Retrofitting for resilience: A multi-hazard approach

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ABSTRACT

Resilience has received increased attention in urban-related research, policies and practice in recent years. Many urban development-related international initiatives have been established, such as the Making Cities Resilient Campaign and 100 Resilient Cities Programme, aiming to assist governments in enhancing urban resilience. Although the building stock is a significant component of the built environment, little work has been done on the scale of buildings compared to the work developed for the city scale. Resilient buildings can deliver their functions in the face of stresses and shocks, which are the converse of buildings that are vulnerable to the city's weaknesses and hazards. Enhancing the resilience of buildings boosts the urban fabric's resilience at a larger scale. This paper discusses what defines resilient buildings, focusing on existing building retrofits as it offers great opportunity to enhance the resilience of the built environment on a larger scale. It establishes a comprehensive understanding of resilience in buildings that consider both stresses and shocks threatening the built environment. Since resilience is a context-specific approach, the study also takes Jordan as an example and identifies the resilience challenges of its buildings according to 200 local professionals' perception who responded to an online questionnaire.

Keywords: *Multi-hazard; resilience; resilient buildings; resilient architecture; retrofitting for resilience.*

INTRODUCTION

The resilience concept has been receiving increased attention in the urban-related research, policies and practice. At the policy level, for example, many highlighted that the interest of policymakers in the last decade is shifting from sustainability to resilience as a driver for policy change in urban-related policy (Shamout et al., 2021; Stumpp, 2013). In practice, cities around the globe are articulating goals and developing plans to enhance urban resilience. Many international initiatives were established to help those cities build resilience such as the Making Cities Resilient Campaign, the City Resilience Profiling Programme and 100 Resilient Cities Programme. According to the 100 Resilience Cities Programme, urban resilience "describes the capacity of cities to function, so that the people living and working in cities – particularly the poor and vulnerable – survive and thrive no matter what stresses or shocks they encounter" (Da Silva & Morera, 2014, p. 3). This definition has been adopted by the participated cities in the 100 Resilient Cities Network, including the city of Amman in Jordan that released its first resilience strategy in 2017 (Greater Amman Municipality, 2017). What makes resilience a key goal is that the global built environment is facing more emerging challenges that require resilience thinking. Those challenges may include natural hazards, climate change-related events (Beilin & Wilkinson, 2015), infrastructure Failure; and man-made hazards, such as conflicts (Scambary, 2013). Those challenges affect the built environment as a whole from the broader city-systems level, including its infrastructure down to the building level. The building stock is a significant component of the built environment, and it provides great opportunities for building resilience at a larger scale (U.S. Green Building Council, 2018). Despite this, little work has been done on the building scale regarding building resilience compared to the work developed for the city scale. This paper first discusses what defines resilience for buildings, with a particular focus on existing building retrofits as it offers great opportunity to enhance the resilience of the built environment on a larger scale. Then, the paper identifies the main resilience challenges of Jordan's buildings, taking Jordan as a relevant example of a built environment exposed to a wide range of both sudden shocks and chronic challenges. This case also provides a potential contribution of knowledge as very little work has been done on the building scale compared to the work developed for the cities' scale such as the Amman Resilience Strategy.

METHOD

This paper mainly uses a literature review to provide a clear understanding of resilience in the context of buildings, resilience buildings tools, resilience challenges and retrofitting for resilience. A second method is an online questionnaire that was offered to around 200 local professionals in Jordan to identify and rank the resilience challenges for buildings in Jordan in terms of priority. To ensure the relevance and accuracy of data, only the participants familiar with Jordan’s built environment and its related issues are included.

DEFINING RESILIENCE FOR BUILDINGS

In the context of buildings, sustainability in the design, construction and operational phases may include reductions in the use of energy, water and materials through efficient means (Amini et al., 2018). It minimises the building's influences on the surrounding environment and provides the building's occupants with a healthier environment and satisfactory service. These aims could also be reflected in buildings when dealing with them from a resilience point of view but, philosophically, resilience may have a broader perspective as it also has an opposite purpose – that is, minimising the impact of the surrounding environment on the built environment.

Resilience is not only about external disturbances. The International Organization for Standardization (ISO) (2016, p. 2) defines resilience as “the capability of a system to maintain its functions and structure in the face of internal and external change and to degrade gracefully when this is necessary”. When applying this to the context of buildings, it may include problems of the building itself as well as the stresses and shocks of the built environment. This paper adopts a multi-hazard perspective on defining resilient buildings. Resilient buildings are the converse of buildings that are vulnerable to internal and external changing conditions, and this may include a wide range of challenges from nature to man-made challenges. A resilient building should be able to function at its normal condition in the face of both stresses and shocks: stresses such as lack of energy or water supply

(Younis et al., 2017); and shocks such as more extreme events such as lower or higher temperatures, flood risks (Golz, 2016), and earthquakes (Samadian et al., 2019). A resilient building should also be able to adapt to the modern way of life and renew its function based on what people needs nowadays. The resilient design can apply to both new and existing buildings to provide a more liveable, safer, and better place for people during, before and after a disruption and/or stress.

RESILIENCE CHALLENGES FOR BUILDINGS

To incorporate resilience thinking when retrofitting existing buildings, there is a need to assess the resilience of a building. To achieve this, it is crucial to identify any hazards that may pose a risk to the building as well as challenges that may prevent the building from functioning at its normal condition. Table 1 summarises several common resilience challenges for buildings, derived from the literature, spanning from nature-related challenges to man-made problems. Nature-related challenges include climate change events, natural hazards and natural resources shortage while human-made challenges include a broader perspective of issues from the city scale, such as infrastructure failure, conflicts, urbanisation, growing demand for housing, and economic crisis, to the building scale such as maintenance (structural).

Resilience challenges	Shocks/ Stresses	Nature-related /man-made	Examples
climate change-related challenges	both	nature-related	temperature changes (e.g. extreme heat event), precipitation changes causing floods or drought, and more frequent extreme weather events such as storms.
natural hazards	shocks	nature-related	high-winds, hurricanes, tornado, flooding, tsunami, earthquake, wildfire, unstable soil, drought, landslides, and winter storms.
infrastructure failure	both	man-made	power outages, loss of access to potable water, and wastewater systems failure
natural resources shortage	stresses	nature-related	energy resources and water.
man-made hazards	shocks	man-made	conflicts
building-related problems	both	man-made	maintenance (structural);
others (building scale)	stresses	man-made	adapting existing buildings into modern standard
others (city scale)	both	man-made	urbanisation, growing demand for housing, and economic crisis.

Table 1: Resilience challenges for buildings. Source: Elaboration of the Author.

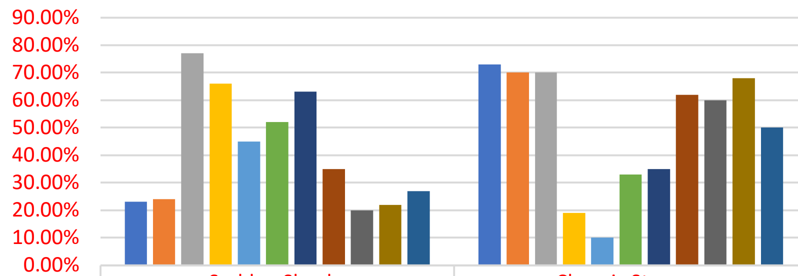
Resilience challenges can also include problems that prevent buildings from operating in line with the modern era and its requirements. Examples of this can vary in terms of the level of hazard or stress; from high levels such as changing existing materials that are recognised as harmful to humans nowadays; to low levels such as adding elevators and escalators to high-rise existing buildings.

Several aspects should be considered to understand better the types of shock and stresses in the built environment including cause (natural or intentional), frequency and magnitude, level of anticipation (can be predicted accurately or not), time scale (instantaneous or chronic), and source (internal or external) (Yamagata & Maruyama, 2016). A good example is an increasing frequency and level of intensity of climate change-related events.

One can argue how some challenges listed in the table, such as conflicts, are related to resilience in buildings. Conflicts may affect the built environment both directly and indirectly: (1) directly by destroying its infrastructure like the ongoing Syrian civil war (Berti, 2018); (2) indirectly by the rapid influx of refugee into safer urban areas, resulting in sudden urban population growth in those areas which can be called the conflict indirectly affected areas (Scambary, 2013; Shamout et al., 2021).

RESILIENCE CHALLENGES FOR BUILDINGS: THE CASE OF JORDAN

Figure 1 shows the complexity of the resilience challenges for buildings in the case of Jordan, making the Jordan example worth investigating. The participants identified the resilience shocks and stresses for buildings in Jordan and ranked them in order of priority.



	Sudden Shocks	Chronic Stresses
High energy costs	23.00%	73.00%
Water scarcity	24.00%	70.00%
Man-made hazards (conflicts)	77.00%	70.00%
Climate change-related challenges (heatwaves, droughts, flash flooding)	66.00%	19.00%
Natural hazards (flooding, earthquake, wildfire, unstable soil, drought, landslides, and winter storms)	45.00%	10.00%
Infrastructure failure (power outages, loss of access to potable water, and wastewater systems failure	52.00%	33.00%
sudden population increase (growing demand for housing)	63.00%	35.00%
Building-related problems (structural maintenance)	35.00%	62.00%
Adapting existing buildings into modern standard	20.00%	60.00%
Urbanization	22.00%	68.00%
Architecture technological challenges	27.00%	50.00%

Figure 1: The participants' ranking of the resilience shocks and stresses for buildings in terms of priority.

Man-made hazards were given similar percentages in both categories, where it was ranked first as shocks by 77% and second for stresses by 70%, while climate change-related hazards were ranked second as shocks by 66% followed by the sudden population increase 63%, infrastructure failure 52%, and natural hazards 45%. In Jordan, the frequency of some shocks has made them become like stresses such as the urban population growth that was caused by the influx of refugees from neighbouring countries, which has resulted in a growing demand for housing. Lack of energy and water resources were given first and second priority as stresses, 73% and 70%, respectively with very close percentages.

RESILIENT BUILDINGS TOOLS

Table 2 shows some examples of resilience standards applicable to buildings that follows the multi-hazard approach. Although the first one, FORTIFIED, focuses on a number of related natural hazards, the rest adopts a holistic approach that includes a wider range of stresses and shocks. Resilience standards were commonly targeting specific types of challenges (hazards), but more recently few standards have been established with a holistic approach that does not focus on specific hazards but take into account a variety of chronic and sudden resilience challenges.

On the one hand, there are many resilience standards that target specific hazards. One example is the Resilience-based Earthquake Design Initiative (REDi™) Rating System (Arup, 2013). It provides a framework for architects, engineers, and buildings' owners to implement resilience-based earthquake design strategies. The framework helps to provide liveable conditions quickly following an earthquake disaster and enable people to resume their business operations. Another example could be the FORTIFIED Home standard. It was designed to make new and existing homes more resilient to hurricanes, high winds, and hail. a set of performance-based engineering and building standards designed to help strengthen new and existing homes through the installation of specific building upgrades that reduce damage from hurricanes, hailstorms, low-level tornados, and severe thunderstorms (Insurance Institute for Business &Home Safety, n.d.; Malik et al., 2013).

Resilience standard	**year**	**launched by**	**Applicable to**		**The included challenges and/or hazards**
			New builds	**Existing buildings**	
FORTIFIED	2010	IBHS[1]	√	√	Wind, hurricanes, low-level tornados, hailstorms, and severe thunderstorms.
BRLA	2015	USGBC[2]		√	Holistic
LEED Pilot Credits	2015	USGBC	√		Holistic
RELi 2.0	2018	USGBC	√		Holistic

Table 2: Multi-hazards resilience standards applicable to buildings. Source: Elaboration of the Author.

On the other hand, there are very little holistic standards and guidelines for resilience. Holistic standards address a variety of hazards (resilience-related challenges) and offer guidance for assessing vulnerabilities and provide resources to improve preparedness. The assessments of vulnerabilities are the foundation of many of resilience standards, such as LEED pilot credits and the Resiliency Action List

[1] IBHS: Florida–based Insurance Institute for Business & Home Safety
[2] USGBC: The U.S. Green Building Council

(RELi). The holistic assessment often includes criteria to identify hazards, such as time frames and geographic location.

The Building Resilience in La Framework (BRLA) is a planning and operational framework that focuses on existing facilities to help them survive and thrive in the face of shocks and stressors. It was developed to better prepare for Los Angeles's risks including climate change, earthquakes, drought, and power outages (U.S. Green Building Council, n.d.).

LEED Pilot credits on resilient design were developed upon the existing LEED programme. The credits' system has three main types. The first type requires emergency planning or a climate change assessment, it can be used for both new builds and existing buildings for strengthening their preparedness. The second requires design strategies for the top three main hazards (risks) linked to the building site (area) such as earthquakes, flooding, heatwaves, and high winds. The third type requires passive design strategies for survivability such as ensuring the access to energy (through backup power) and potable water. The LEED Pilot credits on resilient design are available beside the other LEED Building Design and Construction credits.

RELi 2.0, for example, is one of the most recent comprehensive resilient buildings assessment tools worldwide. It is an in-depth, comprehensive rating system that provides valuable strategies and tools for resilient buildings and design (U.S. Green Building Council, 2018). It helps in identifying and reducing the risk of damage to a building in the event of a natural disaster or other crisis, although no rating system can eliminate risk entirely. The rating tool has 15 requirements as mandatory and they do not carry a point value. The RELi 2.0 Rating System is not intended to provide design guidelines for indefinite building and community operation following a catastrophe. RELi 2.0 synthesises the LEED Resilient Design pilot credits with RELi Hazard Mitigation and Adaptation credits.

RETROFITTING ENHANCES RESILIENCE

The existing building stock is a significant component of the built environment. It is 80 times larger than the new building sector, so the focus should be on retrofitting existing buildings as this provides great potentials for resilience (Shamout et al., 2019). Regarding resilience, the performance of the existing building stock can be strengthened in the face of the main stresses and shocks the built environment is or will be facing, through implementing retrofitting resilience-based measures. There are many examples of retrofitting measures or standards that can help enhance resilience in buildings, whether against a specific shock or stress. For shocks, one example is a FORTIFIED Home, a performance-based standard designed to help strengthen existing and new homes to reduce damage from hailstorms, hurricanes, severe thunderstorms, and low-level tornados, through implementing specific building upgrades (Insurance Institute for Business &Home Safety, n.d.). For stresses, one example is EnerPHit, the Passive House certificate for energy retrofits, designed to help achieve significant energy savings for refurbishments of existing buildings that can reach from 75 up to 90 % (Passipedia, n.d.), and therefore enhance the resilience of buildings against the high energy cost and the lack of energy resources. Energy efficiency measures for existing buildings along with the other solutions aim to reduce the energy demand of buildings. Although energy efficiency measures might get underrated when discussing resilience (Carmichael & Jungclaus, 2018), it enhances resilience through several perspectives. It can decrease backup generation needs at the urban level and up-front capital costs, reduce dependence on outside fuel sources (Sharifi & Yamagata, 2014), and decrease life-cycle costs and increasing value (Liu & Mi, 2017).

Retrofitting provides great opportunities to enhance resilience in the built environment at a larger scale considering all challenges cities are or will be facing. Therefore, it is important to incorporate resilience thinking when retrofitting existing buildings, focusing on both stresses and shocks.

CONCLUSION

The need for incorporating resilient design strategies at the scale of buildings is urgent, mainly as more global challenges facing cities have emerged such as economic disruption, weather extremes and resource depletion (Da Silva & Morera, 2014). A resilient building should not be sensitive to any challenges the built environment is facing, but rather having the ability to adapt to them. The design of resilience measures for buildings requires identifying specific hazards and challenges of the specific context of the building site, as those challenges should become drivers for the design whether it is a retrofitting case or the case of a new building. Resilient design can be associated with adaptation to changing conditions, which are resulting from a wide range of stresses and shocks. For example, it can be related to adaptation measures to earthquakes (Samadian et al., 2019) and the changing climate where climate adaptation aims to reduce climate risk and vulnerability in the built environment (Curtis, 2017; Grynning et al., 2017; Lisø et al., 2017; Song & Ye, 2017). It can further include challenges that are man-made, which is reflected in the case of Jordan, whether: at the city scale such as the growing demand for housing that results in the need for retrofitting to enhance the existing buildings' capacity in terms of the number of people a building can accommodate; or at the building scale itself such as retrofitting to improve the building structure. This article aimed to contextualise a multi-hazard perspective of resilience at the scale of buildings, focusing on existing building retrofits. Since resilience is a context-specific approach, the study takes Jordan as an example and identifies it's the resilience challenges of its buildings and rank them according to 200 local professionals' perception who responded to an online questionnaire.

Retrofitting of the existing building stock to resilience standards through resilience-based measures is of the utmost significance. However, the resilience state of the building would depend on the approach adopted to enhance resilience, where resilience optimisation measures are strongly linked with all the level of adaptation and preparedness with challenges that the building is or will be facing, including stresses and shocks, aligned with the building's functional, safety, economic, and construction demands. Therefore, there cannot be a unified framework to enhance resilience in buildings; it depends on the context where the building lies ecologically, geographically, socially, politically and economically. However, adopting a holistic approach that consider all challenges when retrofitting for resilience with multi objective methods would give a valid support to the integral retrofitting that results in safer, more functional and sustainable, and more robust buildings. The learning from this paper will inform the development of a comprehensive resilience-based design framework for buildings in Jordan as more resilience challenges facing its built environment have emerged.

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