StartClim 2022

Ein physischer Vulnerabilitätsindex für Waldbrände in Österreich als Instrument zur Anpassung an den Klimawandel (PHLoX)

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H-1 Kurzfassung

Es wird erwartet, dass die Auswirkungen des Klimawandels Häufigkeit und Ausmaß von Waldbränden in Österreich und anderen Ländern erheblich verändern werden. Die jüngsten Ereignisse haben deutlich gemacht, dass Waldbrände für viele Länder mit begrenzter Erfahrung im Umgang mit dieser Gefahr ein neues Risiko darstellen. Es besteht daher die Notwendigkeit, Grundlagen für ein verbessertes Risikomanagement zu erarbeiten. Im vorliegenden Projekt PHLoX wurde als erster Schritt in diese Richtung die Vulnerabilität (Anfälligkeit) von Siedlungen, Gebäuden und Infrastruktur in der „Wildland Urban Interface (WUI)“, also in den Gebieten, in denen unsere Siedlungen auf den Wald treffen, untersucht. Die internationale Forschung zu Waldbrand ist bislang vor allem auf den Prozess selbst ausgerichtet (Brandentstehung, Ausbreitung, Vorhersage, Modellierung usw.) und weniger auf seine Auswirkungen. Aus diesem Grund sind Studien, die sich mit der Vulnerabilität der bebauten Umwelt befassen, kaum verfügbar. Das Projekt PHLoX fokussiert auf die Analyse der physischen Vulnerabilität von Gebäuden gegenüber Waldbrand. Das Projekt zielt auf die Identifizierung und Gewichtung jener Gebäudemerkmale und ihrer Umgebung ab, die deren Anfälligkeit für Waldbrände beeinflussen. Diese so genannten Vulnerabilitätsindikatoren basieren auf einer Literaturauswertung und wurden in Zusammenarbeit mit verschiedenen facheinschlägigen österreichischen und internationalen Fachleuten abgeleitet. Das Endprodukt des Projekts ist ein Index für die Gefährdung von Gebäuden durch Waldbrand (WVI), der alle identifizierten Vulnerabilitätsindikatoren zusammenfasst und zur Unterstützung von Entscheidungsprozessen, im Risikomanagement und im Rahmen von Strategien zur Anpassung an den Klimawandel verwendet werden kann. Das Projekt legt den Grundstein für die weitere Forschung im Bereich der Gefährdung durch Waldbrände in Österreich und für eine fruchtbare Zusammenarbeit zwischen Wissenschaft und Praxis.

H-2 Abstract

Climate change is expected to change wildfire frequency and magnitude significantly in many parts of the world including Austria. Nevertheless, socio-economic changes (development of the Wildland Urban Interface for recreational reasons) can also affect the occurrence of wildfires in the future. Recent events have shown that wildfire is an emerging risk for many countries with limited experience in managing wildfires. There is therefore a need to look closer into the vulnerability of settlements, buildings, and infrastructure in the Wildland Urban Interface (WUI), in other words, in these areas where our settlements meet the forest. International research on wildfires, however, is clearly oriented toward the wildfire itself (fire ignition, propagation, forecasting, modelling, etc.) and less on its impacts. Studies dealing with the vulnerability of the built environment are limited especially for countries that have not experienced large wildfires and their catastrophic consequences. The project PHLoX focuses on the physical vulnerability of the buildings located in the Austrian WUI to wildfire. By involving many different Austrian stakeholders and international experts, the project aims at the identification and weighting of these characteristics of buildings and their surroundings (vulnerability indicators) that influence their vulnerability to wildfires. The final product of the project is a wildfire vulnerability index (WVI) which combines all these indicators in a single index for each building and may be used to support decision-making, risk reduction, and climate change adaptation strategies. The development of this index is based on a literature review and the expert judgment of Austrian stakeholders (authorities and policymakers, engineers, emergency services) and international experts. The project sets the foundations for ongoing research in the field of vulnerability to wildfire in Austria and for a fruitful collaboration between researchers and stakeholders.

H-3 Introduction

There is a link between climate change and growing wildfire risk globally (OECD, 2023). As far as Austria is concerned, the effects of climate change are expected to lead to an increase in temperature and a decrease in precipitation. This may eventually affect forest fire (wildfire) risk. Climatic conditions that favour wildfires are the main reason for the increased occurrence of events throughout Europe, as shown by the European Forest Fire Information System (EFFIS) data. The amount of land burned in 2021 was about 2.5 times larger than in the period between 2008 and 2020 (IFRC, 2021). The costs of wildfires globally have also significantly increased (Figure H-1).

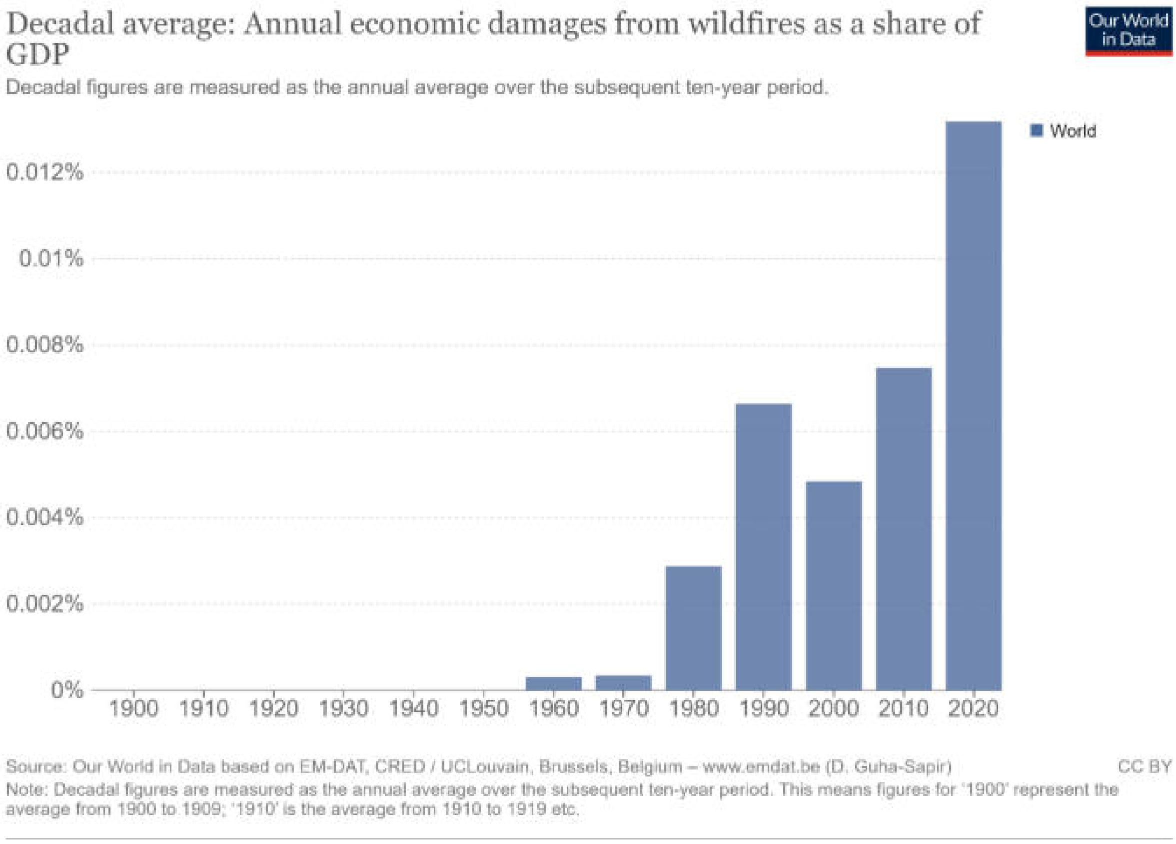

Abb. H-1: Increasing economic damages of wildfires (Ritchie et al., 2022)

Recent projections have shown a rise in the number of days with a higher fire hazard in Austria. These could increase by more than 40 days by the year 2100 (Arpaci et al., 2013), even in areas that did not have significant catastrophic wildfire events in the past (Pörtner et al., 2022; Sass, 2014). Increased forest fire risk is not only influenced by climatic but also by socio-economic change. Austrian forests, for example, serve as a recreation area, a source of raw material for wood and a source of oxygen. Forests also clean the air, bind CO2, and may serve as protection against natural hazards. Until now, forest fires have only insignificantly influenced human lives, settlements, and infrastructure within or close to Austrian forests. Nevertheless, the increasingly important recreational function of the forest may bring negative consequences. It is known that 85 % of forest fires in Austria are directly or indirectly caused by human activity, and the rest by lightning (Müller et al., 2020a) (Müller et al., 2020a). Due to the steady growth of populated areas and the demand for living space close to nature, the surrounding areas of cities are increasingly spreading towards forests and vegetation. This contact area between forests and human settlements is called Wildland-Urban Interface (WUI). The interplay between forest and settlements is dual, as on one hand human activity increases the possibility of wildfires occurring, and on the other hand wildfires threaten the population and infrastructure located in the WUI.

Some recent events (e.g., Rax 2021, Hallstatt 2018, Lurnfeld 2015, Absam 2014) opened a discussion among experts and responsible administrative authorities on how to reduce the risk of forest fires and the associated vulnerability. In recent years, the hazard of forest fires has been relatively well assessed (Müller et al., 2020b), but sufficient research on vulnerability (and thus the impact of forest fires on settlements) has not been carried out so far (Müller et al., 2020a; San-Miguel-Ayanz et al., 2018). Similarly, current strategies for disaster risk reduction are mostly based on the reduction of the wildfire hazard, but not on the vulnerability of elements at risk or their exposure (Papathoma-Köhle, Schlögl, Garlichs, et al., 2022). Vulnerability, however, plays a key role in assessing the risk posed by a natural hazard. Understanding, analysing and quantifying vulnerabilities are prerequisites to reducing vulnerability and eventually risk. Plenty of studies analyse the social, economic, environmental, or physical dimension of vulnerability to different hazard types (Fuchs & Thaler, 2018). Regarding the physical dimension, there are different approaches for its assessment including matrices, curves, or indices (Papathoma-Köhle et al., 2017). In this project, vulnerability indices are used based on vulnerability indicators that represent characteristics of the building and its immediate or wider surroundings.

Factors related to the physical vulnerability of buildings to forest fires have been published mainly for studies from the Mediterranean region (Laranjeira & Cruz, 2014; Xanthopoulos, 2004), Australia (Gibbons et al., 2018; Opie et al., 2014; Penman et al., 2015), and the USA (Alexandre, Stewart, Keuler, et al., 2016; Alexandre, Stewart, Mockrin, et al., 2016; Syphard & Keeley, 2019). However, the question arises as to the transferability of the results to other geographical locations (e.g., the European Alps). Moreover, many studies (Andersen & Sugg, 2019; Ganteaume & Jappiot, 2014; Ghorbanzadeh et al., 2019; Lampin-Maillet et al., 2010; Mhawej et al., 2017; Oliveira et al., 2018; Papakosta et al., 2017; Penman et al., 2015) present a variety of foci (social vs. economic vulnerability) and scales (local vs. regional) and are difficult to be used directly somewhere else. Given the increasing frequency of wildfires in Austria and some recent catastrophic events (Rax 2021, Figure H-2) the motivation has grown to develop an index that depicts the physical vulnerability of buildings in connection with the natural hazard of forest fires.

To close existing gaps regarding the effects of a potential wildfire in Austria, and to make a transdisciplinary contribution to climate change adaptation strategies, PHLoX identified those indicators that play a key role in the vulnerability of exposed buildings, based on an analysis of the available international literature. Similar to other types of natural hazards (e.g. (Papathoma-Köhle, Schlögl, Dosser, et al., 2022)) these indicators were then discussed and evaluated together with stakeholders from public administration, civil protection, and the insurance and fire protection sectors (Attems et al., 2020). Subsequently, these indicators were weighted (Papathoma-Köhle et al., 2019) – considering additionally the knowledge of international experts – and their applicability in the Austrian context was tested. Finally, the results were summarised in the form of recommendations and will be made available to political decision-makers and other stakeholders.

Knowledge about the vulnerability of buildings to forest fire is crucial for risk management. This has also been stressed in the latest OECD report as one of the key recommendations (OECD, 2023). This knowledge can be used by decision-makers such as authorities, emergency organisations or other stakeholders to assess vulnerability and accordingly, plan measures based on the information that will lead to a reduction of negative effects from a forest fire and avoid fatalities altogether. In addition, it is necessary to raise awareness among the population about the risk of forest fires. To develop sustainable solutions, it is important to create a tool that assesses the vulnerability of buildings to upcoming events.

H-4 Aims of the project

Indices have been used in risk and vulnerability science for a long time. They often make use of empirical data to test the relevance and the relative importance of their indicators. Empirical damage data may be quantitative (absolute costs of building repairs, degree of loss) or qualitative (e.g., structural, non-structural damages). However, these empirical data are not always available, mainly because of poor damage data collection methods or limited recent events that caused loss. To fill this knowledge gap, expert judgement may be employed. PHLoX's main aim was therefore the development of a vulnerability index for buildings in Austria based on expert judgement.

In more detail, the objectives of the project were:

(a) To identify key stakeholders in Austria related to buildings in the WUI, coming from different professional backgrounds such as authorities, policymakers, emergency and civil protection organisations, insurance companies, and the building sector.

(b)To co-create knowledge by actively involving Austrian stakeholders and potential end-users (see previous objective) as well as international experts (mainly researchers). The pool of Austrian and international stakeholders was used to identify the relevance and the relative importance of vulnerability indicators of buildings subject to forest fires.

(c) To use this knowledge and to develop a physical vulnerability index for buildings that can be used for vulnerability assessment of individual buildings, as a basis for vulnerability reduction strategies and reconstruction (Build Back Better), and as a tool for climate risk management.

(d) To develop climate change adaptation recommendations for the WUI (focus on forest fires). These include guidance on index creation, data collection, vulnerability reduction strategies, and the needs for future research.

Abb. H-2: Wildfire in Rax (Lower Austria) in October 2021. © R. Köck

H-5 Theoretical background

H-5.1 Wildfire

Globally, catastrophic wildfires have been often recorded in USA and Australia but also in Europe, especially in the Mediterranean region (Portugal, Greece, Spain, Italy, France). Due to climate change, however, the risk is now also increasing in other European regions (e.g., in the Alps). Additionally, forests are increasingly exposed to ecological disturbances, which can be anthropogenically or naturally triggered. The accumulated damaged and dead wood due to disturbed ecosystems forms an increased accumulation of combustible material. In addition to climatic changes, the population's increasing desire for recreational and leisure activities in nature leads to an increasing vulnerability of the latter. The factors that influence the occurrence of wildfire are the topography, the weather and available combustible material (Figure H-3). However, these three factors are also interconnected. Temperature, relative humidity, precipitation, and wind are decisive for the moisture content of the ignition material and therefore influence the ignitability. Especially in the Alps, Foehn winds and inversion weather conditions in the winter months lead to drying out promoting the development of forest fires. Finally, the wind is the decisive factor for the spread of the fire following its ignition (Bundesministerium für Land- und Forstwirtschaft, Regionen und Wasserwirtschaft, 2022).

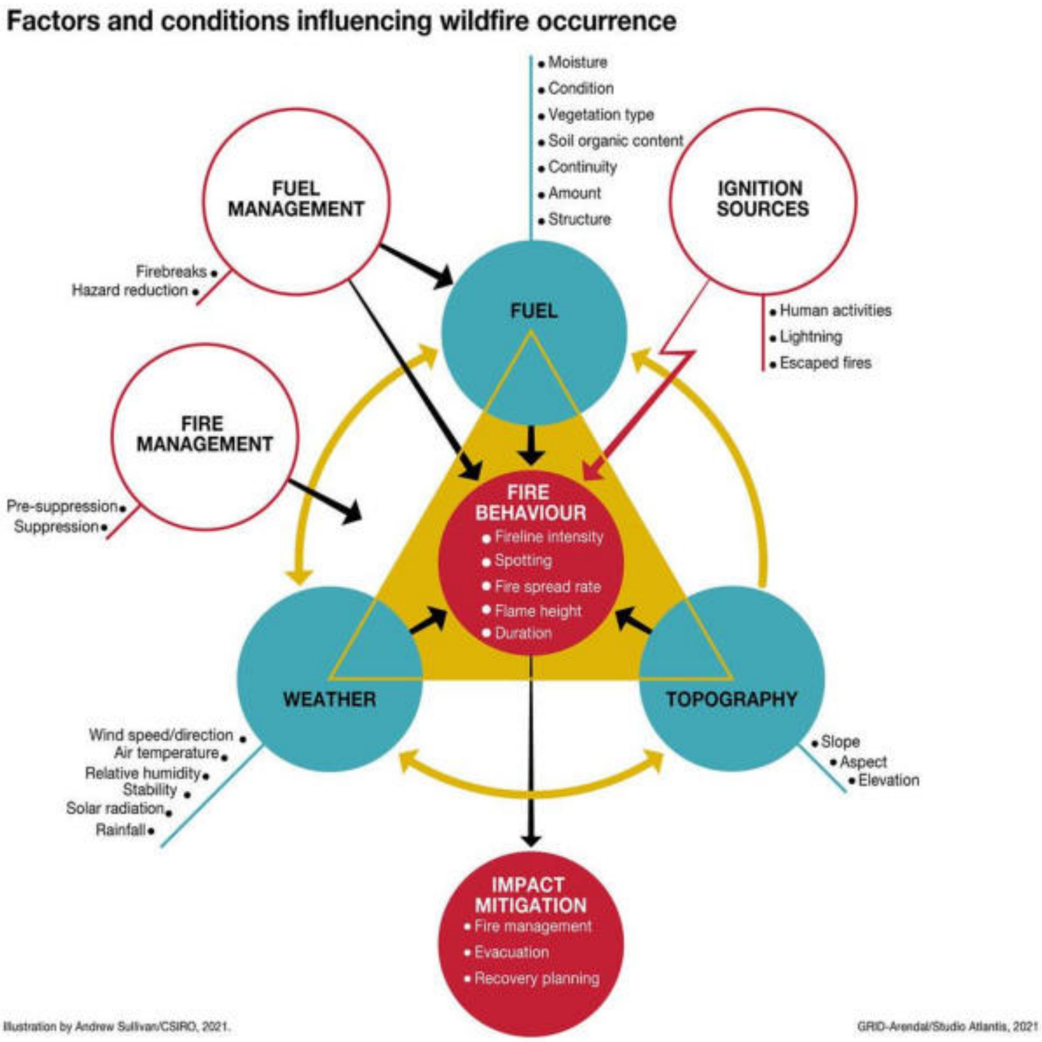

Abb. H-3: Factors and conditions influencing wildfire occurrence (UNEP, 2022)

There are three different types of fire, these are distinguished by the different spreading layer in the forest. The three types are ground fire, surface fire and crown fire (WWF, 2012).

Ground fire:

Soil fire, also called humus fire or smouldering fire, is caused by the ignition of living or dead organic material on the ground. The swelling fire initially spreads in all directions and then moves in the direction of highest oxygen supply, with the wind. The smoke produced has a distinct light grey colour due to the burning of organic matter. Usually, no flames are visible or present and the fire spreads over swelling embers (Food and Agriculture Organisation (F.A.O.), 2001; Henning, 2019; Vacik et al., 2020).

Surface fire:

Surface fire forms in the area between turf, litter, and undergrowth. It can spread horizontally as well as vertically over vegetation, producing flame lengths of one or several metres. If surface fires are driven by wind, they can spread rapidly. When moving in a vertical direction, crown fires can occur. This is the most common type of fire in Austria, often occurring in conjunction with swelling fires (Food and Agriculture Organisation (F.A.O.), 2001; Vacik et al., 2020).

Crown fire:

Hanging vegetation to the ground or rising surface fire can lead to crown fires. The fire is nourished by the oxygen present and the vegetative material in the crown and forms an air suction from the ground, which promotes rapid spread in all directions in the crown. Flying sparks very easily create new sources of fire, and flames can also spread further from tree crown to tree crown, which is called active crown fire. Passive crown fire, on the other hand, is the fire of a solitary tree. Due to its intensity, crown fire is also called full fire. It is the most intense of all types of forest fires and can lead to the destruction of an existing forest stand. Fighting it is only effective with high technical and personnel efforts (Henning, 2019; Vacik et al., 2020).

Since industrialisation at the end of the 19th century, the Earth has been warming steadily. To date, the global mean surface temperature has risen by 1.09°C. There are areas over land where the temperature rise is already plus 1.59°C. In the Arctic, it is rising more than twice as fast as the global average (Arias et al., 2021). In the European Alps, however, the temperatures are rising twice the global average creating problems related to retreating permafrost, water shortages, extreme events and natural hazards including forest fires (European Environment Agency, 2009; Kotlarski et al., 2023). According to Bowman et al. (2011), anthropogenic climate change has a clear effect on the change in the fire regime, as warming promotes extreme weather events that drive the development and spread of fire in areas where until now forest fires have not been often recorded. In addition, the length of fire seasons changes: They start earlier and end later. On the other hand, increased forest fire activity leads to increased greenhouse gas emissions and thus to the amplification of climate change (UNEP, 2022). This leads to the drying of permafrost areas, peat bogs and rainforests, which normally would not burn easily. Figure H-5 shows the potential feedback loop of climate change with forest fire. It shows the positive relationship between frequent extreme weather events and forest fires. Generally, there are three types of influences of climate change on wildfires: direct influences, indirect influences, and a mixture of both. The direct influences are effects on the occurrence of fire such as drought, wind, or the higher temperatures. The indirect influences are related to changes in the nature of the prevailing vegetation, biomass, or fuels in general. The third variant, is related to socio-economic changes such as changes in demography and human behaviour due to the changing climate (Dale et al., 2001; McKenzie & Littell, 2017).

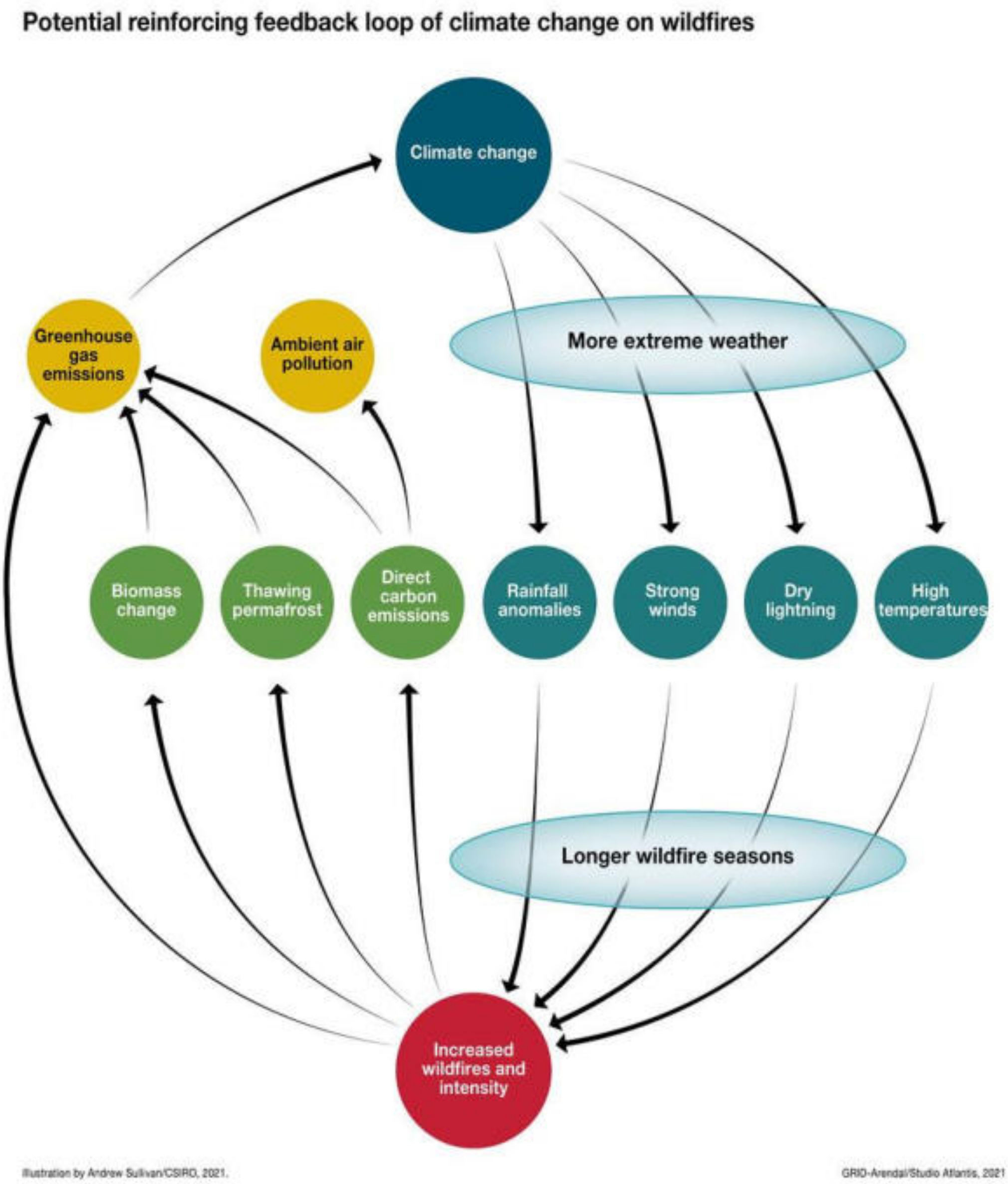

Abb. H-4: The dual relationship between wildfire and climate change (UNEP, 2022)

In Austria, 85 % of the recorded wildfires are caused by humans, for example through arson, discarded cigarettes, ashes, damaged power lines, flying sparks as a result of braking trains along the railway network. Non-anthropogenic triggering is caused by lightning at an average of 15 % of the events, with an increase of up to 40 % during the summer months (Müller et al., 2013). During a project developed in 2008 at the Institute of Silviculture at the University of Natural Resources and Life Sciences (AFFRI, Austrian Forest Fire Research Initiative) and subsequent projects, an online database was set up with more than 7,000 data records of current and historical forest fires from a size of 0.1 ha (https://fire.boku.ac.at). Based on these data, Figure H-4 shows the number and causes of forest fires in Austria from January 1993 until December 2021.

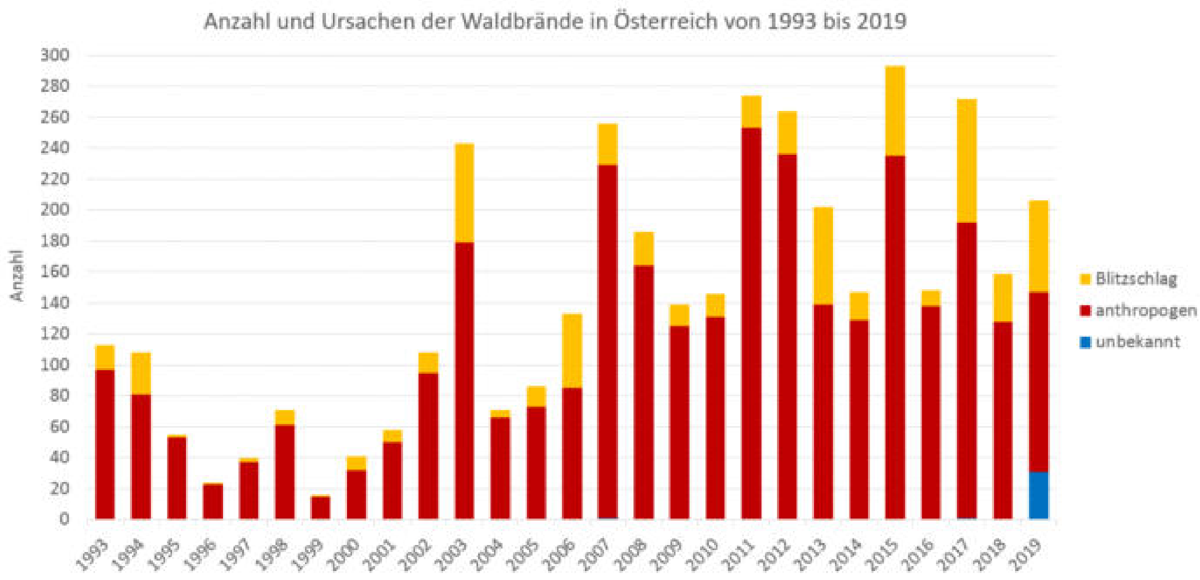

Abb. H-5: Number and cause of wildfires in Austria from 1993 to 2019 (yellow: lightning, red: anthropogenic, blue: unknown) (Source: Institut für Waldbau, BOKU)

In Austria, significant anomalies have been observed in recent years. Long intense dry periods in 2011 and 2012 led to severe spring fires, while summer fires increased in 2013. In 2015, an extremely dry late autumn resulted in full fires in the high mountains that lasted until the end of December. Rising temperatures and the resulting dry conditions caused by human-induced climate change are blamed for these anomalies (Vacik et al., 2020). The changes observed in Austria are also recorded at European level by EFFIS (European Forest Fire Information System). Based on these data, a rising trend towards an increased number and an increased area share of forest fires in the EU is evident.

H-5.2 Wildland-Urban Interface

Due to the steady growth of populated areas and the demand for living space close to nature, the surrounding areas of cities are spreading further and further towards forests and vegetation. Thus, urban areas (e.g., settlements, single-family houses, commercial areas, road network, etc.) directly border open vegetation and forest. The interface between these two zones is called the Wildland-Urban Interface (WUI). The term is usually only used in the context of forest fires. In this area, the risk of forest fires increases considerably due to the interaction of humans and nature. The resulting fires may become crown fires more easily leading to serious consequences for exposed buildings (Müller et al., 2020a). Knowledge of the factors that make buildings and infrastructure vulnerable to fire in the Wildland-Urban Interface is imperative to implement preventive measures for individual buildings or larger built-up areas (Lampin-Maillet et al., 2010; Xanthopoulos, 2004).

Conedera et al. (2011), focusing on the identification and monitoring of WUI areas in the alps, make a clear distinction between American, Australian, Mediterranean and the alpine WUI. As far as the Alps are concerned, they claim that the key factors leading to wildfire events are connected to human activity (related to residential units in the WUI) and mobility (e.g., road network).

Following the ignition, fire behaviour in the WUI is guided by topography, fire materials and weather, and for this reason fire behaviour may have significant regional differences. Characteristics of the WUI (e.g. the positioning of buildings, their design, building materials) and the presence of the combustible materials also play an important role as well as the level of preparedness of the homeowners and the capacities of the emergency services (Xanthopoulos, 2004).

Abb. H-6: The difference between Wildfire-Urban Interface and Wildfire-Urban Intermix

In the literature (Conedera et al., 2011; Kaim et al., 2018; Lampin-Maillet et al., 2010; Xanthopoulos, 2004), three components are always included in the classification of a Wildland-Urban Interface. First, settlement space must be present, although whether there must be a specific building density, number of buildings, number of inhabitants, etc. is not addressed. Secondly, vegetation must be present, which is also not differentiated in terms of plant species, density, or intensity, etc. The last component is the interaction between vegetation and settlement space, i.e., the encroachment of inhabited areas into natural environments and the accompanying mixing.

There are two types of WUI: the Wildland-Urban Interface and the Wildland-Urban Intermix. The Wildland-Urban Interface consists of two separate contact areas between settlement space and vegetation. In contrast, in the Wildland-Urban Intermix, these two areas mix to form a dense unit (Figure H-6). Usually, the two different types are collectively named Wildland-Urban-Interface in the literature.

Due to different interpretations and the lack of a standardised definition in Austria of the Wildland-Urban Interface (WUI), herein WUI refers to the contact area between forest, vegetation, and settlement space in the form of buildings and associated infrastructure. Nevertheless, we do not define a fixed distance between the settlement area, vegetation and forest edge or determine the mixing density in the case of a WUI Intermix.

H-5.3 Vulnerability

Analysing natural hazard risk in a changing environment is essential for planners, local authorities, and insurance companies. A great part of the risk analysis is the assessment of the physical vulnerability of buildings and infrastructure. A thorough vulnerability assessment may help governments and stakeholders on different scales (national, regional, local, and homeowners) to set priorities and use limited resources more effectively. Especially in the case of natural hazards that do not occur very often (e.g., wildfires in Austria) assessing vulnerability may indicate hotspots and areas where action should be concentrated.

There is no universal definition of vulnerability as there is also no common assessment method. A rather general definition (from a disaster risk reduction point of view) is the one of UNISDR: "The characteristics and circumstances of a community, system or asset that make it susceptible to the damaging effects of a hazard" (UNISDR, 2009, p. 30). From a climate change point of view, vulnerability has been defined in the past (IPCC fourth assessment report) as "the degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change, including climate variability and extremes" (IPCC, 2014). This definition focuses mainly on the exogenous influence rather than the intrinsic characteristics of the elements at risk that the UNISDR definition does. Nevertheless, the latest IPCC definition (IPCC, 2021) suggests that vulnerability is "the propensity or predisposition to be adversely affected" and it includes "sensitivity and susceptibility to harm and lack of capacity to cope and adapt". In general, there are three methods for assessing vulnerability: matrices, curves, and indices.

Vulnerability indicators have been mainly used to assess social vulnerability. Only a few studies use indicators to assess physical vulnerability (Agliata et al., 2021; Barroca et al., 2006; Dall'Osso et al., 2009). The PTVA method (Papathoma et al., 2003, Papathoma and Dominey-Howes, 2003, Dominey-Howes and Papathoma 2007, Dominey-Howes et al., 2010, Dall'Osso et al., 2009, Dall'Osso et al., 2016, Papathoma-Köhle et al., 2019a) originally designed for tsunami hazards is a representative indicator-based method. Based on PTVA a similar approach was used for hydro-geomorphic hazards in France (Kappes et al., 2012), Peru (Ettinger et al., 2016; Thouret et al., 2014), and India (Thennavan et al., 2016). The latest development is a Physical Vulnerability Index (PVI) for dynamic flooding in the European Alps (Papathoma-Köhle et al., 2019) and an index for wildfire vulnerability based on empirical data from a wildfire event in Greece in 2018 (Papathoma-Köhle, Schlögl, Garlichs, et al., 2022). The indicator-based approach for the assessment of physical vulnerability is described in the following figure.

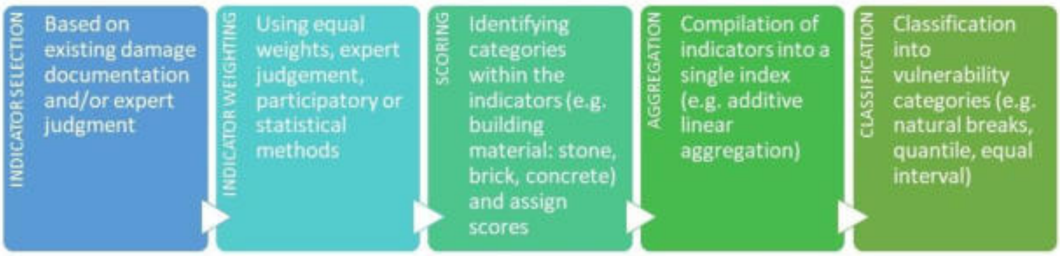

Abb. H-7: The stepwise development of a vulnerability index.

The project PHLoX focuses mainly on the first two and the fourth steps of the approach (indicator selection, weighting, and aggregation into an index). A further development of the project could include the scoring and the classification of the vulnerability categories.

H-6 Methods and application

The project made use of different methods to fulfil the objectives presented in the previous section. In more detail, PHLoX was based on a thorough literature review of scientific articles related to the vulnerability of buildings to wildfire, the identification and mapping of relevant stakeholders in Austria and beyond, the development of a questionnaire where the identified indicators were pairwise compared by the stakeholders and experts identified, and finally, the application of the AHP method to weight these indicators to finally develop the wildfire vulnerability index. The different methods used within the project are presented in the following subsections.

H-6.1 Literature review

In the literature review more than 30 papers were reviewed. The papers were mostly peer-reviewed scientific articles from the last 20 years in German and English. They described studies focusing on case studies in Europe, Australia, and USA. All the papers focused on buildings and their interaction with wildfire in the WUI. Most of the papers did not address vulnerability directly but they gave valuable information about which parts of the buildings and their surroundings contribute to negative consequences and which other characteristics increase the resilience of the building to wildfire.

Tab. H-1: Factors that relate to the vulnerability of a building subject to wildfire according to the literature review: Surrounding environment and nearby forest

Factor	Source
Building density	(FEMA, 2008) (Lampin-Maillet et al., 2010) (Alexandre et al., 2016)
Spatial planning/distance to neighbouring buildings	(Galiana-Martin, 2017) (Laranjeira & Cruz, 2014) (IIBHS, 2017)
Accessibility	(FEMA, 2008)
Width of access road	(FEMA, 2008)
Water sources	(FEMA, 2008) (Xanthopoulos, 2003) (Xanthopoulos, 2004) (Xanthopoulos et al., 2011)
Existence of wildfire risk map	(naturgefahren.at, 2020)

Tab. H-2: Factors that relate to the vulnerability of a building subject to wildfire according to the literature review: Settlement and surroundings

Factor	Source
Forest type (deciduous, mixed, coniferous forest)	(Kaulfuß, S., 2020)
Level of development	(Kaulfuß, S., 2020)
Protective strips, firebreaks	(Kaulfuß, S., 2020)
Water sources	(FEMA, 2008) (Xanthopoulos, 2004) (Xanthopoulos et al., 2011)
Forest fire danger signs	(Civil Protection Board of Catalonia Infocat Working Group, 2022)

Tab. H-3: Factors that relate to the vulnerability of a building subject to wildfire according to the literature review: Building surroundings

Factor	Source
Veranda and railing material	(Laranjeira & Cruz, 2014)
Garden furniture	(Laranjeira & Cruz, 2014)
Terrace/patio	(Civil Protection Board of Catalonia Infocat Working Group, 2022)
Gravel Bed	(Laranjeira & Cruz, 2014)
Bark mulch	(Federal Emergency Management Agency (FEMA), 2008)
Fence	(Laranjeira & Cruz, 2014)
Garage or shed	(Laranjeira & Cruz, 2014; Vacca et al., 2020)
Balcony or loggia	(Federal Emergency Management Agency (FEMA), 2008)
Terrain inclination (>10°)	(Alexandre, Stewart, Keuler, et al., 2016; Institute for Business and Home Safety (IBHS), 2017; Maranghides et al., 2013; Quarles et al., 2013)
Exposure of the building in the terrain	(Maranghides et al., 2013; Vacca et al., 2020)
Distance to vegetation	(Cohen, 2000; Laranjeira & Cruz, 2014; Leonard & Bodwitch, 2003; Mitchell & Patashnik, 2007; Ramsay et al., 1996)(Laranjeira & Cruz, 2014)
Accumulation of vegetation remains and dead wood	(Laranjeira & Cruz, 2014)

Type of vegetation	(Blanchi et al., 2006; Federal Emergency Management Agency (FEMA), 2008; Laranjeira & Cruz, 2014; Ramsay et al., 1996; Vacca et al., 2020)
Condition of vegetation	(FEMA, 2008) (Foote et al., 1991) (Vacca et al., 2020)
Tree tops (touching or overhanging)	(Laranjeira & Cruz, 2014)
Vegetation density	(Laranjeira & Cruz, 2014)
Distance to forest edge	(Laranjeira & Cruz, 2014) (Lampin-Maillet et al., 2009)
Ground cover vegetation	(Ramsay et al., 1996) (Blanchi et al., 2006) (FEMA, 2008) (Leonard & Bowditch, 2003) (Laranjeira & Cruz, 2014)
Power lines/cables	(Xanthopoulos, 2004) (Xanthopoulos et al., 2011)

Tab. H-4: Factors that relate to the vulnerability of a building subject to wildfire according to the literature review: Building characteristics

Factor	Source
Building use	(Ghorbanzadeh et al., 2019)
Building material	(Laranjeira & Cruz, 2014; Papalou & Baros, 2019; Syphard et al., 2017)
Facade/cladding	(Laranjeira & Cruz, 2014)
Insulation	(Frankenfeld, H.S., 2016)
Building foundation	(Laranjeira & Cruz, 2014)
Roof material	(Laranjeira & Cruz, 2014) (Vacca et al., 2020) (Quarles et al., 2010) (Quarles et al., 2013)
Roof form (Complexity)	(Laranjeira & Cruz, 2014) (Vacca et al., 2020)
Roof overhang	(Laranjeira & Cruz, 2014)

	(Quarles et al., 2010)
Roof underlying structure	(Laranjeira & Cruz, 2014)
Gutter	(Xanthopoulos, 2003) (Xanthopoulos et al., 2011)
Shutters/blinds	(Laranjeira & Cruz, 2014)
Material of doors and windows	(Laranjeira & Cruz, 2014) (Ramsay et al., 1996)
Number of doors and windows	(Laranjeira & Cruz, 2014) (Papalou & Baros, 2019) (Ramsay et al., 1996)
Type of windows	(Blanchi et al., 2006) (Vacca et al., 2020)
Flyscreens	(Laranjeira & Cruz, 2014)
Size of the windows	(Ramsay et al., 1996)
Ventilation openings	(Xanthopoulos et al., 2011)(Vacik et al., 2020) (Laranjeira & Cruz, 2014) (Syphard et al., 2017) (Vacca et al., 2020) (FEMA, 2008)
Attic/loft	(Laranjeira & Cruz, 2014)
Chimney / stove pipe	(Xanthopoulos et al., 2011) (FEMA, 2008)
Escape routes	(Xanthopoulos, 2003) (Xanthopoulos, 2004) (Xanthopoulos et al., 2011) (Civil Protection Board of Catalonia Infocat Working Group, 2022)
Open pipelines (e.g., gas, water)	(Australian Standards, 2009)

To avoid overlaps and to support the process of the pairwise comparison, some of the indicators were merged into wider descriptions, and the number of indicators per category was significantly reduced.

H-6.2 Stakeholder mapping

H-6.2.1 Austrian stakeholders

One of the aims of the project was to identify relevant stakeholders in Austria that could be useful for expert judgement. One of PHLoX's main aims was to identify Austrian stakeholders that come from different professional backgrounds. A list of all the stakeholders involved in this study was made but, due to data protection reasons (General Data Protection Regulation, GDPR), we are not publishing this list in the report. The main criterion for choosing the Austrian stakeholders was their involvement in research, decision making or response to wildfires.

The following figure (H-7) shows the professional background of the Austrian stakeholders involved in the project.

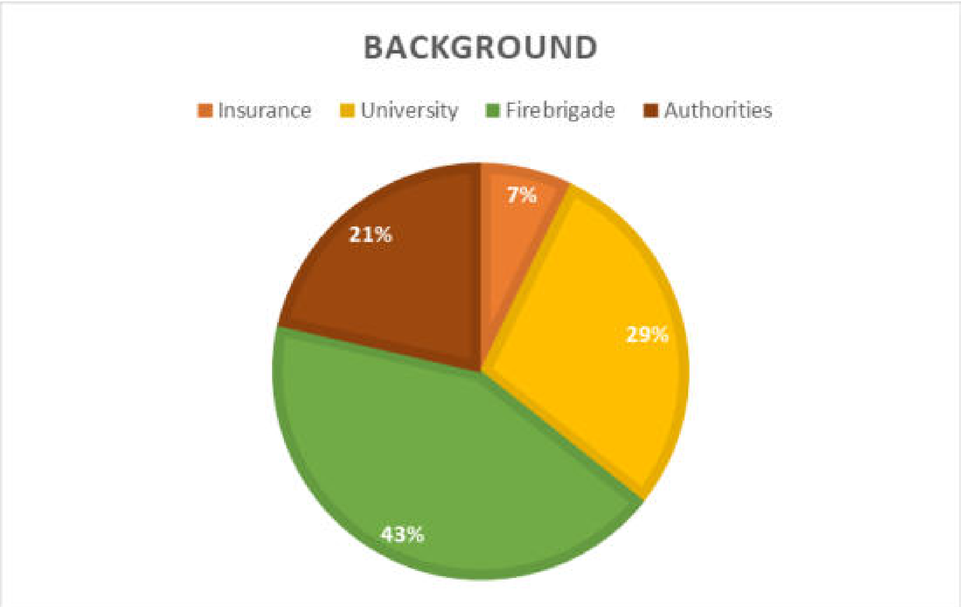

Abb. H-8: The professional background of the Austrian stakeholders involved in the study.

The Austrian stakeholders were twelve experts related to forest fire, building structure, natural hazard insurance, emergency organization and public administration related to natural hazards in Austria.

H-6.2.1 International Experts

More than fifty (54) international experts were chosen to perform expert judgement in the project. The main criterion for choosing them was their involvement with research related to wildfire impacts in the WUI, which could be confirmed by their scientific publications the last 20 years. Consequently, they all had the same background (university, research institute). Nevertheless, they had a wide geographical distribution (Figure H-8), in an effort to gain from the experience and knowledge from countries that have to deal very often with catastrophic wildfires such as Portugal, Australia, Greece, etc.

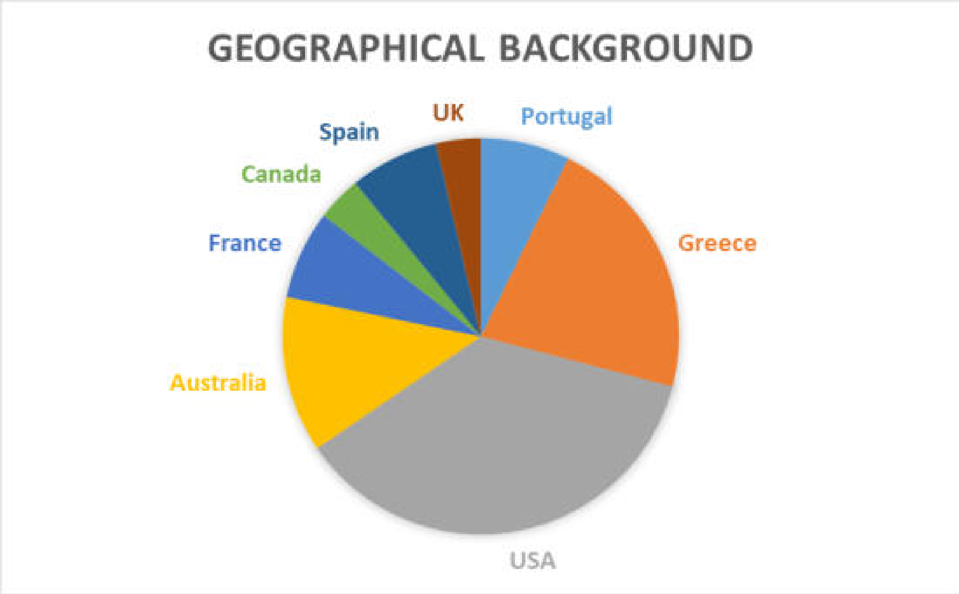

Abb. H-9: The geographical background of the international experts involved in the study.

The response of the international experts was very good (approx. 30 %). Most of them expressed very positive comments for the project and they were also happy to contribute with recommendations for future developments of the study (e.g., additional indicators).

H-6.3 AHP and the development of a questionnaire

The Analytic Hierarchy Process (AHP) is part of prescriptive decision theory and is used to solve multi-criteria decision problems (Saaty, 1987). In AHP, "analytical" is the given nature of a problem constellation, which is examined in all its dependencies. The "hierarchy" describes the form of the problem structured by ranking and divided into levels. The entire decision problem is seen as a process in which a decision is made based on control and discussion. This method shows how decisions can be made rationally and provides the decision-maker with answers for different situations. The procedure of the AHP method is described in the following steps and follows the publications of Saaty (1987), Riedl (2005) and Ronninger (2019).

- Collecting the data

In AHP, based on the goal of the study, criteria are defined that are significant for this goal. In the case of this project, the criteria are indicators that contribute to the physical vulnerability of a building to forest fire. Not every indicator has the same effect on the flammability of a building, the assessment of the indicators by experts based on a survey serves as a basis for the analysis with the AHP method to determine which indicator has a higher significance than another.

- Pairwise comparison

In the second step, the selected criteria are ordered hierarchically. According to this order, the criteria are compared and evaluated. The evaluation is done in pairs using different scale values, for example, 1 – equal importance, 2 – greater importance, 3 – significantly greater importance to 5 – significantly greater importance. It is always evaluated whether the row is more important than the column. Thus, to give an example, the criterion "building material" is rated with half as much importance as the criterion "number of floors", the same applies to the "roof material". Criteria of the same type are described as having the same importance (1). If the importance is reversed, the reciprocal of the scale value must be used for the assessment, e.g., 1/2.

The survey, which was sent out to the experts as a Questionnaire with an evaluation option (checkbox), is structured in such a way that it can subsequently be statistically evaluated. This requires a special design of the evaluation form. All indicators are compared in pairs and an assessment is made as to which of the two opposing options has a greater impact on the vulnerability of the building. This assessment based on a seven-category ranking can express whether the two opposing indicators have the same influence on the vulnerability of a building in the event of a forest fire. If the expert thinks that this influence is equal, he selects the checkbox at the scale "equal" in the assessment form. However, if his subjective assessment is associated with a tendency towards one of the two opposite indicators, there is a three-level classification (weak, medium, strong) for each of the two indicators in which the influence can be selected.

H-6.4 Index Development

Vulnerability indices are directly related to the building and its characteristics that may change reducing in this way the vulnerability of a structure in a cost-effective way. Indices do not make direct use of empirical data (once they have been developed) and can be applied in areas without any historical record of events. Moreover, during the development of an index, we have a closer look at the interaction between buildings and the hazardous process (in this case wildfire) which is beneficial knowledge for building back better and designing building codes in the WUI. Existing methods using indicators (listed in Table H-1) however, are often not in local scale using buildings as the research unit and do not use detailed indicators.

H-7 Results and discussion

Following a thorough literature review of papers focusing directly on the vulnerability of buildings to wildfire or on the detailed impact of wildfire on buildings and the interaction between them, a selection of indicators was possible (Tables H-1, H-2, H-3, H-4). Nevertheless, to compare these indicators pairwise easier, we divided them in the following three categories:

- Surrounding environment and nearby forest,
- Exterior of the building, and
- Building features

The set of indicators considered in the study can be seen in Table H-5. For more detail and description of indicators please see Annex II (Glossary of indicators).

Tab. H-5: The groups of indicators that will be considered for the development of the index.

Surrounding environment and nearby forest	Exterior of the building	Building features
Building density	Combustible materials	Number of floors
Distance to neighbouring buildings	Ground covering	Building material
Water sources	Property boundary	Facade/cladding
Vegetation density	Terrain slope	Roof material
Forest type	Type of vegetation on the property	Roof shape (complexity)
Protective strips or fire breaks in adjacent forest	Distance of tree crowns/vegetation of the building	Roof overhang
	Distance to forest edge	Shutters (external roller blinds)
		Doors/window material

The questionnaires (Annex I) were made based on the three indicator groups presented above. A glossary explaining the relevance of each indicator was also given to support the stakeholders and experts (see Annex II). For each group, the indicators were compared pairwise in all possible combinations. The comparison could be done using 4 degrees of importance (see questionnaires in Annex I): strong, moderate, slight and equal importance. Following the AHP, the weights of the indicators were determined as seen in the following figures:

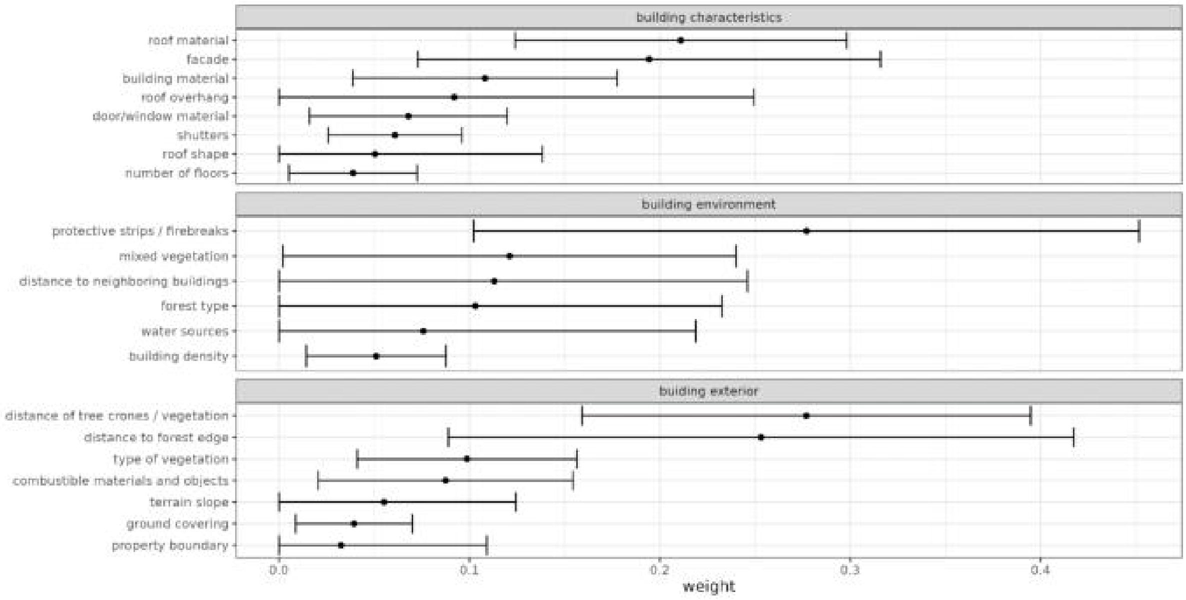

Abb. H-10: The weighting based on the Austrian stakeholders' survey.

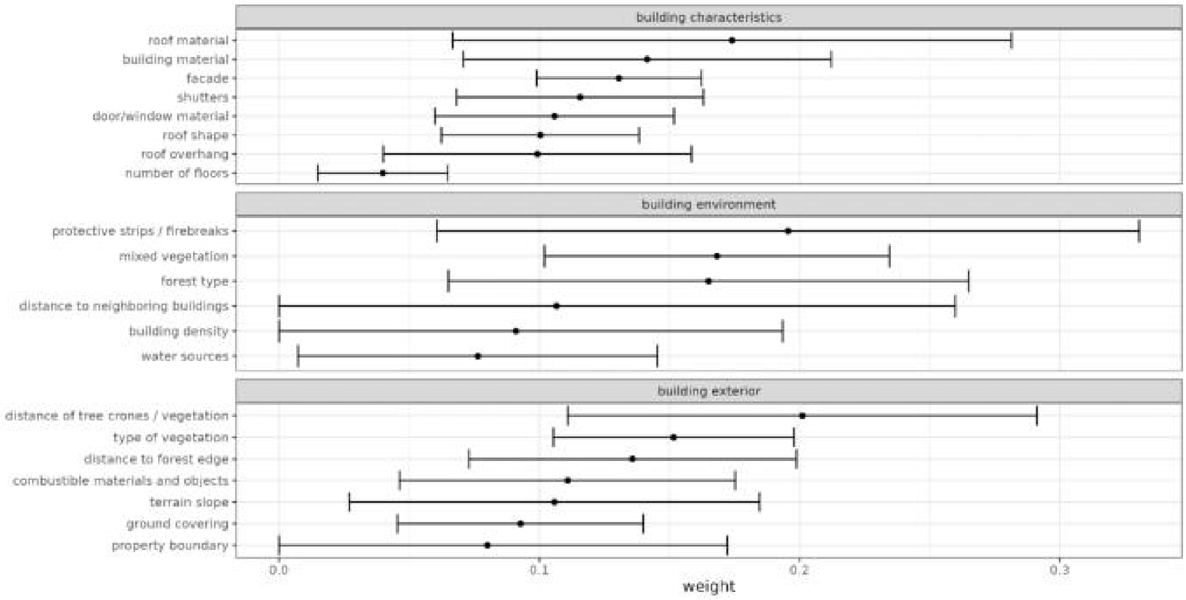

Abb. H-11: The weighting of the indicators based on the international experts' survey.

The weights of each indicator based on the Austrian stakeholders are given in Table H-6. In more detail, the weights are given within each of the three categories but also in the whole set of the indicators (normalized weight). At this point we use the weights given from the Austrian stakeholders since the focus is on Austria. Nevertheless, the results of the weighting based on the international experts confirm the Austrian results since the differences are minimal.

Tab. H-6: The weighting of the vulnerability indicators

Indicators	Weighting	Normalised weighting (wn)
Surrounding environment and nearby forest		
Building Density	0.0511	0.0212
Distance to neighbouring buildings	0.1131	0.0469
Water sources	0.0758	0.0315
Vegetation density	0.1211	0.0503
Forest type	0.1031	0.0428
Protective strips or fire breaks in adjacent forest	0.2770	0.1150
Exterior of the building		
Combustible materials	0.0875	0.0363
Ground covering	0.0395	0.0164
Property boundary	0.0326	0.0135
Terrain slope	0.0552	0.0229
Type of vegetation on the property	0.0987	0.0410
Distance of tree crowns/vegetation of the building	0.2769	0.1150
Distance to forest edge	0.2531	0.1051
Building features		
Number of floors	0.0390	0.0162
Building material	0.1082	0.0449
Facade/Cladding	0.1945	0.0807
Roof material	0.2111	0.0876
Roof shape (complexity)	0.0505	0.0209
Roof overhang	0.0920	0.0382

Shutters (external roller blinds)	0.0609	0.0253
Doors/window material	0.0680	0.0282

To obtain an index, one of five possible scoring (Figure H-12) must also be selected for each indicator. This expresses the degree of possible flammability as a value (Table H-7) for the calculations of the PVI. The factor, with the associated value from one to five, is issued during a building assessment and forms the basis for the calculation of the physical vulnerability index.

Tab. H-7: The scoring of indicators

Scoring of indicators		
Symbol	Vulnerability relevance	Value/score
s1	Vulnerability – very low	1
s2	Vulnerability – low	2
s3	Vulnerability – average	3
s4	Vulnerability – high	4
s5	Vulnerability – very high	5

The indicators that were selected by experts and subsequently weighted form the physical vulnerability index. The calculation is performed using the following equation (1):

$$PVI = \sum_1^n w_n * I_n s_n \qquad (1)$$

Where w1-wn expresses are the weights indicated in Table H-6 of each indicator (I1-In), which receives its assessment against vulnerability from a score (I1s1 - Insn with a value of 1, 2, 3, 4, or 5), as shown in Table H-7. The score will be given according to the description of each indicator. For example, in the case of building material, it is clear that wood will be assigned a high score from Table H-7, whereas concrete or metal a lower one. The scoring of indicators is not part of this project, and it is very much related to local architectural characteristics and spatial planning.

This resulting index is not dependent on hazard intensity, but purely expresses vulnerability to the natural hazard of wildland fire in a Wildland-Urban Interface. If multiple properties in the same area are assessed and compared, a relative comparison of the vulnerability of the assessed buildings to each other is obtained. This step requires classification in different vulnerability categories.

Classification:

The presentation of the index as a vulnerability map requires a classification of vulnerability in vulnerability classes. The map serves as a decision support for questions related to the risk management of the elements at risk. There are different ways to classify the index. On the one hand, a classification by means of quantiles is feasible: In this case, each class contains a certain number of buildings. This form of application is suitable for setting priorities, for example, the 10 most vulnerable buildings will be retrofitted. On the other hand, classifications can be carried out by means of standard deviation: Here, the deviation of the characteristic from the mean value serves as information for the classification. The chosen classification method in this study is the "equal intervals". This method is based on the fact that each class has the same difference between the lower and higher limit. This classification is comprehensible easy to interpret by a variety of users including authorities, engineers or the public (Papathoma-Köhle et al., 2019).

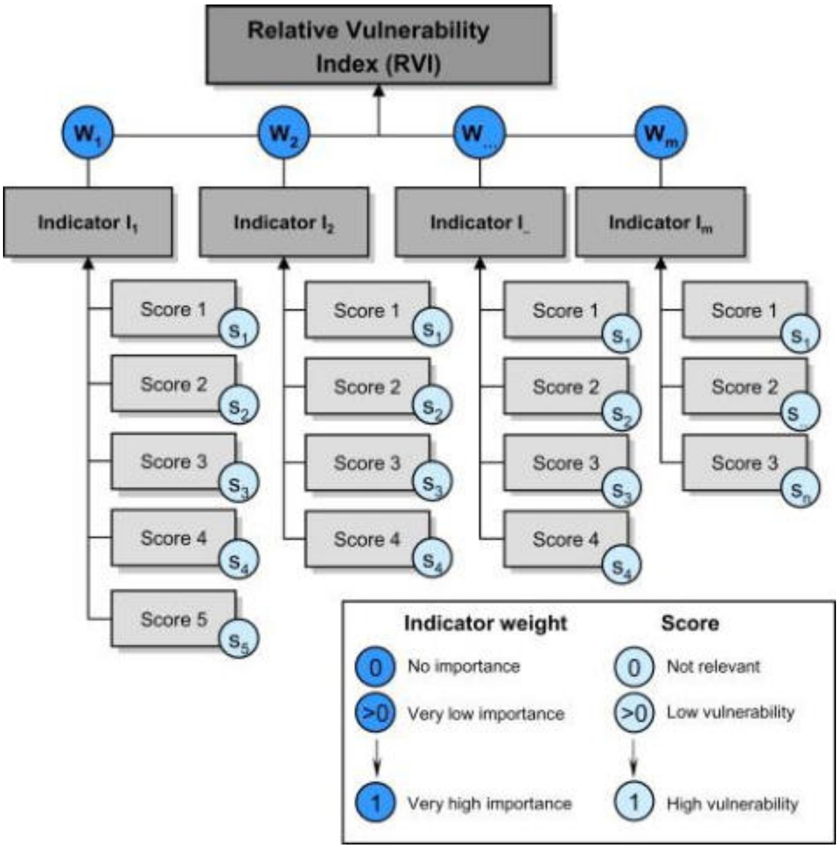

Abb. H-12: The structure of a Vulnerability Index (Kappes et al., 2012)

Feedback from stakeholders and experts:

The questionnaires included also two open questions. The first one concerned indicators that should be reconsidered and the second one encouraged the experts to recommend additional indicators. The feedback of the Austrian and international experts can be summarized as follows:

1. Critique on existing indicators: indicators that may not be relevant include the number of floors, water sources, terrain slope and roof overhang.

2. Additional indicators proposed: height of building, distance to roads, capacity to defend the building, surrounding land use especially on the wind shadow side, vegetation connectivity and condition, building condition and type/cleanliness of gutters.

A very important comment was that indicators related to the wildfire itself (e.g., wind direction and wind speed) should also be included.

H-8 Recommendations, relevance to stakeholders and the way forward

Following the results of the survey given to the Austrian stakeholders and the international experts, an index could be made but also some general recommendations for the reduction of physical vulnerability to wildfire could be drawn:

1. The most relevant indicators according both expert pools as far as the building elements are concerned had to do with materials (roof, the building itself and the facade). It is therefore recommended that in specific areas where the hazard of wildfire is particularly high to prefer specific materials and avoid others. It was also obvious that indicators related to the design (shape of roof) and the size (number of floors) of the building was not marked as very important. (relevant stakeholders: homeowners, engineers, municipalities)

2. Protective/strips and firebreaks were ranked very high as important indicators. This is a significant piece of information for ministries, forest managers and planners in Austria. Firebreaks and similar measures have to be decided and implemented always in consideration of neighbouring settlements and prevailing winds. This kind of measures may protect large, inhabited areas, save lives, and reduce damages to property and costs. (relevant stakeholders: ministries, planners, forest managers)

3. Forest type and density was also marked as very important. Residents of settlements neighbouring forests with specific tree types and density have to be informed about the dangers that may have to face and prepare their property accordingly (see recommendation 1). (relevant stakeholders: homeowners, municipalities, forest managers)

4. Apparently, the most important indicator in both groups was the distance of the tree crowns from the building. This indicates the importance of cleaning around the building, removing dead wood and leaves and minimize the contact of vegetation by pruning and trimming trees in the property. (relevant stakeholders: homeowners, municipalities)

5. The type of vegetation was ranked high. In this case, authorities could also inform the residents about tree types that are less dangerous and should be preferred in comparison with others. (relevant stakeholders: homeowners, municipalities)

6. Some of the experts in Austria and internationally suggested that an indicator could also be the degree of preparedness of a building in terms of evacuation possibilities. Public awareness, education and training on emergency procedures are therefore very important. (relevant stakeholder: homeowners, emergency services, municipalities, policy makers)

The relevant stakeholders have been already contacted during the implementation phase. They will be informed by the results directly but also indirectly through publications in local journals for practitioners. The scientific community will be informed through conference presentations and scientific publications.

PHLoX was a relative short project which nevertheless shed light on a very important topic that is not very well researched in Austria, the one of wildfire vulnerability. As more wildfires are expected in the years to come, research should continue in many directions:

1. Expert pools by local stakeholders can be developed and local indexes that take into consideration the local architecture and context may be developed (e.g., Tyrol).

2. Additional indicators proposed by the experts (e.g., wind direction) could also be included in a future study.

3. Indicators related to the resilience of the building may also be included (e.g., proximity to roads, alternative exits, etc.)

4. Sets of indicators for other elements at risk such as industrial buildings and infrastructure (railway lines, electricity network) may also be developed.

5. The index should be applied in an area. The resulting indices for every house may be displayed in a map that can act as a basis for emergency plans.

6. The index should be validated should a catastrophic event occur in Austria.

7. Finally and according to the latest OECD report on wildfire risk management (OECD, 2023), information on wildfire hazard, exposure and vulnerability should be regularly updated.

H-9 Literaturverzeichnis

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H-10 Anhang I

Ein **Waldbrandvulnerabilitätsindex** für Gebäude in Österreich

EXPERTEN UMFRAGE

Liebe Experten,

PHLoX ist ein StartClim Projekt, welches sich mit der Entwicklung eines **physischen Vulnerabilitätsindexes für Gebäude, die durch Waldbrand gefährdet sind**, beschäftigt. Das Projekt kombiniert Methoden der Literaturanalyse mit Techniken der Wissens-Koproduktion, um fehlende Wissenslücken zu schließen. Durch die Teilnahme von Fachleuten unterschiedlicher Experten aus Österreich und anderen Ländern wird es ermöglicht, jene Gebäudeeigenschaften und Merkmale der Gebäudeumgebung zu identifizieren, die einen signifikanten Einfluss auf die Höhe des Schadensausmaßes bei Waldbränden haben. Diese so genannten **Vulnerabilitätsindikatoren** werden in weiterer Folge gewichtet und zu einem Index für die Gefährdung von Gebäuden durch Waldbrand (WVI) zusammengefasst. Dieser kann zur Unterstützung von Entscheidungsprozessen im Bereich des Risikomanagements sowie zu möglichen Klimawandelanpassungsmaßnahmen eingesetzt werden.
Für die Auswahl und Gewichtung dieser Vulnerabilitätsindikatoren benötigen wir Ihre Unterstützung. Die Indikatoren werden in drei Kategorien eingeteilt:

- Umgebung und Waldbestand
- Außenbereich des Gebäudes
- Gebäudemerkmale

Die Indikatoren müssen für jede Kategorie paarweise verglichen werden. Bitte geben Sie Ihre Präferenz in den unten aufgeführten Fragen an. Das Ausfüllen der Umfrage sollte etwa 5-7 Minuten in Anspruch nehmen.

Bei Fragen wenden Sie sich bitte an:
Maria Papathoma-Köhle
maria.papathoma-koehle@boku.ac.at

Bitte geben Sie mit jeweils einer Auswahl (X) an (ST: starke Wichtigkeit, M: mittlere Wichtigkeit, S: schwache Wichtigkeit, G: gleich Wichtigkeit), welcher der zwei möglichen Indikatoren die Vulnerabilität eines Gebäudes stärker beeinflusst.

1. Umgebung und Waldbestand

WICHTIGKEIT								
	Stark	Mittel	Schwach	Gleich	Schwach	Mittler	Stark	
Gebäudedichte	☐	☐	☐	☐	☐	☐	☐	Distanz zu Nachbargebäude
Gebäudedichte	☐	☐	☐	☐	☐	☐	☐	Wasserquellen
Gebäudedichte	☐	☐	☐	☐	☐	☐	☐	Mischungsform Vegetation (einzeln Bäume, geschlossene Bestand)
Gebäudedichte	☐	☐	☐	☐	☐	☐	☐	Waldart (Nadel, Laub usw.)
Gebäudedichte	☐	☐	☐	☐	☐	☐	☐	Schutzstreifen od. Brandschneisen im angrenzenden Wald
Distanz zu Nachbargebäude	☐	☐	☐	☐	☐	☐	☐	Wasserquellen
Distanz zu Nachbargebäude	☐	☐	☐	☐	☐	☐	☐	Mischungsform Vegetation (einzeln Bäume, geschlossene Bestand)
Distanz zu Nachbargebäude	☐	☐	☐	☐	☐	☐	☐	Waldart (Nadel, Laub usw.)
Distanz zu Nachbargebäude	☐	☐	☐	☐	☐	☐	☐	Schutzstreifen od. Brandschneisen im angrenzenden Wald
Wasserquellen	☐	☐	☐	☐	☐	☐	☐	Mischungsform Vegetation (einzeln Bäume, geschlossene Bestand)
Wasserquellen	☐	☐	☐	☐	☐	☐	☐	Waldart (Nadel, Laub usw.)
Wasserquellen	☐	☐	☐	☐	☐	☐	☐	Schutzstreifen od. Brandschneisen im angrenzenden Wald
Mischungsform Vegetation (einzeln Bäume, geschlossene Bestand)	☐	☐	☐	☐	☐	☐	☐	Waldart (Nadel, Laub usw.)
Mischungsform Vegetation (einzeln Bäume, geschlossene Bestand)	☐	☐	☐	☐	☐	☐	☐	Schutzstreifen od. Brandschneisen im angrenzenden Wald
Waldart (Nadel, Laub, etc.)	☐	☐	☐	☐	☐	☐	☐	Schutzstreifen od. Brandschneisen im angrenzenden Wald

2. Außenbereich des Gebäudes

WICHTIGKEIT								
	Stark	Mittel	Schwach	Gleich	Schwach	Mittel	Stark	
Brennbare Materialien (Totholz) und Gegenstände (z.B. Gartenmöbel)	☐	☐	☐	☐	☐	☐	☐	Bodenbelag
Brennbare Materialien (Totholz) und Gegenstände (z.B. Gartenmöbel)	☐	☐	☐	☐	☐	☐	☐	Grundstückbegrenzung (Material)
Brennbare Materialien (Totholz) und Gegenstände (z.B. Gartenmöbel)	☐	☐	☐	☐	☐	☐	☐	Geländeneigung
Brennbare Materialien (Totholz) und Gegenstände (z.B. Gartenmöbel)	☐	☐	☐	☐	☐	☐	☐	Art der Vegetation auf dem Grundstück
Brennbare Materialien (Totholz) und Gegenstände (z.B. Gartenmöbel)	☐	☐	☐	☐	☐	☐	☐	Distanz der Baumkronen/ Vegetation zum Gebäude (berührend oder überhängend)
Brennbare Materialien (Totholz) und Gegenstände (z.B. Gartenmöbel)	☐	☐	☐	☐	☐	☐	☐	Distanz zu Waldrand
Bodenbelag	☐	☐	☐	☐	☐	☐	☐	Grundstückbegrenzung (Material)
Bodenbelag	☐	☐	☐	☐	☐	☐	☐	Geländeneigung
Bodenbelag	☐	☐	☐	☐	☐	☐	☐	Art der Vegetation auf dem Grundstück
Bodenbelag	☐	☐	☐	☐	☐	☐	☐	Distanz der Baumkronen/ Vegetation zum Gebäude (berührend oder überhängend)
Bodenbelag	☐	☐	☐	☐	☐	☐	☐	Distanz zu Waldrand
Grundstückbegrenzung (Material)	☐	☐	☐	☐	☐	☐	☐	Geländeneigung

Grundstückbegrenzung (Material)	☐	☐	☐	☐	☐	☐	☐	Art der Vegetation auf dem Grundstück
Grundstückbegrenzung (Material)	☐	☐	☐	☐	☐	☐	☐	Distanz der Baumkronen/ Vegetation zum Gebäude (berührend oder überhängend)
Grundstückbegrenzung (Material)	☐	☐	☐	☐	☐	☐	☐	Distanz zu Waldrand
Geländeneigung	☐	☐	☐	☐	☐	☐	☐	Art der Vegetation auf dem Grundstück
Geländeneigung	☐	☐	☐	☐	☐	☐	☐	Distanz der Baumkronen/ Vegetation zum Gebäude (berührend oder überhängend)
Geländeneigung	☐	☐	☐	☐	☐	☐	☐	Distanz zu Waldrand
Art der Vegetation auf dem Grundstück	☐	☐	☐	☐	☐	☐	☐	Distanz der Baumkronen/ Vegetation zum Gebäude (berührend oder überhängend)
Art der Vegetation auf dem Grundstück	☐	☐	☐	☐	☐	☐	☐	Distanz zu Waldrand
Distanz der Baumkronen/ Vegetation zum Gebäude (berührend oder überhängend)	☐	☐	☐	☐	☐	☐	☐	Distanz zu Waldrand

3. Gebäudemerkmale

WICHTIGKEIT								
	Stark	Mittel	Schwach	Gleich	Schwach	Mittel	Stark	
Anzahl Stockwerke	☐	☐	☐	☐	☐	☐	☐	Bausubstanz
Anzahl Stockwerke	☐	☐	☐	☐	☐	☐	☐	Fassade/Verkleidung
Anzahl Stockwerke	☐	☐	☐	☐	☐	☐	☐	Dachmaterial

Anzahl Stockwerke	☐	☐	☐	☐	☐	☐	☐	Dachform (Komplexität)
Anzahl Stockwerke	☐	☐	☐	☐	☐	☐	☐	Dachüberstand
Anzahl Stockwerke	☐	☐	☐	☐	☐	☐	☐	Fensterläden/Rolläden
Anzahl Stockwerke	☐	☐	☐	☐	☐	☐	☐	Tür-/Fenstermaterial
Bausubstanz	☐	☐	☐	☐	☐	☐	☐	Fassade/Verkleidung
Bausubstanz	☐	☐	☐	☐	☐	☐	☐	Dachmaterial
Bausubstanz	☐	☐	☐	☐	☐	☐	☐	Dachform (Komplexität)
Bausubstanz	☐	☐	☐	☐	☐	☐	☐	Dachüberstand
Bausubstanz	☐	☐	☐	☐	☐	☐	☐	Fensterläden/Rolläden
Bausubstanz	☐	☐	☐	☐	☐	☐	☐	Tür-/Fenstermaterial
Fassade/Verkleidung	☐	☐	☐	☐	☐	☐	☐	Dachmaterial
Fassade/Verkleidung	☐	☐	☐	☐	☐	☐	☐	Dachform (Komplexität)
Fassade/Verkleidung	☐	☐	☐	☐	☐	☐	☐	Dachüberstand
Fassade/Verkleidung	☐	☐	☐	☐	☐	☐	☐	Fensterläden/Rolläden
Fassade/Verkleidung	☐	☐	☐	☐	☐	☐	☐	Tür-/Fenstermaterial
Dachmaterial	☐	☐	☐	☐	☐	☐	☐	Dachform (Komplexität)
Dachmaterial	☐	☐	☐	☐	☐	☐	☐	Dachüberstand
Dachmaterial	☐	☐	☐	☐	☐	☐	☐	Fensterläden/Rolläden
Dachmaterial	☐	☐	☐	☐	☐	☐	☐	Tür-/Fenstermaterial
Dachform (Komplexität)	☐	☐	☐	☐	☐	☐	☐	Dachüberstand
Dachform (Komplexität)	☐	☐	☐	☐	☐	☐	☐	Fensterläden/Rolläden
Dachform (Komplexität)	☐	☐	☐	☐	☐	☐	☐	Tür-/Fenstermaterial
Dachüberstand	☐	☐	☐	☐	☐	☐	☐	Fensterläden/Rolläden
Dachüberstand	☐	☐	☐	☐	☐	☐	☐	Tür-/Fenstermaterial
Fensterläden/Rolläden	☐	☐	☐	☐	☐	☐	☐	Tür-/Fenstermaterial

OFFENE FRAGEN

1. Gibt es Ihrer Meinung nach Indikatoren in den obigen Tabellen, die bei der Berechnung des Gefährdungsindexes nicht berücksichtigt werden sollten?

2. Gibt es Ihrer Meinung nach zusätzliche Indikatoren, die berücksichtigt werden müssen?

A WildfireVunerability Index for Buildings in Austria

QUESTIONNAIRE

Dear Experts,

PHLoX is a StartClim project (funded by an Austrian climate research intiative) that focuses on the development of a **physical vulnerability index for buildings** located in the WUI (Wildland Urban Interface) that are subject to wildfire. Building characteristics and features of the building surroundings that have a significant influence on the extent of the damage caused by forest fires, the so-called **vulnerability indicators,** have been selected through literature review. These indicators will be weighed using expert judgment and the Analytic Hierarchy Process (AHP) and aggregated into a wildfire vulnerability index (WVI) for buildings. This index may support decision-making processes in the field of risk management as well as possible climate change adaptation measures.
We would appreciate your assistance in weighing these selected vulnerability indicators. The indicators are divided into three categories:

- Surrounding environment and nearby forest
- Exterior of the building
- Building features

The indicators must be compared **pairwise** for each category. Please indicate your preference in the questions below. The survey should take approximately 5 minutes to complete.

If you have any questions please contact:
Dr. Maria Papathoma-Köhle
maria.papathoma-koehle@boku.ac.at

We thank you in advance for your effort and time.

INSTRUCTIONS: Please indicate with one choice (X) for each pair (strong, moderate, slight, and equal importance) which of the two possible indicators (left or right) has a stronger impact on the vulnerability of a building to wildfire. Please consider also the two open questions in the last page.

1. **Surrounding environment and nearby forest**

IMPORTANCE								
	strong	moderate	slight	equal	slight	moderate	strong	
Building density								Distance to neighbouring buildings
Building density								Watersources
Building density								Vegetation density (single trees, closed forest stand)
Building density								Forest type (Coniferous, etc.)
Building density								Protective strips or firebreaks in the adjacent forest
Distance to the neighbouring building								Watersources
Distance to the neighbouring building								Vegetation density (single trees, closed forest stand)
Distance to the neighbouring building								Forest type (Coniferous, etc.)
Distance to the neighbouring building								Protective strips or firebreaks in the adjacent forest
Watersources								Vegetation density (single trees, closed forest stand)
Watersources								Forest type (Coniferous, etc.)
Watersources								Protective strips or firebreaks in the adjacent forest
Vegetation density (single trees, closed forest stand)								Forest type (Coniferous, etc.)
Vegetation density (single trees, closed forest stand)								Protective strips or firebreaks in the adjacent forest
Forest type (Coniferous, etc.)								Protective strips or firebreaks in the adjacent forest

2. Immediate surroundings of the building

IMPORTANCE								
	strong	moderate	slight	equal	slight	moderate	strong	
Combustible materials and objects (dead wood, garden furniture)	☐	☐	☐	☐	☐	☐	☐	Ground covering
Combustible materials and objects (dead wood, garden furniture)	☐	☐	☐	☐	☐	☐	☐	Property boundary (material)
Combustible materials and objects (dead wood, garden furniture)	☐	☐	☐	☐	☐	☐	☐	Terrain slope
Combustible materials and objects (dead wood, garden furniture)	☐	☐	☐	☐	☐	☐	☐	Type of vegetation in the property
Combustible materials and objects (dead wood, garden furniture)	☐	☐	☐	☐	☐	☐	☐	Distance of tree crones/vegetation from the building (touching or overhanging)
Combustible materials and objects (dead wood, garden furniture)	☐	☐	☐	☐	☐	☐	☐	Distance to forest edge
Ground covering	☐	☐	☐	☐	☐	☐	☐	Property boundary (material)
Ground covering	☐	☐	☐	☐	☐	☐	☐	Terrain slope
Ground covering	☐	☐	☐	☐	☐	☐	☐	Type of vegetation in the property
Ground covering	☐	☐	☐	☐	☐	☐	☐	Distance of tree crones/vegetation from the building (touching or overhanging
Ground covering	☐	☐	☐	☐	☐	☐	☐	Distance to forest edge
Property boundary (material)	☐	☐	☐	☐	☐	☐	☐	Terrain slope

Property boundary (material)	☐	☐	☐	☐	☐	☐	☐	Type of vegetation in the property
Property boundary (material)	☐	☐	☐	☐	☐	☐	☐	Distance of tree crones/vegetation from the building (touching or overhanging)
Property boundary (material)	☐	☐	☐	☐	☐	☐	☐	Distance to forest edge
Terrain slope	☐	☐	☐	☐	☐	☐	☐	Type of vegetation in the property
Terrain slope	☐	☐	☐	☐	☐	☐	☐	Distance of tree crones/vegetation from the building (touching or overhanging)
Terrain slope	☐	☐	☐	☐	☐	☐	☐	Distance to forest edge
Type of vegetation in the property	☐	☐	☐	☐	☐	☐	☐	Distance of tree crones/vegetation from the building (touching or overhanging)
Type of vegetation in the property	☐	☐	☐	☐	☐	☐	☐	Distance to forest edge
Distance of tree crones/vegetation from the building (touching or overhanging)	☐	☐	☐	☐	☐	☐	☐	Distance to forest edge

3. Building Characteristics

IMPORTANCE								
	strong	moderate	slight	equal	slight	moderate	strong	
Number of floors	☐	☐	☐	☐	☐	☐	☐	Building material
Number of floors	☐	☐	☐	☐	☐	☐	☐	Facade/Cladding
Number of floors	☐	☐	☐	☐	☐	☐	☐	Roof material

Number of floors	☐	☐	☐	☐	☐	☐	☐	Roof shape (complexity)
Number of floors	☐	☐	☐	☐	☐	☐	☐	Roof overhang
Number of floors	☐	☐	☐	☐	☐	☐	☐	Shutters/roller blinds
Number of floors	☐	☐	☐	☐	☐	☐	☐	Door/window material
Building material	☐	☐	☐	☐	☐	☐	☐	Facade/Cladding
Building material	☐	☐	☐	☐	☐	☐	☐	Roof material
Building material	☐	☐	☐	☐	☐	☐	☐	Roof shape (complexity)
Building material	☐	☐	☐	☐	☐	☐	☐	Roof overhang
Building material	☐	☐	☐	☐	☐	☐	☐	Shutters/roller blinds
Building material	☐	☐	☐	☐	☐	☐	☐	Door/window material
Facade/Cladding	☐	☐	☐	☐	☐	☐	☐	Roof material
Facade/Cladding	☐	☐	☐	☐	☐	☐	☐	Roof shape (complexity)
Facade/Cladding	☐	☐	☐	☐	☐	☐	☐	Roof overhang
Facade/Cladding	☐	☐	☐	☐	☐	☐	☐	Shutters/roller blinds
Facade/Cladding	☐	☐	☐	☐	☐	☐	☐	Door/window material
Roof material	☐	☐	☐	☐	☐	☐	☐	Roof shape (complexity)
Roof material	☐	☐	☐	☐	☐	☐	☐	Roof overhang
Roof material	☐	☐	☐	☐	☐	☐	☐	Shutters/roller blinds
Roof material	☐	☐	☐	☐	☐	☐	☐	Door/window material
Roof shape (complexity)	☐	☐	☐	☐	☐	☐	☐	Roof overhang
Roof shape (complexity)	☐	☐	☐	☐	☐	☐	☐	Shutters/roller blinds
Roof shape (complexity)	☐	☐	☐	☐	☐	☐	☐	Door/window material
Roof overhang	☐	☐	☐	☐	☐	☐	☐	Shutters/roller blinds
Roof overhang	☐	☐	☐	☐	☐	☐	☐	Door/window material
Shutters/roller blinds	☐	☐	☐	☐	☐	☐	☐	Door/window material

OPEN QUESTIONS:

1. In your opinion, are there indicators in the above questionnaire that **should not be considered** in the development of a wildfire vulnerability index for buildings?

2. In your opinion, should we consider **additional indicators** and if yes, which ones?

H-11 Anhang II

GLOSSARY FOR THE SELECTED INDICATORS

The indicators have been selected following a thorough international literature review of papers focusing on the vulnerability of buildings to wildfire, and the description of damage patterns.

1. **Surrounding environment and nearby forest** (information related to the settlement the building is located in and the adjacent forest)

Building density: the building density of the settlement where the building is located in.
Distance to neighbouring building: distance to the closest neighbouring building
Water sources: natural (e.g. stream) or man-made (e.g., fire hydrant) water sources in the vicinity of the building
Vegetation density: the form of the nearby forest (single trees, groups of trees, dense forest)
Forest type: dominant type of trees in the forest (coniferous, deciduous, or even specific species like pines, firs, etc.)
Protective strips or firebreaks in the adjacent forest: the existence of these features in the nearby forest.

2. **Immediate surroundings of the building**

Combustible materials: natural (e.g., dead wood) and objects (e.g. garden furniture) in the property/surrounding garden).
Ground covering: what is the covering of the ground in the land plot where the building is located (e.g., bare ground/soil, dry grass, man-made, etc.)
Property boundary: the material of the surrounding wall or fence of the land plot if any (wood, brick, stone, or no boundary).
Terrain slope: the slope angle of the land plot where the building is located.
Type of vegetation on the property: type of vegetation surrounding the building within the property (e.g. pot plants, bushes, trees). (Not necessarily the type of vegetation of the adjacent forest)
Distance of tree crowns/vegetation from the building: are the surrounding trees adjacent to the building? Do the crowns touch the building or are they overhanging?
Distance to the forest edge: how far the house is located from the adjacent forest.

3. **Building Characteristics** (information related to the building itself)

Number of floors: ground floor or multiple floors
Building material: The dominant material of the building (e.g., brick, concrete, stone, wood)
Facade / Cladding: the existence of additional material for cladding on the facade of the building may be combustible and may increase its vulnerability to wildfire
Roof material: The material of the roof (wood, brick, metal, etc.)
Roof shape (complexity): the shape of the roof (flat, arched, etc.) and/or the complexity of this shape.
Roof overhang: The length of the roof overhang (the part of the roof that hangs over the walls) may help the fire spread from a lower level to the roof of the building.
Shutters/(external) roller blinds: the existence of these features on the building.
Door/window material: material of the window frames and doors (wood, plastic, metal).