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Resilience in the built environment: Key characteristics for solutions to multiple crises

Raúl Castaño-Rosa^{a,*}, Sofie Pelsmakers^a, Heini Järventausta^a, Jenni Poutanen^a, Lassi Tähtinen^b, Anahita Rashidfarokhi^b, Saija Toivonen^b

^a Sustainable Housing Design Research Group (ASUTUT), Faculty of Built Environment, Tampere University, Finland ^b Real Estate Research Group (REG), Department of Built Environment, Aalto University, Finland

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ABSTRACT

In the last decade, our built environment has been exposed to a significant and wide range of crises, from primary (e.g., pandemic, climate change-induced hazards) to secondary crises, such as their associated physical and mental health impacts. However, previous literature has mainly focused on the impacts of a single type of crisis in the built environment and solutions for individual impacts. Hence, in the face of multiple crises and their impacts that we are facing now, understanding the possible solutions and their characteristics is crucial to achieve a more resilient built environment. This paper aims to gain a better understanding about how different crises impact the built environment and which solutions have been proven effective, particularly as a response to multiple crises. First, a systematic literature review is presented, identifying main crises impacts on the built environment and solutions were established. Findings highlight that the main solutions that provide resilience to multiple crises in the built environment, are (1) green and healthy infrastructures; (2) adaptable infrastructures; and (3) equitable and inclusive infrastructures. Finally, key characteristics for the design of resilient solutions for the built environment are discussed and an evaluation framework is proposed.

1. Introduction

Our society and hence built environment has been exposed to a wide range of crises, from primary (e.g., pandemic, climate change-induced hazards) to secondary crises, such as their associated physical and mental health impacts. As our interconnected societies continuously develop, the possible crises grow in numbers and their multitude of diverse impacts also become more complex and interconnected (Boin & Lagadec, 2000; Quarantelli et al., 2007). In terms of the built environment, Tähtinen et al. (n.d.) underline that this myriad of crises can impact on real estate space, and land use in various material and immaterial ways, affecting human and non-human life and other agents (e.g., assets and resources). These impacts can affect citizens' health and wellbeing, cause the collapse of physical structures, decrease the functionality of infrastructures, decrease real estate values, cause social or political conflicts, and create uninhabitable environments. These are referred to as crisis impacts, which are either an extensive, rapid or permanent change (or a combination of them) in the built environment

(Tähtinen et al., n.d.).

Multidimensional crisis impacts refers to the different causal relationships associated with direct and indirect consequences, e.g., natural hazards can have a direct impact through the loss of buildings while indirectly decreasing market competitiveness (Tähtinen et al., n.d.), and this can create various requirements for the built environment to be resilient to multiple crises. Tähtinen et al. (n.d.) synthesised two types of requirements for resilience to crises: 1) immaterial and organisational preconditions; and 2) material and spatial characteristics and design principles, consisting of reactive and proactive means to plan and manage space and land use. This can be for example local capacity and capability to produce food, water and electricity (i.e., self-sufficiency); or access to alternative physical, augmented and/or virtual spaces (i. e., multi-locality). As the number of crises is rising and their nature is more complex and uncertain, we need to understand how to build more holistic crises resilience in the built environment and through which solutions this can be achieved. Several theoretical frameworks to assess urban resilience in the context of climate risk have been proposed in

* Corresponding author. E-mail address: raul.castanodelarosa@tuni.fi (R. Castaño-Rosa).

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previous research, for instance, Urguiza et al. (2021) developed an urban climate risk assessment through three resilience dimensions: flexibility/persistence to adjust to disturbances, memory and learning to maintain services in response to the disturbances, and self-transformation/governance to adapt and anticipate to potential future disturbances. Summers et al. (2017) suggest the climate resilience screening index (CRSI), a conceptual model to assess urban climate resilience combining 28 indicators within 11 domains: (1) extant and (2) integrity of the natural environment; (3) infrastructure and (4) structures of the built environment; (5) services, (6) economy and (7) characteristics of society; (8) preparedness and (9) responses of governance; (10) losses and (11) exposure to risks; followed by an improved version, the natural hazard resilience screening index (NaHRSI), for natural hazard resilience (Summers et al., 2018). Good governance and social capital are emphasised by Lak et al. (2020), who propose urban design principles for resilience. Shafiei Dastjerdi et al. (2021), through a spatial resilience approach, highlighting the need of combining form and structure, environment and behaviour, and image and meaning to promote resilience. Finally, Al-Humaigani & Al-Ghamdi (2022) reviews the most common resilient qualities to climate change impact mitigation, suggesting the need for a holistic approach through a combination of different assessments, resilient characteristics and qualities.

Vulnerability assessments have also been proposed, for instance, Mercader-Moyano et al. (2021) developed an interdisciplinary index-methodology to assess vulnerable areas based on four dimensions: building, urban, environment and social. Malloy & Ashcraft (2020) present an advocacy coalition framework (ACF) to support the implementation of climate measures without jeopardising social justice. Similarly, Brunetta et al. (2019) propose a transversal approach with new forms of multi-level governance, enhancing equity, participation and social inclusion. In summary, the existing frameworks discussed above highlight preparedness, agility, participatory, restorative, adaptability, and robustness as key attributes for resilience in an urban built environment. Moreover, several organisations have also developed their national strategies for resilience following some of those theoretical frameworks. For example, The Plan for a Strong and Just City in New York (OneNYC, 2015); the Athens Resilience Strategy for 2030 (Municipality of Athens, 2019); the Resilient Boston Plan (City of Boston, 2017); the First National Adaptation Plan for Climate Change in the Republic of South Sudan (South Sudan Ministry of Environment and Forestry, 2021); the Recovery and Resilience Plan in Finland (Finnish Government Helsinki, 2021); The Hague Resilience Strategy (Team, 2019); and the National Adaptation Plan in Nepal (Government of Nepal, 2021). The main limitation of these existing frameworks is that they mainly focus on urban climate and social resilience without considering multidimensional crises impacts (because they aim to address single crisis impacts related to past events), which makes it difficult for actors at different levels to implement resilient solutions to multiple crises impacts related to the six attributes above.

When developing holistic solutions towards the resilience of the built environment, the current nature of crises needs to be understood. According to previous literature, crises are acknowledged as elusive phenomena that include a great deal of urgency, uncertainty, and risks for systemic negative consequences (Blondin & Boin, 2020; Lalonde & Roux-Dufort, 2012). Crises can emerge in various spatial-temporal scales (Rosenthal et al., 2001) and be highly interconnected with each other, having diverse causal relationships (Mitroff et al., 2004). In addition, crises can have different probability and significance based on various factors, such as the geopolitical, historical, socio-cultural, or institutional context (Al-Dahash et al., 2016; Lalonde & Roux-Dufort, 2012; van der Vegt et al., 2015). Thereby, crisis impacts mean either an extensive, rapid or permanent change (or a combination of them) in the built environment (Tähtinen et al. (n.d.)) which depend on the transformative and disruptive characteristics of crises (Blondin & Boin, 2020). This means that the systemic and complex nature of crises and their impacts need to be acknowledged when building an understanding

of which solutions can have applicability for a more holistic resilience.

The concept of resilience has been studied across different disciplines since the early 1900s, however, studying the concept in the built environment is scarce (Galderisi et al., 2020), and there is not a common definition of built environment resilience. In this study, the concept of *resilience in the built environment* is understood as "the ability of any urban system, with its inhabitants, to maintain continuity through all shocks and stresses, while positively adapting and transforming toward sustainability" (UN-Habitat, 2022). In effect, *resilient solutions to multiple crises impacts* are here understood as the solid built infrastructure (physical systems, the buildings' fabric), non-material built infrastructures (governance, institutions, legislation), and the community characteristics (values, culture, knowledge, common interests, collective actions) that help citizens mitigate the impact of specific crises and disruptions while empowering and strengthening them during the recovery process (Cerè et al., 2017; Hassler & Kohler, 2014).

Previous literature has mainly focused on the impacts of a single type of crisis on the built environment, providing typically only solutions for individual impacts and usually in a reactive way, i.e., related to past events (e.g., flood management). However, there is little understanding of resilient responses to *multiple crises in the built environment*. Hence, the aim of this study is to gain a better understanding about how different crises impact on the built environment and what solutions have been proven effective, especially as a response to multiple crises. As such, this paper focuses on the research question 'which built environment solutions have the potential to foster resilience to multiple crises, and under which conditions?'

This article is structured as follows: first, we explain the methods used to collect and analyse the data (section 2). Then, in section 3, we present and discuss the findings, highlighting the solutions that provide resilience to multiple crises and their key characteristics for resilience. In addition, an evaluation framework is proposed. This is followed by a concluding summary and reflections for further research.

2. Methods and data analysis

To answer the research question, the research process followed in this study was divided into three stages (see Fig. 1). First, a systematic literature review was conducted, identifying main crisis impacts on the built environment and their solutions. Secondly, through a qualitative content analysis, the results from the literature review (i.e., the crisis impacts and solutions identified) were categorised and their main interconnections established. Finally, in stage 3, key characteristics for a resilient built environment were investigated and an evaluation framework proposed.

2.1. Systematic literature review

A systematic literature review of peer-reviewed studies was performed following (Xiao & Watson, 2017). A systematic literature review enables to collect evidence of specific questions, summarise existing knowledge and provide a coherent synthesis of the findings through a clearly defined and accountable protocol (Gough et al., 2017). This provided evidence that covered broadly the crises impacts on the built environment and their existing solutions. The systematic literature review consisted of three steps: (1) searching for articles according to the defined research plan; (2) screening of the sample by using inclusion and exclusion criteria; and (3) reviewing the final sample.

Fig. 2 below depicts graphically the literature review methodology defined for this study. The source of data used was Web of Science, guaranteeing peer-reviewed material. The search was based on the fixed term "built environment" combined with the terms "climate crisis", "housing crisis", "pandemic crisis", "financial crisis", "demographic crisis", and "digital crisis". These six crisis terms were the result from clustering 128 crises for Real Estate, Space and Land Use as identified by Tähtinen et al. (n.d.). The term 'crisis' was used to consider the



Fig. 2. Literature review methodology.

spatial-temporal and socio-functional dimensions of the crisis impacts (i. e., space characteristics and perception from different actors). The search was targeted toward the *title, abstract* and *keywords*, resulting in 1808 papers; the number of papers per crisis is shown in Fig. 2. After removing duplicate results, the sample consisted of 1183 papers. To screen the first sample of peer-reviewed publications, a set of inclusion and exclusion criteria was defined. First, all searches were limited to English, Spanish, and the Finnish language as these were the languages of the research team, and peer-reviewed articles that were published in the last 10 years, to reflect the most recent crises and built environment impacts and responses, resulting in 399 papers. Then, two new criteria (C) below were applied after reading the abstract:

C1: The crisis impacts presented in the article do not relate to the built environment.

C2: There is not a clear definition of crisis impacts in the built environment and associated potential solutions.

Therefore, the final sample of articles included in this study consisted of 122 peer-reviewed articles in English (no papers in Spanish or Finnish were found with the stipulated search criteria). Due to the time frame of the papers included in this study (2011–2021) and the above inclusion and exclusion criteria, the selection of articles might not be necessarily exhaustive. A limitation of this study is that only a few papers were included for the financial, demographic and digital crises as relevant to

the built environment.

2.2. Qualitative content analysis

The qualitative content analysis method defined by Schreier (2012) was used in this study because this presents a useful approach for the analysis of a large amount of data, while enabling categorisation and identification of interconnections between the identified crisis impacts and solutions. In this respect, five main categories were defined for the analysis: 1) Scope of the study; 2) Crisis impacts investigated in the study; 3) Solutions defined per crisis impact; 4) Actors affected by the crisis impacts; and 5) Actors involved in the solution definition and implementation. This analysis was undertaken by two researchers who analysed the same material independently to ensure the validity of the analysis and the categorisation described above (Groat & Wang, 2002). The qualitative content analysis (following the theory-guided qualitative content analysis (Tuomi Jouni & Sarajärvi Anneli, 2009)) consisted of the following three steps: 1.) independent analysis of the five defined categories by two researchers; 2.) defining of categorises and their interconnections through an iterative 10-step process (of both collaborative and individual reflection); and 3.) key characteristics were mirrored against multi-level perspectives (i.e., macro, meso and micro levels (Geels, 2004)).

3. Results and discussion

Reviewed studies were mostly conducted globally (n=83), specifically those studies that investigated climate and pandemic crises. Studies on the demographic crisis were mainly based in Japan, Greece, Canada, the USA and Russia. Central Asia and the UK were the main sources for the digital crisis, and Central and Southern Europe and the USA provided the main publications for the financial and housing crises. The fact that most of the studies included for analysis focused on the climate and pandemic crises highlighted that most of the crisis impacts to the built environment were associated with climate change-induced hazards, and the COVID-19 pandemic situation experienced since

2020. Literature on the crisis impacts in the built environment related to the digital crisis was still limited, however, it is expected to increase in the future due to the fast digital transition that society has experienced in the last decade, with a radical digitalisation move in the last two years due to the COVID-19 pandemic (Papadonikolaki et al., 2022). A total of 48 crisis impacts were identified in the reviewed literature, along with 114 solutions, which were grouped into 19 solution groups through the qualitative content analysis as described earlier.

3.1. Crisis impacts on the built environment

48 crisis impacts on the built environment were identified from the literature review. Fig. 3 shows the six main crises analysed in this study (i.e., climate, pandemic, digital, demographic, housing, and financial) and the associated impacts, in pink and red colour respectively. The overlapping among the different crises and impacts shows their interconnections; the more interconnections, the larger the severity of the impacts. This is shown in Fig. 3 through the size of crisis impact bubbles.

Based on the number of reviewed articles, the climate crisis, can be considered the main crisis impacting the built environment (Ajjur & Al-Ghamdi, 2021); this crisis is defined as the consequences of the use of fossil fuels and natural resources on the planet, i.e., nature out of balance (World Health Organization (WHO), 2022; Ajjur & Al-Ghamdi, 2021). The impacts found included heavy snowfall and rain, flooding, droughts (Forootan et al., 2017), extreme temperatures, increased heat-island effect and CO2 emissions and, consequently, increased pollution (Kolvir et al., 2020) - see Fig. 3 (top-left side). Other listed impacts from the climate crises included biodiversity loss (Knapp et al., 2021), affecting building functions (e.g., poor environmental air quality, high energy demand and, consequently, risk of frequent blackouts) (Andrić et al., 2019) and food security (Singh, 2012). Natural hazards were also mentioned as being triggered by the climate crisis, e.g., glaciers melting that alter the Earth's crust and its pressure affects the frequency and intensity of earthquakes (Boukri et al., 2018), wildfires (Robinne et al., 2021), landslides (Picarelli et al., 2021) and others (Duarte et al., 2022). Furthermore, physical and socioeconomic conditions of the urban



Fig. 3. Six main crises analysed in this study (i.e., climate, pandemic, digital, demographic, housing, financial) in pink colour and the associated impacts identified from the literature review in red colour. Note that the different interconnections are shown by the overlapping among the different crises and associated impacts, and where the more interconnections, the larger the severity of the impacts; which is depicted by the size of the different bubbles.

environment (i.e., urban configuration, geographic location, governance) were highlighted as influencing the impacts and vulnerability level (Apreda et al., 2019). For example, a low-income population living in buildings with low-thermal performance in high density urban areas that lack access to green spaces are highly exposed to heat-wave impacts (Apreda et al., 2019).

The pandemic crisis, triggered by a new virus that spread globally (Centers for Disease Control and Prevention (CDC), 2016), has had a huge impact on society, from the way people interact, work and live, to the associated post-traumatic symptoms, i.e., stress, depression, anxiety (Saladino et al., 2020). As shown in Fig. 3, when climate and pandemic crises impacts overlap, the effects are intensified, increasing the vulnerability of the built environment further. To illustrate this point, exposure to high levels of pollution (not explicitly related to climate change) were found to be a major threat to public health (D'Accolti et al., 2022), which is intensified in high urban density (Batista e Silva et al., 2020), increasing the incidence of antimicrobial resistant bacteria (Cave et al., 2021). Lockdown-related restrictions made people spend more time at home, affecting their lifestyle, which when combined with poor indoor air quality and low-energy efficiency led to unhealthy indoor environments (Reshetnikov et al., 2021). A period of isolation and quarantine led some of the population, specifically young people, to decrease the regularity of outdoor activities and, on the other hand, to increase the use of digital technologies and social media, leading to a decline in healthy lifestyles (Mitra et al., 2020); regular outdoor activities have been proven to improve mental health in times of pressure, stress, depression (Yogman et al., 2018). Fig. 3 (top-right side), highlights that moving from the physical to the digital environment creates a higher vulnerability to digital threats.

Combining physical, digital and human systems was reported as an effective solution to deliver more energy efficient and pleasant homes (Sovacool & Furszyfer Del Rio, 2020). Similarly, literature highlighted that smart ecosystems, i.e., the integration of smart technology in urban greenery management, can bring unlimited opportunities and benefits to a resilient built environment (Nitoslawski et al., 2019). However, when a digital crisis happens, i.e., evasive phenomena originated by cyber-attacks and the inappropriate use of virtual/digital assets that provokes urgency, uncertainty, and risks for public health and safety (Parn & Edwards, 2019), the reliability and security of smart ecosystems are threatened. This in turn jeopardises the security, safety and well-being of citizens (Parn & Edwards, 2019), and exposes the importance of the continuity of basic public services provision (Hussein, 2019) - see Fig. 3 (top-right side). It was also noted that the design and implementation of digital technologies in the built environment can also impact on citizens' day-to-day activities, increasing the risk of ageism and social exclusion due to the digital division of society (Nagenborg, 2020; Papadonikolaki et al., 2022). This is because many older people do not know how to use e-commerce, e-health services and e-services in general, mainly because they did not have any training or experience on how to make efficient and reliable use of them (Heponiemi et al., 2022). As a result, older people are left behind, facing social exclusion, e.g., they may struggle to buy public transport tickets to socialise and meet with relatives (Mubarak & Suomi, 2022). As shown in Fig. 3, in an ageing society, a combination of digital and pandemic crises may lead to a new scenario of an excluding and unsustainable built environment (Seifert et al., 2021).

The *financial crisis* can be triggered by a broad variety of situations, e. g., significant financial disruptions, global panic, etc., simply defined as a phenomenon where credit volume and asset values decline rapidly (Claessens & Kose, 2013). The reviewed literature highlighted that the global financial crisis in 2007 had economic and political implications in all countries and at all different levels (Claessens & Kose, 2013), with asset bubbles and unemployment being the major consequences (Hashimoto et al., 2020). This in turn led, for example, to cash-rich buyers to take advantage of the market depreciation, mobilising their capital to enter the housing market (Forrest et al., 2017). This

overconsumption of housing and other resources by the super-rich then created an unequal situation where social values were overwhelmed by capital investment (Fernandez et al., 2016), leading to gentrification, societal inequalities and loss of culture and feeling of community (Bilal et al., 2019).

The *housing crisis*, e.g., shortage of affordable housing or the decline in housing quality, was shown to directly impact on social exclusion, triggering the creation of vulnerable areas with low-income households living in energy poverty situations (Karpinska & Śmiech, 2020). Literature showed that financial and housing crises are closely interconnected (see Fig. 3, bottom-right corner), and when overlapping, it may create an unstable economic and housing market (Zwiers et al., 2016). Similarly, high unemployment rates, tenure inequality, and unequal development of urban areas with loss of social diversity were seen to increase the number of people with no place to live (Pongrácz et al., 2021).

These issues were also highlighted as part of the demographic crisis in the reviewed literature. The *demographic crisis*, in this study, refers to significant changes in the long-term growth of the population (Ehmer, 2015). When the financial and demographic crises overlap, the overconsumption and disproportional use of spaces by the few, can lead to empty residential spaces owned by the super-rich, prompting vacant housing and depopulation (Atkinson, 2019). As a result, an excluding and unsustainable urban development (C.-H. Wang & Chen, 2020) can create inaccessible housing for mid- and low-income groups (Gentili & Hoekstra, 2021), raising the risk of homelessness among vulnerable groups (see Housing and Financial crises overlaps in Fig. 3, bottom-right side). Literature highlighted that this anti-social and unsustainable situation in turn can provoke demographic changes such as social, political and cultural polarisation within segregated and excluded areas (Jungkunz, 2021; Lorenzen et al., 2020).

A lack of governance (i.e., a complex and a poorly coordinated policy system) was common among all studied crises impacts in this review and was seen as a common driver of a lack of resilience (see Fig. 3, where lack of governance is placed in the middle). Low-income groups, elderly and immigrants were observed as the most vulnerable groups in the literature (Gentili & Hoekstra, 2021; Gürdür Broo et al., 2021; Hanley et al., 2019; Hashimoto et al., 2020; Janoschka et al., 2019; MacAskill et al., 2021; Mercader-Moyano et al., 2021; Minguez Garcia, 2021; Mitra et al., 2020; Parn & Edwards, 2019; Phipps et al., 2021; Pour-yarmohammadi et al., 2021; Syahrul Nizam Kamaruzzaman Emma Marinie Ahmad Zawawi, Michael Riley, Siti Arni Basir, 2018; Tammaru et al., 2020; Tancogne-Dejean & Laclémence, 2016; Therrien et al., 2020; Worzala, 2021; Zwiers et al., 2016).

3.2. Resilient solutions to multiple crises

As explained above, the built environment is affected by multiple crisis impacts, and often it is unknown when they may occur, whether on their own or in combination, or as illustrated earlier in Fig. 3, when one crisis leads to other crises impacts. Hence, there is a need to investigate and implement solutions that may be applicable to the impacts of multiple crises when developing a resilient built environment. After analysing the interconnections between the 48 crisis impacts (red colour in Fig. 3) and the associated 114 solutions identified from the literature review, 19 solutions groups were defined. Fig. 4 illustrates the 19 solutions groups (in green) overlapping with the 48 crises impacts identified from the literature review grouped in the six main crises analysed in this study (i.e., climate, pandemic, digital, demographic, housing, financial) and graphically depicted in Fig. 3. These solution groups were further clustered into three key strategies for resilient infrastructures in response to multiple crises in the built environment: (1) green and healthy infrastructures; (2) adaptable infrastructures; and (3) equitable and inclusive infrastructures, following the six main resilience attributes defined in existing conceptual frameworks for a resilient urban built environment (i.e., preparedness, agility, participatory, restorative,



Fig. 4. 19 solutions groups (in green) are clustered into the three key solution strategies for resilience to multiple crises in the built environment (green and healthy infrastructure in magenta dotted line, yellow for adaptable infrastructure and dark purple colour for equitable and inclusive infrastructures), overlapping the six main crises and the associated impacts identified from the literature review (pink) and depicted in Fig. 3.

adaptability, and robustness - see section 1, page 3) (Al-Humaiqani & Al-Ghamdi, 2022; Brunetta et al., 2019; Elmqvist et al., 2019; Lak et al., 2020; Malloy & Ashcraft, 2020; Mercader-Moyano et al., 2021; Schreier, 2012; Shafiei Dastjerdi et al., 2021; Summers et al., 2017, 2018; Urquiza et al., 2021). These three key resilient infrastructures, that are interconnected, are described in more detail below and highlighted in Fig. 4, grouping the 19 solution groups.

Green and healthy infrastructure is a common resilient strategy in the reviewed literature to develop more resilient, liveable and resourceefficient cities (Reynolds et al., 2020). This consists of ecosystem restoration, which has emerged as a nature-based solution to mitigate climate change impacts (Bustamante et al., 2019). Solutions in this group aim at reversing the degradation of ecosystems, such as landscapes, lakes, and green areas to regain their ecological functionality (see Fig. 4 (top-left side) for overlaps with crisis impacts). This means improving the productivity and capacity of ecosystems to meet the needs of society, re-stabilising ecosystem services and taking care of all living species within them (Simonson et al., 2021). Urban greenery improvement has also innumerable environmental and socioeconomic benefits (Allen, 2012) in addition to being an effective strategy to design a resilient built environment (Cheng et al., 2021; Reynolds et al., 2020). According to the literature review, solutions consist of providing open-space areas reserved for parks and other "green spaces", including plant life, water features (blue spaces) and other types of natural environment to maximise biodiversity (Di Sacco et al., 2021) and to address biodiversity loss, heat island, extreme weather impacts (see Fig. 4). However, it requires an efficient urban system management, by means of water supply, sanitation, drainage, pollution, and waste management, reducing the exposure to floods (Müller et al., 2011), and avoiding food shortages and waste management issues (Dasgupta & Robinson, 2022). Integrating natural resource-based solutions, i.e., the use of natural resources such as water, flora, fauna, sunlight, etc., and including the use of renewable energy sources such as solar, wind, hydro, geothermal, and tidal, can support resilience in the built environment through energy security (Kabisch et al., 2016) (mitigating the impact of 'disruption and scarcity

in supply' - see Fig. 4, middle-left side). Main solutions from the literature range from green roofs and facades at the building level (Ziogou et al., 2018), space provision for natural surroundings, stormwater runoff systems, urban parks (Loughran, 2018), to biophilia (i.e., connection to the natural world) at the city level (Bayulken et al., 2021). Furthermore, literature highlighted securing water-supply infrastructure (Robinne et al., 2021), watershed restoration (Gooden & Pritzlaff, 2021) and beaver dams (Fairfax & Whittle, 2020) as key natural hazards preparedness solutions to mitigate the impact of all aspects of natural hazards, including atmospheric, hydrological, oceanographic, volcanic, seismic, neo-tectonic and environmental impacts (see Fig. 4, top-left side). Nevertheless, policies, actions and practices that combine both anticipatory and reactive approaches (Birchall & Bonnett, 2021) are needed to promote citizens' trust (i.e., in others, in institutions, and self-confidence) and people's capability to adapt to situations of crises and disruption (Tancogne-Dejean & Laclémence, 2016). The reviewed literature also highlighted the need for urban health measures to ensure health determinants and outcomes in urban areas, i.e., a clean and healthy environment. Most common solutions from the literature are the provision of open spaces with shading and a high ratio of greenery, enabling healthy behaviours (Mitra et al., 2020); access to natural light, visibility, adequate acoustic levels and use of healthy materials were also considered to support well-being (Zarrabi et al., 2021) (see Fig. 4, top area). Also, important for well-being were adaptation-based solutions, community spaces for socialising and bringing people together, friendly transport systems and the use of smart technology in urban management (Ahsan, 2020). Similarly, implementing hygiene measures in the built environment was shown to reduce infection risks and promote healthiness, e.g., adequate solar access in indoor spaces, views to the outside and/or touch free solutions (Franca & Ornstein, 2021); with ventilation, waste and sewage management to ensure good indoor environmental quality (IEQ) (Reshetnikov et al., 2021), social distancing measures (Sun & Zhai, 2020), and operation and maintenance measures were also considered important (Sarvari et al., 2022).

Adaptable infrastructure was another key resilient strategy and is

required to ensure the supply of basic services and society's wellbeing during rapid changes in environmental, societal and energy demand conditions (Chester & Allenby, 2019, 2021; Gilrein et al., 2021). The literature highlighted the need to reuse and rethink existing buildings and materials either for the same, or new purposes, made through circular construction principles, improving existing buildings' characteristics, and extending the life span of buildings and components (Roetzel et al., 2017) (see Fig. 4, middle-left side). Practical solutions are implementing passive strategies such as optimising building orientation and good daylighting, and designing a building to take advantage of natural ventilation opportunities in warm periods, and - in a cold climate - good air tightness, continuous insulation, and high performing windows (Dabaieh & Elbably, 2015; Hossain, 2017), improving building energy efficiency. With regards to energy-efficiency solutions, key solutions from the literature highlighted energy efficient building systems, services and appliances that help the building use less energy to perform the same tasks (Ferrante, 2014). Furthermore, multi-criteria analysis models come up as an (emerging) effective tool to assess the optimal configuration of building components considering context-related characteristics (Bataineh & Al Rabee, 2022). However, solutions must ensure that the building works as intended, and meets users' needs - meaning Building performance is crucial (S. Attia, 2018). In this respect, developing efficient and adaptable building management systems, by means of a set of operations and management systems required to ensure that the building is managed and used in accordance with its purpose (e.g., maintenance, operation, repair), can support energy efficient building performance (Hossain, 2019). Also, energy demand control systems are presented in the reviewed literature as an effective solution to reduce building energy demand while ensuring indoor air quality (Y. Wang et al., 2018) (see Fig. 4 top-right side). Similarly, the literature highlighted that the implementation of new technologies in the built environment has rapidly emerged in the post-pandemic period to improve building safety and resilience (Xie et al., 2021), e.g., Smart Building Sensing Systems to avoid outbreaks of disease (Al-Humairi & Kamal, 2021), provide high indoor environmental quality (Dong et al., 2019) and control microclimates (Bhujel et al., 2020) with a combination of Artificial Intelligence (AI) and Machine Learning (ML) techniques to provide a sustainable and safe built environment (Xu et al., 2019). Mention was made of Autonomous Mobile Robots for disinfection, remote supply, emergency assistance, etc. (Bačík et al., 2020; Tsuruta et al., 2019); Internet of Things (IoT) to control home electrical energy consumption (Iqbal et al., 2018) or combined with cloud-based building management systems to ensure building efficient operation (Yu et al., 2016). Finally, an effective and secure data collection network is required to provide reliable data that support a well-structured intelligence building management system (BMS) (reducing the risks of cyber attacks, digital divide, ageism - see Fig. 4, top-right corner). Moreover, data collection enables decision-making in built environment resilience assessments (Cariolet et al., 2019), while enabling to answer relevant questions and evaluate future outcomes (i.e., predict and prepare) (Rogatka et al., 2021).

Equitable and inclusive infrastructures are a key resilient strategy and means that inhabitants are part of the participatory processes in the built environment, creating a feeling of ownership. Sustainable urban growth was seen in the literature as the main solution that aims to ensure that social, environmental, and economic factors are included in the urban development process without putting at risk the wellbeing of the community, while reducing natural resource pressures (Zeng et al., 2022; Zhang & Li, 2018). To achieve this, a consensus-building approach through a participatory and citizen empowerment strategy that helps citizens come together to develop and empower their community, organisation, or environment is needed (see Fig. 4, bottom area). In other words, citizens participate within the community as a means to improve service quality and local needs, often in co-operation with city planners or councillors. The reviewed literature highlighted participatory budgeting, i.e., a process in which citizens are actively involved in

decision-making about public resources expenditure (Cabannes, 2021), and Citizen Science Initiatives, where citizens participate in gathering and analysing scientific data (Hicks et al., 2019), to be an effective tool for disaster risk management strategies development. Similarly, the reviewed literature highlighted the need for a robust market system that promotes an equitable market system where society is placed in the core, e.g., regionalisation of housing policies, flexible housing market financing, and affordable rented and home ownership sectors (Boelhouwer, 2020), thereby mitigating the impact of an unstable economic and housing market (see Fig. 4, bottom-right corner). Solutions also included the allocation of stimulus packages to mitigate the impacts of housing price drops, increasing the social housing stock, and protecting the mortgage market (Yates, 2014), and the development of effective climate finance policy (i.e., green bonds, tax credits, etc.) (Bhandary et al., 2021). However, it was identified that robust institutions (i.e., policies, strategic plans, ecosystems) can determine the success (or lack thereof) of the implementation of resilient strategies (Birchall & Bonnett, 2021) (see Fig. 4, placed in the middle over 'lack of governance'). Specifically, the literature showed that decision-(policy) making must be supported by a well-structured ecosystem that ensures and promotes public goods through honesty, cultural empathy, and efficiency to the exclusion of private benefits (Krigsholm et al., 2022). Critical is a clear and reliable connection between inhabitants, local and national authorities that ensures citizens' active participation (Farbøl, 2021). This is also essential to develop effective tools that improve civil defence, i.e., citizens' protection from natural and social disruptions and disturbances, e.g., natural disasters, terrorism attacks, war (Slivkova et al., 2021; F. Wang et al., 2022). According to the literature review, critical is to include civil defence principles in land-use planning, e.g., provision of public shelter spaces (Farbøl, 2021; Tolis, 2018).

Among the solutions identified in this review, robust institutions and democratic governance (i.e., well-structured policies, strategic plans, ecosystems) were shown to be essential to the development of green and healthy, adaptable, and equitable and inclusive infrastructures (see Fig. 4, where robust institutions are highlighted in the middle over 'lack of governance'). This is underpinned by the crises impacts analysis in section 3.1, where a lack of governance (i.e., a complex and a poorly coordinated policy system) was seen as a common driver of the crises impacts studied here (see Fig. 3).

3.3. Key characteristics for resilient solutions

Based on the solutions identified from the literature review explained above and the six main resilience attributes (i.e., preparedness, agility, participatory, restorative, adaptability, and robustness) defined in existing conceptual frameworks for a resilient urban built environment (see section 1, page 3), the key characteristics for resilient solutions to multiple crises in the built environment are discussed below.

Existing infrastructures that addressed specific disruptions were mainly designed at the meso (i.e., neighbourhood, community) - or micro (by means of building, people) -scales, with little mention of the macro-scale (i.e., policy, city level). This gap in the studied literature highlights a missing interconnection between the three dimensions: people and building, local community, and policy (Sharifi, 2019a, 2019b; Sharifi et al., 2017). The systematic literature review highlighted that resilient solutions must be developed through a combination of both top-down and bottom-up approaches, negotiating between scales and between policymakers, stakeholders, and local communities (Janda & Parag, 2013). Moreover, it was highlighted that inclusivity through community engagement and consultation was essential to develop effective policies (Al-Humaiqani & Al-Ghamdi, 2022; Salimi & Al-Ghamdi, 2020), and creating a sense of joint vision. The contextual characteristics, physical and social structures of a place shape the ability of a community to resist external disruptions and they are therefore the key characteristics for the creation of resilient communities (Mirti Chand, 2018; Sharifi & Yamagata, 2018).

An example of how actions at different levels must be defined and interconnected between each other for solutions at the micro-scale to be successfully implemented is described below and in Fig. 5. The global food crisis caused by the COVID-19 pandemic showed the need for a resilient urban food system (United Nations, 2020), and requires a holistic transformation, mitigating environmental impacts such as biodiversity loss, greenhouse gas emissions, land, water, and ecosystem overconsumption and degradation (El Bilali et al., 2019; Hodbod & Eakin, 2015). Literature findings pointed to edible urban commons as an effective solution to develop a resilient food system (Ng, 2019; Russo & Cirella, 2019; Sardeshpande et al., 2021). Edible urban commons are common green spaces within the city with free access for passers-by to grow edible plants for the local community (Colinas et al., 2019; Scharf et al., 2019) and bring health, economic and environmental benefits (Sofo & Sofo, 2020) (*Micro-scale* in Fig. 5).

As shown in Fig. 5, a well-coordinated policy system plays an important role in *restorative* and *adaptability* attributes as it coordinates the relations and activities of all stakeholders involved in the process (Béné et al., 2018; Huang et al., 2021). Furthermore, it enables a smooth communication across the different scales (policymakers, regional and local communities), improving the agility of urban systems to react to certain disruptions, while preventing further damages - i.e. *preparedness* and *agility* attributes (Huang et al., 2021).

However, unequal distribution of urban green spaces led to not everyone having the possibility to own a private garden or access to public parks and green spaces (Wolch et al., 2014). Being able to access green spaces affects public health, and this has recently been recognised as an environmental and social justice issue (Jennings et al., 2012). Instead, literature emphasised that understanding contextual, physical and social challenges is essential for the development of resilient solutions, and that including society as part of the policymaking process (i.e., participatory approaches) is an effective strategy for regenerative development (*Meso-scale* in Fig. 5) (Bhandary et al., 2021; Cheng et al., 2021; Fischer et al., 2019; Simonson et al., 2021; Zeng et al., 2022). Regenerative development is based on equality among all stakeholders to co-create a built environment in which all actors meet their needs (Mang & Reed, 2012). This means that a bottom-up approach is needed, in which local people (*micro*) and communities (*meso*) are involved in the policy-making process (*macro*) to ensure that solutions will be effectively implemented at the local level (Janda & Parag, 2013).

The reviewed literature also emphasised that key characteristics for resilience were improving the social capital within a community as it has an important role in enhancing restorative and adaptability attributes (Habibov & Afandi, 2017). Social capital is the social relationships that enable people and communities to overcome challenges and find opportunities afterwards (Habibov & Afandi, 2017). However, two important social capital factors were found that should be combined to contribute to resilience: 'bonding' and 'bridging' social capitals. Bonding social capital (based on relationships among close people) was found to promote solidarity and confidence within the group, hence the adaptive capacity of the community to cope with different crisis impacts more effectively. On the other hand, bridging social capital (i.e., the social connections with other networks) was found to provide new opportunities to access different networks and to benefit from other resources; enhancing the restorative capacity of a community (Mngumi, 2021). In this respect, participatory strategies and community development through good communication, social learning activities and knowledge sharing within the local community were found to be key characteristics for resilience (Wilson et al., 2020), which must be supported by effective governance management (i.e., equitable and inclusive infrastructures) (Cavaye & Ross, 2019) - illustrated by the edible commons example (Fig. 5). Moreover, the capacity to react and adapt to



Fig. 5. Example of how actions at different levels must be interconnected between each other for solutions at the micro-scale to be successfully implemented.

certain disruptions was also found to be dependent on the resources available in the built environment at different scales. This means that efficient public resources and services management, by means of reserving emergency funds (Norris & Byrne, 2021) and allocation of spaces for emergency (Huang et al., 2021) were found to be essential for a community to be able to recover from disruptions and to adjust to the post-disaster environment while improving the initial functions (i.e., *restorative* and *agility* attributes). It was noted that well-organised emergency supply reserves and spaces would guarantee the continuing operation of a city and enhance the *robustness* attribute of the city in the face of disasters. It is therefore clear that when combined, the three (green and healthy, adaptable, equitable and inclusive) infrastructures make a more resilient built environment – as illustrated by the overlapping solutions in Fig. 4.

This discussion also highlighted that implementing resilient solutions to multiple crises impacts requires the development of holistic solutions through the combination of different characteristics to meet the main attributes for resilience fully. Fig. 6 below provides a graphical evaluation framework of key characteristics for resilient solutions to multiple crises impacts, highlighting that solutions need to be defined through both bottom-up and top-down approaches in which a wellcoordinated policy system (macro-scale) defines effective policies and strategies to provide actors at the meso- and micro-scale resources that enhance their robustness and participatory attributes. A bottom-up approach, in which society is part of the policy-making process, is crucial to connect the different dimensions (policy, stakeholders and local people) among each other, supporting social learning and knowledge sharing - i.e., social capital in Fig. 6. This can be supported by a systematic communication across the different scales, promoting a regenerative development in which allocation of green spaces and emergency funds will enhance their agility, restorative, preparedness, and adaptability attributes (see Fig. 6).

The evaluation framework in Fig. 6 presents a novel contribution to the topic of resilient responses to *multiple crises* in the built environment as existing frameworks mainly focus on *single types of crises*, for instance, climate (Abebe et al., 2020; Ahsan, 2020; Al-Humaiqani & Al-Ghamdi, 2022; Álvarez de Andrés et al., 2019; Andrić et al., 2019; Apreda et al.,

2019), policy (Béné et al., 2018; Birchall & Bonnett, 2021) or demographic (Ehmer, 2015). Thus, a more resilient built environment to multiple impacts can be developed by implementing the key characteristics and attributes proposed in the evaluation framework above (see Fig. 6). Note that Key Performance Indicators (KPIs) were excluded in the framework proposed in this study because KPIs aim to measure the performance and quality of a specific object instead of supporting its implementation (Lavy et al., 2014), which is the proposed framework's main aim, alongside evaluation of resilient responses at different stages of creation and realisation.

3.4. Limitations and further research

Limitations of this research include the following: first, due to the time frame defined for the literature review (2011–2021), new research may emerge, specifically on pandemic, demographic, and digital crises, adding further insights on how to achieve resilience in the built environment. Secondly, the interpretation of concepts used in different fields (e.g., resilience, solutions, crisis) and this research, which focuses on the built environment, may be different and therefore this may have affected inclusion in the systematic literature review. Thirdly, while some institutions have developed their own frameworks for assessing vulnerability and resilience, e.g., (City of Boston, 2017; Finnish Government Helsinki, 2021; Government of Nepal, 2021; Municipality of Athens, 2019; OneNYC, 2015; South Sudan Ministry of Environment and Forestry, 2021; Team, 2019) (see section 1, page 3), those frameworks were not described in our systematic literature review that was based on peer-review inclusion criteria, and therefore excluded from the analysis.

Regarding the results, future research employing quantitative and qualitative methods could be used to map the most likely combinations of multiple crises impacts, and then test the proposed key characteristics for resilient solutions to the built environment; however, this is outside the scope of this study. Furthermore, the authors acknowledge the complexity of implementing the proposed solutions to multiple crises for resilience in the built environment due to the multidimensional complex nature of the problematic which depends on a wide range of factors.

While the proposed evaluation framework in Fig. 6 can support the





Fig. 6. Evaluation framework of key characteristics for resilient solutions to multiple crises impacts and the main urban built environment resilience attributes, covering the three key strategies (i.e., (1) green and healthy, (2) adaptable, and (3) equitable and inclusive infrastructures).

implementation process, further research is needed to test and adapt the proposed solutions and framework application in contexts that are very different to those included in the systematic literature review, specifically those with different climatic, cultural and built environment characteristics.

4. Conclusions

The main focus in existing literature on primary and secondary crises and associated impacts primarily concerns the impacts of a single type of crisis in the built environment and solutions for individual impacts. Through a systematic literature review, this paper first mapped, analysed and provided an overview of the different potential impacts for the built environment associated with multiple crises. Six crises were included: climate, housing, pandemic, financial, demographic, and digital crises. 48 crisis impacts on the built environment were identified from the literature review (see Fig. 3), with climate crisis being the main one, likely reflected by the time frame in which the literature review was conducted. For the six crises, main crisis impacts included impacts from the physical (such as flooding, heat island, building malfunction), social (e.g., racism, social exclusion, citizens' well-being and safety issues, loss of culture and sense of community), economic (through market depreciation, asset bubble, unemployment increase), digital (i.e., cyberattacks, lack of trust, digital divide, lack of public service provision), to political divides. As depicted in Fig. 3, which highlights crises and associated impacts connections, the analysis of the interconnections among the different crisis impacts also showed a lack of governance (by means of complex and poor-coordinated policy systems) as a common driver of all the crisis impacts. Furthermore, low-income groups, elderly, and immigrants were highlighted as the most vulnerable groups. These results may support policymakers to design effective policy where actors at different levels are involved in the discussion and considered through the design process, with focus of measures on the most vulnerable groups.

Secondly, existing solutions that can enhance resilience to multiple crises impacts in the built environment encompassed a total of 114 solutions; their interconnections were analysed, clustering them into 19 solutions groups and three key strategies (see Fig. 4). Findings highlight that the provision of (1) green and healthy infrastructures (e.g., climate parks, edible urban commons, access to urban green spaces, provision of shading, natural light, view to the outside, good ventilation, waste and sewage management system); (2) adaptable infrastructures (such as waterways restoration, temporal structures, provision of open spaces); and (3) equitable and inclusive infrastructures (by means of participatory budgeting, reserving emergency funds, flexible housing policies) were essential strategies to achieve resilient built environments when faced with a multitude of different crises (see Fig. 4). A detailed definition and explanation of the three main infrastructures and how a combination of the three of them can lead to a more resilient built environment was provided in section 3.2. Note from the analysis that robust institutions (i. e., well-structured policies, strategic plans, ecosystems) were shown to be essential to the development of green and healthy, adaptable, and equitable and inclusive infrastructures (see Fig. 4).

Thirdly, key characteristics for resilience in the built environment to multiple crises impacts were discussed in section 3.3, and a graphical example on how to implement actions at different levels provided by Fig. 5, highlighting that a combination of both bottom-up and top-down approaches is crucial, i.e., policymakers (macro-scale) must define effective policies and strategies to provide actors at the meso- and micro-scale resources that enhance their *robustness, restorative, adaptability, agility, preparedness,* and *participatory* capacities.

Finally, based on the six main attributes for resilience (see section 1), an evaluation framework of key characteristics for resilient solutions to multiple crises impacts was defined to support their implementation in different contexts (see Fig. 6). The testing and adapting of the proposed solutions and framework application in different climatic, cultural and built environment contexts (e.g., those that are very different to those included in the systematic literature review) has been highlighted for further research. In conclusion, the findings contribute to the existing research gap on how to develop a more sustainable and resilient built environment when faced with multiple crises impacts, promoting future practices in the field and practical implications for policymaking.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data Availability

No data was used for the research described in the article.

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