ten was the minimum number of occurrences of a keyword to be shown on the map. The normalisation was performed with the association strength method. Four clusters were identified. Four clusters can be identified on the map: blue, light blue, green, and yellow. In VOSviewer occurrence analysis, the distance between two words corresponds to a greater distance in terms of the research topic. The blue cluster is dominated by sustainability/resilience/implementation-related words. The light blue cluster is related to management and monitoring. The green cluster contains terms related to the performance of the building. The yellow cluster, which is the last in terms of the number of words, contains topics pertaining to vulnerability and risk analysis. This is a preliminary analysis that will be refined in the following paragraphs.

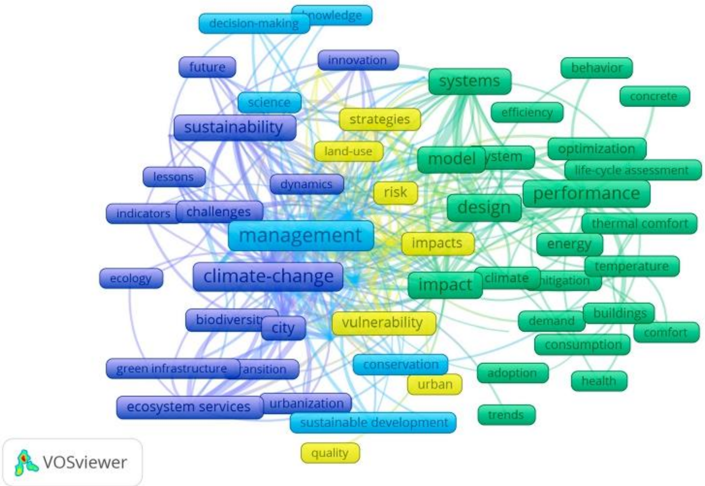


**Figure 7.** The output of the keywords analysis from the literature, performed in VOSviewer. The figure shows the clusters of keywords considering their occurrences.

Figure 8 depicts the distribution patterns of the selected records after they were filtered, duplicates were removed, and eligibility was determined.

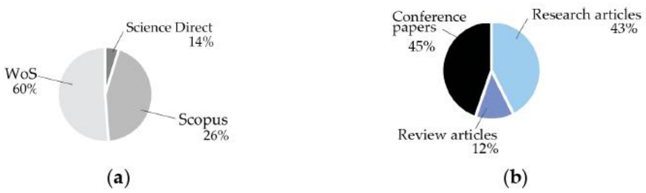


**Figure 8.** (**a**) Distribution pattern by electronic databases (after removing duplicates but before the eligibility process). (**b**) Distribution pattern by record typology (records included in the study).

Figure 9 illustrates the annual distribution of the records from 2012 to 2022. In comparison with Figure 6, it is evident that there has been a reduction in quantity since the duplicates were removed, and only the most eligible documents were considered. It is plain that the topic has attracted an increasing amount of attention over the last seven years.

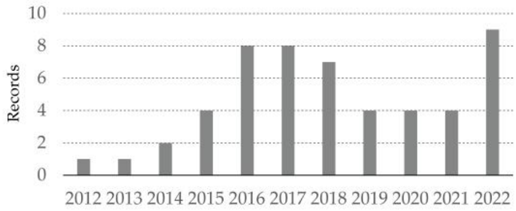


**Figure 9.** Annual distribution of the literature that considers both sustainability and resilience in buildings.

In the analysis of the records regarding the combination of sustainability and resilience, nine recurring clusters were identified (Figure 10), which illustrates that simultaneous consideration of both domains has already been recognised in some specific instances.

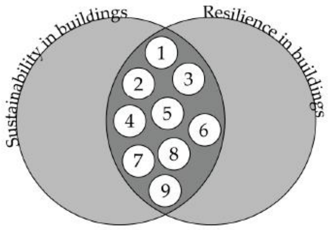


**Figure 10.** Venn diagram of the common ground between sustainability and resilience in buildings. Nine clusters were identified.

The identified clusters are listed in Table 3. In many records, one option to achieve a sustainable and resilient building entails considering low-energy solutions, as reported by [37] and [38], thus falling in the "Energy Performance" category. Other examples are the studies of Menna et al. [39] and Marini et al. [40] that consider Life Cycle Assessment for structural retrofitting against seismic hazards while including environmental impacts, thus falling in the "Life Cycle Thinking" category.

**Table 3.** Theoretical contributions are classified by category. In this table, each record falls into one category only, even if some records consider more than one topic.

| S.No. | Cluster | References | No. of Records |
|---|---|---|---|
| 1 | Energy Performance | [21,37,38,41–45] | 8 |
| 2 | Life Cycle Thinking | [39,40,46–51] | 8 |
| 3 | Vulnerability | [52–59] | 8 |
| 4 | Flexibility | [60–66] | 7 |
| 5 | Indoor Comfort | [67–72] | 6 |
| 6 | Material Effectiveness | [73–76] | 4 |
| 7 | Passive Solutions | [77–79] | 3 |
| 8 | Water Efficiency | [80,81] | 2 |
| 9 | Biodiversity | [82] | 1 |
| | Total Number of Records | | 47 |

These clusters are a way of clustering the topics that were investigated in the selected records and reported in Figure 11, where primary references and secondary references are highlighted. Appendix A presents the other clusters (Figures A1–A4).

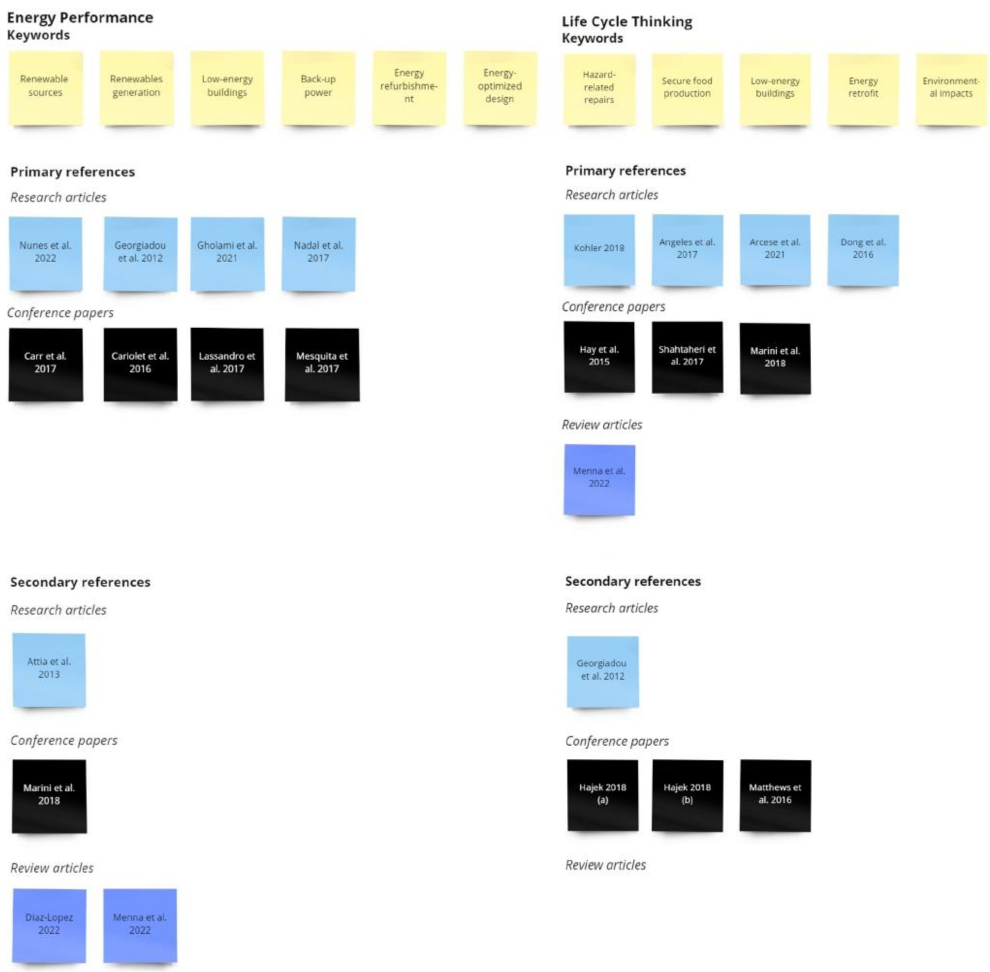


**Figure 11.** Clusters (specifically Energy Performance [21,37–45,57,77] and Life Cycle Thinking [37,39,40,46–52,63,76]) and selected records (keywords found in the records belonging to each thematic category in yellow stickers, research articles in light blue ones, review articles in blue ones, and conference papers in black ones). The other clusters are shown in Appendix A.

Primary references are those whose focus is primarily on the topic in question, while secondary references are those which refer to the topic but in a relatively generalised manner. More subsets of topics are pertinent to different clusters, such as adaptable technologies (e.g., the study of [62] or [69]), which falls into the Indoor Comfort category and the Flexibility one.

### *3.2. Rating-Systems-Based Approach*

#### 3.2.1. Analysis of GBRSs

Traditionally, resilience and sustainability have been approached as separate issues [45]. For the aim of this paper, five GBRSs were reviewed (i.e., LEED, BREEAM, DGNB, Level(s), and RIBA). According to the reported methodology, eight common clusters were detected. The methodological system based on clusters allows the definition of a sort of circle in which more subsets can be considered. However, the circle has blurred edges because the cluster may eventually be specified more in detail, adding new features but without necessarily introducing new clusters.

Table 4 shows these clusters and their definitions. Most of these tools chosen for the investigation do not equally address all three levels of sustainability (i.e., environmental, social, and economic). Most emphasis is placed on environmental impacts, ignoring the importance of social and economic impacts [83]. Indeed, the economic level was present only in Level(s), DGNB, and RIBA, which is why economic sustainability is not included in the table. Therefore, it can be argued that these systems provide a measure of sustainability even though they focus primarily on environmental impacts.

**Table 4.** List of sustainability clusters detected from the investigation of GBRSs and other methods and their explanations. The order is based on the importance of the category within the rating systems.

| Sustainability Clusters | Definition |
|---|---|
| Energy performance | Reduce the energy demand and incentivise renewable energy sources and passive solutions. |
| Greenhouse gas and air pollutant emissions cycle | Minimise the total GHG emissions along a building's life cycle with a focus on emissions from building operational energy use and embodied energy. |
| Sustainable Connectivity and Transport | Guarantee quality of access and transport. |
| Land use and ecology | Reuse of previously developed land and enhance biodiversity. |
| Resource-efficient and circular material life cycles | Optimise the building design, extend the long-term material utility, and reduce significant environmental impacts (embodied and operational). |
| Healthy and comfortable spaces | Comfortable, attractive, and productive building to live and work in, guaranteeing high quality of life. |
| Efficient use of water resources | Make efficient use of water resources with efficient measures to minimise water use. |
| Adaptation and resilience to climate change | Resilient buildings against potential future changes in the climate to protect people's health and comfort and minimise long-term risks. |

As shown in Figure 12, each cluster is included in each protocol, but in a different proportion based on the number of criteria that fall within each—in the figure, it is not the weight of each criterion/credit but the credit itself, rather than its "importance", that is considered in the overall framework. For example, within the cluster Healthy and Comfortable spaces, there are criteria such as Light Pollution Reduction under the LEED system (Sustainable Site category) or Design for All under the DGNB system (SOC2.1). Each tool contains a percentage labelled "Others", which represents criteria/credits that are not present in every tool (and therefore it was not possible to cluster them), e.g., Life Cycle Costing.

Based on the criteria weights of each tool, Figure 13 illustrates the distribution of clusters. The analysis was limited to tools that operate on a point basis.

Sustainability performance needs to be measured, quantified, and/or assessed in order to determine which construction system, technique, or material performs from a sustainability point of view. Thus, a metric is always specified and stated. Indeed, the clusters present indicators and specific metrics that are shown in Figure 14 and were taken from the analysis and comparison of the sustainable tools and methods. Examples include LCA for new potential material, energy consumption and $CO_2$ emissions of a building, etc.

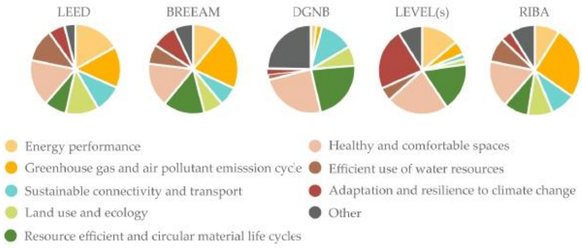


**Figure 12.** Overview of clusters in the considered tools, showing the sum of credits/criteria that fall under each cluster.

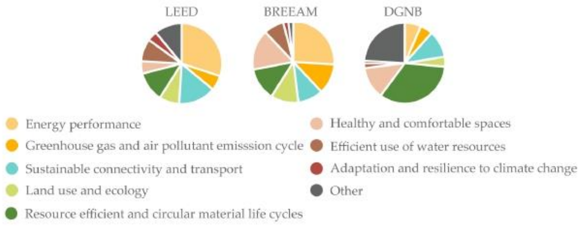


**Figure 13.** Overview of clusters in the considered tools according to the sum of the criteria weights.

| Sustainability Clusters | Indicator | Metric |
|---|---|---|
| Energy performance | Use stage energy performance | kWh/m²/yr |
| | Renewable energy sources | kWh/m² \| kg $CO_2$e/m² and % of PENR |
| Greenhouse gas and air pollutant emissions cycle | Cradle to grave Life Cycle Assessment (LCA) | Various Impact Categories (e.g. GWP [kg $CO_2$ eq./m$^2$) |
| Sustainable Connectivity and Transport | Access to quality transit | Number |
| | Reduced parking footprint | % |
| Land use and ecology | Soil sealing factor | % |
| | Reused of previously developed land | % |
| Resource efficient and circular material life cycles | Design for adaptability and renovation | Adaptability score |
| | Locally Sourced Materials | % or kg/m² |
| | Construction & demolition waste and materials | kg of waste/materials per m² total floor area |
| | Ease of recovery and recycling | % |
| Healthy and comfortable spaces | Thermal Comfort | ISO 7730 -2005 (PMV and PPD) |
| | Daylight | Lux or % |
| Efficient use of water resources | Use stage water consumption | m³/yr of water per occupant |
| | Rainwater management | percentile |
| Adaptation and resilience to climate change | Local Environment and Hazards likelihood | Classification of the environmental risks |

**Figure 14.** Description of the selected indicators for each cluster and the specific metric.

### 3.2.2. Analysis of RRSs

To define how the building sector conceptualises resilience and to determine the metrics, resilience initiatives, programs, and frameworks that directly address the resilience of buildings were investigated. These involved general guidance documents, standards, and building design and construction strategies that stakeholders could use within the building sector to identify strategies to enhance building resilience.

These documents address different hazards, as Figure 15 shows. Many extreme events, such as strong winds, earthquakes, and floods, have specific design criteria in current codes and standards for the built environment. However, three of the five resilience documents (PEER, RELi, and B-READY) address climate change hazards as part of a vulnerability assessment or all-hazards approach. They usually describe and set general pathways to follow that can be applied to any disaster event. For example, strategies such as maintaining back-up power to critical systems, building community ties, providing refuge areas for at least four days, developing emergency management plans, planning for long-term monitoring and maintenance, and managing system redundancy are not hazard-specific. They can be applied to improve the overall resilience of a building.

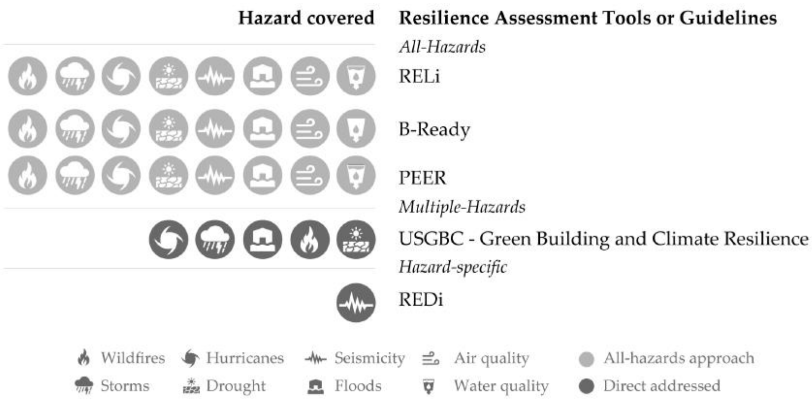


**Figure 15.** Resilience assessment tools and guidelines and the specific hazards they address.

Conversely, the other documents are more hazard-specific (developed to face one or two types of extreme events), such as REDi, a framework mainly focused on seismic activity resilience.

However, the most common hazards covered by these documents are flooding, heat waves, and severe storms, while other hazards, such as air and water quality, drought, and wildfires, are not as extensively covered

Following the analysis performed according to the proposed methodology, the results of this investigation are presented in Table 5 as resilience clusters.

Even in this case, there are more or fewer criteria/credits for each tool that fall within those clusters (Figure 16). For example, within the cluster Thermal Safety and Passive Survivability, there are criteria such as Passive Thermal Safety, Thermal Comfort + Lighting Design Strategies under the RELi system (hazard mitigation + adaptation, HA3) or Passive Solar Design under the USGBC guidelines (heating, cooling, lighting category). As for the sustainability clusters, each protocol contains a part labelled “Other”, which represents criteria/credits that are not present in every tool (and therefore it was not possible to cluster them).

**Table 5.** Description of the resilience clusters highlighted by analysing five resilience assessment tools and guidelines. The order is based on the importance of the category within the rating systems.

| Resilience Clusters | Definition |
|---|---|
| Thermal safety and passive survivability | Provide opportunities to moderate the indoor building comfort during regular operation and during grid-supplied power and fuel outages, heat waves, and other emergencies when local self-reliance is critical. |
| Back-up energy system and on-site renewable energy | Resilient power systems capable of lessening the likelihood of long-duration electrical outages thanks to battery energy storage and generator on site. |
| Water management | Improved integration of human development with the natural hydrological cycle, maintaining a balance with surface water, rain events, and water use. |
| Location and biodiversity | Explore shock-resistant planning and design for an extreme event with a site assessment and identification of long-term adaptability strategies to face the climate change consequences. The protection of biodiversity and greenfield plays an important role. |
| Transportation system protection | Increased accessibility and the diversity of the transportation options available in times of crisis. This leads to improving social cohesion and knowledge of the local surroundings. |
| Material effectiveness | Improving the ecological and economic life cycle of all materials used in the project by increasing material recycling and reuse, local extraction, and harvesting. Running the Life Cycle Assessment and using EPD-certified products with a positive life cycle impact and reduced embodied energy and carbon. |
| Passive lighting and ventilation | Guaranteed indoor comfort via passive systems that allow the building to be operative even in case of disruptive events. |
| Community education and training | Education and building capacity to successfully embed resilience into buildings and communities. |

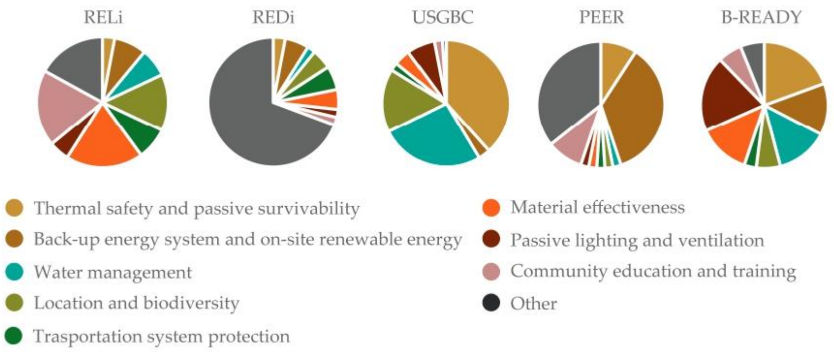


**Figure 16.** Overview of clusters in the considered tools, showing the sum of credits/criteria that fall under each cluster.

The resilience metrics of these clusters, shown in Figure 17, come in various types. They can be qualitative or quantitative, as for the local renewable generation or indoor water use reduction; they can be based on interviews, expert opinion, engineering analysis, or pre-existing datasets, such as the site risk assessment. They can also be presented as an overall score or a set of separately reported scores across physical, economic, social, and environmental dimensions as for the hazard-resilient materials. These metrics help assess each objective's current level of resilience and the potential benefits of actions to improve its resilience.

| Resilience Clusters | Indicator | Metric |
|---|---|---|
| Thermal safety and passive survivability | Passive heating (gain with glazing and sunspace) | Qualitative assessment |
| | Passive cooling (green roof) | Qualitative assessment |
| Back-up energy system and onsite renewable energy | Local renewable generation | kWh/m² |
| Water management | Indoor water use reduction | m³/yr of water per occupant |
| | Reuse of greywater | % |
| | Rainwater harvesting | m³/yr of water collected |
| | Climate-appropriate landscaping | Qualitative assessment |
| Location and biodiversity | Site risk assessment | Classification of the environmental risks |
| | Elevated floor and infrastructure | Above the 500-years floodplain |
| Transportation system protection | Access to quality transit | Number |
| | Protected accessibility points and egresses | Qualitative assessment |
| Material effectiveness | Hazards resilient materials | Various Impact Categories (e.g. Solar reflectance and thermal emittance) |
| Passive Lighting and Ventilation | Passive ventilation (cross ventilation, stack effect, operable windows) | Qualitative assessment |
| | Passive lighting (exterior shading, light shelves, building orientation) | Qualitative assessment |
| | Daylight | Lux or % |
| Community education and training | Emergency response plan | Qualitative assessment |

**Figure 17.** Description of the selected indicators for each cluster and their specific metrics.

3.2.3. Common Clusters

According to the previous analysis, it was possible to highlight the common clusters, indicators, and metrics for each of the two domains, as shown in Figures 18 and 19.

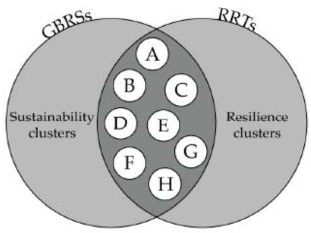


**Figure 18.** Venn diagram of sustainability (left) and resilience (right). Eight common clusters were identified (listed from A to H).

| Common Clusters | Definition | Measured Effects |
|---|---|---|
| A Renewables generation | Local renewables generation for GHG emission reduction | Increase in renewable energy production (kWh)<br>Reduction in GHG emission (kg - CO2eq) |
| B Water Efficiency and Rainwater management | Climate-appropriate landscaping, efficient appliances, and rainwater collection on the roof or in the parking areas | Reduced risk of flood or storm damage<br>Reduction of potable water use (litres)<br>Reduced annual water usage (litres)<br>Reduced risk of sewage backup into a building |
| C Thermal Safety | Energy-efficient building with passive solutions for cooling and heating and backup power for HVAC and boilers | Reduction in annual electrical energy (kWh)<br>Reduction in peak electrical demand (kW)<br>Reduction in annual electrical cost (EUR)<br>Reduction of interior air temperature (degrees) |
| D Hazards Assessment | Hazards assessment to highlight the potential risks of the area and preparation of mitigation strategies | Increase of awareness<br>Reduced risk of flood or storm damage (victims or EUR)<br>Reduced risk from storm surge and/or sea level rise |
| E Daylight and Ventilation | Passive solutions for daylighting and ventilation to maintain the indoor environmental quality also in case of energy disruption | Reduction of solar heat gain (W/square meter)<br>Reduction of interior air temperature (degrees)<br>Reduction in peak electrical demand (kW)<br>Reduction in annual electrical energy (kWh)<br>Reduction of interior glare (candela/$m^2$) |
| F Ease of recovery and recycling | Locally sources materials and life cycle perspective | Reduction in GHG emission (kg - CO2eq)<br>Reduction in primary embodied energy (MJ)<br>Reduced risk of moisture damage from floodwater |
| G Site ecology | The design of the building protects and enhances the rich ecology and habitat of the natural environment. | Reduced risk of flood or storm damage<br>Reduction of potable water use (litres)<br>Biodiversity enhancement |
| H Access to quality transit | Diverse transport options to reach the building (bus stop, bike routes, ferry station, metro) | Reduction of vehicle-kilometre (vkm) travelled<br>Reduction of air pollution<br>Increased number of transportation options<br>Increased floor area ratio (FAR)<br>Reduced risk from storm surge and/or sea level rise<br>Reduced risk of flood or storm damage |

**Figure 19.** Common clusters derived from RSs.

Figure 19 shows the common clusters of sustainability and resilience in buildings, along with their descriptions and the expected effects of using strategies that belong to those clusters. The most recurrent strategy is designing passive solutions that can be applied for different purposes (heating, cooling, lighting, and ventilation), or, for example, renewable energy strategies will reduce a building's dependency on the electrical grid and reduce carbon emissions and potentially make the building more resilient to power outages.

## 4. Discussion

It has been observed from the literature review that sustainability and resilience at the building level have been receiving increased attention in recent years as researchers, architects, designers, and other pertinent stakeholders have been working to mitigate the effects of climate change. In the records selected from the literature review, the main clusters into which the strategies and solutions were grouped were Energy Efficiency and Passive Solutions. The same results emerged considering the RSs. Indeed, in these ratings, the energy consumption indicator is a core concept because the total energy demand is used to evaluate the building's energy efficiency. The components are the heating, cooling, ventilation, and lighting that work with HVAC systems, boilers, and lighting appliances, and consequently they need electricity to be operative. Still, passive techniques that replace the previously mentioned systems are recommended. Figure 20 shows how these approaches resulted in the clustered topics. For example, regarding the Materials topic, both approaches suggest a willingness to encourage reuse of, recycling of, and prolonging the life cycle of a material in order to reduce the amount of waste that must be sent to a landfill.

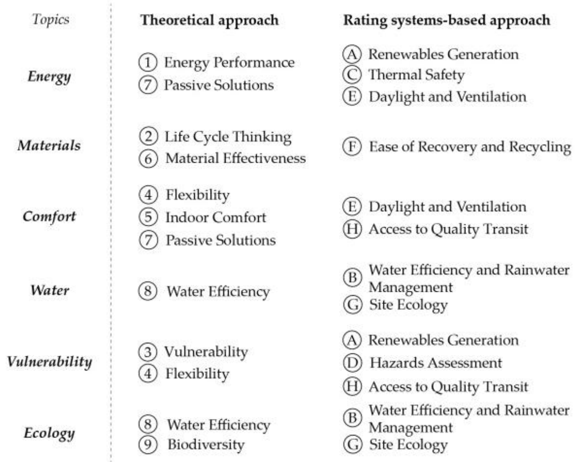


**Figure 20.** Common clusters are derived from theoretical and rating-systems-based approaches.

Figure 20 makes evident the commonalities between the two domains and highlights how much room there is to introduce resilience-enhancing criteria into existing GBRSs, mostly employed during the building design since resilience should be viewed as a prerequisite for a green rating and vice versa.

The common clusters are generated by the current knowledge of the two domains with respect to the activity of the scientific community and RSs, but this can rapidly evolve over time. Based on the exponential increase in publications in the field of sustainability, it is reasonable to conclude that progress and a greater interest in the investigation of resilience are likely to occur in the near future, providing an opportunity for updating this study. Nevertheless, it is possible to consider the proposed methodology solid enough to let the clusters be eventually specified without necessarily introducing new ones. If it is necessary to add a new category, it would be sufficient to add scores and evaluate their weight. Clusters do not all weigh the same, as, for instance, GBRSs highlight, but this study has not focused on determining the weight of each cluster which could represent a further step in the process. Further, it is important to note that aspects of social and economic sustainability were not included, despite the fact that it might have been interesting to highlight whether these aspects are also relevant to resilience. This choice was taken because most of the GBRSs selected do not address all levels of sustainability (i.e., environmental, social, and economic) equally; thus, a boundary encompassing only the environmental aspects was set. The authors are aware that there are differences in terms of priorities and effects, but this will be the subject of future studies.

## 5. Conclusions

Recent years have seen many European countries introduce the requirement to undergo environmental assessment for building projects; in the UK, for example, each new-build construction project must achieve a BREEAM Outstanding rating as part of the government's Construction Strategy [84]; in Germany, federal buildings must meet BNB

(Assessment System for Sustainable Building) certification requirements as required by the federal government's sustainable development strategy [85]; and in Italy, specifically in the Puglia region, non-residential buildings are required to comply with Protocollo ITACA when they are financed in part by public funds [86]. This trend is likely to increase over the next 5–10 years to improve the built environment's quality.

Even if many actions have been made to include sustainability at the building level, the concept of resilience is still quite recent and not fully considered yet, but several concerns have arisen regarding identifying the common ground between sustainability and resilience at the level of the building.

By combining two different approaches (i.e., a theoretical-based one (literature review) and rating-systems-based one), this study identified common clusters and indicators that encompass both domains. Based on the findings, both approaches share similar clusters, implying that sustainability and resilience can be considered simultaneously while designing a project. In the process of implementing sustainable and resilient measures, it is crucial to balance the performance of each domain without skewing too much in one direction or the other. These common clusters may assist in finding a balance.

Further, it is essential to identify some irreplaceable key indicators in the design process. This would allow a building to reflect the concept of resilience while incorporating aspects of sustainability. Therefore, there would be greater opportunities to address the building sector, especially new construction, to meet the SDGs' future challenges.

A number of stakeholders in the building sector, including architects, managers and operators, and community organisations, may benefit from this study, which indicates that synergies between the two domains are possible and a consistent overlap exists, demonstrating the importance of incorporating sustainability and resilience strategies into building planning processes when performance-based tools are typically employed. The purpose of this research was to lay the groundwork for a quantitative study to be conducted in the future.

**Author Contributions:** Conceptualisation, L.F., A.L. and J.G.; methodology, L.F., A.L. and J.G.; formal analysis, L.F.; investigation, L.F.; resources, L.F.; data curation, L.F.; writing—original draft preparation, L.F.; writing—review and editing, L.F., A.L. and J.G.; visualisation, L.F.; supervision, A.L. and J.G. All authors have read and agreed to the published version of the manuscript.

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## Appendix A

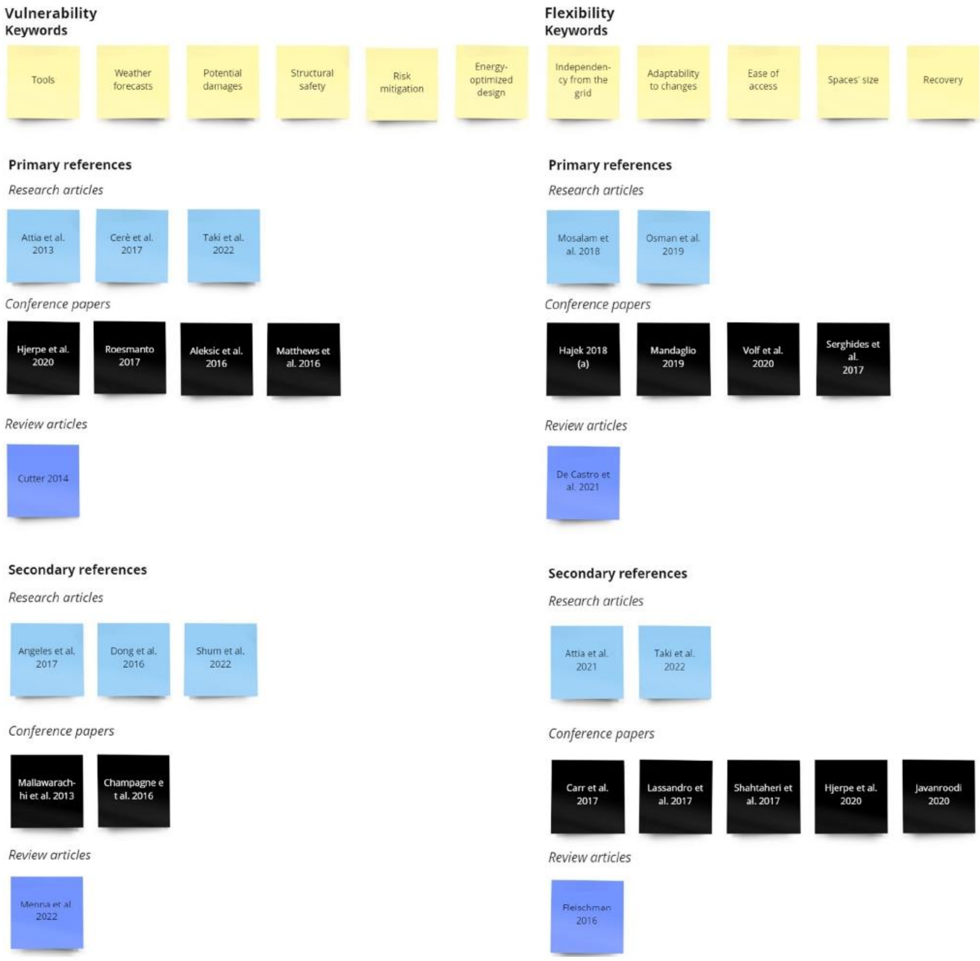


**Figure A1.** Clusters (specifically Vulnerability [39,46,50,52–59,69,79,80] and Flexibility [43,44,49,56,59–66,68,74,81]) from the selected records resulted from the literature review and selected records (keywords found in the records belonging to each thematic category in yellow stickers, research articles in light blue ones, review articles in blue ones, and conference papers in black ones).


**Figure A2.** Clusters (specifically Indoor Comfort [38,41,44,67–72,74,77,78,81] and Material Effectiveness [40,47,63,66,73–76]) from the selected records resulted from the literature review and selected records (keywords found in the records belonging to each thematic category in yellow stickers, research articles in light blue ones, review articles in blue ones, and conference papers in black ones).


**Figure A3.** Clusters (specifically Passive Solutions [61,62,64,68,69,71,72,75,77–79,82] and Water Efficiency [53,68,77,80–82]) from the selected records resulted from the literature review and selected records (keywords found in the records belonging to each thematic category in yellow stickers, research articles in light blue ones, review articles in blue ones, and conference papers in black ones).


**Figure A4.** Biodiversity category from the selected records [41,48,75,77,80,82] resulted from the literature review and selected records (keywords found in the records belonging to each thematic category in yellow stickers, research articles in light blue ones, review articles in blue ones, and conference papers in black ones).

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**Conference paper II: Environmental, Social, and Economic Resilience in Multi-Residential Buildings: Assessing SBToolCZ Rating System**

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*International Conference on Construction, Energy, Environment and Sustainability (CEES) 2023 Proceedings.*

This conference paper presents the work conducted to assess the extent to which the SBToolCZ 2022 multi-residential building version incorporates resilience principles. These principles, derived from the research presented in "Research Paper I," were used as benchmarks to compare with the criteria of SBToolCZ. The results show that while some resilience principles are partially addressed in SBToolCZ, others, such as the presence of a backup power system, are entirely absent. This highlights that rating systems like SBToolCZ still do not adequately account for resilience to climate change hazards. Therefore, action is needed to integrate these resilience principles, ensuring buildings are both sustainable and resilient. This work has also been used to demonstrate the necessity of incorporating resilience principles into existing sustainability rating systems.

**Authors' contributions**

Licia Felicioni carried out the assessment of how much SBToolCZ aligns with certain resilience principles under the supervision of Antonin Lupíšek and Martin Volf. Licia Felicioni also took the lead in drafting the research paper, with all authors participating in the review and approval of the final version.

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# ENVIRONMENTAL, SOCIAL AND ECONOMIC RESILIENCE IN MULTI-RESIDENTIAL BUILDINGS: ASSESSING SBTOOLCZ RATING SYSTEM

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## Keywords

SBToolCZ; Central Europe; Resilience; Sustainability; Hazards; Rating System.

## Abstract

Sustainable Building Tool for the Czech Republic (SBToolCZ) is the Czech national green building rating system that encourages the design of sustainable buildings by incentivising reductions in energy, water, and building materials consumption, as well as improving occupant health and community connections. In addition to reducing the overall environmental impacts, certified green buildings must also be resilient enough to withstand external stressors, most frequently the symptoms of climate change that may arise throughout the building's lifetime. Therefore, a resilient building should be capable of adapting and remaining functional under the pressure of more frequent and severe challenges. The purpose of this study is to examine where the SBToolCZ certification system has inherent overlaps with the topics of resilience, considering the environmental, social and economic factors relevant to Central European contexts. This is accomplished by comparing the criteria of this certification system with the most accepted principles of resilient design that have emerged from the international resilience rating systems or guidelines. A number of synergistic opportunities, as well as improvements for better integrating resilient design into the SBToolCZ framework and, therefore, into green construction, are discussed to implement existing criteria or propose supplementary ones. A key component of implementing resilience for multi-residential buildings is the SBToolCZ Site category, which is key to addressing the unique regional needs of each project and should be integrated with resilience-enhancement indicators. Finally, climate projections should be used instead of historical climate data at an early design stage to improve the resilience of the building.

## 1. INTRODUCTION

At the United Nations Climate Change Conference (COP27), delegates, attendees, and industry practitioners agreed that efforts to prevent global warming from reaching 1.5 degrees warmer than pre-industrial levels are failing [1]. A significant rise in temperatures has contributed to devastating weather events, such as wildfires and flooding. Yet, public authorities, industry, and citizens have not yet adequately prepared for climate change and must focus more on retrofitting and resilient design solutions. The design of a building should adhere to the minimum standards for sustainability while also addressing the concept of resilience contextually. Both resilience and well-established sustainability analyses must be considered when assessing the built environment, and neither should be ignored. Recent years have seen a huge debate about sustainability and resilience in the construction industry; do they share a common ground [2,3]? In fact, there is a persistent knowledge and implementation gap about these two domains that must be filled. In all world regions, including Europe, many public authorities have developed adaptation plans, but only a small number have been realised. The main reason for the slow implementation is the lack of an integrated framework and effective digital planning tools that can combine resilience and sustainability indicators when assessing design and renovation measures. In its first version, Level(s) [4], the common European framework for sustainability assessment, seeks to cover both domains within six macro-objectives and related criteria.

Hence, due to the increasing impact of climate extremes on our daily lives, with temperatures rising and life-threatening weather events, it is not possible anymore to ignore their effects [5]. Adapting to this new reality means finding innovative ways to safeguard people, property, and essential infrastructure. New buildings, such as multifamily housing, should be designed considering future climate forecasts and not just today's circumstances. Buildings should be constructed with materials capable of standing up to extreme temperatures and equipped with systems that can maintain power during outages due to storms. This can be achieved by incorporating resilience into sustainability rating systems to reduce buildings' vulnerability to several climate change-related disasters and other shocks.

### 1.1. OBJECTIVES

The objective of this study was to evaluate the emphasis placed on resilience by the Sustainable Building Tool for the Czech Republic (SBToolCZ [6]) - environmental, economic and social resilience aspects are considered - and to identify if specific resilience criteria could be incorporated into the certification system so that it better reflects the needs for resilient construction in the context of a rapidly changing global climate.

## 2. BACKGROUND

In 1998, iiSBE (international initiative for a Sustainable Built Environment) developed the Sustainable Buildings Tool (SBTool), formerly known as the Green Building Tool (GBTool), to assist countries in developing an international open-source methodology for assessing buildings' sustainability based upon contextualisation [7]. Although SBTool considers regional conditions and values, the calibration of the model to local conditions does not affect the value of a common structure and terminology. The tool produces both relative and absolute results. SBTool's flexibility and ease of adaptability to local conditions - even down to a municipality or university campus - make it more relevant and finely graduated than other commercial systems, even in regions where other systems, such as Building Research Establishment (BREEAM) [8] or Leadership in Energy and Environmental Design (LEED) [9], are predominant. Indeed, SBTool is a multicriteria tool that measures the sustainability of buildings by considering more than 200 criteria. In the last decades, custom versions of SBTool have been developed for several European countries, including Italy (the Protocollo ITACA [10]), Spain (the VERDE [11]), Portugal (the SBToolPT [12]), and the Czech Republic (the SBToolCZ [6]). These versions are based on the generic framework and have been localised. As for the methodology, it remains the same, but criteria are selected according to the context from the general list.

Taking into consideration the Czech version, SBToolCZ presents a set of criteria inclusive of all three pillars of sustainable development (environmental, social, and economic). Moreover, this system covers a wide range of building types, ranging from single-family homes to university buildings [6]. There are variations in the criteria and weights within each tool version; this study examined the multi-residential building version. The framework is divided into four main categories; only three of these influence the final score since the Site category includes criteria, but they are not weighted (Figure 1).


Figure 1. Categories and respective weights of SBToolCZ – these shares are valid for multi-residential buildings, office buildings, and single-family houses.

However, besides sustainability, it is important to ensure that buildings are resilient. This guarantees that buildings can withstand changes in climate and the environment, as well as any unexpected external events. Considering sustainability aspects and, at the same time, resilience from the very beginning of the design process would be a great opportunity to address the building sector, especially new construction, to meet the United Nations Sustainable Development Goals (SDGs) [3]. Currently, there is not a shared definition of resilience but different shades of it; for instance, the Rockefeller Center states that city resilience is the "overall capacity of a city (individuals, communities, institutions, businesses and systems) to survive, adapt and thrive no matter what kinds of chronic stresses or acute shocks they experience" [13].

The European Taxonomy, as well as the Sixth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) [14], have pointed out the most likely-to-happened climate-related hazards for Northern, Central and Southern Europe [15,16]. Figure 2 shows fifteen climate indices for nine climate hazards, which are most likely to impact Central Europe, particularly Czechia.

| | | |
|---|---|---|
| MEAN AIR TEMPERATURE | MEAN TEMPERATURE | ↗ |
| | HEATING DEGREE DAYS | ↘ |
| | COOLING DEGREE DAYS | ↗ |
| EXTREME HEAT | HOT DAYS | ↗ |
| | CLIMATOLOGICAL HEATWAVE DAYS | ↗ |
| FROST | FROST DAYS | ↘ |
| MEAN PRECIPITATION | TOTAL SUMMER PRECIPITATION | ↘ |
| HEAVY PRECIPITATION AND RIVER FLOOD | FREQUENCY OF EXTREME PRECIPITATION | ↗ |
| | MAXIMUM CONSECUTIVE 5-DAY PRECIPITATION | ↗ |
| | RIVER FLOOD INDEX USING RUNOFF | ↗ |
| DROUGHT | MAGNITUDE OF METEOROLOGICAL DROUGHTS | ↗ |
| FIRE WEATHER | DAYS WITH FIRE DANGER EXCEEDING A THRESHOLD | ↗ |
| SEVERE WIND STORM | EXTREME WIND SPEED DAYS | ↗ |
| SNOW, GLACIER AND ICE SHEET | SNOWFALL AMOUNT | ↘ |
| | PERIOD WITH SNOW WATER EQUIVALENT ABOVE THE THRESHOLD | ↘ |

*Legend: ↗ Likely to increase throughout most of a region, ↘ Likely to decrease throughout most of a region*

Figure 2. List of primary climate-related hazards for Central Europe. Source: [15,16].

Resilience design principles and criteria for buildings were taken from previously conducted studies [3,17], which were established from an analysis of resilience assessment tools (RATs) available worldwide – i.e. RELi [18], REDi [19], Envision [20], United States Green Building Council (USGBC) Climate resilience guidelines [21]. While the cumulative list of principles proposed by [3,17] may be exhaustive, they have been condensed and listed below, and they are divided into environmental resilience criteria (Figure 3), social resilience criteria (Figure 4) and economic resilience criteria (Figure 5).

| Criteria | Metrics |
|---|---|
| Oversized drainage system | Account for linear increases in precipitation over 30-year period.<br>Proof of installed oversized rainwater pipes based on future forecasts. |
| Avoidaince of specific sites | Avoidance of high ecological value sites and 500-year floodplains and establishment of protective buffet zones.<br>Identification of hazard risks based on geographic location for the project and climate forecasts. |
| Locally-sourced resistant material | Average distance (km) to the building site.<br>Percentage of the project materials that are locally-sourced. |
| Passive survivability | Extend to which passive solutions for landscape cooling, passive heating, passive cooling, passive lighting, and passive ventilation are provided. |
| Protection of wilderness | Number of ecologically significant species in different habitats.<br>Use native or adapted vegetation to restore the portions of the site identified as previously disturbed. |
| Back-up energy system | Provision of permanent back-up power, switching gear and/or power hook-ups and infrastrcuture(above 500-year floodplain) for temporary generators to provide power for critical utilities such as HVAC and boilers. |

Figure 3. Environmental resilience criteria for multi-residential buildings.

| Criteria | Metrics |
|---|---|
| Safe and appropriate access | Incorporating and providing clear access, safety, and wayfinding measures to accomodate emergency services and regular vehicular or pedestrian traffic. |
| Perception of safety | Proof of clear and attractive views and the minimization of unwanted insights.<br>Site identification and crime risk assessment report. |
| Community disaster preparedness | Guarantee at least one meeting/workshop per year that should cover forecasts for climate change and weather-related impacts and two meetings per year covering food, energy and water. |
| Inclusive design | Demonstrate increased access beyond local regulatory requirements by including strategies for the interior and exterior spaces, inclusive spaces and mental health. |
| Community space | Provision of community access to useful space (number of spaces). |

Figure 4. Social resilience criteria for multi-residential buildings.

| Criteria | Metrics |
|---|---|
| Affordability and flexibility | Extent of the affordability of the building for different user groups and its versatility to change its use to prolong its service life. |
| Independency from the grid | Extent to which renewable energy sources are incorporated. |
| Water catchment and reuse | Degree to which the project infiltrates, evapotraspirates, reuses, and/or treats rainwater while not exceeding quantity of runoff targets.<br>Provide recycled water storage to cover operations, including toilet flushing and mechanical equippment for emergency stand-alon operations. |
| User comfort | Extent to which both thermal and visual comfort is guaranteed even in case of a disruption event. |
| Food security | Urban farming area ($m^2$) by the number of residents.<br>Extent to which site's final vegetated area is dedicated to food production. |

Figure 5. Economic resilience criteria for multi-residential buildings.

## 3. METHOD

The SBToolCZ rating system thrives in the sustainable design aspect but has not sufficiently defined the requirements of resilience. Finding synergies between resilient design principles and the Czech building rating system was investigated, and improvements to better integrate the two design principles were recommended at the conclusion of the study.

For the analysis, SBToolCZ multi-residential building version criteria were used as the baseline; resilience principles and metrics listed in Section 2 were linked to the climate-related hazards they would mitigate. This was done to evaluate the extent to which the different criteria of the SBToolCZ system already considered resilience principles and to identify any gaps that could be filled with additional brand-new criteria.

## 4. RESULTS AND DISCUSSION

### 4.1. ENVIRONMENTAL RESILIENCE CRITERIA

Figure 6 illustrates how the SBToolCZ incorporates all of the principles of environmental resilience. Regarding the oversized drainage system, the Czech rating does not present any related criteria. Indeed, this principle means that designers who aim to build a resilient building should calculate the dimensions of the system based on the projected water flow. They should consider local topography, soil type, and future forecasts. There is, however, a criterion for the general management of rainwater and the slowing down of runoff that can be accounted for under the economic resilience criteria.

Regarding the principles of site selection and wilderness protection, the Czech tool uses a variety of criteria for protecting a site, including the preservation of biodiversity and the management of excavated land. However, under the Site category – which does not have any weight on the overall framework, meaning that it does not affect the final result and the level of building's sustainability – there is a particular criterion regarding Locality risks that requires an assessment of the land to determine if it is prone to flooding or seismic activity. This criterion is especially important, as it could help ensure that the chosen site is resilient and safe to inhabit and utilise; failure to consider resilience and weather forecasts as a core value could directly affect a chosen site's safety and durability. In addition, SBToolCZ also suggests that the environmental impact of the building be evaluated; six criteria are devoted to this purpose.

SBToolCZ presents several criteria related to the third resilience principle, locally sourced resistant materials, including certified products (such as those holding an Environmental Product Declaration) and wood-based materials, which are more likely to resist environmental changes, thus reducing the project's cost and environmental impact.

Passive survivability is one of the most well-known principles of resilience associated with backup energy systems. The Czech tool assesses thermal comfort in both summer and winter, focusing on specific parameters such as air temperature and humidity, but it does not suggest how a decent result could be achieved using passive solutions for heating, cooling, and daylighting, mostly during a disruption event. For instance, applying strategies such as increasing thermal mass, applying green roofs to reduce heat shocks, and installing shading devices (elements present within the tool) can play a key role in reducing the energy needs of a building. However, RATs advocate incorporating additional passive design strategies to ensure the building can function even during energy or water disruption (e.g., waterless human waste disposal toilets or elevator systems designed with a backup power source or automatic return to the ground floor and its machinery located above the flood level).

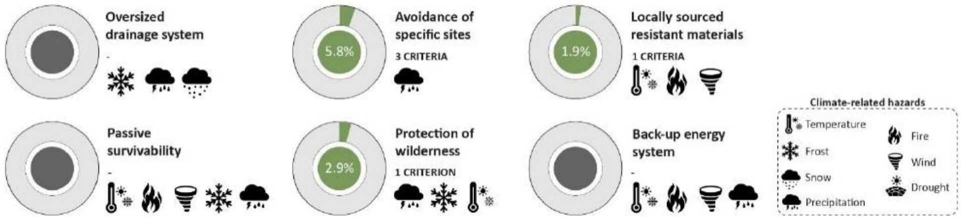


Figure 6. Overlap of SBToolCZ criteria with environmental resilience principles associated with the potential climate-related threats they could mitigate. The percentage indicate the total weights of those SBToolCZ criteria closely related to the resilient principle.

## 4.2. SOCIAL RESILIENCE CRITERIA

Figure 7 illustrates that the social resilience principles within the Czech rating system do not overlap widely. A key component of social resilience is providing safe and appropriate public access, which means that the project has different available access points designed to ensure broad accessibility and wayfinding. Moreover, these principles would assist with the trend of population ageing, ensuring barrier-free accesses, as well as mitigating flood hazards by highlighting safe and convenient routes/access to take during such an event.

Concerning the perception of safety, one criterion regarding criminality prevention is available in the tool; however, it is under the Site category, which does not carry any weight in the overall system. The planning of an emergency plan and community disaster preparedness are other proactive principles that are widely used in resilience preventive action programs. Following these principles, residents would be made aware of potential future risks, but SBToolCZ does not currently take this into account.

As a final point, both inclusive design (i.e. diverse user base design) and environmentally friendly transport (i.e. non-motorised vehicles, car sharing, public transport) criteria are present in the tool, each represented by two criteria. By improving both principles, the tool can help designers develop buildings tailored to the needs of the local population while still reducing emissions and conserving energy. This can help achieve sustainability and resilience goals while also providing a better quality of life for all their residents.

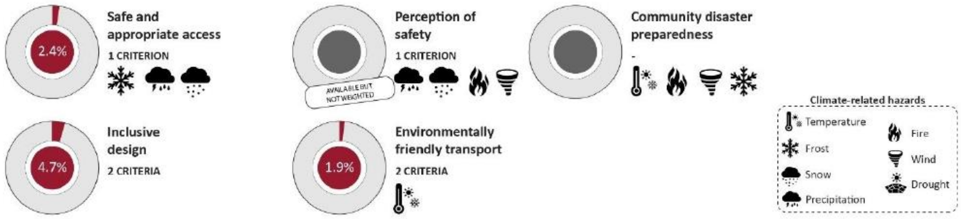


Figure 7. Overlap of SBToolCZ criteria with social resilience principles associated with the potential climate-related threats they could mitigate. The percentage indicate the total weights of those SBToolCZ criteria closely related to the resilient principle.

## 4.3. ECONOMIC RESILIENCE CRITERIA

Figure 8 depicts the overlap between economic resilience principles and the SBToolCZ system. As an indicator of the durability of a building, affordability and flexibility are considered by two criteria within the tool. This allows for the forecasting of possible changes during the life cycle of a building. Being independent of the grid in the event of blackouts resulting from climate-related shocks, such as floods, storms, or heavy snowfall, is one of the most important principles of resilience. Although SBToolCZ addresses one criterion related to the use of renewable energy sources produced on-site, it still lacks the implementation of a backup energy system and generator that would allow the building to remain functional if a shock occurs.

In addition, the low operation cost, which results from low energy consumption, ensures users do not experience energy poverty. Low energy consumption can be achieved through well-designed insulation systems that reduce thermal envelope conduction. This can reduce indoor air temperature, peak electrical demand, and annual cooling requirements during summer. A combination of shading, light-coloured roofs, and effective insulation systems can reduce the amount of heat absorbed by buildings, thereby lowering cooling costs while maintaining high levels of comfort for occupants.

SBToolCZ proposes four criteria that ensure residents can live in thermally and visually comfortable spaces without incurring high costs. Another strategy related to user comfort and economic resilience entails providing an appropriate education for users to maximize the potential of technology installed in their homes. Education can assist users in becoming confident and comfortable with the use of technology, thereby reducing their energy consumption and saving money.

A fundamental principle of environmental and economic resilience is the capture and reuse of rainwater. This principle is considered to some degree in SBToolCZ. By collecting and reusing rainwater, the reliance on other water sources can be reduced. This can help reduce water scarcity and costs, as well as lower the environmental impact of water consumption.

Growing food in common spaces of the building can increase access to healthy food (supporting food security), build community resilience, and create opportunities for meaningful work for people living in cities (increasing the sense of belonging to the place and strengthening social cohesion). It also supports creating green spaces, which can help mitigate the urban heat island effect and reduce air pollution. SBToolCZ, however, does not cover this principle.

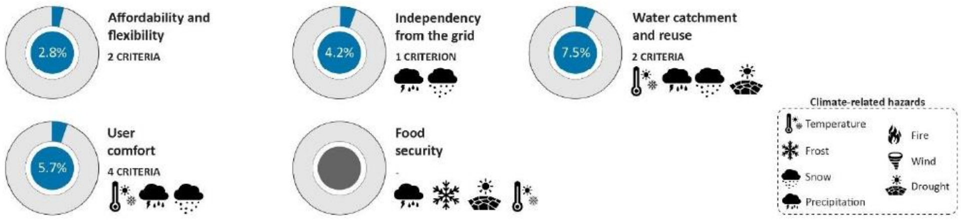


Figure 8. Overlap of SBToolCZ criteria with economic resilience principles associated with the potential climate-related threats they could mitigate. The percentage indicate the total weights of those SBToolCZ criteria closely related to the resilient principle.

## 5. CONCLUSION

As resilience has gained greater importance in sustainable development, some concerns regarding incorporating resilience into sustainable rating systems are emerging. This study examines SBToolCZ, the national Czech rating system for buildings, to determine whether resilience principles have already been incorporated. As a matter of fact, SBToolCZ is primarily used for sustainability assessment; it does evaluate some aspects that are related to resilience, such as the building's ability to withstand natural disasters and its energy efficiency. However, it is not designed to measure the resilience of a building explicitly, and the framework does not contain any indicators specifically related to resilience. Additionally, a few of these principles are incorporated into criteria included in the Site category, which do not directly impact the overall evaluation of the project itself.

In order to effectively assess the resilience of a system, it is important to consider the social, economic, and environmental factors that influence its ability to respond, adapt, and recover from the impacts of climate change and other potential stressors. To ensure that SBToolCZ is fully reflective of resilience principles, it is essential to consider and implement the proposed recommendations: (i) revision of the Site category's weight; this category plays an important role in the system and it should be included in the final score; (ii) risk assessment reports should incorporate a greater number of climate-related threats and other potential stressors based upon future projections rather than historical reference data; (iii) creation of a brand new resilience category/module in order to keep pace with international priorities regarding climate change mitigation and adaptation (Figure 9).


Figure 9. Categories and respective weights of SBToolCZ plus the additional resilience category (unspecified number of criteria and weight of the category).

By modifying and possibly adding these features, designers would be inspired to integrate resilience into their projects, which would reduce the impact on the environment, society and the economy that occurs when climate-related events strike a building. This, in turn, would create healthier, more sustainable buildings that are better equipped to handle the unpredictability of the climate, as clearly supported by the European framework Level(s) [4].


### Acknowledgements

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## Conference paper III: Implementing Resilience in Sustainable Building Design: Testing Selected Resilience Criteria in a Case Study

(ACCEPTED FOR PUBLICATION AS OF 13/09/2024)

**Felicioni L., Lupíšek A. and Gaspari J.**

*NEXTBUILT 2024 – International Conference on Challenges for the Next Generation Built Environment, IOP Conference Series: Earth and Environmental*

This conference paper represents another key milestone for the PhD thesis, as it provides an overview of how the Resilience Module functions as a stand-alone system for assessing the resilience of a case study building. In this instance, a building previously certified by the SBToolCZ system in 2013 was evaluated using five criteria, one from each Resilience Module category. The results were crucial for understanding the accuracy and effectiveness of the criteria, evaluating whether they were precise enough to be adequately addressed, and determining the time required for this partial assessment. Based on this analysis, minor adjustments were made to the criteria used in the evaluation. This work was conducted prior to the full evaluation of the building case studies, offering valuable preliminary insights for the future complete evaluation fo the building case studies.

### Authors' contributions

Licia Felicioni assessed the building case study using five criteria from the Resilience Module under the supervision of Antonin Lupíšek and Jacopo Gaspari. She also took the lead in drafting the research paper, with all authors contributing to the review and approval of the final version.

# Implementing resilience in sustainable building design: Testing selected resilience criteria in a case study

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**Abstract**. Climate change is causing unprecedented changes in precipitation, extreme temperatures, and weather-related threats. Without effective intervention, these changes are expected to escalate in the coming years, potentially causing substantial damage to buildings. Paradoxically, the buildings themselves possess the potential to both exacerbate and alleviate climate change. To achieve a balance, the design of the building must adhere to minimal sustainability standards, taking into account resilience. Popular building rating systems, currently skewed towards sustainability, often neglect resilience principles. This paper aims to assess five selected resilience criteria from a new module incorporated into an existing building certification system, SBToolCZ. Validation occurs through a multi-residential building case study in Prague, evaluating the effectiveness of the criteria in terms of feasibility, accuracy, consistency, and time/data requirements. The results of this criteria test determine the clarity, achievability, and informativeness of the selected criteria. If gathering information and meeting benchmarks within a specific time frame proves challenging, adjustments to the criteria may be necessary for attainability and specificity. Integrating resilience features into sustainability rating systems, typically used in the early stages of design, can encourage designers to incorporate resilience into their projects. This proactive approach could lead to long-term reductions in environmental, social, and economic impacts, especially during weather-related hazards.

**Keywords:** resilience design, rating systems, resilience assessment, survivability, preparedness, risk assessment.

## 1. Introduction

A changing pattern of precipitation, extreme temperatures, and other weather-related hazards is becoming recurrent evidence of climate change, reaching unprecedented levels [1]. Without effective actions, these changes are expected to intensify in the coming years, with more serious global consequences [2,3]. Extreme weather events can seriously impact the built environment which, at the same time, can become a valuable contributor to mitigating climate change, by remarkably reducing GHG emissions, and implementing an adaptive strategy by increasing the resilience [4].

Building design should adhere to minimum sustainability standards while also considering the resilience to future threats. In recent years, there has been a huge debate about these two concepts in the construction industry: Do they share a common ground? [5]

Across global regions, including Europe, numerous public authorities have formulated adaptation plans, yet only a limited number have been implemented [6,7]. The primary factor that hinders rapid implementation is the absence of an integrated framework and robust digital planning tools capable of seamlessly incorporating resilience and sustainability indicators in the evaluation of design and renovation measures [8].

## 2. Background

Existing building rating systems, such as Leadership in Energy and Environmental Design (LEED) or Building Research Establishment Environmental Assessment Methodology (BREEAM), are primarily focused on sustainability assessment with less attention paid to resilience principles [8]. Therefore, some studies (e.g., Roostaie et al. [9] and Felicioni et al. [5]) are exploring the opportunity to embed resilience principles within already existing rating systems to foster their adoption by architects, designers and planners who already use these tools in shaping the built environment of the next decades.

The purpose of this paper is to test the selected resilience criteria developed as part of a resilience module, which could be implemented into already existing sustainability rating systems, and to validate them in a building case study. This work is part of a 4-year PhD project focused on finding the balance between sustainability and resilience in buildings through the implementation of a set of resilience criteria and indicators in the Czech national building rating system SBToolCZ [10], which has been chosen for this research as a case study tool. This work aims to highlight the efficacy of the use of criteria to assess resilience by determining their feasibility, precision, and consistency, as well as the amount of time and data needed to complete them.

## 3. Materials and Methods

The research began with an analysis of what has already been addressed by SBToolCZ [10] in terms of resilience, in particular in the multi-residential building version of the system that comprises 45 criteria divided into environmental, economic, societal and site-related groups [8]. After completing this phase, a resilience module consisting of five macro-categories was drafted considering what already existing resilience assessment tools for buildings, taking as a starting point the outcome of previous work [5].


**Figure 1.** Overview of SBToolCZ categories plus the additional new resilience module [8].

Hence, Figure 2 shows the linear diagram of this process, starting from gathering information from the international background to the validation of the criteria in case studies (the scope of the article) and the final implementation of the resilience module in the rating system.

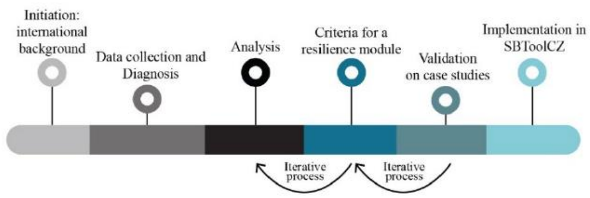


**Figure 2.** Linear diagram for the design of the resilience module.

The module's effectiveness must first be evaluated and validated by building case studies to identify any potential weaknesses. Indeed, the development of criteria is an iterative process that is influenced by the results of the validation of case studies – see Figure 2. Therefore, these criteria will be redefined and properly adjusted to ensure that they accurately reflect the desired result. The accuracy, reliability, and validity of the values obtained from the five criteria are considered part of the investigation.

*3.1 Resilience calculation tool*

As part of the PhD research, a method has been developed to develop a new criteria module focused on resilience in multi-residential buildings. Subsequently, this method was adapted into an MS Excel tool for enhanced usability and convenience. This adaptation aligns with the overarching approach of the SBTool rating systems, which rely on manuals where the method of assessment is described and can then be used to assess for building case studies using MS Excel tools (e.g., [11,12].

The Resilience calculation tool allows for the easy input of data, as well as the ability to quickly analyse and present the results. Furthermore, Excel is widely available, making it an accessible solution for many users.

Indeed, all criterion sheets are converted into dedicated Excel sheets, one for each criterion, containing information concerning the name of the criterion, its purpose, a brief description of its benefits if achieved, the indicator – qualitative or quantitative – and the evaluation modules. Each module consists of a list of items to which amount of points are assigned if implemented successfully.

Depending on the significance that the item would have to the building in terms of safety, the number of points per item may vary. Each item, and therefore its points, may be simply summed up in some cases; in others, a single item may be selected from the list, in which case the final score of the module is determined by the number of points of that item.

Following the calculation of each module, based on the method of evaluating the criterion, which is usually a sum of modules' scores, the final value of the criteria can then be normalised in a range of 0 (minimum number of points achievable from the item list) to 10 (maximum number of points achievable from the item list) by linear interpolation. The final results will then be multiplied by the weight assigned to each criterion. A panel of experts in the field of building and urban resilience expressed a proportion preference according to the pre-set module structure.

*3.2 Resilience Criteria*

The criteria of the new add-on module include both qualitative and quantitative indicators. These evaluation criteria are formulated as interrogative statements, necessitating the corresponding responses and supporting documentation. Illustrative examples of evaluation criteria include:

- Yes/No: Verification of the implementation of a specific action or attainment of a particular outcome (e.g., incorporation of antiflood measures in the project).
- Target: Specification of a particular outcome with identifiable and quantifiable benchmarks (e.g., maintenance of indoor temperature below 27 degrees Celsius).
- Accomplishment: Executing a process with a broad or unspecified outcome (e.g., completion of a rapid site assessment).

Each criterion consists of a list of items to which points are assigned if implemented successfully. Due to the point-based nature of the system, the number of points awarded for the achievement of an item depends on the level of safety that it would enhance within a building. The higher the level of safety, the more points it will receive. A brief description of the five representative criteria selected for this work is reported in Table 1.

**Table 1.** Five resilience criteria examined in this work.

| Criterion | Category | Indicator | Typology |
|---|---|---|---|
| Site risk assessment | Preparedness | Likelihood of hazards to happen | Qualitative |
| Passive survivability | Redundancy | The absence / presence of passive systems for heating, cooling, ventilation, and lighting. | Qualitative/ Quantitative |
| Heat-wave-resistant building envelope and structure | Robustness | Readyness in terms of anti-extreme heat solutions implemented | Qualitative |
| Emergency power supply | Response Capability | Presence/absence of emergency power supply | Qualitative |
| Access to useful shared spaces | Community Cohesion | Number of available useful community areas | Quantitative |

Each criterion is assigned to a distinct category within the module. The module comprises five different categories; each criterion is designed to elevate specific resilience levels corresponding to the category. For example, in the "Robustness" category, various criteria focus on fortifying the building in terms of proper design solutions and suitable materials to withstand climate-related hazards. In the next sub-chapters, a brief description of each criterion considered for this work.

### *3.2.1 Site Risk Assessment*

The objective of this criterion is to identify the probability, intensity and time scale of potential hazards, such as floods, heavy rainfall, storms, heatwaves, subsidence, and drought, specific to a given location. These are the the hazards that are most likely to affect buildings, according to Appendix A of the EU Taxonomy [13].

Indeed, a fundamental lesson derived from the concept of resilience underscores its profound connection to the local context and regional dynamics. This highlights the need to follow an approach focused on the most relevant hazards to the specific location where a building is planned, rather than applying a uniform approach. It should be noted that a European climate risk assessment is currently being prepared and is scheduled to be completed in 2024 [14].

However, in initiating the creation of a site risk assessment, the expertise provided by the C40 Cities Climate Leadership Group has been considered. This approach employs a methodology that is accessible even to non-experts in the field, making it more convenient for architects or designers [15].

### *3.2.2 Passive Survivability*

The purpose of this criterion is to ensure that a building can maintain crucial life support conditions during prolonged interruptions in power, heating fuel or water supply. This is achieved by incorporating passive survivability solutions during the design phase. The criterion consists of four distinct modules: passive solar heating, passive cooling, passive lighting, and thermal safety temperature.

The initial three modules primarily involve design strategies integrated into the building layout. For instance, daylighting spaces from multiple sides enhance even lighting, reduces glare around people and objects. Additionally, solar-facing clerestory and sloped skylights contribute to increased privacy, shading of the solar facade, heating of deeper spaces, and spaces along other facades. This design approach helps to avoid direct sunlight on people and furniture, mitigating glare [16,17].

The last module focusses on determining the maximum daily calculated indoor air temperature in the hottest habitable room of the building or apartment. This calculation follows ISO 7730:2005 - Ergonomics of the thermal environment.

To meet the criterion, specific documentation must be provided, verifying that the building possesses passive survivability to some extent in the absence of power. For example, a report detailing calculations and drawings could serve as evidence.

#### *3.2.3 Heat-wave-resistant building envelope and structure*

The purpose of this criterion is to minimise extreme heat discomfort by ensuring the safety of the building and the well-being of users. Table 2 describes the hazard. As part of the Robustness category, this criterion is closely tied to the results of the Site Risk Assessment, as it identifies the most likely hazards that should be addressed during the early design stage.

**Table 2.** Overview of the hazard. Source: [18].

| Heat wave | Extended period of exceptionally high temperatures in a specific location compared to the average |
|---|---|
| Origins | Trapped air circulation, high pressure system, heated, stagnant air |
| Issues | Lack of awareness, outdoor work-related tasks/jobs, health issues |
| Damaging components | High heat, extreme exertion on body, drought conditions |

The proposed solutions to be implemented include the utilisation of light-coloured and reflective materials, green roofs, and vegetation on the sun-exposed sides to shade the building and mitigate its susceptibility to extreme heat. To address specific vulnerabilities, recommendations are outlined for various building components. For instance, to enhance openings, suggestions involve implementing sufficient insulation for windows, doors, and walls to impede the building's heat gain, along with the incorporation of solar shading for windows. Regarding building services, recommendations include the adoption of passive cooling and ventilation techniques and/or integration with a district cooling system to optimise energy efficiency [19,20].

Meeting this criterion requires the submission of documentation that highlights the solutions implemented. Since extreme heat protection measures are typically not included in standard project documentation, they must be explicitly specified in the project documentation on resilience assessment.

#### *3.2.4 Emergency power supply*

The purpose of this criterion is to validate the presence of sufficient emergency power to sustain crucial loads identified by the design team as essential for the building's operation for a minimum of a 96-hour period (four days) during a disruptive event. The criterion includes a list of potential power demands that the building may require, and it is imperative to include at least three of them in the building design to earn points in this category.

To successfully fulfil this criterion, documentation, including drawings illustrating backup power equipment, product data sheets clearly indicating power production capacity, and a roster of critical loads supported by the backup power system. Furthermore, calculations for the electricity demand in kWh based on the critical loads and their duration must be included.

*3.2.5 Access to useful shared spaces*

The purpose of this criterion is to provide building users with services and shared areas, fostering stronger social networks and connections among neighbours. This approach not only enhances material and spatial efficiency but also establishes meaningful social interactions.

The effectiveness of this strategy is exemplified by the residential complex Gleis 21 in Vienna (AT) [21]. A significant aspect of the Gleis 21 concept is its open ground floor, accessible to everyone in the neighbourhood. This design is intentionally permeable, creating a link between the promenade and the park. This open space functions as an extension of urban space and features a multifunctional room equipped for use as a theatre, cinema, or seminar room.

To meet this criterion, documentation with detailed descriptions and illustrations of shared spaces must be provided. The drawings should serve as proof of the incorporation of these communal areas, highlighting their role in improving social connectivity within the building.

*3.3 Case study*

These criteria were used in the analysis of a specific case study involving a multi-residential building located in Prague [CZ], known as X-LOFT [22] – Figure 3 and Figure 4. Chosen among a range of possible candidates, this building is particularly suitable for the scope of the study, already silver certified according to SBToolCZ [10] with the opportunity to explore if it also matches with resilient criteria. This choice was made to investigate whether a building certified as sustainable could also be considered, to some extent, as resilient. Furthermore, it aligns with the implementation of the resilience module as the initial step in the Czech national sustainable tool.

**Figure 3.** Photo of the building.

**Figure 4.** Photo of the building – focus on the sun-shade blinds.

Nevertheless, it is important to acknowledge that evaluating resilience based on the aforementioned five criteria is conducted on an already constructed building. Ideally, the module's original intent is to address resilience enhancements during the early design phase of the project, enabling adjustments to be made to the design to incorporate as many resilience-boosting solutions as possible.

The case study is located in an east-west direction within a former "brownfield" space, a traditional Prague suburb. The area was originally home to the Libeň brewery and now features a mix of residential apartment blocks from the 20th century, industrial structures, and a small suburban colony – Table 3 lists the main information of the building.

**Table 3.** Main information of the building case study.

| Criterion | Category |
|---|---|
| Location | U Libeňského pivovaru, Prague |
| Year of construction | 2011-2013 |
| Residential unit | 48 |
| Floor | 2 underground floors + 4 double-height floors |
| Total internal usable floor area in heated zones | 4078 $m^2$ |
| Annual energy consumption | 81.2 kW/m2/y |
| Sustainability features | Solar collectors, reuse of harvested rainwater, accessibility to public transport |

The building adapts to its surroundings by bridging the gap between industrial and residential structures and integrating elements from both typologies into its design. This integration is particularly evident on the facade, which features a mix of geometrically precise sections reminiscent of industrial architecture alongside more traditionally arranged windows. The roof design, inspired by 20th-century industrial architecture, further emphasises this integration while also accommodating the building's structural system.

The apartments are designed with a higher ceiling height of 4.9 meters to maximise natural light and sunlight. To optimise space utilization, apartment floor plans overlap toward the facade, allowing for expanded living areas.

Structurally, the building comprises two underground floors that house garages, cellars and technical facilities, while above ground it consists of four floors with 48 apartments and an attic. Each floor typologically follows a three-section layout, with a central vertical communication area flanked by basic housing units. These units feature spacious living areas with expansive glazed facades, while the layout broadens toward the facade to enhance the living space. Additionally, the upper floors benefit from roof terraces, and those on the ground floor facing east have direct access to front gardens.

The vertical load-bearing structures use a set of arrangement of lamellar reinforced concrete walls, rotated by 10° between apartment units on each floor. This rotation pattern is reversed on consecutive floors and influences the layout of windows. The facade itself serves as a heavy load-bearing perimeter shell.

In terms of sustainability, features such as triple glazing, solar collectors, rainwater retention for greenery irrigation, and the option for air recovery systems in apartment units are incorporated to meet the SBToolCZ evaluation criteria.

## 4. Results and Discussion

Criteria testing involved evaluating their clarity, the sufficiency of providing information, and the time invested in successfully obtaining the required material to meet the criteria and, subsequently, achieve the objective. If the collection of information and the meeting of the benchmarks prove impractical due to time constraints or insufficient data, the criterion may need to be rephrased to enhance achievability and specificity. The resilience module should ideally not require excessive time from a potential evaluator, as sustainability rating systems typically serve as guidelines for informed decision-making during the design stage.

However, since the building case study is an existing building and not an ongoing design, some criteria remained unmet because the building was not originally designed with resilience in mind in those specific aspects. Indeed, the module aims to be incorporated into an existing sustainability rating system tailored for new multi-residential buildings. Table 4 summarises the information necessary to meet each criterion.

**Table 4.** List of criteria and relative information needed.

| Criterion | Information needed |
|---|---|
| Site risk assessment | Historical and future data |
| Passive survivability | Building drawings |
| Heat-wave-resistant building envelope and structure | Building drawings |
| Fundamental access to basic supply | Building drawings and technical supply |
| Access to useful shared spaces | Building drawings |

*4.1 Site Risk Assessment*

To assess this criterion, a thorough analysis of historical and future data has been carried out to identify the most probable risks for the designated area. Specifically, databases and maps were consulted for this location, which included research on past occurrences of heatwaves, droughts, storms, and floods. This involved reviewing historical climate patterns and projecting future trends under various scenarios. The use of hazards maps has proven to be particularly effective in connecting climate science with areas susceptible to vulnerabilities.

Specifically, an examination was carried out on maps related to the city of Prague. A satellite image captured by NASA's ECOSTRESS instrument, which recorded ground temperatures in June 2022, revealed the hottest surfaces. The image also clearly depicted the cooling influence of parks, vegetation, and water [23]. However, the X-LOFT building case study is located in an area where the surface temperature ranges between 42 and 44 degrees Celsius. This underscores the intense hazard posed by extreme heat in that location, which emphasises the necessity for the implementation of adaptation measures.

The city has faced significant exposure from river floods, with a major flood occurring in 2002, requiring an expenditure of over 5 million CZK for the installation of flood shields (both fixed and mobile). The X-LOFT area remains unaffected by this hazard, as evidenced by the images of Bezpecnost.praha.eu [24]. These images even illustrate the floodplain in the event of a 100-year flood, confirming the absence of this threat in the vicinity of X-LOFT.

Ultimately, the new Excel tool designed for the resilience module allows the completion of the dedicated sheet for the Site Risk Assessment criterion. Points are assigned based on the achieved items, and these points are subsequently interpolated on a scale of 0-10. The resulting score reflects the total of points obtained for that criterion. In this particular case, since there has been no workshop with specific stakeholders to identify potential location hazards, only one item has been achieved, leading to the assignment of one point. Consequently, on a scale of 0 to 10, three points have been designated for this specific criterion – Figure 6.

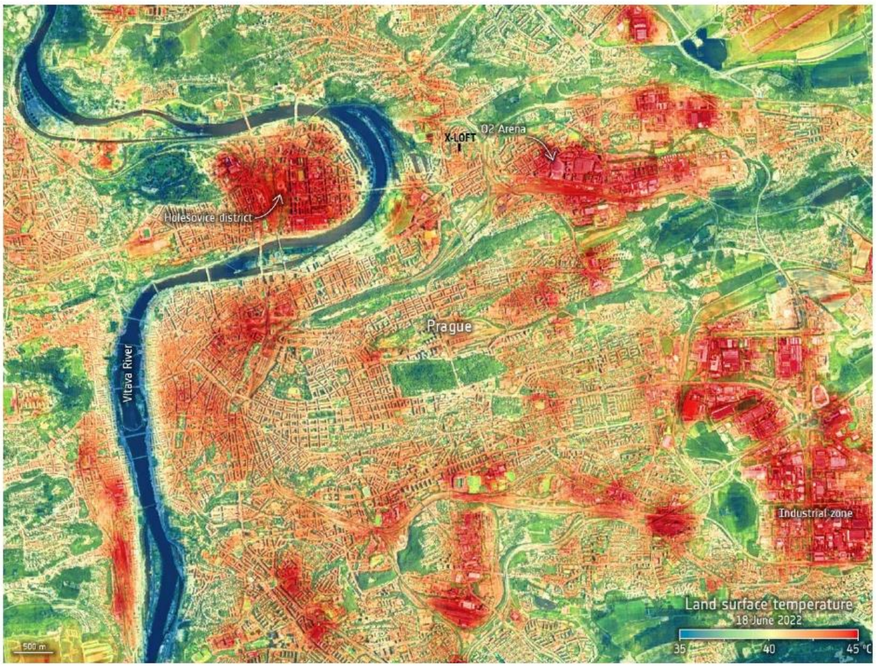


**Figure 5.** Land surface temperature in Prague on 18 June 2022. Source: [23].

| | | |
|---|---|---|
| PREPAREDNESS | | |
| **PRE.SA – Rapid site assessment** | | |
| *Intent of the evaluation* | | |
| Identification of the probability, intensity, and timescale of the most likely happening hazards (floods, heavy precipitation and storm, heatwaves, subsidence, and drought) of a specific location. | | |
| *Description* | | |
| Several factors should be considered when characterizing the risks associated with climate change in a specific location, such as the climate threat, the geographical context (e.g., coastal area, mountain region), and the affected systems and sectors (e.g., people, infrastructure, properties, etc.) as well as the impacts on the most vulnerable groups. The purpose of site risk assessments is to determine the likelihood of future climate hazards occurring and the potential impacts on buildings and their users. Climate action and adaptation strategies must be prioritized based on this information. | | |
| *Indicator (qualitative)* | | |
| Assessment of exposure to specific hazards to identify those that are most likely to occur. | | |
| *Evaluation modules* | | |
| PRE.SA1 - Site Risk Assessment | | |
| **PRE.SA1 - Site risk assessment** | | |
| Item | YES/NO | pt |
| A - Perform an hazards assessment | YES | 1 |
| B - Perform the site risk assessment through a workshop | NO | 0 |
| **Value KSA1** | - | 1 |
| *Overall evaluation* | | |
| KPRE.SA = KPRE.SA$_1$ | **Total value K** | 1 |
| | **pt** | 3 |
| | | *min 0 - max 10* |

**Figure 6.** Extract from the Resilience calculation tool.

*4.2 Passive Survivability*

This criterion comprises four modules, each meticulously assessed. Regarding passive heating, the building shows strong performance with the installation of triple-glazed windows, effectively minimising heat loss and sound transmission. Additionally, thermal insulation consisting of a 14-cm thick layer of mineral wool further enhances energy efficiency.

Regarding passive cooling, the dual exposure allows for cross ventilation, facilitating natural airflow, and reducing indoor temperatures. To counteract excessive warmth, both external and internal blinds can be used to shade the large windows. Moreover, 2% of the building façade is covered with greenery which slightly improves the thermal efficiency.

In terms of passive lighting, the building benefits from its favourable orientation with main facades facing east-west, which helps minimise exposure to intense Southern sunlight. Tall windows extending from floor to ceiling enable ample natural light, creating well-illuminated spaces.

The fourth module involves determining the maximum daily calculated indoor air temperature in the hottest habitable room, following the ISO 7730:2005 standards. As the building is SBToolCZ-certified, information regarding the successful completion of this module was obtained from certification reports. Architectural drawings and on-site inspections proved instrumental in fulfilling the requirements of the remaining modules. As a result, eight points out of a possible ten were allocated to this criterion.

*4.3 Heat-wave-resistant building envelope and structure*

As identified in the Site Risk Assessment (see 4.1), the building and its surroundings are susceptible to the potential impact of heatwave hazards. An analysis of the building design, based on documentation and drawings, reveals the implementation of effective solutions to combat extreme summer heat, some of which were previously mentioned in the section on passive cooling (see 4.2).

Another notable feature of the building is the presence of a rainwater tank, which allows water collection from an underground reservoir for reuse. This practice helps reduce the demand for water for irrigation purposes during summer. The glazed areas facing the street and the courtyard façade are triple-glazed wood windows. The opaque surfaces are currently equipped with mineral wool with the best thermal technical properties at a thickness of 14 cm.

*4.4 Emergency power supply*

Heating and hot water provision is facilitated by two 90 kW gas boilers. Additionally, hot water preparation benefits from a roof solar collectors, which fully contributes to heating domestic hot water during the summer months.

For individual residential units, a residential recuperation unit was installed. This unit significantly reduces energy losses through ventilation and ensures that the carbon dioxide concentration remains below the permissible limit of 1200 ppm (classified as "C" according to ČSN EN 1752). Furthermore, it helps to maintain optimal relative humidity levels during both heating and transition periods within the range of 35% to 42%.

Nevertheless, the lack of a backup power source inhibits further examination of this criterion. Implementing solutions such as water pumps to ensure the availability of potable water, maintaining the operation of cable modems and wireless routers for online access, or utilising an accessible common room as a storage for emergency supplies could improve the building's resilience in the event of a prolonged blackout or other disruptive incidents.

*4.5 Access to useful shared spaces*

This criterion is achieved only partially in the specific building case study. In fact, there are common parking areas and bike storage as well as the essential connecting halls between apartments. It would have been compelling to plan shared areas given the substantial number of units and residents.

Allocating space for amenities such as a gym, laundry room, or multipurpose room (e.g., coworking space) would have been beneficial, especially considering the prevalence of relatively small apartments, suitable for single individuals or couples - 40 out of 48 apartments have a surface area below 50m².

However, the decision not to incorporate shared spaces within the building is influenced by the proximity to external amenities, such as sports facilities, located within a 5-minute walk. In the outdoor area, residents have unrestricted access to a shared courtyard and pergola. The information to meet this criterion arises from a review of the drawings and led to 2 out of the 10 available points.

## 5. Conclusion

This paper reports the outcome of the application five criteria proposed as part of a potential add-on module for an existing rating system, specifically within the SBTool family, aimed at evaluating the resilience level of buildings. The assessment was carried out using a case study of a multi-residential building located in Prague, Czech Republic, to determine the effectiveness of these criteria.

The analysis revealed that the Passive Survivability and Heat wave-resistant building envelope and structure criteria could encompass additional solutions and strategies beyond those currently included in the framework and Excel tool.

Additionally, the Site Risk Assessment criterion emerged as the most time-consuming to achieve, requiring extensive desk work involving historical and forecast data, including hazard map investigations.

The Emergency Power Supply criterion received limited investigation due to data scarcity. The building's age, constructed over a decade ago, lacked recognition of backup power systems for prolonged operational sustainability. Furthermore, in the previous version of SBToolCZ, a criterion dedicated to building autonomy emphasised the importance of backup power sources and sustained consumption during power outages. However, this criterion was omitted in the latest SBToolCZ version to prioritise building quality and sustainability, despite the critical role of resilience.

The criterion regarding Access to useful shared space was the easiest to fulfil, as the time required to review documentation and examine floor plans to locate common areas was relatively short.

Finally, it was recognised that certifying an existing sustainable building does not necessarily indicate resilience in various aspects.

In conclusion, this new resilience module is primarily intended for application during the design phase, where adjustments to the drawings can be made to improve resilience to specific hazards. Integrating resilience characteristics into sustainability assessments during the early stages of design can encourage designers to incorporate resilience into their projects, ultimately minimising long-term impacts on the environment, society and economy, particularly during weather-related hazards.

**Author Contributions**

Conceptualization LF; methodology LF; formal analysis LF; investigation LF; writing-original draft preparation LF; writing-review and editing AL and JG; visualization LF; supervision AL and JG. All authors have read and agreed to the published version of the manuscript.

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