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EVADING DANGER: THE CRISIS IMPACT FRAMEWORK FOR REAL ESTATE

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Abstract. With continuing urbanisation, real estate (RE) has become increasingly important in crisis management. The field of crisis research is still fragmented, especially in the RE context and focuses on the retrospective analysis of single crisis events. This qualitative, futures studies-based paper aims to build a more holistic, foresight-driven understanding of how diverse crises affect RE. It identifies 128 possible future crises from a societal perspective and adopts a novel method in the field, the Futures Wheel, to collect the views of 179 practicing and academic experts via 58 multidisciplinary workshops to analyse the impacts of the identified crises. From this analysis emerged the Crisis Impact Framework for Real Estate, which includes 23 impact themes that synthesise the variety of direct and indirect crisis impacts on RE's hard elements (e.g. the physical condition of materials) and soft elements (e.g. economic value changes). This study contributes an integrated and foresight-driven perspective to the existing research literature. The framework can assist RE market participants in preparing and assessing critical elements of RE before, during and after crisis impacts have manifested and can help spatial planners, investors and RE managers to reflect in a more multidimensional manner on their vulnerabilities and crisis preparedness.

Keywords: real estate, built environment, crisis, crisis management, risk management, resilience, urban resilience.

Introduction

In an urbanising and increasingly complex and uncertain world (Heinonen et al., 2017), the built environment (BE) and real estate (RE) play growing roles in crisis management and resilience development (e.g. Haigh & Amarantunga, 2010; Pelsmakers, 2021). RE is noted to consist of interconnected hard elements (e.g. land and physical space) and soft elements (e.g., institutions, governance, and values) (Hassler & Kohler, 2014; Dyer et al., 2019). Thus, through this multidimensional nature, RE is affected by diverse forces of change (Kiviahio & Toivonen, 2023) and is tightly connected to society, embracing significant economic, social and physical assets and supporting the functioning of utilities, governance, living, services and well-being (Eichholtz & Kok, 2012; Rashidfarokhi & Danivska, 2023). This can be seen for example as notable crises, such as 9/11, the 2008 financial crisis, the Russian invasion of Ukraine and the Covid-19, have shown that RE can play a significant role in both creating crises and coping with them (Mouratidis & Yiannakou, 2022; Toivonen et al., 2023). In this complex, interconnected set-

ting, preparing for future crises is highly challenging for RE market participants.

Scholars have shown that RE is exposed to different types of crisis, but the field of crisis research is still fragmented, especially in the context of RE. Crises are often narrowly identified based on prioritization on probabilities or severity of impacts (Wolbers et al., 2021), which can exclude seemingly distant, but potentially relevant phenomena. Crisis studies also often focus on case studies (Wolbers et al., 2021) or a single type of event, such as natural disasters escalating from natural hazards (Forzieri et al., 2018). Such analysis retrospectively emphasises crises' primary impacts without acknowledging the broader consequences (Saunders & Kilvington, 2016), which makes it challenging to understand the comprehensive nature of crises and to account holistically for those phenomena and their possible direct and indirect impacts when considering the planning, use and management of space and land. Indeed, there seems to be little understanding of multidimensional direct and indirect crisis impacts, which may not be fully considered in risk and crisis management plans and assessments (cf. Eisenberg, 2016;

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Pelsmakers, 2021). RE market participants need to make decisions with complex, far-reaching economic, social, political, technological, environmental, cultural and legal impacts (Kaklauskas et al., 2013; Toivonen, 2021; Toivonen & Viitanen, 2015), making it fundamentally contradictory to take a myopic, unilateral approach to risk and crisis management. Overall, a more holistic understanding of crisis impacts is needed to develop resilience in the BE (Hassler & Kohler, 2014; Rashidfarokhi & Danivska, 2023) against known and unknown crises, and achieving this requires a new methodology and a multidisciplinary approach (see Bundy et al., 2017; Wolbers et al., 2021).

To meet this need, this paper offers an integrated, foresight-driven understanding of how diverse crises affect RE. To achieve this aim, the paper first comprehensively identifies possible future crises from different societal domains instead of focusing on a specific sector such as RE to avoid overlooking potentially relevant crisis impacts. Also the study acknowledges the future horizon, broadly including many vastly different crises known from the history as well as crises not yet experienced. The impacts of these crises are identified by 179 experts through 58 multidisciplinary workshops employing the Futures Wheel (FW) method, a novel approach in crisis research that originated in the field of futures studies. Finally, the crises' impacts are further analysed to identify how they affect the diverse concrete dimensions of RE, including both hard (material) and soft (non-material) elements, resulting in the Crisis Impact Framework for Real Estate. This holistic synthesis contributes to the existing RE crisis literature by offering a novel, foresight-driven and comprehensive multidisciplinary perspective that deepens understanding of the crisis impacts relevant to the various domains of RE. The framework can also be used as a tool for practical risk, vulnerability and crisis impact assessments before, during and after crisis impacts materialise.

The article is structured as follows. First, it draws on the extant literature to examine the concept of crisis and the existing understanding of crisis impacts on RE. Next, the study design is elaborated, and then the article presents the empirical results regarding possible future crises and the themes of their impacts on RE. Thirdly, the value of the results is discussed, followed by considerations of the study's limitations and contributions. Lastly, concluding remarks are offered with considerations for possible future research.

1. Theoretical setting

This section draws on the existing crisis and BE-related literature to explore conceptualisations of crises and the scope of research on crises' impacts on RE. These matters lay the foundation for the empirical part of the study.

1.1. On concept and emergence of crises

To analyse crisis impacts, crises should be first conceptualized and identified. Crises are difficult to define as specific

phenomena, but in essence they are seen as complex, disruptive and decisive phenomena that embrace considerable uncertainty, time pressure and institutional/functional overload (Blondin & Boin, 2020; Rosenthal et al., 2001). The broadness of this definition means it can be applied to very different types of phenomena (Boin, 2004). Furthermore, crises are often transboundary in nature, crossing geographical and sectoral borders and making their origin difficult to locate (Blondin & Boin, 2020). However, diverse crises can share characteristics on the basis of, for example, the societal domain from which they emerge, and one approach to identifying and structuring them based on variety is the political, economic, social, technological, legal, environmental (PESTLE) framework.

For instance, political crises may be direct confrontations or emerge from various institutional fractures and power struggles in society. They encompass developments ranging from armed conflict (Baumann & Kuemmerle, 2016) and state collapse (Yannis, 2002) to terrorist attacks (Chernick, 2005). Economic crises, by contrast, emerge from market failures and dysfunctions of the economic system, embracing occurrences such as the 2008 financial crisis (Holgersen, 2014; Tulumello et al., 2020), the European debt crisis (Hui & Chan, 2013) and various market bubbles and shocks (Brzezicka & Wisniewski, 2021). Social crises develop through demographic dynamics and exogenous disruptions (e.g. armed conflicts), escalating as segregation, gentrification (Howell, 2016; Unceta et al., 2020), and housing crises (Lima, 2021). Even though pandemics are often labelled as health crises, they are noted also as social crises as they can highlight and amplify social inequalities (Haase, 2020). Technological crises are somewhat more tangible phenomena, comprising human-induced hazards such as chemical disasters (Dhara & Dhara, 1995), nuclear accidents (Steinhauser et al., 2014) and major traffic accidents (Smiley, 1990). Legal crises can be seen as more specific in nature, reflecting failures in legal frameworks. They involve matters such as dysfunctional building regulations (Fakunle et al., 2020) and distrust in the criminal justice system (Van Damme & Pauwels, 2012). Lastly, environmental crises emerge from natural systems as natural hazards such as floods (Brody et al., 2008), earthquakes (Lara-Pulido et al., 2022), wildfires (Mockrin et al., 2020) and climate change-related disruptions (Al-Humaiqani & Al-Ghamdi, 2022). They can be also human-induced phenomena such as extensive soil erosion (e.g., Pimentel, 2006).

The recent polycrisis-encompassing Covid-19, the Russian invasion of Ukraine, major inflation, rising interest rates and an energy crisis—demonstrates the multifaceted and transboundary nature of crises. Therefore, multi-hazard studies have become crucial to understanding the impacts of concurrent crises. Earlier instances include the study of earthquakes and tsunamis by Bonacho and Oliveira (2018) and that of floods and wildfires by Athukorala et al. (2016). Pescaroli et al. (2018) also note the interconnectivity and cascading effects of crises, whereby

one crisis can amplify others. This is particularly relevant in interconnected urban systems (Al-Humaiqani & Al-Ghamdi, 2022; Serre & Heinzle, 2018), including RE, which may trigger secondary crises if their resilience fails (Pelsmakers et al., 2021).

1.2. On crisis impacts on real estate

Crises can impact RE in various ways. One approach to examining crisis impacts is to divide RE into hard and soft elements. These are symbiotic and overlap each other but still have fundamental distinctions. Hard elements comprise land areas, the physical space (internal and external) and fabric of buildings and the physical systems that enable governance, business, living, working and provision of utilities (e.g. transport, waste management and energy). The soft elements are more ambiguous, but, according to Hassler and Kohler (2014) and Dyer et al. (2019), they include the institutions, rules, governance, networks, knowledge and diverse values within RE. In this paper, the soft elements also embrace RE market dynamics, participants and their social and economic interactions (cf. Hurlimann et al., 2022). Soft elements may include interest rates, knowledge and expertise, mortgage availability, tenants' solvency, community dynamics, market data availability and building regulation (see Bailey et al., 2018; Brzezicka & Wiśniewski, 2021; Theurillat et al., 2015; Wisniewski et al., 2021). The literature shows that crisis impacts on RE are multidimensional and that, in actuality, crises often affect both the hard and soft elements of RE. There is no widely acknowledged framework to categorise crisis impacts on RE in more specific terms, and impact analyses often focus on material and economic impacts. For consistency, however, this literature review structures crisis impacts on RE according to the PESTLE framework.

To begin with political impacts, these include disruptive changes in the institutional framework of the RE market. For example, Warren-Myers and Hurlimann (2022) note that climate change mitigation action includes many policies (e.g. new taxes) to, for example, reduce greenhouse gas emissions in the RE sector. Studies by Gabellini (2014) and Rossi (2015) (as cited in Ponzini, 2016) show that crises can cause significant policy reforms in urban planning, leading to, for example, the selling of public RE assets and the retrofitting of old building stock. Next, economic impacts include the effects of crisis on both the investment value and use value of RE. For instance, material damage can lower the value of RE due to poor condition, but, after the direct physical destruction, there may also be significant economic impacts on RE market participants through debris removal and infrastructure restoration (Lindell, 2013). Furthermore, studies on seismic risks highlight that even the possibility of earthquake impacts housing values (Keskin et al., 2017; Lara-Pulido et al., 2022). According to Baen (2003), in addition to the immediate impacts, the 9/11 terrorist attacks had longer-term consequence for RE via higher operating costs due to additional security and insurance requirements in case of further attacks. Social

impacts can vary greatly, but a central impact is evolving supply-demand dynamics. For example, Wolday and Böcker (2023) found empirical evidence that Covid-19 heightened urban dwellers' demand for amenities, such as outdoor assets (e.g. gardens and balconies), as well as for motility by car and public transport. In addition, Baumann and Kuemmerle (2016) note that armed conflicts can have far-reaching social impacts (e.g. through refugee migration) that also change supply-demand dynamics. Regarding technological impacts, these embrace, for example, toxic construction materials (Gulzar et al., 2022) and property technology malfunctions, such as disruptions to energy systems (Al-Humaiqani & A-Ghamdi, 2022). Legal impacts may include, for example, new building regulations resulting from climate change policies (Sanders & Phillipson, 2010). Finally, environmental impacts are more tangible in nature, including e.g., the damage and loss of buildings, structures, materials, infrastructures and land (e.g. Al-Humaiqani & Al-Ghamdi, 2022; Warren-Myers & Hurlimann, 2022). For example, Al-Humaiqani and Al-Ghamdi (2022) associate climate change impacts with the deterioration of building materials, and Baumann and Kuemmerle (2016) show that armed conflicts can cause major environmental impacts through, for example, deforestation and changes in land use planning.

The extant studies show that diverse kinds of phenomena can become crises that impact RE in various direct and indirect ways, bringing serious consequences to RE market participants and society. This underscores the need for a comprehensive analysis of crisis impacts on RE. However, the current research landscape is fragmented, lacking a holistic, forward-looking approach to identifying crisis impacts on both hard and soft RE elements. Consequently, this paper proposes an integrated, foresight-driven framework to systematically capture the complexity of crises and their impacts on RE.

2. Study design

The present multidisciplinary study combines futures studies, RE and crisis management research. It employs a qualitative, exploratory, futures studies-based approach to create "What if?" speculation (see van Ittersum et al., 1998) by identifying possible future crisis phenomena and their potential impacts. A central objective was to include not only probable or historical crises but also ones not yet experienced so as to identify RE's future role in relation to these crises. This holistic perspective was preferred over the typical probability-based reductionist approach that prevails in risk assessments and crisis management as future cannot be known and probability-based assessment may overlook potentially high-impact and still possible crisis phenomena (cf. Wolbers et al., 2021). This paper focuses on forming more universal impact themes which can be contextualized further in academia and practice. Previously, a futures studies-based approach has been deemed suitable for RE studies due to its flexibility, ability

Table 1. The research process: objectives, results and methods

	Step 1	Step 2	Step 3
Objectives	To comprehensively identify possible future crisis phenomena across societal domains	To identify direct and indirect impacts of all 128 identified possible future crises	To synthesise joint themes for the crisis impacts on RE
Results	128 identified possible future crises	128 FWs that identify primary, secondary and tertiary impacts on RE	1) 23 crisis impact themes 2) two impact theme categories: hard and soft elements
Methods	Literature review, expert questionnaire	58 multidisciplinary FW workshop sessions with 179 experts	Qualitative content analysis

to detect causal development paths and the fitness of its multidisciplinary nature in addressing complex issues (Riekkinen et al., 2016; Toivonen, 2021; Toivonen et al., 2021; Toivonen & Viitanen, 2016). In addition, a futures studies approach has been taken in crisis studies by, for example, the School of International Futures (2021), Daffara (2020), Cannonier et al. (2021) (who studied the impacts of Covid-19), Heinonen and Ruotsalainen (2011), and Hosseinihah and Zarrabi (2021) (who employed futures studies in natural hazard research).

The present study's research process (as shown in Table 1) comprised the following three steps: (1) comprehensively identifying possible future crises through a literature review and expert questionnaire, (2) identifying the possible crisis impacts in FW workshops and (3) analysing the crisis impacts in the RE context through qualitative content analysis. The following paragraphs describe in detail the methodology and study steps.

2.1. Methodology

The FW is the main method used in this study. As shown in Figure 1, the FW is a visual brainstorming method fundamentally designed to identify direct as well as indirect impacts of diverse phenomena and forces of change (Daffara, 2020; Glenn, 2009), thus aligning with the aim of this

study. The FW was also considered appropriate for this study due to its ability to stimulate nonlinear and collective thinking and divert the mind from simplistic, linear patterns, thus facilitating the detection of unforeseen implications of change that are difficult to perceive (Benckendorff, 2008; Bengston, 2016). In addition, indirect impacts often remain unrecognised, despite their importance to strategic planning (Daffara, 2020; Glenn, 2009) and relevance to RE, which has been recognised to play a crucial role in preventing secondary crises (Pelsmakers et al., 2021). According to Keskin et al. (2017), impact analyses of crises such as natural hazards on the RE market lean towards hedonic regression modelling and its variants. These work well when aiming to identify, for example, the impacts of well-known individual risks on housing prices. However, when considering the comprehensive impacts on diverse dimensions of RE of vastly different types of crisis (from sudden earthquakes to slowly rising rates of depression in populations), it becomes particularly challenging to obtain adequate variables, parameters and observations, especially in cases of yet-to-be-experienced hypothetical future crises. In addition, this study's multidisciplinary approach required the inclusion of a broad range of expertise, so the FW method was deemed suitable due to its usability and clear visualisation. The FW expert groups were designed to include at least one expert specialising

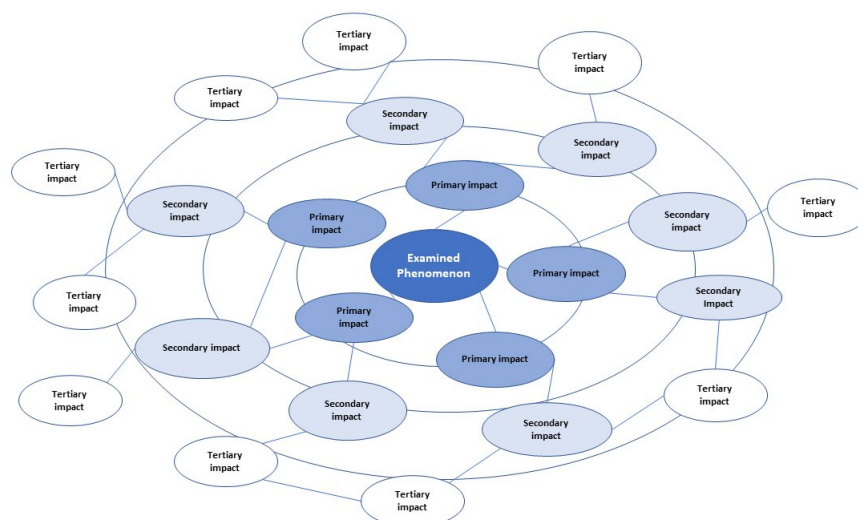


Figure 1. A FW template used in the study

in the discussed crisis's subject field (e.g. religious extremism, cyber warfare or seismic hazards) and at least one expert with knowledge of the RE context (e.g. architecture or RE economics). All the FWs were also examined by other experts in different fields (e.g. economics, natural sciences and emergency services) to build a more holistic and multidisciplinary view.

2.2. Study steps

Step 1: Comprehensive identification of possible future crises

Possible future crises were identified in two phases: (1) a literature review and (2) an expert questionnaire. Altogether, these identified 128 crises (Appendix A). The literature review was undertaken to systematically examine phenomena identified as possible crises on the basis of crisis conceptualisations in the literature (e.g. Blondin & Boin, 2020; Boin, 2019; Rosenthal et al., 2001). Crises were examined from a societal perspective, i.e., not limiting the investigation into a specific field or sector such as real estate or economy to include diverse and possibly previously overlooked phenomena, which indirect impacts could be relevant. It was conducted from December 2020 through January 2021 and examined 249 sources, including news articles, scientific journal articles and global risk reports, with an emphasis on 21st- and late 20th-century publications. To include possible crises with no existing and concrete instances, science fiction and fictional movies and books were also examined. The aim was to collect a comprehensive, diverse set of crises known from history but also including unconventional ideas (cf. Bostrom, 2019). To make the review more comprehensive, crises were sought using diverse keyword combinations to cover society's political, economic, social, health, cultural, technological, legal and environmental domains. The first phase produced 115 identified crises. The expert questionnaire was conducted from March 2021 through April 2021 as a part of a larger survey research. This phase included a multidisciplinary group of 54 experts (Appendix B) in the fields of, for example, astrophysics, economics, engineering, international politics, medicine, military sciences and sociology. The rationale was to include ample field-specific and multidisciplinary knowledge and perspectives to identify additional crises. Altogether, 324 experts were contacted by phone and/or email, yielding a final participation rate of 17%. Possible reason for a low participation rate was an extensive nature of the questionnaire as the identification was only a minor part of a whole. This phase added 13 crises to the list.

A detailed analysis of the identified crises is beyond the scope of this study, and the crises' role is to build the foundation of the following research steps. It was observed that the 128 identified possible future crises vary in nature in many ways. First, they embrace all the PESTLE categories. Second, they can emerge at the individual, meso (i.e. organisational) and macro levels (see Boin, 2019). Also, their epicentres (cf. Drennan et al., 2014) can be both

within and external to the RE market environment (e.g. a biological terrorist attack at city hall vs. a volcanic eruption 100 km from the city).

Step 2: Identification of the crises' possible impacts

The FW approach was used to study the impacts of the 128 crises identified in Step 1. The FWs were created in multidisciplinary workshops with 179 Finnish and international academic and practical experts from a broad range of fields (see Appendix C), including experts on, for example, architecture, civil engineering, emergency and rescue services, futures studies, international relations, land use planning, law, macroeconomics, medicine, meteorology, military tactics, nuclear safety, RE economics and sociology. The criteria for selecting experts were to include multidisciplinary expertise and to have substance knowledge for diverse crises as well as generalist understanding. Prospective experts were sought through university homepages, on the basis of their authorship of research papers and through the study authors' researcher networks, after which they were contacted by email or phone. The initial number of contacted experts was 324, yielding a 55% participation rate. Finally, the 179 experts were divided into 58 multidisciplinary groups that took part in workshops organised as Zoom sessions in March and April of 2021.

During the workshop sessions, the experts were divided into facilitated groups consisting of approximately five experts on average to study and discuss the possible impacts of two to three distinct crises and to collaboratively build the FW. When drawing the FW (see Figure 2), the studied phenomenon (i.e. a case crisis) was placed in the centre of the wheel (the white text on dark blue background in Figure 2). The origin of the crisis was not stated, and the analysis started from the crisis's commencement (i.e. acute phase) to identify impacts as comprehensively as possible rather than focusing on a fixed scenario. The case crisis's impacts were then identified, analysed and organised visually based on their identified causal relationships. First, the group identified direct primary impacts resulting from the crisis's escalation (black text on dark blue background in Figure 2). Next, the members discussed how these direct impacts could develop further and identified secondary impacts (black text on light blue background) and tertiary impacts (black text on white background). The impacts included trajectories known from history as well as unexperienced yet possible ones (based on reasoning of the experts' combined understanding). Some indirect impacts were seemingly unrelated to the initial crises but were identified based on causalities, and it was important to take them into account to support a more comprehensive and holistic analysis. The connector lines in the FW (shown in blue in Figure 2) show relationships, but the order of events was not important for the analysis, as the aim was to identify as many potential impacts as possible regardless of their sequence. In addition, some impacts were already identified as impacts on hard elements (bubbles with red borders in Figure 2), and others were

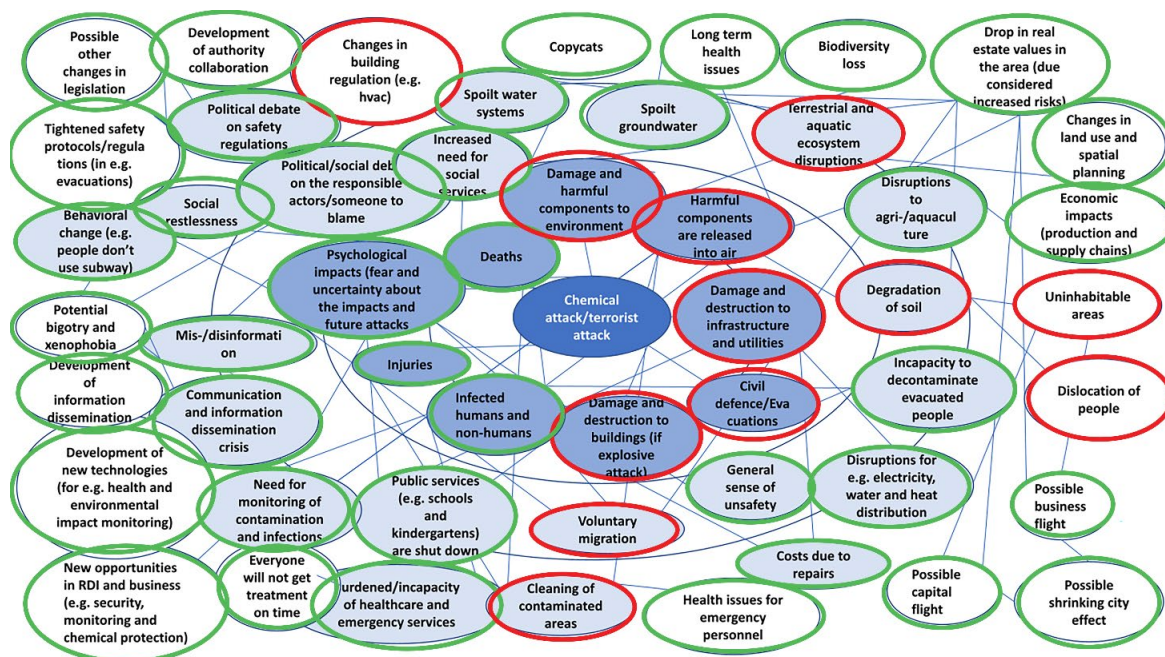


Figure 2. An example of a filled Futures Wheel from the expert workshops¹

identified as impacts on soft elements (bubbles with green borders). At this step, however, the division was only indicative and, in some cases, for example, physical damage to people (i.e. injuries and deaths), even though a physical impact, there is an impact on soft elements from the RE perspective, as it implies an impact on RE users rather than impacts on hard elements of BE. Hence, the more deliberate analysis of the elements was conducted in the next step. During the session, the facilitator recorded the discussion and documented it on the FW template. After the wheels were created, they were circulated to another group of experts to complement and validate the contents of the wheels to more comprehensively identify impacts.

Step 3: Analysis of the crisis impacts

This step involved further analysing the crisis impacts identified in Step 2 to identify the various impact dimensions in relation to RE (Figure 3). First, the researchers examined all 128 built FW templates and listened to the recordings. During this process, all the impacts were compiled on a single document. Recurring themes were inductively identified from all the documented impacts on the basis of their common denominators (e.g. “damage

and destruction of buildings”; “changes in building regulations”) and were synthesised into themes based on the core element from the RE perspective (e.g. physical condition and requirements). Ultimately, 23 crisis impact themes were identified to describe general crisis themes. Step 2’s division of the impacts according to hard or soft elements was deliberately fine-tuned on the basis of theoretical considerations (as presented in section 1.2. of this paper), and, during the analysis, the impact themes were divided into two main impact categories: (1) impacts on hard elements and (2) impacts on soft elements. No additional explicit categorisation such as PESTLE was used to avoid parallel structures and extensive complexity, but PESTLE was a built-in feature in the categorisation employed, i.e. PESTLE-oriented impacts can be applied through the categorization used in this study. All the crisis impact themes are described in detail in the next section.

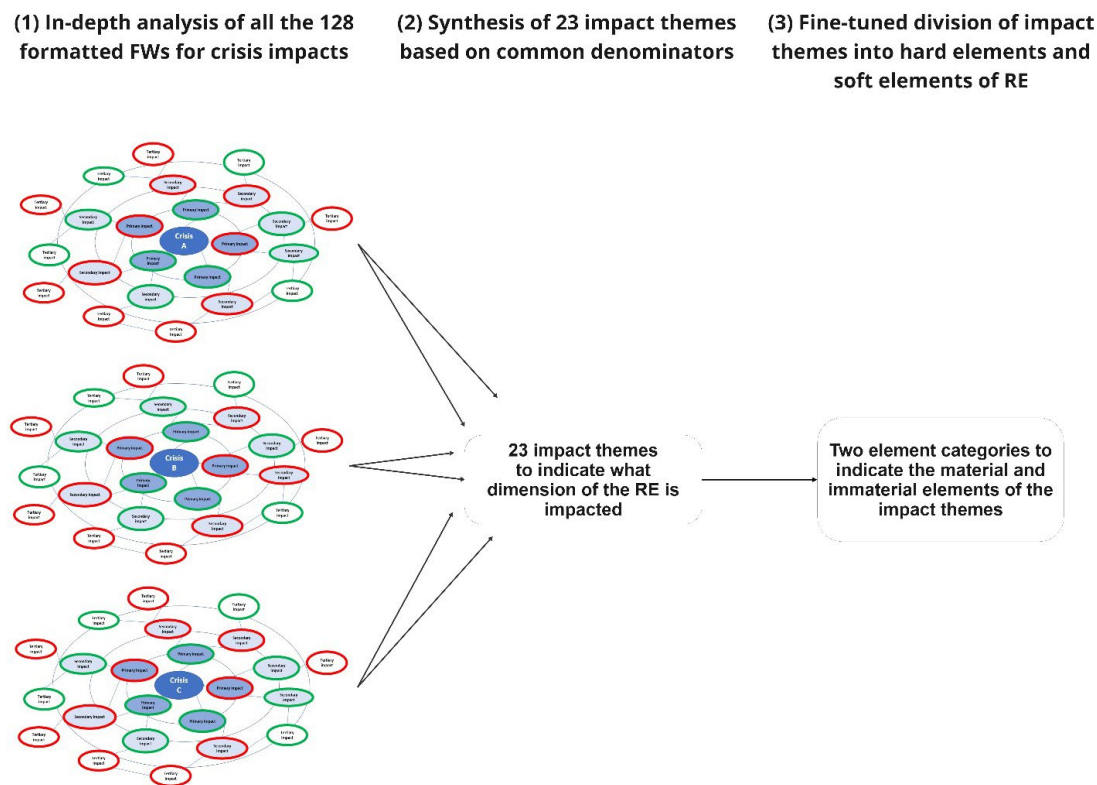
3. Results

The results of this study emerged from the three steps presented in the study design of this paper. The identified possible future crises are provided in Appendix A and served as the basis for identifying the crises’ impacts. The result of the impact analysis is a synthesis of 23 crisis impacts presented as the Crisis Impact Framework for Real Estate (henceforth “Impact Framework”), which holistically shows the variety of RE-related crisis impacts on hard and soft elements of RE.

3.1. Crisis impacts on real estate

The impacts of the 128 identified crises (Appendix A) were examined in FW workshops with 179 experts, which yielded 23 crisis impact themes including both material

¹ The case crisis is in the centre (white text on dark blue background). The first round of bubbles (black text on dark blue) shows the primary level impacts, while the second round of bubbles (black text on light blue) indicates secondary level impacts. The third round of bubbles (black text on white) show the tertiary and, in some cases (e.g. Possible shrinking city effect), quaternary level impacts. The blue connecting lines indicate causal relations (predominantly going from primary to secondary level and so on, although these are sometimes difficult to determine). Initially identified hard elements are bordered in red and examples of soft elements in green.



and non-material impacts (Tables 2 and 3, respectively; Appendix D provides the combined list). Based on categorisations by, for example, Dyer et al. (2019), Hassler and Kohler (2014) and Hürlimann et al. (2022), the themes are divided into two symbiotic groups: (1) hard elements (the fabric and interior of buildings, land areas, physical structures and support systems, such as wires, plumbing and servers related to utilities, governance, services, business, work and living) and (2) soft elements (institutions, rules, governance, networks, knowledge, RE market dynamics, social and economic interactions and diverse values within RE). The impacts vary from minor disruptions to systemic collapses and may occur rapidly or develop slowly over time. The following two sections elaborate the characteristics of the Impact Framework. The framework does not rank impacts by importance, as that depends on the user and the objectives of the user.

3.2. Crisis impacts on hard elements of real estate

The 14 impact themes in the hard elements concern changes to material reality (i.e. the condition of buildings, materials and structures), the supply of physical space and the functioning of RE systems, such as energy, waste management and transport. In concrete terms, this category

includes material damage of all kinds, whether the sudden destruction or collapse of buildings and infrastructure or slowly deteriorating material conditions due to, for example, contamination, extreme weather or lack of maintenance. However, this category assumes that the physical infrastructure can incur changes for other reasons than direct physical damage. For example, changes in the soft elements (e.g. changing regulation or lack of know-how for information and communications technology [ICT] systems maintenance) can cause obsolescence and major changes in the functionality of hard elements. The supply, distribution and demand for space and land embraces the need for and availability of the physical space provided throughout the RE market as well as how much of it is needed and is provided for various purposes and in various neighbourhoods. This can change due to various sudden or creeping crises and their impacts (e.g. discriminatory spatial planning practices or contamination of the soil reducing availability or a sudden influx of refugees causing an abrupt need for shelter). Notably, the crisis literature often bundles critical infrastructure as a single entity, but this study divides it into various subsystems due to the major differences in functionality, utility and services they provide to various actors. The rationale for dividing the various infrastructures (food, waste, water, etc.) is that each has specific types of facilities, equipment, technology, etc., so they are not included only in the supply and distribution of space, which, in this research, refers to the quantity (distribution of square meters per area) and quality (e.g. of-fices, housing or green spaces) of physical space and land.

² The alphabetical indicators (Crisis A, B, C) serve to show that Step 1 included all 128 crisis scenarios but with no hierarchical relationships suggested. All the impacts identified in Step 2 were divided into hard and soft elements during the analysis.

Table 2. Crisis impact themes related to hard elements of real estate

	Impact themes
H1	Physical condition and requirements
Description	Changes to structural and material condition as well to established requirements (e.g. for tensile strength) for buildings and infrastructure
Examples	A missile destroys a bridge; moisture creates mould and structural weaknesses in a building's structure; a new building regulation establishes stricter requirements for building materials
H2	Supply and distribution of space and land
Description	Changes to the quality and quantity of space and land supply
Examples	Zoning causes segregation; contamination makes areas uninhabitable
H3	Use and demand for space and land
Description	Changes to the quality and quantity of space and land use demand
Examples	A pandemic makes office spaces obsolete; a large-scale influx of refugees creates a sudden need for shelter for thousands of people in a city
H4	Transportation and logistics infrastructure
Description	Changes to the functioning and capacity of the tangible road, rail, waterway and air networks, including cycling and pedestrian modes
Examples	Roads cannot be used due to flooding; warehouse operations cease due to a strike
H5	Information communications technology (ICT) infrastructure
Description	Changes to the functioning and capacity of tangible hardware (e.g. servers), software, networks, data centres, facilities and related equipment
Examples	A property's telecommunications and internet go offline due to a cyberattack; satellite monitoring collapses due to a geomagnetic storm
H6	Energy and heating infrastructure
Description	Changes to the functioning and capacity of the tangible facilities, buildings and equipment providing networks for generating, transmitting and distributing electricity, natural gas, geothermal energy, biomass energy and oil
Examples	A foreign power cuts off the natural gas supply; the current energy infrastructure does not meet new international climate requirements
H7	Solid waste management infrastructure
Description	Changes to the functioning and capacity of the facilities, buildings and equipment providing solid waste collection, transportation, processing, recycling and disposal
Examples	Waste collection vehicles cannot operate due to a lack of fuel; a property's waste collection facilities cannot be used due to pest infestation
H8	Water and wastewater infrastructure
Description	Changes to the functioning and capacity of the tangible facilities, buildings and equipment providing water supply, collection, treatment, storage, resource management, flood prevention and hydropower
Examples	Terrorists contaminate the water reservoir; water pipes freeze due to prolonged cold weather
H9	Food infrastructure
Description	Changes to the functioning and capacity of the tangible facilities, buildings and equipment required for producing, processing, storing, distributing, retailing and consuming food and managing food waste
Examples	Multiple major farms go bankrupt; cold storage facilities fail due to an electricity blackout
H10	Health and emergency infrastructure
Description	Changes to the functioning and capacity of the tangible facilities, buildings and equipment required to deliver health care and emergency services
Examples	A property's alarm systems do not work; a hospitals' equipment is inadequate for a new type of infectious disease
H11	Education, research and innovation infrastructure
Description	Changes to the functioning and capacity of the tangible facilities, buildings and equipment providing learning, research and innovation environments
Examples	Research laboratories and special university facilities are outdated due to a lack of funds; an urban co-creation space is found to have substantial amounts of hazardous materials
H12	Cultural, sports and recreational infrastructure
Description	Changes to the functioning and capacity of the tangible facilities, buildings and equipment providing cultural, sports and recreational environments
Examples	Parks are not accessible due to a curfew; all sports fields are turned into refugee camps

End of Table 1

H13	Economic and manufacturing infrastructure
Description	Changes to the functioning and capacity of the tangible facilities, buildings and equipment that enable economic and financial interaction and the production, manufacturing and processing of goods and services
Examples	An industrial park becomes vacant due to the collapse of a specific industry; a large-scale cyberattack disables multiple banks' critical equipment
H14	Defence and security infrastructure
Description	Changes to the functioning and capacity of the tangible facilities, buildings and equipment necessary for the support, deployment and operation of military and security services
Examples	A newly established government implements facial recognition in public spaces; a digital twin of a city hall is used to plan a terrorist attack

Table 3. Crisis impact themes related to soft elements of real estate

	Impact themes
S1	Formal institutional framework
Description	Changes to the formal institutions shaping the behaviour of individuals and organisations within society, including financial, health care, emergency, security, education and spatial planning services as well as law enforcement
Examples	A military coup changes the government, leading to reform of property rights; corruption and clientelism lead to misconduct and inequality in spatial planning
S2	Informal institutional framework
Description	Changes to the informal institutions shaping the behaviour of individuals and organisations within society, including cultural traditions and practices, social norms and expectations, informal networks and relationships and informal rules in specific settings
Examples	Only a particular religion or ideology is generally accepted in the symbols, colours and architecture of RE; one social group is prohibited from owning land
S3	Safety in space and land use
Description	Changes to the objective and subjective quality and quantity of safe space and land supply
Examples	Extreme weather causes health problems for dwellers in urban environments (the heat island effect); organisations are afraid to establish an office in a city due to news of emerging gang violence
S4	Values of space and land
Description	Changes to the cultural, economic, environmental, social and other values of space and land
Examples	Soil contamination causes local RE market values to drop; urban sprawl damages natural ecosystems and biodiversity
S5	Supply and distribution of utilities, services and amenities
Description	Changes to the quality and quantity of provided utilities, services and amenities
Examples	Office space experience power outage due to a blizzard; a homeowner is unable to get insurance due to rising risk of flooding; urban parks are eliminated due to new construction
S6	Demand for utilities, services and amenities
Description	Changes to needs for utilities, services and amenities in terms of quality and quantity
Examples	A chemical accident causes a sudden need for decontamination; a curfew reduces demand for transportation; a real estate investor needs RE valuation due to identified soil contamination
S7	Research, development and innovation (RDI) capacity
Description	Changes to the quality and quantity of RDI in relation to proptech and land use planning
Examples	Reallocation of investments from RDI leads to outdated smart building technologies; a critical need arises for quicker land use planning processes
S8	Maintenance and repair capacity
Description	Changes to the quality and quantity of maintenance and repair of RE
Examples	Lack of investment creates growing repair debt for a property; the existing know-how does not meet the needs of new technology
S9	Resource use and availability
Description	Changes to the supply and use of adequate material, non-material and human resources
Examples	There is a total depletion of sand for construction; banks are unable to provide loans for RE development; the municipality lacks an adequate number of urban planning personnel

3.3. Crisis impacts on soft elements of real estate

The soft elements are gathered into nine impact themes that emphasise changes in various non-material capacities within RE, such as governance and management, knowledge, networks, and the economic and social interactions, values and needs of RE market participants. These elements can, for example, concern various perceptions of safety related to space (e.g. due to natural hazards, mis-/disinformation or rising threats of armed conflict) or the knowledge to repair a building's energy systems. Crises can also cause a lack of crucial resources, such as mortgages or loans for RE development. This category also includes new regulations, policies and standards, such as curfews and lockdowns, that may reduce demand for office space and increase the need for ICT connections in homes and close-proximity recreational spaces. Additionally, rising interest rates can cause a serious downturn in the RE and construction industries. As mentioned, the soft elements are symbiotic with the hard elements but highly distinctive, so it is necessary to detach them from the hard elements to identify the affected root element in relation to RE. The impact themes in this category can create or amplify crises related to the institutional vulnerabilities of RE and the BE at large through, for example, depreciated repair capacity, lack of crucial skills and know-how and inaccessibility of services and utilities. These can create the risk of breakdowns in complex technical systems (e.g. proptech applications) or hinder coping with and recovery from crises such as pandemics, natural hazards, economic collapses and mental health problems, thus leading to secondary crises.

4. Discussion

4.1. Crisis impacts on real estate

This study aimed to enable a holistic understanding of the variety of distinct crisis impacts on RE. First, 128 possible future crises were identified, and their direct and indirect impacts on the various dimensions of RE were analysed. This informed the development of the Impact Framework establishing the variety of RE-related crisis impacts, including soft and hard elements. The process of identifying possible future crises revealed that, in addition to commonly examined crises, such as natural hazards and financial shocks, vastly different types of phenomena can actualise as crises. Another important insight was that the number of crises was even greater than previously expected. The prevailing crisis research, especially in the RE field, typically focuses retrospectively on one or only a few crises, leading to a situation in which the understanding of resilience covers a limited number of crises. Due to the broad applicability of the concept of crisis, however, numerous phenomena can actualise as crises. This is noted in the literature by, for example, Boin (2004) but still not applied in academic studies or practical crisis management, especially in the RE field.

What is especially surprising is that, despite the high number and major differences among the identified crises, their impacts could be synthesised into a relatively small number of thematic categories. The study identified 14 themes representing crisis impacts on the hard elements of RE and nine themes related to soft elements, the latter describing changes to diverse non-material capacities within RE. Further analysis of the impacts of possible future crises on various dimensions of RE revealed that, in addition to the more obvious impacts on hard elements, the soft elements can play a significant role, which is relevant to future resilience development. In real-life situations, many of the impacts are combinations of various impact themes in both categories. Crises can have direct impacts on either hard or soft elements, and those impacts can develop further. For example, consider the impacts of a chemical attack (see Figure 2 in section 2.2). The direct impacts on hard elements (e.g. a reduction in space supply due to contamination of neighbourhoods) can cause indirect impacts on soft elements (e.g. a decreased supply of amenities, such as green spaces/parks). Consequently, the lack of amenities can lead to changes in supply-demand dynamics and value of nearby RE. With the Impact Framework, these direct and indirect impacts can be pinpointed and in a real-life use case, a detailed, comprehensive analysis would be conducted based on the RE submarket, the characteristics of individual RE, the country and region the analyst wished to understand and the analyst's objectives.

It is also important to consider the implications of various impacts on communities and actors in the field of RE. As noted in the FW workshops, many of the impacts can cause either suffering (exacerbating existing vulnerabilities) or benefits (providing new business opportunities to, for example, facility management security services) depending on the affected party and existing inequalities and power relations. For example, disruptive impacts, such as a sudden need for housing due to an influx of refugees, can cause a lack of adequate space. However, this can create new business for interior designers and architect consultants to meet the need through space development and hybridisation. Decisive systemic collapses, such as critical supply chain breakdowns (a lack of materials or collapsed transportation infrastructure bringing construction to a halt) can also pose challenges, for example, to RE developers. Changes in formal institutions can lead to entirely new urban design, or structural changes in space and land supply standards can lead to severe segregation or ecological destruction. This can result in public figures, such as policy-makers and urban planners, losing their legitimacy (which is a central aspect of crises in the public sector according to Boin, 2019). This, however, can create new opportunities for grassroots movements and "Do it yourself" urbanism. Notably, the impacts are also heavily influenced by the context as well as pre-impact conditions (hazard exposure and physical and social vulnerability) and event-specific conditions (such as hazard characteristics) as well as the prevalent emergency management interventions (Lindell, 2013).

This study comprehensively and holistically examined both crises and their impacts because narrow, sector-focused and probability-based crisis judgements were deemed to present a high risk of failure in light of the highly interconnected, turbulent environment in which we live as expressed in the concepts of the VUCA world (Heinonen et al., 2017), polycrisis (Vannelli & Rossi-Schwarzenbeck, 2022) and permacrisis (Zuleeg et al., 2021). The crisis identification in this study suggests that, in crisis management, actors in the RE market environment should not only consider known historical crisis events, such as Covid-19, Hurricane Katrina, the 2008 financial crisis and 9/11, but also develop a future consciousness (see Toivonen, 2021) and take a more exploratory, “What if?” view of what can materialise as a crisis. This shows the importance of an in-depth environmental analysis of meso- and macro-level political dynamics, technological developments and economic, social, cultural and ecological trajectories. In other words, phenomena that originally may not seem relevant to, for example, land use planning, occupancy choices or investment strategies may, through their indirect impacts, turn out to be critical for RE market actors, such as investors, tenants, developers and the public sector. Hence, RE market participants should consider not only how to adapt to material or economic disruptions but also how to adapt to losing access to various hard and soft elements or to changed institutional standards of the entire operational environment. This leans on a rather orthodox strategic thinking but as related to the core element of RE and what RE means for strategy. To build crisis management and resilience for the crisis impact themes, organisations and decision-makers should consider both non-material and organisational as well as material, spatial and design domains relevant to RE. Both reactive and proactive means should be developed to plan and manage space and land use by responding to infrastructure collapse via, for example, self-sufficiency (local capacity and capability to produce food, water and electricity) or access to alternative physical, augmented and/or virtual spaces.

4.2. Limitations

Although this study's approach supported achieving its aim, some limitations must be considered. First, even though this study aimed at comprehensiveness, it is not possible (or even fruitful) to identify and understand all possible future crises and all their possible impacts (Williams et al., 2017). Furthermore, in the field of futures studies, it is not possible to use empirical evidence from the future, so this research offers only prospective views of possible events and trajectories (see Bell, 2003; Glenn, 2009) to inform contemporary strategic thinking, anticipation and decision-making. However, the goal is to show that there are multiple crises with diverse dimensions of impacts on RE and thus to open new perspectives on crisis management in urban policies, RE market actors' strategic and operational planning, management and urban design. Second, the results are based on the extant literature at the time of the study and the views of the participating

experts in the FW workshops, which affects the results' validity, reliability and generalisability. This is a common element in qualitative studies (Morgan & Drury, 2003). To address these limitations, the literature review included sources from a wide range of platforms and dates, and the FW workshops included a considerable number of experts from various fields and countries. The created FWs were also circulated between diverse expert groups, and investigator triangulation (see Patton, 1999; Robson, 2000) was employed in all the study steps. Another limitation is that this study provides no quantitative results, but this reflects a deliberate decision to take a qualitative approach to descriptively explore and include more open-ended views of crisis impacts (Glenn, 2009). In terms of generalisability, the provided Impact Framework is applicable and modifiable for various contexts. Also, this study is part of a larger multidisciplinary research effort that aims to build foundations and provide more universal results to be concretised and applied in various contexts. It is acknowledged that these applications require additional research and contextualisation for more specific findings.

4.3. Contributions

This study makes several academic and practical contributions to the field of RE and BE research. In terms of academic contribution, the study presents a novel futures studies-based holistic approach and a new method in RE and urban crisis studies: the FW. The results build on the existing literature and provide a synthesising, comprehensive, interdisciplinary and more universal view of which kinds of phenomena may actualise as crises in the future and which dimensions of RE they may affect.

Concerning practice, the results of this study support the communication of systemic risks and crises through a holistic and structured overview of what to consider when developing crisis management and resilience for RE. This study's non-probabilistic, futures studies-based approach includes the impacts of crises with potentially lower probabilities in many contexts, but even though the crisis phenomenon itself may be deemed irrelevant, its hypothetical impacts can benefit resilience and response capacity-building against other crises. This research contributes to urban governance and strategic decision-making by providing structured knowledge to better understand how to divide crisis impacts throughout the complex systems of cities, no matter which kind of crisis occurs. What if an unknown future crisis causes the ICT infrastructure to collapse? What if an office space does not meet the new safety requirements? What if banks cannot provide mortgages? From the identification of impacts, the user can conduct a vulnerability and preparedness analysis to determine the capability to react or adapt to these impacts or to identify the capability to react or adapt to these impacts in case of a future crisis situation. The results can be contextualised for strategic and operational decision-making to concretise the meaning of preparedness in terms of which dimensions of RE must be considered in risk management,

scenario planning and vulnerability detection. Municipal governments, spatial planners, architects, RE investors and developers, construction companies, housing cooperatives, households and non-governmental organizations can all benefit from this study's comprehensive and prospective view of crises and their impacts. Hence, these actors can formulate more future-conscious strategies, crisis scenarios and plans. Understanding the general theme of crisis impacts can help to build more systematic crisis preparedness, help to reflect one's currently prioritized risks and assess the concrete effects of different impact themes, as well as enhance the spatial and organisational capacity for improvisation and creativity. This, in turn, can lay a stronger foundation for countering crises not known or experienced beforehand. In an increasingly complex and uncertain RE market environment, being prepared for the unknown can greatly benefit resilience.

Conclusions

Adopting the FW method, this paper comprehensively identifies many distinct possible future crises and analyses their impacts on RE, benefitting from the insights of 179 academic and practical experts. The results offer a holistic synthesis of the prevalent impact themes among the direct and indirect impacts of 128 identified possible future crises. The study shows that, in addition to commonly examined crises, such as natural hazards and financial shocks, vastly different phenomena can actualise as crises and have multidimensional impacts on the hard and soft elements of RE. These crisis impacts can affect the material dimensions of RE, quantitative and qualitative spatial dynamics as well as the institutions, values, perceptions, resources and diverse maintenance and development capacities of RE. Actors who plan, use and manage RE should build crisis management capacity and resilience throughout the hard and soft elements and view those elements as a whole, understanding that they are interconnected and impact each other. It is important to prioritise the more probable and severe crises and analyse them in depth to efficiently allocate resources. Still, it is impossible to know which kind of crisis will happen in the future. Hence, to be prepared for unknown crises, it is important to understand the prevalent impact themes and build resilience for RE in holistic terms.

The results of this study offer various possibilities for future research. For example, sector-oriented or geographically contextualised studies of the identified crises and their holistic impacts could broaden actors' or the academic field's perspectives. The provided framework could be evaluated or ranked based on criteria on e.g., probability or severity of impact themes in various case studies, and a critical examination of the strategic and operational means to build crisis management and resilience capacity for diverse crises in a holistic manner could contribute to more sustainable space- and land-related policy-making and management in the BE. In addition, explanatory

comparative case studies could yield important insights on different geopolitical, administrative and geographical contexts in terms of how the impact themes could actualise in the existing hard and soft elements and on the kinds of more specific vulnerabilities those contexts embrace.

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Author contributions

Lassi Tähtinen (corresponding author): conceptualization (equal), methodology (equal), investigation (lead), data curation (lead), formal analysis (lead), developing discussion and conclusions (lead), writing – original draft (lead), writing – review or editing of the manuscript (equal). Saija Toivonen: conceptualization (equal), methodology (equal), writing – drafting the initial manuscript (supporting), writing – review or editing of the manuscript (equal). Anahita Rashidfarokhi: investigation (supporting), writing – drafting the initial manuscript (supporting), writing – review or editing of the manuscript (supporting).

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The authors report there are no competing interests to declare.

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Appendix A. The list of identified possible future crisis phenomena

1. War: being attacked by a foreign country	2. War: neighbouring country is attacked by a foreign power
3. Large-scale cyber-attack/terrorist attack	4. Nuclear attack/terrorist attack
5. Chemical attack/terrorist attack	6. Biological attack/terrorist attack
7. Nanotech attack/terrorist attack	8. Extra-terrestrial encounter/attack
9. International resource wars	10. Rising levels of loneliness
11. Majority of the population are elderly	12. Established martial law/state of emergency
13. Reputational crisis	14. No access to healthcare, emergency, and safety services
15. Knowledge of older generations is not transferred to newer ones	16. Famine
17. Increasing numbers of abandoned and shrinking cities, towns, and villages	18. Uncontrolled urban sprawl
19. Rising levels of depression	20. Sudden population decline
21. The international climate cooperation/agreements cease to exist	22. Refugee crisis (large-scale influx)
23. Rapidly rising terrorism	24. Established surveillance society
25. The end of market economy and capitalism	26. The end of globalization and international trade
27. Non-existing/undefined regulation in the built environment context	28. Extreme alienation
29. Extensive digital divide	30. Extreme structural unequal treatment
31. Total loss of personal liberty	32. Extensive suppression of science
33. Extensive slummification	34. Loss of shared values in the society
35. No access to social services and social housing	36. Large-scale misuse of data and information (e.g., data leaks and forged IDs)
37. Sudden population decline	38. Disinformation crisis
39. Established cosmocracy/Non-liberal global federation	40. Rising religious fanaticism
41. Civil war	42. Large scale riots
43. Nuclear accident	44. Nuclear fallout
45. Extreme spatial segregation	46. Abolition of animal rights (large-scale mistreatment)
47. Mass poverty	48. Grand chemical accident
49. State collapse	50. Crisis of democracy
51. Emerging nationalism	52. Extensive internet censorship and surveillance
53. Mistrust towards the legal system	54. The legal system is replaced with an alternative
55. Extensive organized crime and human trafficking	56. Increasing domestic violence
57. Increasing addictions and drug use	58. Rise of authoritarianism
59. Established plutocracy	60. Re-emerging city-states
61. Extra-terrestrial encounter/attack	62. Mass unemployment
63. Housing market bubble/crash	64. Decline of major industries

End of Appendix A

65. Farm crisis (recession of agriculture)	66. Abrupt economic depression
67. Mass bankruptcies	68. Scarcity/depletion of natural resources
69. Data ownership crisis (Oligopolization)	70. Systemic banking crisis
71. Hyperinflation	72. Hyperdeflation
73. Series of strikes/General strike	74. Extensive corruption
75. Fiscal crisis (prolonged state economic deficit)	76. Stock market crash
77. Workforce crisis (skill mismatch)	78. Large-scale cyber-attack on stock market
79. Extensive shadow economy and illicit trade	80. Large-scale cyborgization of the population
81. Toxic, harmful, and unreliable building materials	82. Grand industrial explosion
83. Virtual and augmented realities become the new “normal”	84. Robots replace the human workforce
85. Humans lose control of the artificial intelligence	86. Lack of critical building materials
87. Massive resistance/distrust towards technological development and innovations	88. Technological development is halted
89. No access to fuel	90. No access to domestic transportation logistics
91. No access to global transportation logistics	92. Non-existing transportation infrastructure
93. No access to public transport	94. No access to private transport
95. No access to global passenger transport	96. No access to broadband or telecommunications
97. No access to energy systems (electricity and heat)	98. No access to water resources
99. No access to waste management systems	100. Prolonged drought
101. Extreme temperatures: cold	102. Extreme temperatures: hot
103. Ecological collapse and large-scale biodiversity loss	104. Growing antibiotic resistance
105. Increasing animal, plant, food & water -based diseases	106. Powerful geomagnetic storms
107. Geomagnetic reversal	108. Rising sea level
109. Extensive soil contamination	110. Crowding of near-Earth space (substantial amounts of objects and space debris)
111. Asteroid impact	112. Mass invasion of harmful species
113. Major disruptions in the Gulf Stream	114. Thawing permafrost
115. Fatal pollution levels	116. Powerful blizzards
117. Extensive floods	118. Powerful storms/thunderstorms/cyclones
119. Giant waves/tsunamis	120. Powerful earthquakes
121. Volcanic eruptions	122. Landslides/extensive soil instability
123. Acid rain and extensive air pollution	124. Grand traffic accident
125. Spreading wildfires	126. Built environment firestorm
127. Pandemic	128. Increasing non-communicable diseases

Appendix B. The fields of expertise in the expert questionnaire

Anthropology	Humanitarian logistics
Architecture	International politics
Business management	Law: international, corporate, economic, environment
Cognitive sciences	Military sciences
Construction	Political decision-making
Design	Real estate economics
Facility and environment management	Real estate security and preparedness management
Futures studies and foresight	Strategic management and organization theory
Geography	Sociology
Geoinformatics	Transportation
Geology	Urban physics
Global security and governance	

Appendix C. The disciplines and fields of expertise represented in the Futures Wheels workshops

Discipline/ Field	Built Environment & Engineering (1)	Social Sciences & Law (2)	Natural & Life Sciences (4)	Security & Military Sciences (5)	Other (6)
Sub-field/ areas of expertise	1.1 Architecture & Urban Design 1.2 Real estate and urban economics 1.3 Transportation systems and safety 1.5 Construction & real estate development 1.6 Geoinformatics 1.7 Land use planning 1.8 Civil engineering 1.10 Smart buildings 1.11 Environmental engineering 1.12 Facility management 1.13 Energy systems 1.14 Fire safety engineering 1.15 Sustainability and resilience 1.16 Material engineering	2.1 Sociology 2.2 Anthropology 2.3 Futures studies & foresight 2.4 Economics and finance 2.5 International relations 2.6 Geography 2.7 History 2.8 Global development studies 2.9 Environmental law 2.10 International law 2.11 Corruption and corporate crime 2.12 Poverty & inequality 2.13 Environmental economics 2.14 Religious radicalism 2.15 Political science, social, and economic geography	4.1 Astrophysics 4.2 Chemistry 4.3 Limnology 4.4 Geology 4.5 Biology 4.6 Ecology 4.7 Veterinary 4.8 Nuclear physics 4.9 Oceanography 4.10 Neuroscience 4.11 Meteorology 4.12 Epidemics and zoonotic diseases 4.13 Space weather 4.14 Geophysics and seismology	5.1 Chemical, biological, radiological, and nuclear security, and safety 5.2. Military medicine 5.5 War economics 5.6 Military tactics 5.7 Military history 5.8 Military strategy 5.9 Cyber security 1.10 Food security 5.11 Terrorism 5.12 Nano safety	6.1 Data & computer science 6.2 Nanomaterials 6.3 Emergency & rescue services 6.4 Civil protection 6.6 Law enforcement 6.7 Social and healthcare policy 6.8 Rural policy 6.10 Animal welfare 6.11 Occupational health 6.12 Drug use and drug policy 6.13 Domestic violence

Appendix D. All the identified crisis impact themes on hard and soft elements of RE

	Impact themes
H1	Physical condition and requirements
Description	Changes to structural and material condition as well to established requirements (e.g. for tensile strength) for buildings and infrastructure
Examples	A missile destroys a bridge; moisture creates mould and structural weaknesses in a building's structure; a new building regulation establishes stricter requirements for building materials
H2	Supply and distribution of space and land
Description	Changes to the quality and quantity of space and land supply
Examples	Zoning causes segregation; contamination makes areas uninhabitable
H3	Use and demand for space and land
Description	Changes to the quality and quantity of space and land use demand
Examples	A pandemic makes office spaces obsolete; a large-scale influx of refugees creates a sudden need for shelter for thousands of people in a city
H4	Transportation and logistics infrastructure
Description	Changes to the functioning and capacity of the tangible road, rail, waterway and air networks, including cycling and pedestrian modes
Examples	Roads cannot be used due to flooding; warehouse operations cease due to a strike
H5	Information communications technology (ICT) infrastructure
Description	Changes to the functioning and capacity of tangible hardware (e.g. servers), software, networks, data centres, facilities and related equipment
Examples	A property's telecommunications and internet go offline due to a cyberattack; satellite monitoring collapses due to a geomagnetic storm
H6	Energy and heating infrastructure
Description	Changes to the functioning and capacity of the tangible facilities, buildings and equipment providing networks for generating, transmitting and distributing electricity, natural gas, geothermal energy, biomass energy and oil
Examples	A foreign power cuts off the natural gas supply; the current energy infrastructure does not meet new international climate requirements

Continued of Appendix D

H7	Solid waste management infrastructure
Description	Changes to the functioning and capacity of the facilities, buildings and equipment providing solid waste collection, transportation, processing, recycling and disposal
Examples	Waste collection vehicles cannot operate due to a lack of fuel; a property's waste collection facilities cannot be used due to pest infestation
H8	Water and wastewater infrastructure
Description	Changes to the functioning and capacity of the tangible facilities, buildings and equipment providing water supply, collection, treatment, storage, resource management, flood prevention and hydropower
Examples	Terrorists contaminate the water reservoir; water pipes freeze due to prolonged cold weather
H9	Food infrastructure
Description	Changes to the functioning and capacity of the tangible facilities, buildings and equipment required for producing, processing, storing, distributing, retailing and consuming food and managing food waste
Examples	Multiple major farms go bankrupt; cold storage facilities fail due to an electricity blackout
H10	Health and emergency infrastructure
Description	Changes to the functioning and capacity of the tangible facilities, buildings and equipment required to deliver health care and emergency services
Examples	A property's alarm systems do not work; a hospitals' equipment is inadequate for a new type of infectious disease
H11	Education, research and innovation infrastructure
Description	Changes to the functioning and capacity of the tangible facilities, buildings and equipment providing learning, research and innovation environments
Examples	Research laboratories and special university facilities are outdated due to a lack of funds; an urban co-creation space is found to have substantial amounts of hazardous materials
H12	Cultural, sports and recreational infrastructure
Description	Changes to the functioning and capacity of the tangible facilities, buildings and equipment providing cultural, sports and recreational environments
Examples	Parks are not accessible due to a curfew; all sports fields are turned into refugee camps
H13	Economic and manufacturing infrastructure
Description	Changes to the functioning and capacity of the tangible facilities, buildings and equipment that enable economic and financial interaction and the production, manufacturing and processing of goods and services
Examples	An industrial park becomes vacant due to the collapse of a specific industry; a large-scale cyberattack disables multiple banks' critical equipment
H14	Defence and security infrastructure
Description	Changes to the functioning and capacity of the tangible facilities, buildings and equipment necessary for the support, deployment and operation of military and security services
Examples	A newly established government implements facial recognition in public spaces; a digital twin of a city hall is used to plan a terrorist attack
S1	Formal institutional framework
Description	Changes to the formal institutions shaping the behaviour of individuals and organisations within society, including financial, health care, emergency, security, education and spatial planning services as well as law enforcement
Examples	A military coup changes the government, leading to reform of property rights; corruption and clientelism lead to misconduct and inequality in spatial planning
S2	Informal institutional framework
Description	Changes to the informal institutions shaping the behaviour of individuals and organisations within society, including cultural traditions and practices, social norms and expectations, informal networks and relationships and informal rules in specific settings
Examples	Only a particular religion or ideology is generally accepted in the symbols, colours and architecture of RE; one social group is prohibited from owning land
S3	Safety in space and land use
Description	Changes to the objective and subjective quality and quantity of safe space and land supply
Examples	Extreme weather causes health problems for dwellers in urban environments (the heat island effect); organisations are afraid to establish an office in a city due to news of emerging gang violence

End of Appendix D

S4	Values of space and land
Description	Changes to the social, economic, cultural, environmental and other values of space and land
Examples	Soil contamination causes local RE market values to drop; urban sprawl damages natural ecosystems and biodiversity
S5	Supply and distribution of utilities, services and amenities
Description	Changes to the quality and quantity of provided utilities, services and amenities
Examples	Hospitals are not able to treat patients due to an inadequate workforce; urban parks are eliminated due to new construction
S6	Demand for utilities, services and amenities
Description	Changes to needs for utilities, services and amenities in terms of quality and quantity
Examples	A chemical accident causes a sudden need for decontamination; a curfew reduces demand for transportation
S7	Research, development and innovation (RDI) capacity
Description	Changes to the quality and quantity of RDI in relation to proptech and land use planning
Examples	Reallocation of investments from RDI leads to outdated smart building technologies; a critical need arises for quicker land use planning processes
S8	Maintenance and repair capacity
Description	Changes to the quality and quantity of maintenance and repair of RE
Examples	Lack of investment creates growing repair debt for a property; the existing know-how does not meet the needs of new technology
S9	Resource use and availability
Description	Changes to the supply and use of adequate material, non-material and human resources
Examples	There is a total depletion of sand for construction; banks are unable to provide loans for RE development; the municipality lacks an adequate number of urban planning personnel