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EDITED BY
Giridharan Renganathan,
University of Kent, United Kingdom

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Giles Bruno Sioen,
National Institute for Environmental Studies (NIES), Japan
Maria Rosa Trovato,
University of Catania, Italy

*CORRESPONDENCE
Sami G. Al-Ghamdi,
sami.alghamdi@kaust.edu.sa

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Robustness, redundancy, inclusivity, and integration of built environment systems: resilience quantification from stakeholders' perspectives

Mohammed M. Al-Humaiqani[1,2,3] and Sami G. Al-Ghamdi[1,2,3]*

[1]Division of Sustainable Development, College of Science and Engineering, Hamad Bin Khalifa University, Qatar Foundation, Doha, Qatar, [2]Environmental Science and Engineering Program, Biological and Environmental Science and Engineering Division, King Abdullah University of Science and Technology (KAUST), Thuwal, Saudi Arabia, [3]KAUST Climate and Livability Initiative, King Abdullah University of Science and Technology (KAUST), Thuwal, Saudi Arabia

The built environment faces a growing number of challenges due to changing climates. A resilient built environment system (BES) can withstand disruptions and shocks, and resilient design allows communities to bounce back quickly. Considering present and future needs, BESs can be oriented to adapt to new uses or modified to handle changing climates. This study examines the resilience qualities (RQs) of built environment systems (BESs) in responding to and recovering from climate change disruptions effectively. A survey was designed to capture the views of various stakeholders about the different indicators to assess the four RQs: robustness (*Rb*), redundancy (*Rd*), inclusivity (*Ic*), and integration (*It*). Regulatory and engineering stakeholders participated in the survey, and the results were analyzed using statistical methods. Stakeholders generally agree on the need to enhance transformative capacity for addressing uncertainties and climate challenges. While stakeholders trust the role of BESs' robustness against climate impacts, some suggest improving standards for better resilience. There is consensus on the importance of regulatory measures mandating emergency resources in BESs. The study highlights the need to enhance adaptive capacities and tools within BESs. Incorporating reconfigurability and spare capacity in BESs is crucial to prevent disruptions. Participants tend to think promoting good practices at the community level is essential to address climate impacts effectively. The analysis highlights the importance of inclusive community consultation and involvement in fostering a shared responsibility for enhancing urban ecosystems against climate change impacts. This involves aligning processes across various city systems to support cohesive decision-making and strategic investments. The study suggests developing objective engineering techniques to establish a standardized approach for evaluating the RQs of BESs.

KEYWORDS

climate change, built environment, resilience qualities, redundancy, robustness, inclusivity, integration, capacity

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1 Introduction

Resilience is a critical objective for built environment systems (BESs) confronting climate change (Meerow et al., 2016; Tahir et al., 2021). A resilient built environment is crucial to protect human life, property, and economic activity and helps achieve and retain Sustainable Development Goals (SDGs) (Tahir et al., 2021). It can also help ensure communities bounce back from disruptions

TABLE 1 Built environment resilience qualities and characteristics.

Resilience quality	Related capacities	Quality boundaries	The phase of resilience	Selected references
Robustness (*Rb*)	- Absorptive Capacity (Absorption)	*Rb* refers to the ability to minimize or prevent impacts, withstand climate-related disturbances, assess system performance, and uphold an acceptable level of service	During a disturbance event [refer to Supplementary Figure S1 by Al-Humaiqani and Al-Ghamdi, 2022 (Al-Humaiqani and Al-Ghamdi, 2022)]	(Rus et al., 2018; Lak et al., 2020; Shafiei Dastjerdi et al., 2021; Faturechi and Miller-Hooks, 2015; Bruneau et al., 2003; Deshkar and Adane, 2016; Wardekker et al., 2017)
	- Scalability			
Redundancy (*Rd*)	- Reserve Capacity (Absorption)	*Rd* in the provisions of governance roles and functions and the management of public resources and services	During a disturbance event (Al-Humaiqani and Al-Ghamdi, 2022)	(Kanno and Ben-Haim, 2011; Huang et al., 2021; Wardekker et al., 2017; Bruneau et al., 2003)
	- Diversity			
	- Backup capacity			
Inclusivity (*Ic*)	- Engagement of Community	*Ic* addresses stresses and shocks a specific sector, location, or community faces	After the disturbance event (Reliability state) (Al-Humaiqani and Al-Ghamdi, 2022)]	(Pfefferbaum et al., 2013; Arup and The Rockefeller Foundation, 2014a; Sharifi, 2016; UNDP Drylands Development Centre, 2016; Salimi and Al-Ghamdi, 2020; Schwind, 2020; U.S. IOTWS, 2007a)
Integration (*It*)	- Adaptive Capacity	*It* involves promoting consistent decision-making and making investments	After the disturbance event (Reliability state)	(Shafiei Dastjerdi et al., 2021; Arup and The Rockefeller Foundation, 2014a; Chelleri and Marta, 2012)
	- (Adaptability or Adaptation)			

FIGURE 1
RQs of BESs discussed in this paper (Part 2), including *Rb*, *Rd*, *Ic*, and *It*.

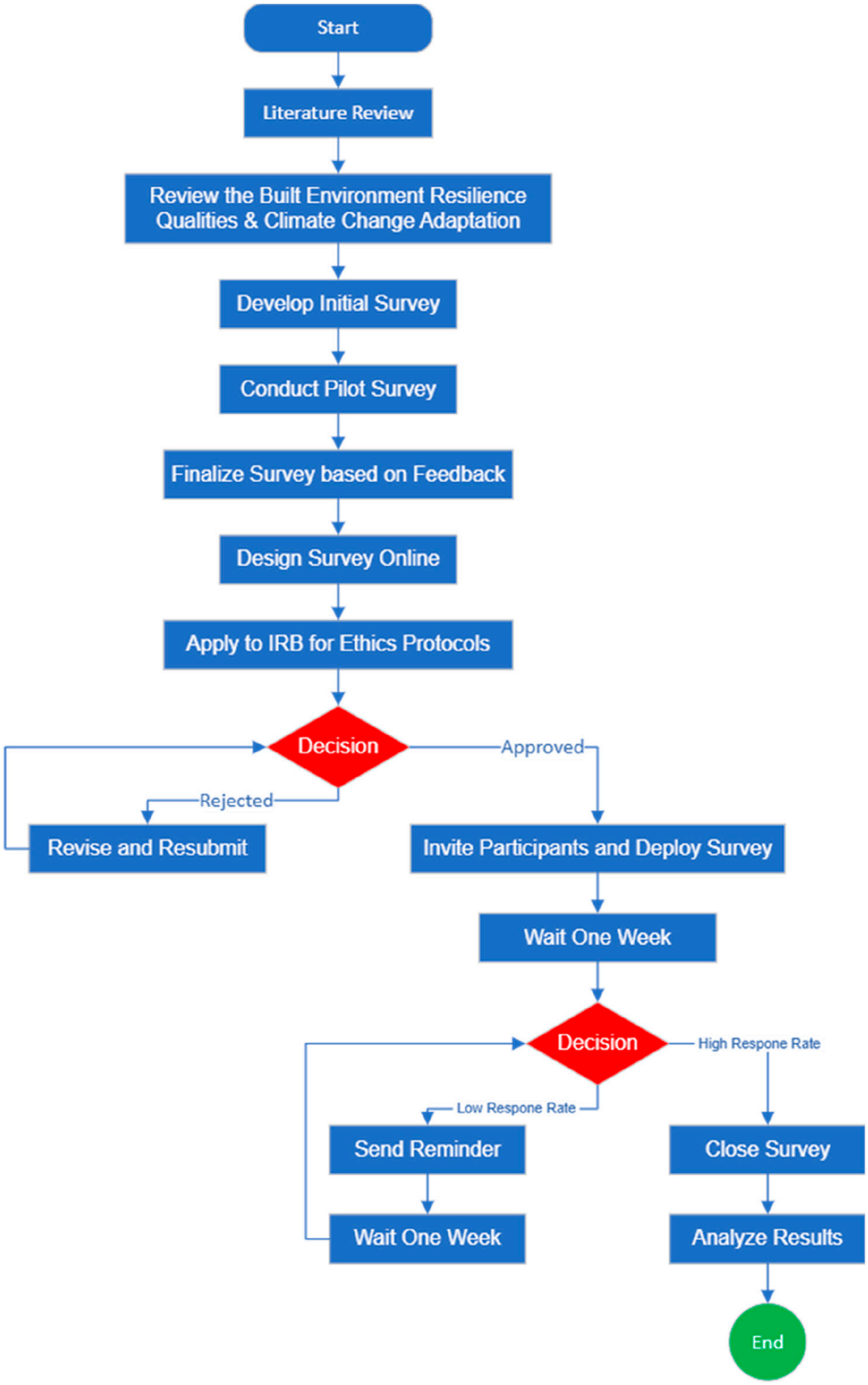

FIGURE 2
Research methodology showing the survey diagram and distribution process.

and continue to thrive (Al-Humaiqani and Al-Ghamdi, 2023a; Al-Humaiqani and Al-Ghamdi, 2023b). Resilience enhances a system's ability to cope, adapt, and recover from external changes effectively and promptly (Al-Humaiqani and Al-Ghamdi, 2023c; Al-Humaiqani and Al-Ghamdi, 2023d; Serdar and Al-Ghamdi, 2023). A resilient system can swiftly return to its original state or even improve upon it after a disaster. The system's recovery capability hinges on prior mitigation measures and preparations taken to ensure readiness to withstand such impacts (Rose, 2004; Rose et al., 2007; Zobel, 2011). Resilience encompasses various

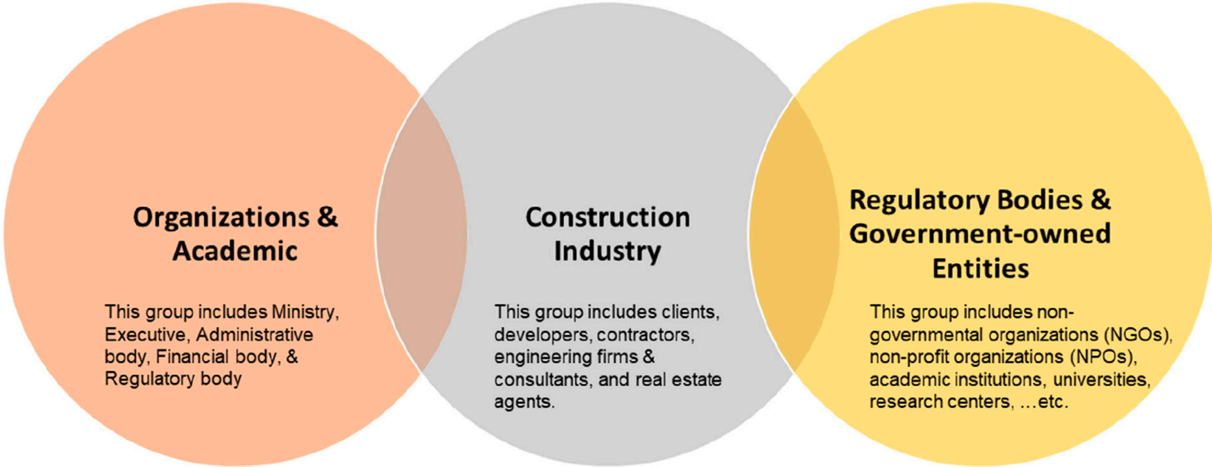

FIGURE 3
Respondents grouping.

TABLE 2 Survey questionnaire content and structure.

Question #	Question type	Issues tackled/Investigated
S#2: Q 1	Consent question	A general question that allows participants to end their participation
S#2: Q 5–10	Demographic questions	These questions gather demographic information about the audience
S#2: Q 11–12	Notes	Two additional notes help participants to understand how the questions are connected
S#2: Q 13–65	G1 questions	Questions regarding the *Rb*, *Rd*, *Ic*, and *It* dedicated to Group 1
S#2: Q 66–117	G2 questions	Questions regarding the *Rb*, *Rd*, *Ic*, and *It* dedicated to Group 2
S#2: Q 118–167	G3 questions	Questions regarding the *Rb*, *Rd*, *Ic*, and *It* dedicated to Group 3

definitions, all linked to the system's capacity to anticipate adverse effects, absorb, resist, adapt, and promptly recover from disruptive events (Ayyub, 2020; McAllister, 2013).

The resilience of a BES is directly impacted by its robustness (*Rb*) and ability to recover from disruptive events quickly. Resilient built environments aim to minimize the impact of shocks on their systems and enhance their adaptive capacity (Bazrkar et al., 2015). Resilience in the built environment involves a combination of essential qualities crucial for designing, constructing, and managing infrastructure that can withstand diverse climate challenges and disruptions. Al-Humaiqani and Al-Ghamdi have identified eight key qualities for BES resilience: reflectivity (*Rf*), robustness (*Rb*), redundancy (*Rd*), flexibility (*Fx*), resourcefulness (*Rs*), rapidity (*Rp*), inclusivity (*Ic*), and integration (*It*). Four resilience qualities (RQs), including reflectivity (*Rf*), flexibility (*Fx*), resourcefulness (*Rs*), and rapidity (*Rp*), have previously been studied and published by the authors (Al-Humaiqani and Al-Ghamdi, 2023e), as explained in Appendix A.

The qualities of *Rb* and *Rd* can be compared, and it is evident that structural *Rd* enhances *Rb* in uncertain conditions. As demonstrated by Kanno and Ben-Haim, *Rd* is strongly linked to *Rb* as *Rb* bounds strong *Rd*, making the two qualities identical (Kanno and Ben-Haim, 2011). In general, the *Rd* of any structure means a structure's ability to withstand degradation without losing specified elements (Kanno and Ben-Haim, 2011). *Rd* is essential in the philosophy of structural designs. However, the literature has defined *Rd* into two concepts: strong and weak, where strong *Rd* is the lower bound of *Rb* and may exceed the *Rb* (Kanno and Ben-Haim, 2011). Strong and weak *Rds* can be explained against each other. On the other hand, *Rb* is the ability of a structure to maintain some functionality against environmental uncertainty. Although strong *Rd* and *Rb* may be equivalent in many cases, this does not mean only the survivability aspects of a structure after degradation are represented by these two characteristics.

Improving system resilience involves enhancing *Rp* and ensuring sufficient repair resources are available. This approach encourages assessing resilience as a combination of *Rb* and *Rp* (Ouyang, 2017). Additionally, the *Rb* of systems, such as infrastructure, ecosystems, policies, and strategic plans, contribute to the determination of the ability to build resilience (Birchall and Bonnett, 2021). Building robustness (*Rb*) is a crucial aspect of resilience, as it pertains to the system's stability and strength in the face of both short and long-term shocks (Rus et al., 2018; Lak et al., 2020; Shafiei Dastjerdi et al., 2021). *Rb* is measured by evaluating the system's performance from the onset of a disruptive event until the point just before restoration begins (Ouyang, 2017). At the urban level, resilient systems require combining planning, efficiency, adaptability, diversity,

TABLE 3 Indicators, structure, subject, and the occupations and roles of participants in question formulation.

Questions	Boundaries and audience	Subject and indicators
S#2: Q 1–12, All Participants: Multiple Choice	Mandatory questions: All respondents were asked to answer	Demographic information was used to analyze the participants' identity and background characteristics. They include educational background, geographical exposure, experience, industry, affiliation, and role
RQ2	The audience's perspectives on enhancing resilience through understanding system stability and strength against short and long-term shocks, as well as assessing performance during disruptive events, are as follows	*Rb* is a measure of urban infrastructure resilience, indicating its stability and strength against short and long-term shocks. It assesses the system's performance during a disruptive event, from the beginning until restoration efforts begin
S#2: Q 13–22, G1 Participants: Multiple Choice	1) Governmental, regulatory, and governmental authorities	The main *Rb* indicators are
		1) Strength and Stability of the System
		2) Withstanding Disruptive Events
		3) Maintaining Functionality during the Event
S#2: Q 70–79, G2 Participants: Multiple Choice	2) Construction sector	4) System Performance
		5) Minimizing Losses from Hazards
		6) Low Failure Probability
S#2: Q 127–136, G3 Participants: Multiple Choice	3) Research and academic institutes, NGOs, and NPOs	
RQ3	Respondents' perspectives on promoting *Rd* through understanding the ability of systems and facilities to maintain functionality and integrity when faced with disruptions	*Rd* refers to the ability of systems, facilities, and their components to maintain functionality and structural integrity when faced with disruptions
S#2: Q 23–44, G1 Participants: Multiple Choice	1) Governmental, regulatory, and governmental authorities	The main flexibility indicators are
		1) Reserve Capacity
		2) Adaptive and Absorptive Coping Capacity
		3) Diversity and Backup Capacity
		4) Governance Frameworks
S#2: Q 80–101, G2 Participants: Multiple Choice	2) Construction industry	5) Emergency resources and supplies
		6) Insurance and disaster funds
S#2: Q 137–158, G3 Participants: Multiple Choice	3) Research and academic institutes, NGOs, and NPOs	
RQ7	The respondents' opinions about broadening *Ic* through extensive consultation and communities engagement and how a specific community, sector, or location can address shocks and stresses. Promoting inclusivity (*Ic*) to enhance and inform decision-making	*Ic* focuses on broad community consultation and engagement to address shocks and stresses. Actioning *Ic* to enhance and inform decision-making
		The main *Ic* indicators are
S#2: Q 45–55, G1 Participants: Multiple Choice	1) Governmental, regulatory, and governmental authorities	1) Communities' Engagement
		2) Shared Ownership Action
		3) Feeding the Future Decision-Making
		4) Improving Resilience
S#2: Q 102–112, G2 Participants: Multiple Choice	2) Construction industry	
S#2: Q 159–169, G3 Participants: Multiple Choice	3) Research and academic institutes, NGOs, and NPOs	
RQ8	The responses about consolidating integration by understanding the integration between systems and across various operational scales. This helps maintain consistency in decision-making. By networking information from different parts of the city's systems, they can operate cohesively and respond promptly	Integrating city processes would promote consistent decision-making and investment placement. Networking information from different city systems would enable them to operate together and respond quickly. Aligning and integrating systems across operational scales would support outcomes and maintain decision-making consistency
S#2: Q 56–69, G1 Participants: Multiple Choice	1) Governmental, regulatory, and governmental authorities	The main *It* indicators are
		1) Adaptive Capacity
		2) Systems Integration

(Continued on following page)

TABLE 3 (*Continued*) Indicators, structure, subject, and the occupations and roles of participants in question formulation.

Questions	Boundaries and audience	Subject and indicators
S#2: Q 113–126, G2 Participants:Multiple Choices	2) Construction industry	3) Systems' Information Exchanging
		4) Decision-Making Promotion
		5) Resilience policies are integrated with other policies and programs
S#2: Q 170–183, G3 Participants: Multiple Choice	3) Research and academic institutes, NGOs, and NPOs	

TABLE 4 Statistical tests used in this study.

Questions and statistical tests	Respondent role	Subjects
S#2: Q 13–69:	Group 1	Measuring urban infrastructure resilience involves evaluating its ability to withstand and recover from short- and long-term shocks. *Rb* is measured by the system's performance during a disruptive event. It is important to consider the built environment's ability to withstand and cope with disruptive events and its absorptive capacity to minimize negative impacts caused by climate change
Governmental Authorities: Decision-makers and Planners: Ranking and Multiple ChoicesStatistical Test: Relative Importance Index (RII), Pearson's Chi-Squared	Understanding the adaptation strategies and actions to address the impacts, integrating climate considerations into current planning, and setting climate-informed goals	The description of essential elements is integral to various design philosophies, particularly in structural design. It refers to the systems' ability, facilities, and components to maintain functionality and structural integrity when faced with disruptions
S#2: Q 70–126,	Group 2	Performance may deteriorate if a component of a BES fails as a result of climate stress or shock
Sustainability Professionals and Practitioners, Sustainability Experts, Senior Environmental Managers and Engineers Ranking and Multiple Choice Statistical Test: Pearson's Chi-squared, Cronbach's Alpha (α), Mann–Whitney *U*-test, Relative Importance Index (RII),	Implementing resilience management practices and adopting new best practices while prioritizing resilience traits in their day-to-day work is critical in reducing potential climate change impacts. Furthermore, it assumes a prominent role in coordinating processes for different components of BESs while also facilitating the implementation of optimal resilience plans	The description emphasizes the importance of extensive consultation and community engagement to address shocks and stresses in specific communities, sectors, or locations. Actioning *Ic* will enhance and inform future decision-making
S#2: Q 127–183,	Group 3	Description of integrating city's processes to promote consistent decision-making and investment placement. By networking information from various city systems, they can operate together and respond quickly. This alignment and integration across operational scales support consistent decision-making
Climate Scientists, Experts, Scholars, Researchers, *etc.*, Representatives of NGOs, and Sustainability entities Ranking, Likert and Multiple ChoiceStatistical Test: Pearson's Chi-Squared, Cronbach's Alpha (α), Relative Importance Index (RII), Mann–Whitney *U*-test	Integrating accountability for climate change into the framework of a growing city or system incentivizes businesses to amplify environmental transparency and improve system efficiency. This, in turn, fosters increased participation in mitigating the impacts of climate change. (Asfaw et al., 2017)	

interdependence, redundancy, strength, and flexibility, as emphasized by Godschalk (2003).

Improving *Rb* and resistance and introducing efficient recovery strategies can minimize both direct and indirect losses caused by hazards (Bocchini et al., 2014). However, researchers like da Silva et al. (2012) have come to an understanding of the difference between robustness and resilience. For them, resilience is defined as the ability to return a system to a stable equilibrium after disturbance, while *Rb* focuses on maintaining functionality during the event. However, some researchers argue that the resilience of a critical system is reflected in its performance after a disaster event and before restoration, emphasizing the importance of robustness (Ouyang, 2017). For instance, Kammouh et al. (2020) found a linear relationship between resilience, robustness, and recovery capacity, where higher robustness leads to higher resilience. Similarly, Moghadas et al. (2019) emphasize that resilient cities prioritize robustness and adaptive capacities. Bruneau et al. (Bazrkar et al., 2015) believe that *Rb* represents the system's strength to withstand disruption and is used to measure its absorptive capability in reducing negative impacts and consequences.

The concept of *Rd* plays a crucial role in various design philosophies and structural designs, as it determines the extent to which a system can minimize the impact of a disruption. However, there is still debate about the precise definition of *Rd* (Kanno and Ben-Haim, 2011). *Rd* can be described as the system's capacity to remain functional and maintain its operations in the face of disruptions (Faturechi and Miller-Hooks, 2015; Samsuddin et al., 2018). According to Tong (2021), the built environment resilience dimensions encompass robustness, redundancy, efficiency, and multi-functionality. Furthermore, the relationship between *Rd* and *Rb* is demonstrated by two key characteristics (Yazdani and Jeffrey, 2012). The strong *Rd* is bounded by the *Rb*, and in some cases, they may share identical qualities (Kanno and Ben-Haim,

TABLE 5 Summary of the typical *Rb*, *Rd*, *Ic*, and *It* resilience qualities/indicators covered in this research.

#	Resilience quality (RQ)/ Indicator	Definition/Scope	References
2.0	Building Robustness (*Rb*)	*Rb* is a measure of urban infrastructure's resilience, assessing its stability and strength against shocks. It is determined by the system's performance during disruptive events	(Ouyang, 2017; Rus et al., 2018; Lak et al., 2020; Birchall and Bonnett, 2021; Shafiei Dastjerdi et al., 2021; Bocchini et al., 2014; da Silva et al., 2012; Kammouh et al., 2020; Moghadas et al., 2019; Tong, 2021; Bruneau et al., 2003; Deshkar and Adane, 2016)
2.1	Strength and Stability of the System		
2.2	Withstanding Disruptive Events		
2.3	Maintaining Functionality during the Event		
2.4	System's Performance		
2.5	Minimizing Losses from Hazards		
2.6	Low Failure Probability		
3.0	Promoting Redundancy (*Rd*)	The concept of *Rd* holds paramount significance in various design philosophies, especially in the context of structural designs. *Rd* can be defined as the degree to which systems, facilities, and their components can uphold functionality and structural integrity when confronted with disruptions	(Kanno and Ben-Haim, 2011; Godschalk, 2003; Astaneh-Asl, 2008; Agrawal et al., 2010; Yazdani and Jeffrey, 2012; Faturechi and Miller-Hooks, 2015; Lounis and McAllister, 2016; Samsuddin et al., 2018; Tong, 2021; Nik and Moazami, 2021)
3.1	Reserve Capacity		
3.2	Adaptive and Absorptive Coping Capacity		
3.3	Diversity and Backup Capacity		
3.4	Governance Frameworks		
3.5	Emergency resources and supplies		
3.6	Insurance and disaster funds		
7.0	Broadening Inclusivity (*Ic*)	*Ic* centers around extensive consultation and engagement with communities, addressing how specific communities, sectors, or locations can effectively cope with shocks and stresses. Taking action on *Ic* serves to enhance and contribute to future decision-making processes	(Salimi and Al-Ghamdi, 2020; Sharifi, 2016; Arup and The Rockefeller Foundation, 2014a; Sharifi, 2016; US IOTWS, 2007a; Pfefferbaum et al., 2013; UNDP Drylands Development Centre, 2016; Schwind, 2020; Sharifi, 2016; UNDP Drylands Development Centre et al., 2014; Sharifi, 2016; Pfefferbaum et al., 2013)
7.1	Communities' Engagement		
7.2	Shared Ownership Action		
7.3	Feeding the Future Decision-Making		
7.4	Improving Resilience		
8.0	Consolidating Integration (*It*)	Incorporating *It* processes into the city's systems promotes consistency in decision-making and investment placement. Networking information from various parts of the city's systems enables them to operate collaboratively and respond swiftly. Ensuring alignment and integration across systems and their operational scales not only supports desired outcomes but also maintains coherence in decision-making processes	(Shafiei Dastjerdi et al., 2021; Arup and The Rockefeller Foundation, 2014a; Owens, 2005; Chelleri and Marta, 2012; Morphet, 2010; Lynch, 1960)
8.1	Adaptive Capacity		
8.2	Systems Integration		
8.3	Systems' Information Exchanging		
8.4	Decision-Making Promotion		
8.5	Resilience policies are integrated with other policies and programs		

2011). On the other hand, insufficient *Rd* of a system can lead to premature deterioration and eventual collapse. This can be observed in the case of highway bridges constructed in North America during the mid-20th century (Astaneh-Asl, 2008; Agrawal et al., 2010; Lounis and McAllister, 2016). To enhance the *Rd* of a system, it is important to establish comprehensive plans that ensure an abundance of disaster resources. These plans should include sufficient funding and necessary materials to mitigate future disasters effectively (Huang et al., 2021).

Inclusivity (*Ic*) involves consulting and engaging communities to address shocks and stresses in specific communities, sectors, or locations. *Ic* improves and feeds future decision-making processes through proper stakeholder feedback (Salimi and Al-Ghamdi, 2020; Sharifi, 2016). By actively involving various stakeholders, shared ownership actions promote efficient information exchange and integration within the city's systems (Salimi and Al-Ghamdi, 2020). Community engagement in discussions about the threats to the built environment fosters collective actions, improving resilience and preventing community isolation (Arup and The Rockefeller Foundation, 2014a). Methods such as questionnaire surveys, focus group discussions, interviews with key informants, and community conversations facilitate community participation (Sharifi, 2016; US IOTWS, 2007b; Pfefferbaum et al., 2013; UNDP Drylands Development Centre, 2016; Schwind, 2020). According to the (UNDP Drylands Development Centre et al., 2014), community participants would help develop resilience tools, systems, or indicators by reaching a consensus. Surveys and stakeholders' participation in

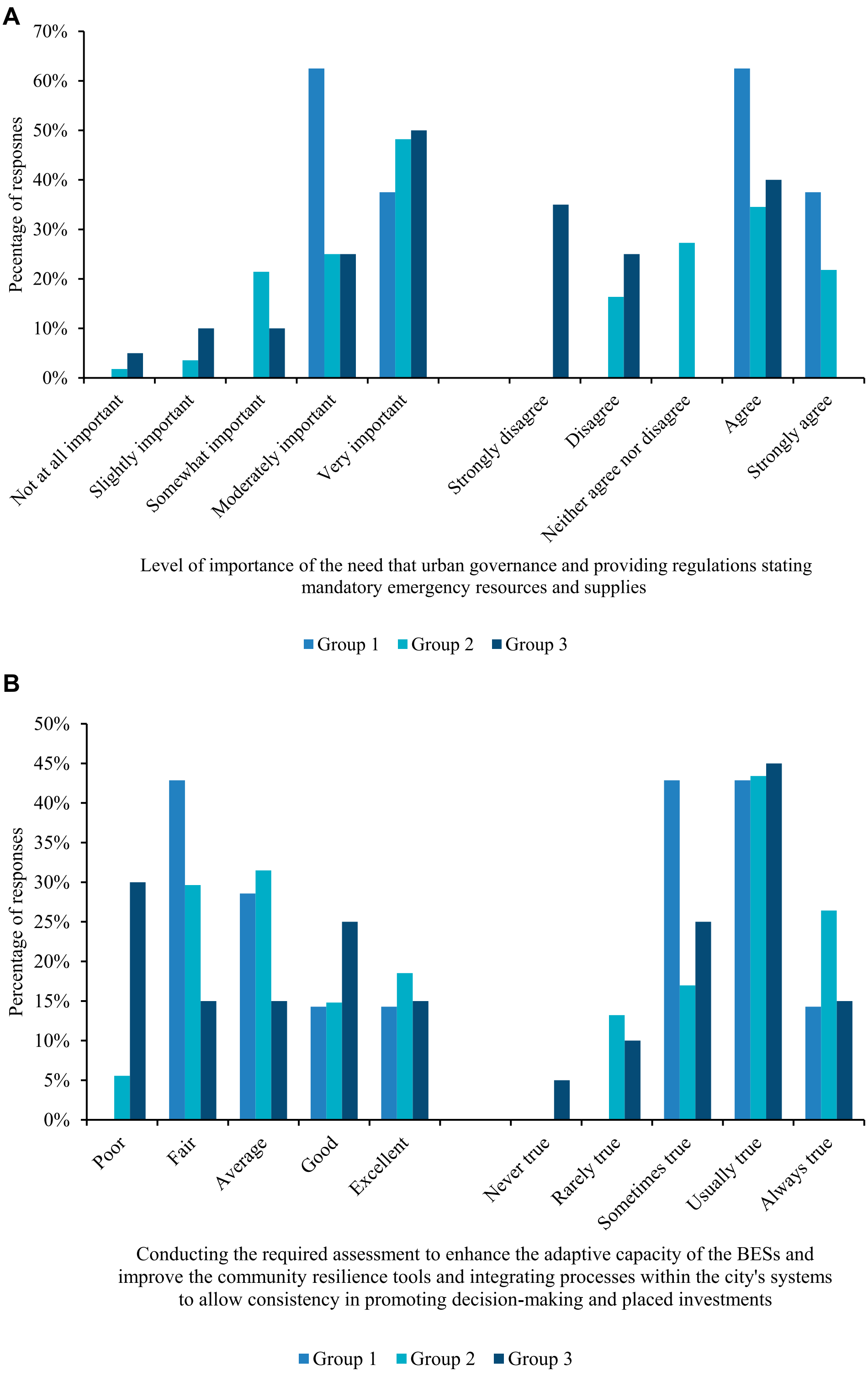

FIGURE 4
Groups' responses to **(A)** leveling the importance of the need for urban governance and providing regulations stating mandatory emergency resources and supplies, **(B)** conducting the necessary assessment to improve the adaptive capacity of BESs, improve the resilience of community tools by the government authorities, and processes integration within the city's systems.

the discussions help assess community resilience and identify improvement strategies (Sharifi, 2016; Pfefferbaum et al., 2013). *Ic* of people and places is supported by a place-based approach (Owens, 2005), which encourages understanding of the way of acting and behaving through collective culture and reflective past (Shafiei Dastjerdi et al., 2021).

Integrating processes across different city systems enhances decision-making reliability. This integration involves networking

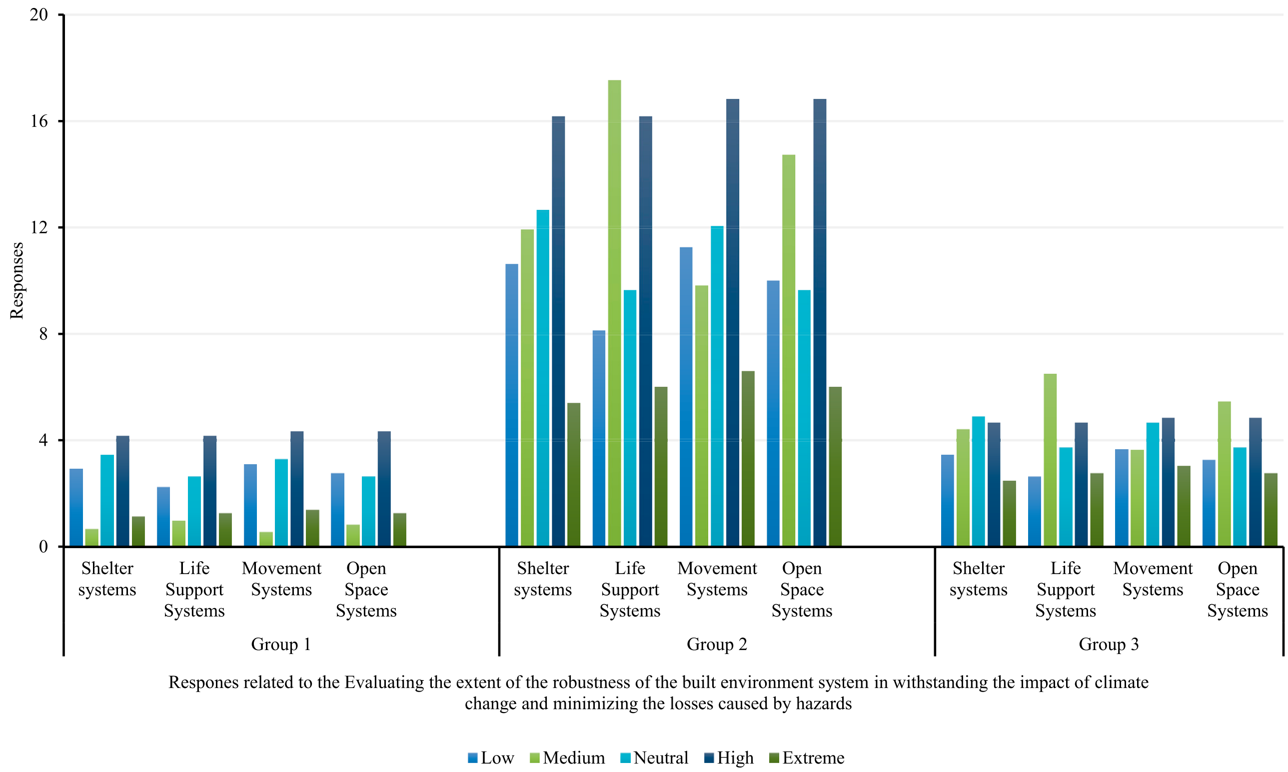

FIGURE 5
Evaluating the extent of the *Rb* of the BESs.

the systems' information to facilitate mutual operation and rapid response (Salimi and Al-Ghamdi, 2020). The information exchange among city systems enables collective functioning and swift response to threats and disasters (Arup and The Rockefeller Foundation, 2014a). For instance, integrating natural systems with the constructed form will improve ecological resilience and reduce the occurrence of such disasters (Shafiei Dastjerdi et al., 2021; Chelleri and Marta, 2012). The alignment and integration of systems across various operational scales are crucial for maintaining consistency in decision-making and supporting positive outcomes. This involves sharing information among systems to enable them to function collectively and respond quickly to threats or disasters within a city (Arup and The Rockefeller Foundation, 2014b).

Similarly, in spatial resilience, it is critical to integrate all components of a special network and places through adaptive capacity in a multi-scale hierarchy to ensure consistency and functionality (Shafiei Dastjerdi et al., 2021). Collaboration between relevant authorities and stakeholders in adopting design approaches and integrated planning can reduce the associated implications and result in a holistic model (Morphet, 2010). Also, policies, including the functioning and nature of places, and other procedures and programs must be integrated for spatial resilience. Spatial resilience relies on the adoption of guidelines specific to the place, encompassing both bottom-up integrated and top-down institutional frameworks (Shafiei Dastjerdi et al., 2021). So, in this context, the community's social role and the importance of integrated physical settings have been emphasized by Lynch's theory (Lynch, 1960). Table 1 outlines the resilience qualities and characteristics covered in this study.

1.1 Objectives

It is essential to integrate pertinent strategies for better system preparedness and response (Rus et al., 2018), which can be achieved through collaborative efforts of stakeholders (Samsuddin et al., 2018; Schipper and Pelling, 2006; Lin et al., 2008; Malik et al., 2019; AlQahtany and Abubakar, 2020) and by ensuring the integration of RQs into the systems (Samsuddin et al., 2018). This paper intends to quantify four different resilience qualities for the built environment's ability to withstand climate change risks and stresses. The quantification follows procedures used in previous research by Al-Humaiqani and Al-Ghamdi for the other four resilience qualities assessed (Al-Humaiqani and Al-Ghamdi, 2023e). This study involves the second part of the survey that collects the target audience's perception. The objective of this paper is driven by the increasing climate change threats and their direct and indirect impacts on the BESs (Schipper and Pelling, 2006; IFRC, 2003; Li et al., 2012; Sato, 2017; Alec Tzannes, 2019; Andrić et al., 2019; Halder and Bandyopadhyay, 2021; Al-Humaiqani and Al-Ghamdi, 2022; Auffhammer, 2022; Bamdad et al., 2022; Blekking et al., 2022; Hidalgo-Galvez et al., 2022; Hürlimann et al., 2022; Larsson Ivanov et al., 2022; Mayo and Lin, 2022; Wang et al., 2022; Wollschlaeger et al., 2022; Al-Humaiqani and Al-Ghamdi, 2023f; Tahir and Al-Ghamdi, 2023). Hence, understanding the built environment

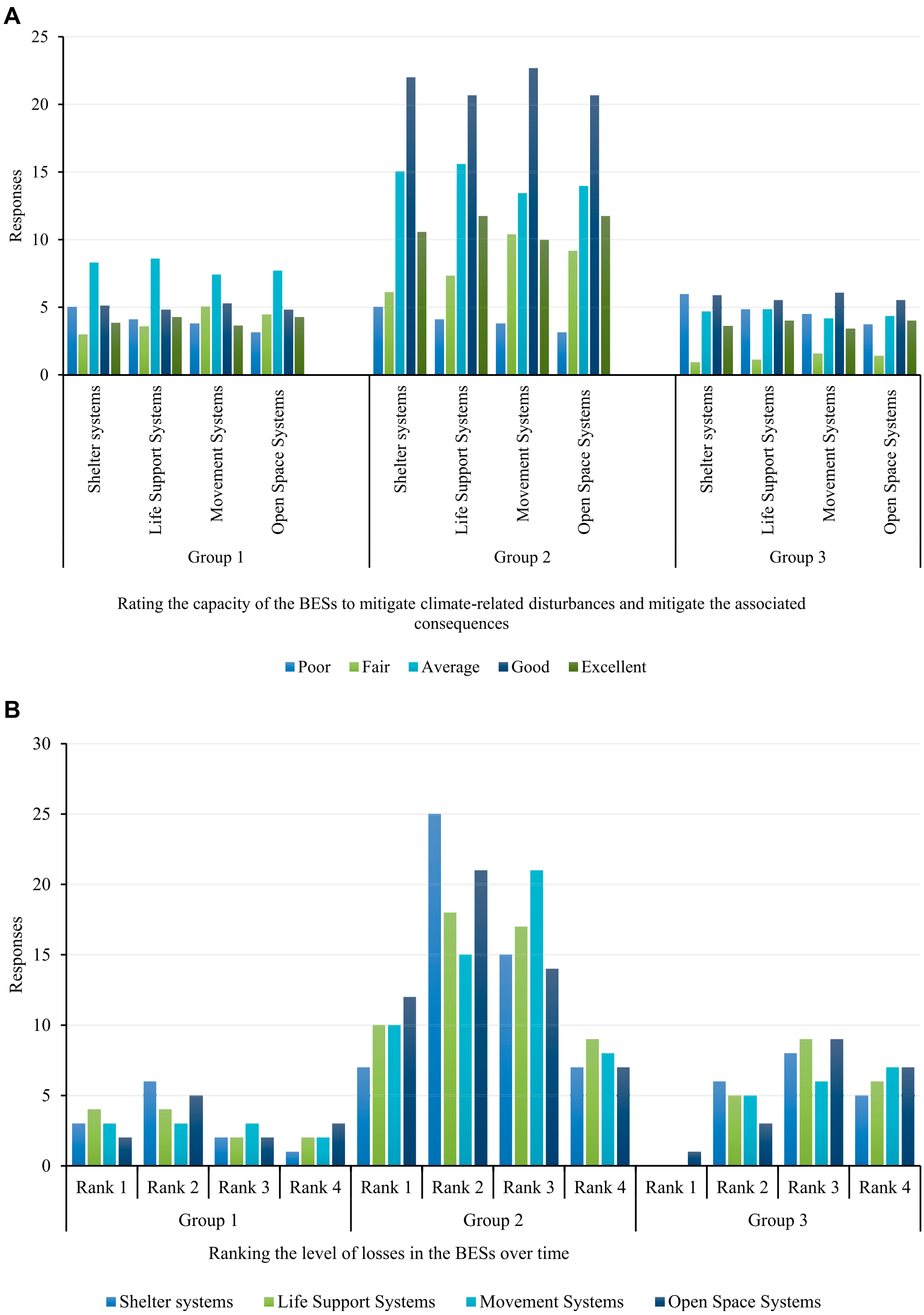

FIGURE 6
Evaluations of the **(A)** BESs' ability to mitigate climate-related disruptions and minimize associated consequences and rating the capacity and **(B)** ranking the level of losses over time.

resilience can underscore the importance of enhancing relevant policies and strategies (Al-Humaiqani and Al-Ghamdi, 2022; Alyami et al., 2023). The different objectives include 1) the determination of stakeholders' perceptions about the built environment resilience; 2) the investigation of the interrelations among different resilience indicators, characteristics, and measures; and 3) the determination of the importance of the BESs' RQs.

The first objective is to assess the quality of responses and evaluate the audience's understanding of climate change resilience. The second objective is to investigate the interrelationships and interconnections

TABLE 6 Evaluating the capacity of the BESs to buffer climatic disturbances and reduce or prevent the resulting consequences (Relative importance index).

Statement subject	Group 1		Group 2		Group 3		Overall	
	RII	Rank	RII	Rank	RII	Rank	RII	Rank
Shelter systems	0.6080	1	0.6060	2	0.4200	1	0.5607	2
Life Support Systems	0.6080	1	0.6299	1	0.4067	2	0.5705	1
Movement Systems	0.6080	1	0.6060	2	0.4200	1	0.5607	2
Open Space Systems	0.6080	1	0.6060	2	0.4200	1	0.5607	2

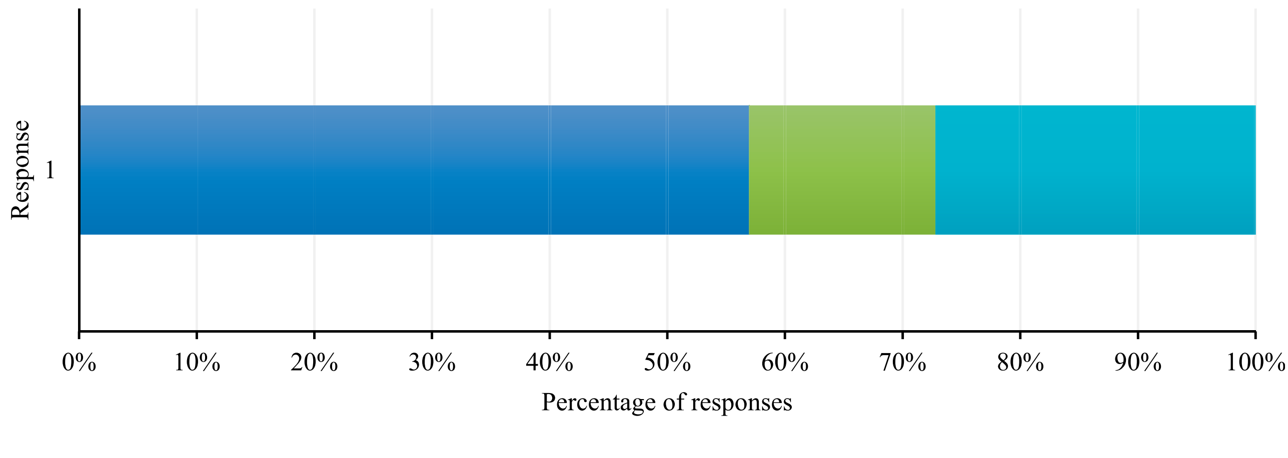

FIGURE 7
The progress in promoting good practice in the built environment at the community level and advancing future measures to reduce the impacts of climate change.

TABLE 7 Ranking the diversity and backup capacity of the BESs to withstand climate hazards.

Statement subject	Group 1		Group 2		Group 3		Overall	
	RII	Rank	RII	Rank	RII	Rank	RII	Rank
Shelter systems	0.1600	2	0.5493	3	0.3800	1	0.4279	3
Life Support Systems	0.1920	1	0.5791	1	0.3800	1	0.4508	1
Movement Systems	0.1920	1	0.5731	2	0.3733	2	0.4459	2
Open Space Systems	0.1920	1	0.5791	1	0.3800	1	0.4508	1

between resilience indicators. The third objective is to assess the importance level of these resilience indicators. The rationale behind these objectives is the challenges posed by climate change and the need to adapt. Numerous studies have highlighted the importance of improving resilience in the design, construction, and operation of BESs (Li et al., 2012; Sato, 2017; Alec Tzannes, 2019; Halder and Bandyopadhyay, 2021; Al-Humaiqani and Al-Ghamdi, 2022; Auffhammer, 2022; Bamdad et al., 2022; Hürlimann et al., 2022; Larsson Ivanov et al., 2022; Wollschlaeger et al., 2022; Mayo and Lin, 2022; Andrić et al., 2019; Blekking et al., 2022; Hidalgo-Galvez et al., 2022; Wang et al., 2022; Forzieri et al., 2018; Khavarian-Garmsir et al., 2019; Gallego-Schmid et al., 2020; Mallen et al., 2020; Saranko et al., 2020; Carter et al., 2021; Koc and Acar, 2021; Barnes et al., 2022; Caby et al., 2022; Gür, 2022; Hiruta et al., 2022; Manes et al., 2022; Mattauch et al., 2022; Murshed et al., 2022; Sovacool et al., 2023). To achieve these objectives, insights from urban planners, policymakers, developers, professionals, and experts on resilience indicators are required.

2 Methods and procedures

A questionnaire on RQs of BESs was distributed to participants from regulatory and governmental authorities, the construction industry, and academic institutes. The numerical, structured, and

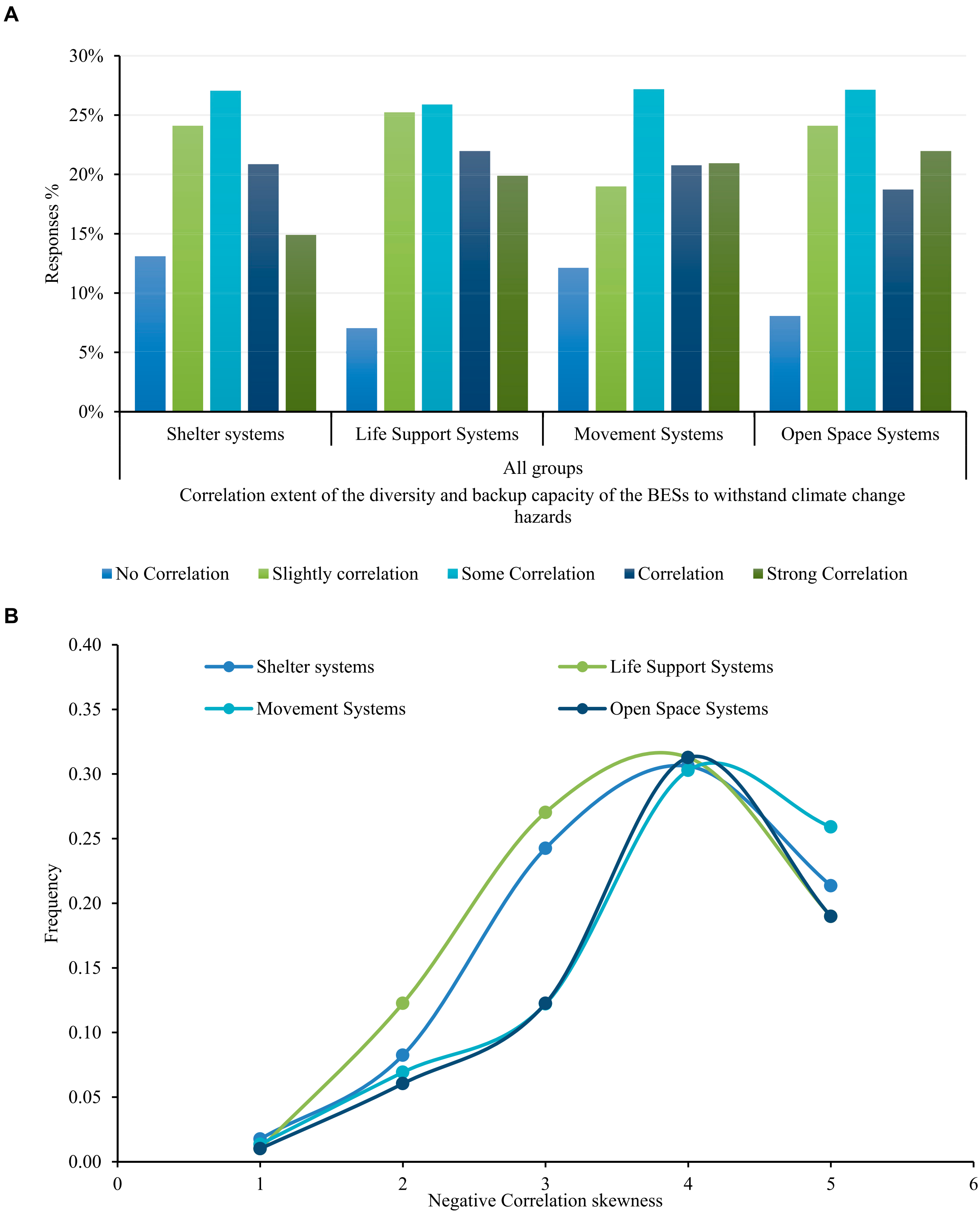

FIGURE 8
Evaluations of *(A)* correlation of the diversity and backup capacity of the BESs to withstand climate change hazards and *(B)* progress in promoting good practice in the built environment at the community level and advancing future measures to reduce the impact of climate change disturbances.

closed-ended questionnaire ensured the objectivity and standardization of the engagement (Cohen et al., 2018). This survey covered the four RQs: robustness (*Rb*), redundancy (*Rd*), inclusivity (*Ic*), and integration (*It*). These four RQs are visually represented in Figure 1. The remaining four RQs, depicted in grey hatch marks, were independently examined. These eight RQs form

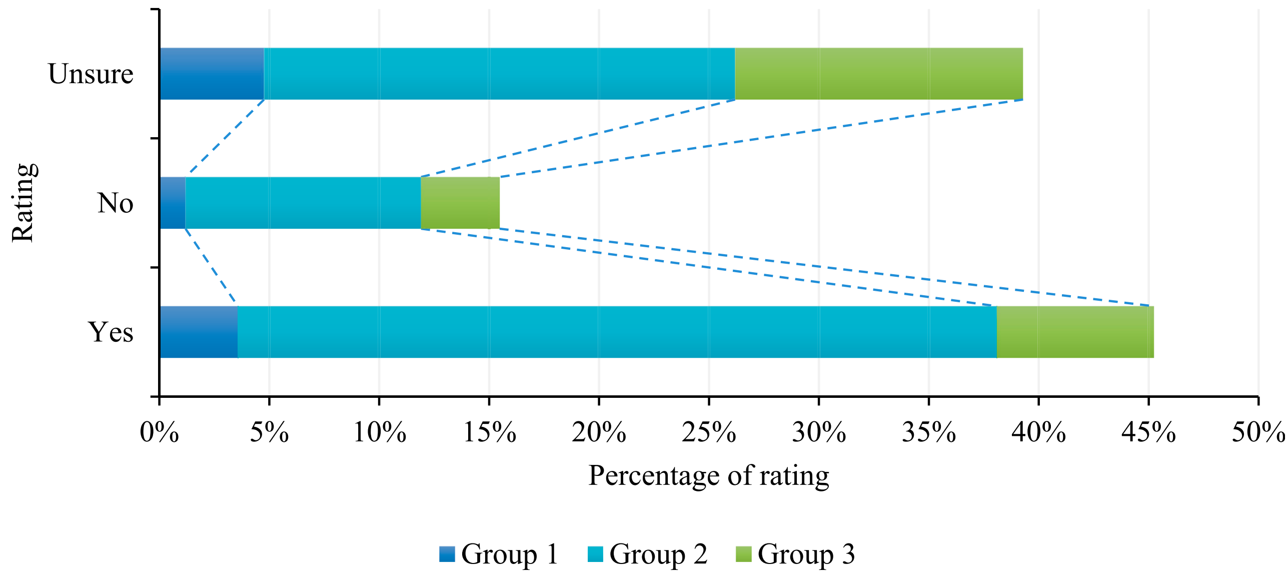

FIGURE 9
The progress in promoting good practice in the built environment at the community level and advancing future measures to reduce the impact of climate change disturbances.

the basis of the proposed holistic RQs framework. The graphic depicting these RQs is used consistently in all publications resulting from this research, aiming to maintain connection and inform readers about the covered RQs. Figure 2 provides an explanation of the questionnaire survey distribution procedures.

2.1 Questionnaire design

In Figure 3, stakeholders were categorized into three groups based on their professional and task scope The first group consists of participants from governmental authorities and regulatory bodies. The second one includes professionals from the construction industry, while group 3 focuses on academic institutions and non-governmental organizations. The first group consists of regulatory bodies and government-owned businesses. To start, the participants' working fields, experiences, occupations, roles, capacity-building backgrounds, and current sectors of work were determined. The survey questionnaire consists of three parts, starting with a briefing of the audience about its scope and objectives. It also declares the no-risk engagement and confidentiality of information. The survey continued with questions related to demographics and the consent to accept or decline participation in the study. The demographic questions covered education level, occupation, experience, and the sector of work, which determined the appropriate group for each participant. The third part covers four main topics: 1) Building Robustness (*Rb*), 2) Promoting Redundancy (*Rd*), 3) Broadening Inclusivity (*Ic*), and 4) Consolidating Integration (*It*). Table 2 summarizes the content and structure of the questionnaire, while Table 3 outlines the boundaries, structure of the questions, audience, subject, and Indicators. Also, it outlines the occupations and roles of the participants. Table 4 presents the respondents' groups and statistical tests applied to the questions. Each group was allocated approximately fifty questions to address the discussed objectives in section 1.1.

Determining the populations of the three stakeholder groups was challenging due to the limitations of the target audience. Nevertheless, the calculations show that the population ranges between 350 and one thousand. The sample size was determined accordingly based on various scientific references, including the guidelines recommended by Cohen et al. (2018). These guidelines primarily suggest using online calculators such as those provided by Raosoft (2022), MaCorr (Research, 2022), Creative Research Systems (2022), Qualtrics (2022), and the SurveyMonkey website (SurveyMonkey, 2022). The chosen level of confidence is 95%, with a margin of error of 5%. Considering the limitations of each group, the total sample size for the three groups ranges between 169 and 278.

2.2 Questionnaire distribution process

The participants were chosen using the probability (random sampling) method, taking into account their audience profiles, background knowledge, and experiences. Group one consists of respondents from institutions and organizations owned by the government and regulatory agencies. Group two comprises professionals in the construction sector, such as developers, consultants, design firms, contractors, project managers, and real estate professionals. On the other hand, group three consists of respondents who work for NGOs, NPOs, academic institutions, and universities. The entities were contacted directly and informed of the study's scope and goals. They were asked to disseminate the survey among possible respondents from engineering departments in their organizations. Apart from that, the researchers contacted certain regulatory agencies and governmental authorities through phone

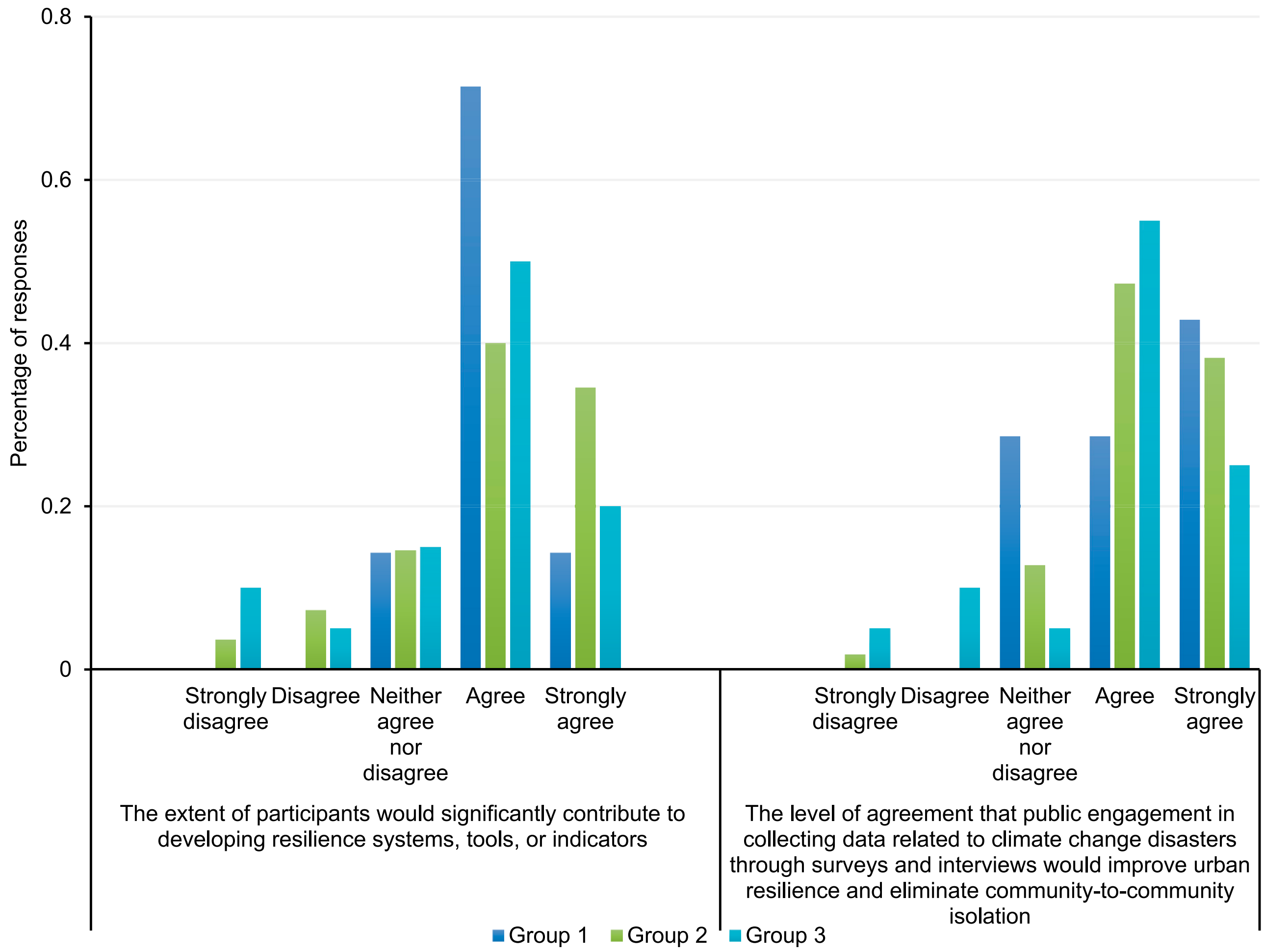

FIGURE 10
The public crucial role in developing resilience systems, tools, and indicators, as well as improving urban resilience and reducing community isolation through public engagement.

and email and visited some others in person. In addition, the researchers made local calls to several engineering and construction firms. In addition, the participation of many NGOs, NPOs, academic institutions, and universities was requested in several ways.

The survey was conducted using the SurveyMonkey platform and distributed electronically to the audience. An introductory email and approval letter from the institutional review board (IRB) at Qatar Biomedical Research Institute (QBRI) were sent to the audience. This included a diverse group of approximately two thousand individuals from various engineering backgrounds, including decision-makers, regulators, researchers, academics, experts, and professionals. A turnover of 240+ responses was accomplished with 188 completed responses. The demographic information was discussed in section 3, including occupation, educational background, geographical exposure of expertise, roles, experience, and the entity they represent. Supplementary Figure S1 outlines the research methodology and survey distribution process applied in this study. The survey consisted of general questions for all participants and specific questions for three groups based on their affiliations: Group 1 (questions 13–69), Group 2 (questions 70–126), and Group 3 (questions 127–183). Additional instructions were provided in questions 11 and 12 to guide participants in answering the survey.

2.3 Validity and reliability of the questionnaire

The survey questions were extracted from the detailed review conducted on the up-to-date studies on the built environment's *Rb*, *Rd*, *Ic*, and *It*. The first draft was shared with three professionals from different groups with deep experience in urban resilience, sustainability, environmental sciences, and engineering. Specific questions against every six indicators of each resilience quality were prepared for each group separately, as shown in Table 3. The aim was to obtain responses that accurately represent the understanding and knowledge of each group. The selected indicators under each quality remain the same for all the groups, maintaining the reliability and consistency of comparisons. After a thorough review, the professionals agreed on the proposed questions, making minor adjustments based on their comments before distributing the survey to the intended audience. Survey approval was obtained from the Institutional Review Board (IRB) at Hamada Bin Khalifa University's Qatar Biomedical Research Institute to ensure ethical standards and the protection of respondents' privacy. The approval letter confirmed compliance with ethical guidelines and assured the confidentiality of respondents' information and involvement.

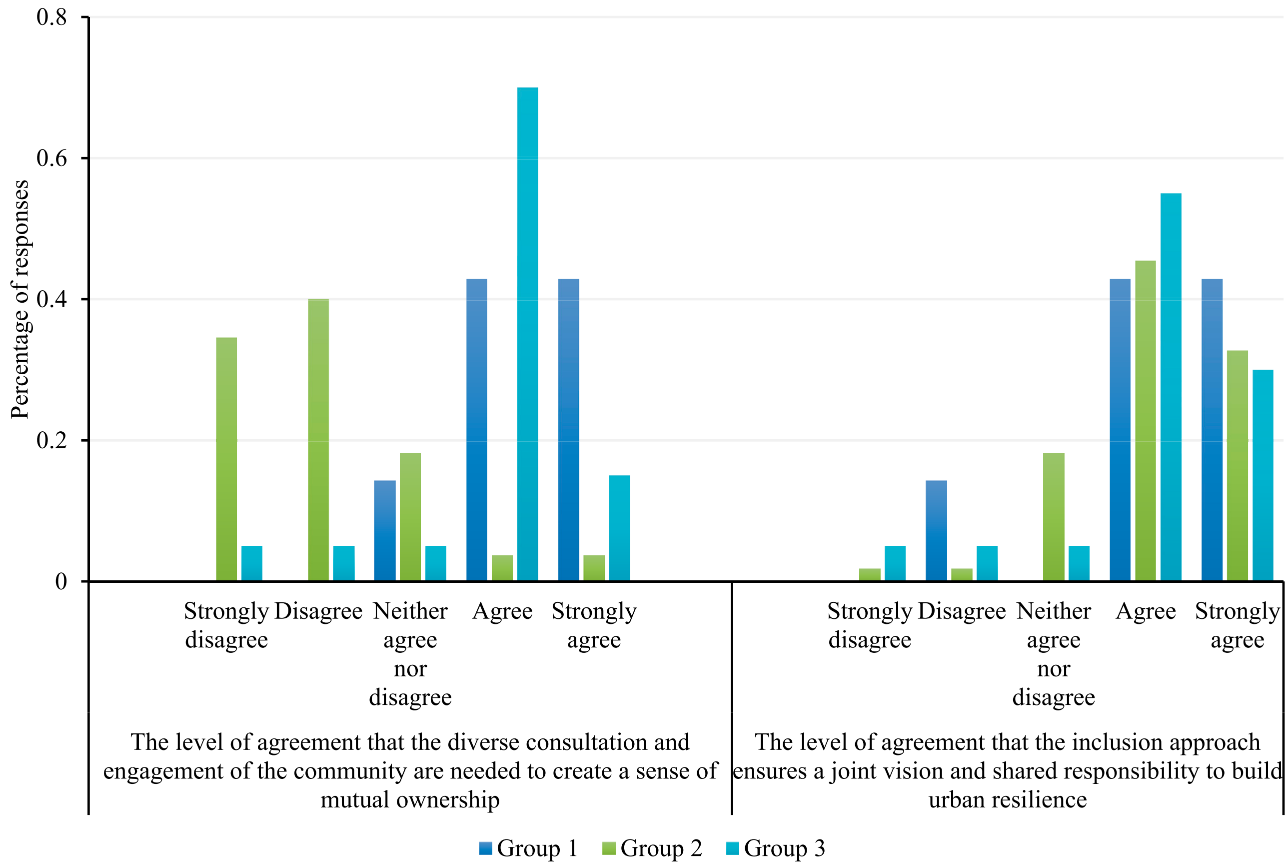

FIGURE 11
The community required inclusive consultation and engagement to establish a collective sense of ownership and agreement. This approach to inclusion ensures a unified vision and shared responsibility for developing urban resilience.

The survey was conducted using the SurveyMonkey platform for 4 months to gather data from the audience. Various statistical techniques were employed to assess the validity and reliability of the obtained results. Pearson's chi-squared (X2) and Students' T-tests were used to understand the complexity and correlations among the measured indicators. Additionally, the reliability and consistency of the measures, including the Likert scales, were evaluated through Cronbach's Alpha (α) test.

2.4 Ranking *Rb*, *Rd*, *Ic*, and *It* qualities

Various ranking scales were chosen based on the type of question and assessed indicator. Level 1 represents the most important resilience quality in all cases, and five indicates the lowest. The importance of the assessed quality or indicator was evaluated through the relative importance index (RII) method, with rankings ranging from 1 to 5 as per Eq. (1).

$$RII = \sum \frac{W_i}{A\,x\,N'} \tag{1}$$

Where W_i represents the weight assigned to each variable by the respondent, A is the highest weight, and N' is the total number of respondents.

A Pearson's Chi-squared (X^2) test was used to assess the influence of group type on evaluating the *Rb* extent of the BES in withstanding the climate change impacts and minimizing the losses caused by hazards.

The study utilized the procedures outlined by Al-Humaiqani and Al-Ghamdi (2023e) and Ngin et al. (2020) to assess participants' perceptions of specific resilience characteristics and indicators of the built environment concerning climate change. The survey examined the impact of climate change on city systems, exploring coping and adaptation strategies to boost resilience against potential damage. Questions aimed to gather respondents' views on enhancing the resilience characteristics of BESs against climate change. The participation definitions and categories are illustrated in Figure 3 and Supplementary Figure S2, while the assessment of the BESs' robustness is based on six main indicators, detailed in Table 5. Respondents' perceptions of these systems' capacity to withstand climate-related disturbances and minimize their effects were collected to assess system performance.

Feedback was gathered on the role of urban governance in developing the ability to adapt to uncertainty and change, particularly in BESs. Opinions were also obtained on conducting assessments to enhance the adaptive capacity of BESs and community resilience tools. Additionally, participants provided input on integrating processes within city systems to promote consistent decision-making and investments.

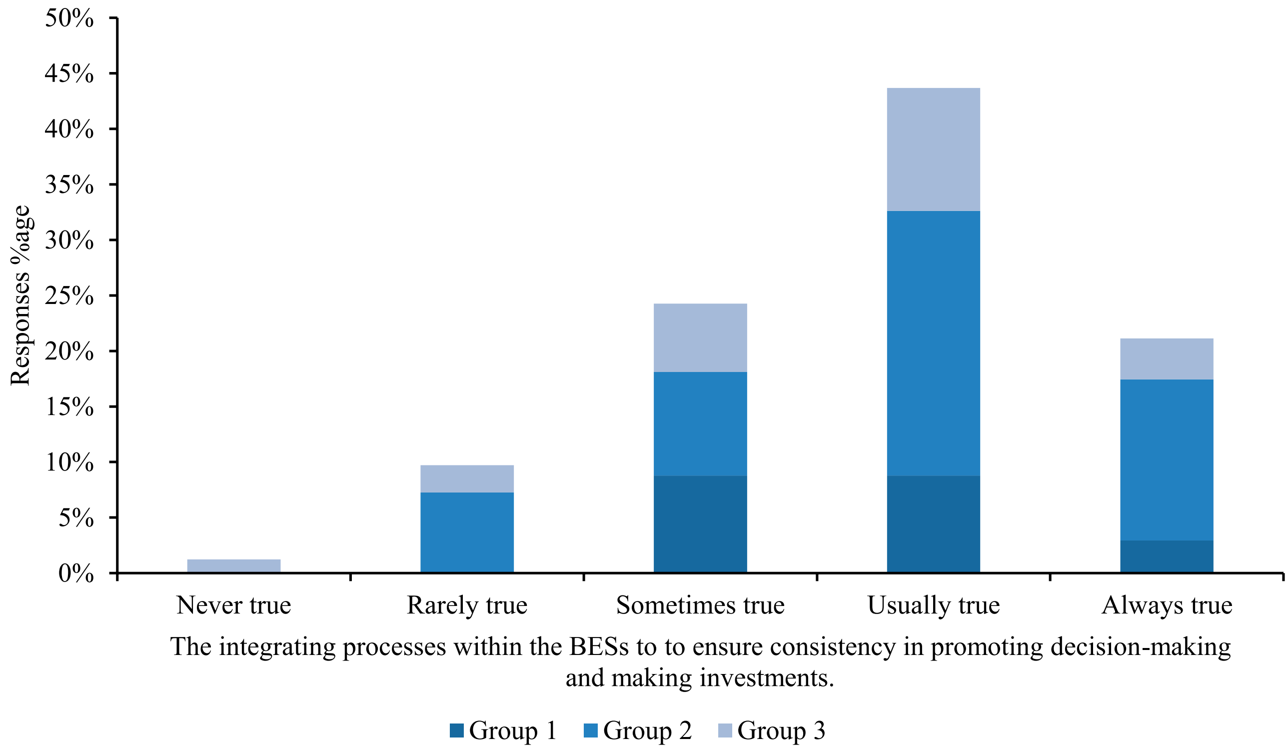

FIGURE 12
Responses on the integrating processes within the BESs to ensure consistency in promoting decision-making and making investments.

3 Results and discussion

The collection of survey responses took place during the period from September to December 2022. The majority of responses came from construction professionals (group 2), comprising 55% of the total, while groups 1 and 3 accounted for 20% and 25%, respectively, as illustrated in Supplementary Figure S3.

3.1 Importance of urban governance and providing regulations stating mandatory emergency resources and supplies

The analysis presented in Figure 4A highlights the significance of urban governance in building resilience to uncertainty and change, especially in Built Environment Systems (BESs). The findings indicate a collective inclination towards considering urban governance moderately to highly important. Group 1 displayed a tendency towards moderate importance, while groups 2 and 3 leaned more towards deeming it highly important. This analysis suggests a shared agreement among respondents across all three groups on the need for urban governance to strengthen its transformative capabilities in addressing uncertainty and change within BESs. Moreover, Figure 4A depicts a strong consensus among most respondents regarding the importance of regulations that mandate emergency resources and supplies for BESs, particularly those situated in vulnerable areas.

The analysis indicates that group 1 finds the assessment of enhancing the adaptive capacities of BESs and related tools inadequate, with responses mostly falling between fair and average. Similarly, over 60% of Group 2 members feel that efforts to enhance adaptive capacities are insufficient. However, less than 30% of all respondents find the actions taken satisfactory.

In contrast, in group 3, 30% consider the actions by relevant authorities to be poor, while another 30% rate them as fair to average. Conversely, 25% view the actions as good, as depicted in Figure 4B. Respondents also shared their opinions on integrating processes among the city's systems to ensure consistency in decision-making and investments. In group 1, 65% believe the integration level is average, with the rest strongly agreeing. Group 2 presents a different trend, with around 50% disagreeing with this notion. Group 3's perspective aligns more with Group 2's, but no participant strongly agrees on integrating the processes of existing BESs.

3.2 Building robustness (*Rb*)

This section discusses response rates from various groups on their comprehension of the importance of enhancing resilience against the impacts of climate change. Figure 5 illustrates the extent of the *Rb* of the BESs in line with notes by Ouyang (2017) that emphasize the BESs' resilience in enduring and recovering from disasters, referencing the resilience of a BES to its robustness in withstanding and recovering from a disaster. The results did not provide enough evidence to reject the null hypothesis that there are no differences in grouping and expertise types (p-value of 0.995 at 5% significance level). Most

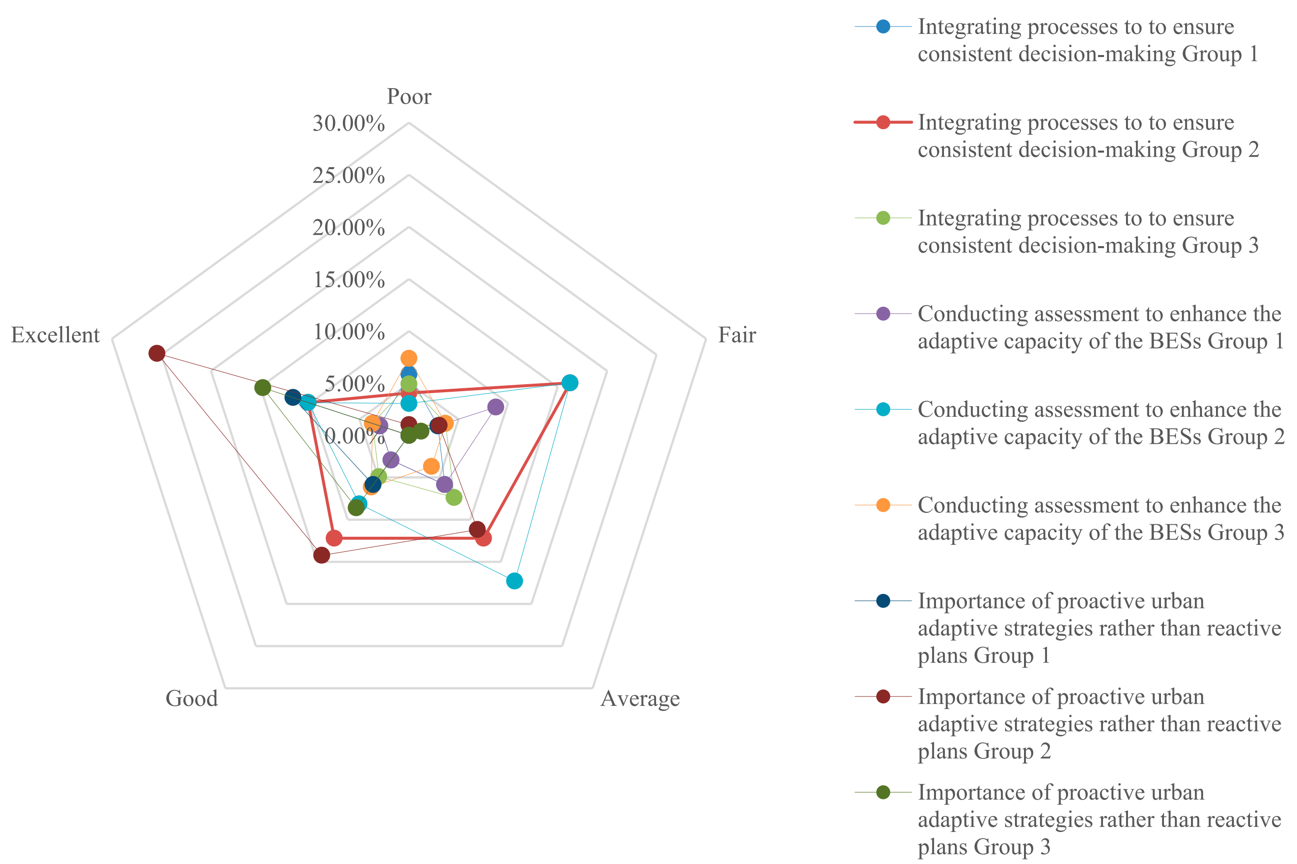

FIGURE 13
Groups' ranking of the significance of several indicators, including the BESs' ability to adapt to long-term changes that contribute to uncertainty, conducting the required assessment to improve the adaptive capacity of the BESs and improve the tools of community resilience assessment and level of importance of implementing proactive urban adaptive strategies instead of reactive plans and integrating disaster resilience into urban planning.

respondents in Group 1 and Group 2 perceive the *Rb* extent of the BESs to climate change impacts and hazard-induced losses as high. In contrast, Group 3 respondents see this *Rb* extent at a moderate level, suggesting potential for enhancing building standards, particularly from a research and academic standpoint. According to Kammouh et al. (2020), a system is deemed resilient when it demonstrates high robustness, low failure likelihood, and rapid recovery capabilities. Figure 6 present evaluations of the BESs' ability to mitigate climate-related disruptions and minimize associated consequences, echoing (Bruneau et al., 2003) view that *Rb* is the system's strength to withstand disruption and measure absorptive capability to reduce the negative impacts and consequences.

The robustness of a project is attributed to its early phase preparation, indicating the urban ecosystem's capacity to maintain essential functions (Tong, 2021). In group 1, most respondents rated the capacities of the four BESs between good and excellent, averaging at about 50%. For group 2, the majority perceived the systems' capacities as generally good, with approximately 55% rating them between average and excellent. This confirms that protective infrastructure targeting climate hazards lacks resilience and diversity, the research by Birchall and Bonnett (2021) indicates. Group 3 showed different perceptions, with their views falling within a similar range for different systems. The analysis suggests that group 2's confidence level is high, likely influenced by their experience and skills in system construction. Conversely, the perspectives of groups 1 and 3 are notably influenced by each group's role. Table 6 displays the results of the relative importance index analysis, ranking the BESs' capacity to mitigate climate-related disturbances and their consequences. Group 1 ranked the four BESs equally, while groups 2 and 3 had different rankings. Group 2 prioritized life support systems, whereas Group 3 considered the remaining two systems more crucial. The results showed a consensus with the findings of the study by Salimi and Al-Ghamdi (2020), which proposes that strategic approaches to building resilient infrastructure should prioritize robustness, redundancy, and resourcefulness. The statistical analysis did not yield enough evidence to reject the null hypothesis of grouping and professionalism differences, with *p*-values ranging between 0.875 and 0.999 at a 5% significance level.

3.3 Promoting redundancy (*Rd*)

Redundancy (*Rd*) is fundamental in design philosophies, especially structural designs (Al-Humaiqani and Al-Ghamdi, 2022). It refers to the ability of systems and facilities to sustain functions (Samsuddin et al., 2018) and integrity in the face of disruptions (Faturechi and

Miller-Hooks, 2015). The participants shared their opinions on whether authorities and organizations can prepare for expected or unexpected climate change disasters. Figure 7 indicates that 56% of respondents agree with the notion, and 44% expressed doubts about the progress in promoting good practices in the built environment. This observation may be attributed to the lack of progress due to limited community involvement in proactive measures, which authorities and regulatory bodies should address. On the other hand, Table 7 summarizes the ranking of the diversity and backup capacity of the BESs to withstand climate hazards. The results show that life support systems and open spaces are ranked highest, followed by movement and shelter systems.

This study determined the relationship between the diversity and backup capacity of BESs in relation to their ability to withstand climate change hazards for different built environment systems (Supplementary Figure S4). The *Rb* and *Rp* of an urban system is influenced by its *Rd*, with *Rb* often equated to strong *Rd* according to Kanno and Ben-Haim (2011). Based on specific questions, the analysis presented in Figure 8 identified correlations within BESs, underscoring the importance of *Rd* in enhancing their resilience. Participants also shared views on promoting good practices in the built environment at the community level and future strategies to mitigate the climate change impacts. Figure 9 illustrates diverse opinions among the groups, with 45% in agreement, 15% disagreement, and approximately 40% unsure about the advancement of good practices. This highlights the critical notion that inadequate *Rd* may result in premature system deterioration and subsequent collapse, as evidenced by Astaneh-Asl (2008); Agrawal et al. (2010); Lounis and McAllister (2016).

3.4 Broadening inclusivity (*Ic*)

Broad consultation and community engagement are essential for establishing a shared sense of ownership. As per the Rockefeller Foundation and Arup, community engagement encompasses all groups, including vulnerable populations, collaboratively addressing the challenges faced by various sectors and working to reduce isolation between communities. This inclusive approach promotes a cohesive vision and joint accountability in building a resilient city (Arup and The Rockefeller Foundation, 2014b). It is widely acknowledged that an inclusive strategy ensures a unified vision and collective responsibility for urban resilience, emphasizing the importance of valuable stakeholder input in shaping a decision-making process that is inclusive (Sharifi, 2016).

This section analyzes the relationship between *Ic's* indicators and their correlations, which include community engagement, shared ownership action, informing future decision-making, and enhancing resilience. Achieving an inclusive decision-making process involves obtaining feedback from relevant stakeholders (Salimi and Al-Ghamdi, 2020; Sharifi, 2016). The study assessed participants' confidence in contributing to resilience development by achieving consensus as a united community. It also evaluated agreement levels on improving urban resilience and reducing community isolation through public engagement in collecting data on climate change disasters through surveys and interviews. The results for both perceptions are displayed in Figure 10, highlighting the importance of various stakeholders participating in shared ownership actions to facilitate information exchange and promote efficient integration among different components and systems as suggested by Salimi and Al-Ghamdi (2020).

To evaluate community resilience effectively, it is essential to identify priorities, utilize assessment tools, and create action plans through participatory approaches and mapping techniques (Al-Humaiqani and Al-Ghamdi, 2022). Research surveys and stakeholder involvement are crucial for assessing the enhancement of community resilience performance over time (Sharifi, 2016; Pfefferbaum et al., 2013). The analysis explored the importance of involving the community in discussions to establish mutual ownership of BESs resilience, as depicted in Figure 11. It also assessed the consensus on adopting an inclusive approach to promote shared responsibility and a common vision for urban resilience.

3.5 Consolidating integration (*It*)

Incorporating integration (*It*) processes into the BESs would ensure consistency in decision-making and investment placements and ensure they function together and respond quickly (Salimi and Al-Ghamdi, 2020; Al-Humaiqani and Al-Ghamdi, 2022). According to Shafiei Dastjerdi et al., preserving the integrity and functions of places and spatial networks relies on integrating all elements through adaptive capacity within a multi-scale hierarchy (Shafiei Dastjerdi et al., 2021). The survey investigates the impact of integrating city systems' processes on decision-making and investment placement. Results indicate that 45% of Group 1 respondents sometimes believe in this integration. However, all three groups generally agree on its effectiveness, with over 45% consensus, as shown in Figure 12. The groups also prioritize different indicators, such as the adaptability of BESs to long-term changes that lead to uncertainty, illustrated in Figure 13. This figure outlines the assessments required to enhance the adaptive capacity of BESs and improve community resilience tools. Additionally, the text stresses the importance of proactive urban adaptive strategies over reactive plans and integrating disaster resilience into urban planning.

4 Conclusion

This study examines the resilience qualities of BESs, focusing on *Rb*, *Rd*, *Ic*, and *It*, along with their corresponding indicators. The research is based on a survey that gathered input from three main stakeholder groups. Responses were analyzed rigorously to assess the four resilience qualities and their relationships. Stakeholders, such as regulatory bodies, government entities, contractors, experts, academia, and NGOs, participated in the survey to assess the RQs of BESs, associated measures, and indicators. The survey explores how current built environment resilience indicators are interconnected and their perceived effectiveness in addressing climate change impacts.

The study investigates the significance of urban governance in enforcing regulations for emergency resources and supplies. The results show that respondents generally view these regulations as moderately to very important. There is a consensus across all respondent groups that urban governance needs to be able to adapt to uncertainty and change in urban environments. The study also examines the integration of processes within systems to ensure coherent decision-making and investments. The statistical analysis, however, did not provide enough evidence to reject the null hypothesis. There is a strong belief in the importance of BESs being resilient to climate change and reducing hazards. Despite this, there are opportunities to improve the resilience of BESs by enhancing standards to mitigate disturbances and their consequences. More than 40% of respondents noted a lack of progress in promoting best practices in the built environment, possibly due to limited community engagement. The study suggests that relevant authorities and regulatory bodies should address this issue. The study found that life support systems and open spaces were rated as the most important, followed by movement and shelter systems.

The study focused on participants' readiness to contribute to developing resilience systems, indicators, or tools through community consensus. Results showed agreement on the importance of involving diverse community input to cultivate shared ownership in enhancing resilience to climate change. The study underscores the significance of gathering comprehensive stakeholder feedback to facilitate an inclusive decision-making process, ensuring a cohesive vision and collective responsibility for urban resilience. The integration analysis evaluated if city processes support consistent decision-making and investment allocation, with a general consensus that they do. The study also highlights the necessity of evaluating and strengthening the adaptive capacity of BESs and improving community resilience assessment tools. Furthermore, it suggests that proactive urban adaptive strategies are more crucial than reactive plans and emphasizes the importance of integrating disaster resilience into urban planning.

Data availability statement

The original contributions presented in the study are included in the article/Supplementary Material, further inquiries can be directed to the corresponding author.

Ethics statement

The studies involving humans were approved by Institutional Review Board (IRB) at Qatar Biomedical Research Institute (QBRI) at Qatar. The studies were conducted in accordance with the local legislation and institutional requirements. The participants provided their written informed consent to participate in this study.

Author contributions

MA-H: Writing–original draft, Visualization, Methodology, Formal Analysis, Data curation, Conceptualization. SA-G: Writing–review and editing, Supervision, Resources, Project administration, Investigation, Funding acquisition, Conceptualization.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fbuil.2024.1343334/full#supplementary-material

References

Agrawal, A. K., Kawaguchi, A., and Chen, Z. (2010). Deterioration rates of typical bridge elements in New York. *J. Bridg. Eng.* 15 (4), 419–429. doi:10.1061/(ASCE)BE.1943-5592.0000123

Alec Tzannes, A. M. (2019). Matthaios santamouris: minimising energy consumption, energy poverty and global and local climate change in the built environment: innovating to zero: casualties and impacts in a zero concept world. *J. Wind Eng. Ind. Aerodyn.* 193, 103952. doi:10.1016/j.jweia.2019.103952

Al Humaiqani, M. M., and Al Ghamdi, S. G. (2023a). "Unveiling urban resilience: exploring the qualities and interconnections of urban systems," in *Sustainable cities in a changing climate* (Wiley), 139–154. doi:10.1002/9781394201532.ch10

Al Humaiqani, M. M., and Al Ghamdi, S. G. (2023b). "Quantifying urban resilience: methods and approaches for comprehensive assessment," in *Sustainable cities in a changing climate* (Wiley), 155–182. doi:10.1002/9781394201532.ch11

Al Humaiqani, M. M., and Al Ghamdi, S. G. (2023c). "Enhancing built environment resilience: exploring themes and dimensions," in *Sustainable cities in a changing climate* (Wiley), 121–137. doi:10.1002/9781394201532.ch9

Al-Humaiqani, M. M., and Al-Ghamdi, S. G. (2023d). *Exploring the significance of resilience qualities in the context of the Middle East built environment*, 319–330. doi:10.1007/978-981-99-4101-8_25

Al-Humaiqani, M. M., and Al-Ghamdi, S. G. (2023e). Assessing the built environment's reflectivity, flexibility, resourcefulness, and rapidity resilience qualities against climate change impacts from the perspective of different stakeholders. *Sustainability* 15 (6), 5055. doi:10.3390/su15065055

Al Humaiqani, M. M., and Al Ghamdi, S. G. (2023f). "Integrating green–blue–gray infrastructure for sustainable urban flood risk management: enhancing resilience and advantages," in *Sustainable cities in a changing climate* (Wiley), 207–226. doi:10.1002/9781394201532.ch13

Al-Humaiqani, M. M., and Al-Ghamdi, S. G. (2022). The built environment resilience qualities to climate change impact: concepts, frameworks, and directions for future research. *Sustain. Cities Soc.* 80, 103797. doi:10.1016/j.scs.2022.103797

AlQahtany, A. M., and Abubakar, I. R. (2020). Public perception and attitudes to disaster risks in a coastal metropolis of Saudi Arabia. *Int. J. Disaster Risk Reduct.* 44, 101422. doi:10.1016/j.ijdrr.2019.101422

Alyami, S. H., Abd El Aal, A., Alqahtany, A., Aldossary, N., Jamil, R., Almohassen, A., et al. (2023). Developing a holistic resilience framework for critical infrastructure networks of buildings and communities in Saudi arabia. *Buildings* 13 (1), 179. doi:10.3390/buildings13010179

Andrić, I., Koc, M., and Al-Ghamdi, S. G. (2019). A review of climate change implications for built environment: impacts, mitigation measures and associated challenges in developed and developing countries. *J. Clean. Prod.* 211, 83–102. doi:10.1016/j.jclepro.2018.11.128

Arup and The Rockefeller Foundation (2014a). *City Resilience Index: City Resilience Framework*. London: Arup.

Arup and The Rockefeller Foundation (2014b). *City Resilience Index: Understanding the City Resilience Index*. London: Arup, 24. Available at: https://www.arup.com/projects/city-resilience-index.

Asfaw, T. S., Botes, V., and Mengesha, L. G. (2017). The role of NGOs in corporate environmental responsibility practice: evidence from Ethiopia. *Int. J. Corp. Soc. Responsib.* 2 (1), 2. doi:10.1186/s40991-017-0013-0

Astaneh-Asl, A. (2008). *Progressive collapse of steel truss bridges, the case of i-35w collapse*. Seattle, United States: Semantic Scholar. Available at: https://www.semanticscholar.org/paper/PROGRESSIVE-COLLAPSE-OF-STEEL-TRUSS-BRIDGES%2C-THE-OF-Astaneh-Asl/1ba709e2b26b36ab709b89b1cb58db964794660d (Accessed February 28, 2022).

Auffhammer, M. (2022). Climate Adaptive Response Estimation: short and long run impacts of climate change on residential electricity and natural gas consumption. *J. Environ. Econ. Manage.* 114, 102669. doi:10.1016/j.jeem.2022.102669

Ayyub, B. M. (2020). Infrastructure resilience and sustainability: definitions and relationships. *ASCE-ASME J. Risk Uncertain. Eng. Syst. Part A Civ. Eng.* 6 (3), 02520001. doi:10.1061/AJRUA6.0001067

Bamdad, K., Matour, S., Izadyar, N., and Omrani, S. (2022). Impact of climate change on energy saving potentials of natural ventilation and ceiling fans in mixed-mode buildings. *Build. Environ.* 209, 108662. doi:10.1016/j.buildenv.2021.108662

Barnes, M. L., Datta, A., Morris, S., and Zethoven, I. (2022). Navigating climate crises in the great barrier reef. *Glob. Environ. Chang.* 74, 102494. doi:10.1016/j.gloenvcha.2022.102494

Bazrkar, M. H., Zamani, N., Eslamian, S., Eslamian, A., and Dehghan, Z. (2015). "Urbanization and climate change," in *Handbook of climate change adaptation* (Berlin, Heidelberg: Springer Berlin Heidelberg), 619–655. doi:10.1007/978-3-642-38670-1_90

Birchall, S. J., and Bonnett, N. (2021). Climate change adaptation policy and practice: the role of agents, institutions and systems. *Cities* 108, 103001. doi:10.1016/J.CITIES.2020.103001

Blekking, J., Giroux, S., Waldman, K., Battersby, J., Tuholske, C., Robeson, S. M., et al. (2022). The impacts of climate change and urbanization on food retailers in urban sub-Saharan Africa. *Curr. Opin. Environ. Sustain.* 55, 101169. doi:10.1016/j.cosust.2022.101169

Bocchini, P., Frangopol, D. M., Ummenhofer, T., and Zinke, T. (2014). Resilience and sustainability of Civil infrastructure: toward a unified approach. *J. Infrastruct. Syst.* 20 (2), 04014004. doi:10.1061/(ASCE)IS.1943-555X.0000177

Bruneau, M., Chang, S. E., Eguchi, R. T., Lee, G. C., O'Rourke, T. D., Reinhorn, A. M., et al. (2003). A framework to quantitatively assess and enhance the seismic resilience of communities. *Earthq. Spectra* 19 (4), 733–752. doi:10.1193/1.1623497

Caby, J., Ziane, Y., and Lamarque, E. (2022). The impact of climate change management on banks profitability. *J. Bus. Res.* 142, 412–422. doi:10.1016/j.jbusres.2021.12.078

Carter, T. R., Benzie, M., Campiglio, E., Carlsen, H., Fronzek, S., Hildén, M., et al. (2021). A conceptual framework for cross-border impacts of climate change. *Glob. Environ. Chang.* 69, 102307. doi:10.1016/j.gloenvcha.2021.102307

Chelleri, L., and Marta, O. (2012). *Multidisciplinary perspectives on urban resilience*.

Cohen, L., Manion, L., and Morrison, K. (2018). *Research methods in education, no. 8*. New York, NY, USA: Routledge.

Creative Research Systems (2022). *Sample size calculator*. Available at: https://www.surveysystem.com/sscalc.htm (Accessed July 18, 2022).

da Silva, J., Kernaghan, S., and Luque, A. (2012). A systems approach to meeting the challenges of urban climate change. *Int. J. Urban Sustain. Dev.* 4 (2), 125–145. doi:10.1080/19463138.2012.718279

Deshkar, S., and Adane, V. (2016). *Community resilience approach for prioritizing infrastructure development in urban areas*. Elsevier Inc. doi:10.1016/B978-0-12-802169-9.00016-1

Faturechi, R., and Miller-Hooks, E. (2015). Measuring the performance of transportation infrastructure systems in disasters: a comprehensive review. *J. Infrastruct. Syst.* 21 (1), 1–15. doi:10.1061/(ASCE)IS.1943-555X.0000212

Forzieri, G., Bianchi, A., Silva, F. B. e., Marin Herrera, M. A., Leblois, A., Lavalle, C., et al. (2018). Escalating impacts of climate extremes on critical infrastructures in Europe. *Glob. Environ. Chang.* 48, 97–107. doi:10.1016/j.gloenvcha.2017.11.007

Gallego-Schmid, A., Chen, H.-M., Sharmina, M., and Mendoza, J. M. F. (2020). Links between circular economy and climate change mitigation in the built environment. *J. Clean. Prod.* 260, 121115. doi:10.1016/j.jclepro.2020.121115

Godschalk, D. R. (2003). Urban hazard mitigation: creating resilient cities. *Nat. Hazards Rev.* 4 (3), 136–143. doi:10.1061/(ASCE)1527-6988(2003)4:3(136)

Gür, H. (2022). The future impact of climate and land-use changes on Anatolian ground squirrels under different scenarios. *Ecol. Inf.* 70, 101693. doi:10.1016/j.ecoinf.2022.101693

Halder, B., and Bandyopadhyay, J. (2021). Evaluating the impact of climate change on urban environment using geospatial technologies in the planning area of Bilaspur, India. *Environ. Challenges* 5, 100286. doi:10.1016/j.envc.2021.100286

Hidalgo-Galvez, M. D., Barkaoui, K., Volaire, F., Matías, L., Cambrollé, J., Fernández-Rebollo, P., et al. (2022). Can trees buffer the impact of climate change on pasture production and digestibility of Mediterranean dehesas? *Sci. Total Environ.* 835, 155535. doi:10.1016/j.scitotenv.2022.155535

Hiruta, Y., Ishizaki, N. N., Ashina, S., and Takahashi, K. (2022). Regional and temporal variations in the impacts of future climate change on Japanese electricity demand: simultaneous interactions among multiple factors considered. *Energy Convers. Manag. X* 14, 100172. doi:10.1016/j.ecmx.2021.100172

Huang, G., Li, D., Zhu, X., and Zhu, J. (2021). Influencing factors and their influencing mechanisms on urban resilience in China. *Sustain. Cities Soc.* 74, 103210–103211. doi:10.1016/J.SCS.2021.103210

Hürlimann, A. C., Nielsen, J., Moosavi, S., Bush, J., Warren-Myers, G., and March, A. (2022). Climate change preparedness across sectors of the built environment – a review of literature. *Environ. Sci. Policy* 128, 277–289. doi:10.1016/j.envsci.2021.11.021

IFRC (2003). "PREPAREDNESS for climate change: a study to assess the future impact of climatic changes upon the frequency and severity of disasters and the implications for humanitarian response and preparedness," in 28th International Conference of the Red Cross and Red Crescent, 15.

Kammouh, O., Gardoni, P., and Cimellaro, G. P. (2020). Probabilistic framework to evaluate the resilience of engineering systems using Bayesian and dynamic Bayesian networks. *Reliab. Eng. Syst. Saf.* 198, 106813–106820. doi:10.1016/J.RESS.2020.106813

Kanno, Y., and Ben-Haim, Y. (2011). Redundancy and robustness, or when is redundancy redundant? *J. Struct. Eng.* 137 (9), 935–945. doi:10.1061/(ASCE)ST.1943-541X.0000416

Khavarian-Garmsir, A. R., Pourahmad, A., Hataminejad, H., and Farhoodi, R. (2019). Climate change and environmental degradation and the drivers of migration in the context of shrinking cities: a case study of Khuzestan province, Iran. *Sustain. Cities Soc.* 47, 101480. doi:10.1016/j.scs.2019.101480

Koc, M., and Acar, A. (2021). Investigation of urban climates and built environment relations by using machine learning. *Urban Clim.* 37, 100820. doi:10.1016/j.uclim.2021.100820

Lak, A., Hasankhan, F., and Garakani, S. A. (2020). Principles in practice: toward a conceptual framework for resilient urban design. *J. Environ. Plan. Manag.* 63 (12), 2194–2226. doi:10.1080/09640568.2020.1714561

Larsson Ivanov, O., Bärring, L., and Wilcke, R. A. I. (2022). Climate change impact on snow loads in northern Europe. *Struct. Saf.* 97, 102231. doi:10.1016/j.strusafe.2022.102231

Li, D. H. W., Yang, L., and Lam, J. C. (2012). Impact of climate change on energy use in the built environment in different climate zones – a review. *Energy* 42 (1), 103–112. doi:10.1016/j.energy.2012.03.044

Lin, S., Shaw, D., and Ho, M.-C. (2008). Why are flood and landslide victims less willing to take mitigation measures than the public? *Nat. Hazards* 44 (2), 305–314. doi:10.1007/s11069-007-9136-z

Lounis, Z., and McAllister, T. P. (2016). Risk-based decision making for sustainable and resilient infrastructure systems. *J. Struct. Eng.* 142 (9). doi:10.1061/(ASCE)ST.1943-541X.0001545

Lynch, K. (1960). *The image of the city*. Cambridge, MA: The M.I.T Press.

Malik, K., Rahman, S. M., Khondaker, A. N., Abubakar, I. R., Aina, Y. A., and Hasan, M. A. (2019). Renewable energy utilization to promote sustainability in GCC countries:

policies, drivers, and barriers. *Environ. Sci. Pollut. Res.* 26 (20), 20798–20814. doi:10.1007/s11356-019-05337-1

Mallen, E., Bakin, J., Stone, B., Sivakumar, R., and Lanza, K. (2020). Thermal impacts of built and vegetated environments on local microclimates in an Urban University campus. *Urban Clim.* 32, 100640. doi:10.1016/j.uclim.2020.100640

Manes, S., Vale, M. M., Malecha, A., and Pires, A. P. F. (2022). Nature-based solutions promote climate change adaptation safeguarding ecosystem services. *Ecosyst. Serv.* 55, 101439. doi:10.1016/j.ecoser.2022.101439

Mattauch, L., Hepburn, C., Spuler, F., and Stern, N. (2022). The economics of climate change with endogenous preferences. *Resour. Energy Econ.* 69, 101312. doi:10.1016/j.reseneeco.2022.101312

Mayo, T. L., and Lin, N. (2022). Climate change impacts to the coastal flood hazard in the northeastern United States. *Weather Clim. Extrem.* 36, 100453. doi:10.1016/j.wace.2022.100453

McAllister, T. (2013). *Developing guidelines and standards for disaster resilience of the built environment: a research needs assessment*. United States: National Institute of Standards and Technology Publications, 1–142.

Meerow, S., Newell, J. P., and Stults, M. (2016). Defining urban resilience: a review. *Landsc. Urban Plan.* 147, 38–49. doi:10.1016/j.landurbplan.2015.11.011

Moghadas, M., Asadzadeh, A., Vafeidis, A., Fekete, A., and Kötter, T. (2019). A multi-criteria approach for assessing urban flood resilience in Tehran, Iran. *Int. J. Disaster Risk Reduct.* 35, 101069. doi:10.1016/j.ijdrr.2019.101069

Morphet, J. (2010). *Effective practice in spatial planning*. 1. London: Routledge, Taylor and Francies Group. doi:10.4324/9780203851838

Murshed, S., Griffin, A. L., Islam, M. A., Wang, X. H., and Paull, D. (2022). Assessing multi-climate-hazard threat in the coastal region of Bangladesh by combining influential environmental and anthropogenic factors. *Prog. Disaster Sci.* 16, 100261. doi:10.1016/j.pdisas.2022.100261

Ngin, C., Chhom, C., and Neef, A. (2020). Climate change impacts and disaster resilience among micro businesses in the tourism and hospitality sector: the case of Kratie, Cambodia. *Environ. Res.* 186, 109557. doi:10.1016/j.envres.2020.109557

Nik, V. M., and Moazami, A. (2021). Using collective intelligence to enhance demand flexibility and climate resilience in urban areas. *Appl. Energy* 281, 116106–116117. doi:10.1016/j.apenergy.2020.116106

Ouyang, M. (2017). A mathematical framework to optimize resilience of interdependent critical infrastructure systems under spatially localized attacks. *Eur. J. Oper. Res.* 262 (3), 1072–1084. doi:10.1016/j.ejor.2017.04.022

Owens, P. M. (2005). *Beyond density: measuring neighborhood form in new england's upper Connecticut river valley*. Berkeley: University of California.

Pfefferbaum, R. L., Pfefferbaum, B., Van Horn, R. L., Klomp, R. W., Norris, F. H., and Reissman, D. B. (2013). The communities advancing resilience toolkit (CART): an intervention to build community resilience to disasters. *J. Public Heal. Manag.* 19, 250–258. doi:10.1097/phh.0b013e318268aed8

Qualtrics (2022). *Sample size calculator and complete guide in 2022*. Available at: https://www.qualtrics.com/blog/calculating-sample-size/ (Accessed July 18, 2022).

Raosoft (2022). *Sample size calculator by Raosoft, inc.* Las Vegas, United States: Raosoft, Inc. Available at: http://www.raosoft.com/samplesize.html (Accessed July 18, 2022).

Research, M. (2022). *Sample size calculator for market research surveys*. Available at: https://www.macorr.com/sample-size-calculator.htm (Accessed January 15, 2023).

Rose, A. (2004). Defining and measuring economic resilience to disasters. *Disaster Prev. Manag. Int. J.* 13 (4), 307–314. doi:10.1108/09653560410556528

Rose, A., Oladosu, G., and Liao, S. Y. (2007). Business interruption impacts of a terrorist attack on the electric power system of Los Angeles: customer resilience to a total blackout. *Risk Anal.* 27 (3), 513–531. doi:10.1111/j.1539-6924.2007.00912.x

Rus, K., Kilar, V., and Koren, D. (2018). Resilience assessment of complex urban systems to natural disasters: a new literature review. *Int. J. Disaster Risk Reduct.* 31, 311–330. doi:10.1016/j.ijdrr.2018.05.015

Salimi, M., and Al-Ghamdi, S. G. (2020). Climate change impacts on critical urban infrastructure and urban resiliency strategies for the Middle East. *Sustain. Cities Soc.* 54, 1–17. doi:10.1016/j.scs.2019.101948

Samsuddin, N. M., Takim, R., Nawawi, A. H., and Syed Alwee, S. N. A. (2018). Disaster preparedness attributes and hospital's resilience in Malaysia. *Procedia Eng.* 212, 371–378. doi:10.1016/j.proeng.2018.01.048

Saranko, O., Fortelius, C., Jylhä, K., Ruosteenoja, K., Brattich, E., Di Sabatino, S., et al. (2020). Impacts of town characteristics on the changing urban climate in Vantaa. *Sci. Total Environ.* 727, 138471. doi:10.1016/j.scitotenv.2020.138471

Sato, S. (2017). Climate change, the built environment and triple-helix innovation. *Energy Procedia* 143, 843–850. doi:10.1016/j.egypro.2017.12.772

Schipper, L., and Pelling, M. (2006). Disaster risk, climate change and international development: scope for, and challenges to, integration. *Disasters* 30 (1), 19–38. doi:10.1111/j.1467-9523.2006.00304.x

Schwind, K. (2020). *Community resilience toolkit A workshop guide for community resilience planning*.

Serdar, M. Z., and Al Ghamdi, S. G. (2023). "Assessing infrastructure resilience: approaches and considerations," in *Sustainable cities in a changing climate* (Wiley), 97–109. doi:10.1002/9781394201532.ch7

Shafiei Dastjerdi, M., Lak, A., Ghaffari, A., and Sharifi, A. (2021). A conceptual framework for resilient place assessment based on spatial resilience approach: an integrative review. *Urban Clim.* 36, 100794. doi:10.1016/j.uclim.2021.100794

Sharifi, A. (2016). A critical review of selected tools for assessing community resilience. *Ecol. Indic.* 69, 629–647. doi:10.1016/j.ecolind.2016.05.023

Sovacool, B. K., Baum, C., and Low, S. (2023). The next climate war? Statecraft, security, and weaponization in the geopolitics of a low-carbon future. *Energy Strateg. Rev.* 45, 101031. doi:10.1016/j.esr.2022.101031

SurveyMonkey (2022). *Sample size calculator: understanding sample sizes*. Available at: https://www.surveymonkey.com/mp/sample-size-calculator/?ut_source=help_center&ut_source2=en%2Fsolutions%2Fcalculating-respondents&ut_source3=inline (Accessed July 18, 2022).

Tahir, F., and Al-Ghamdi, S. G. (2023). Climatic change impacts on the energy requirements for the built environment sector. *Energy Rep.* 9, 670–676. doi:10.1016/j.egyr.2022.11.033

Tahir, F., Ajjur, S. B., Serdar, M. Z., Al-Humaiqani, M., Kim, D., Al-Thani, S. K., et al. (2021). *Proceedings of the Qatar Climate Change Conference 2021: a Platform for addressing key climate change topics facing Qatar and the world*. 1. Doha: Hamad bin Khalifa University Press HBKU Press. doi:10.5339/conf_proceed_qccc2021

Tong, P. (2021). Characteristics, dimensions and methods of current assessment for urban resilience to climate-related disasters: a systematic review of the literature. *Int. J. Disaster Risk Reduct.* 60, 102276. doi:10.1016/j.ijdrr.2021.102276

UNDP Drylands Development Centre (2014). "Understanding community resilience: findings from community-based resilience analysis (CoBRA) assessments," in *Under the framework of the European commission directorate general for humanitarian aid and Civil protection's drought ri*. Editor C. M. Way.

UNDP Drylands Development Centre (2016). *Community based resilience analysis (cobra) conceptual framework and methodology. Under the framework of humanitarian aid and Civil protection department of the European commission's drought risk reduction action plan*.

US IOTWS (2007a). *How Resilient is Your Coastal Community? A guide for evaluating coastal community resilience to tsunamis and other hazards, no. September 2016*.

U.S. IOTWS (2007b). *How resilient is your coastal community? A guide for evaluating coastal community resilience to tsunamis and other hazards | enhanced reader*.

Wang, H., Zhang, Q., Liu, R., Sun, Y., Xiao, J., Gao, L., et al. (2022). Impacts of changing climate on the distribution of *Solenopsis invicta* Buren in Mainland China: exposed urban population distribution and suitable habitat change. *Ecol. Indic.* 139, 108944. doi:10.1016/j.ecolind.2022.108944

Wardekker, A., Wilk, B., and Brown, V. (2017). *Assessing urban resilience in Rotterdam using resilience principles: workshop report*. Utrecht, Netherlands: Utrecht University.

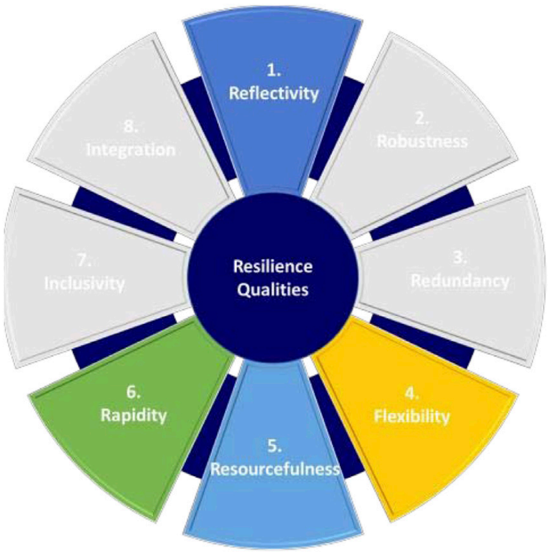
Wollschlaeger, S., Sadhu, A., Ebrahimi, G., and Woo, A. (2022). Investigation of climate change impacts on long-term care facility occupants. *City Environ. Interact.* 13, 1–15. doi:10.1016/j.cacint.2021.100077

Yazdani, A., and Jeffrey, P. (2012). Applying network theory to quantify the redundancy and structural robustness of water distribution systems. *J. Water Resour. Plan. Manag.* 138 (2), 153–161. doi:10.1061/(ASCE)WR.1943-5452.0000159

Zobel, C. W. (2011). Representing perceived tradeoffs in defining disaster resilience. *Decis. Support Syst.* 50 (2), 394–403. doi:10.1016/j.dss.2010.10.001

Appendix A

In a previous study (Al-Humaiqani and Al-Ghamdi, 2023e), the authors "Al-Humaiqani and Al-Ghamdi" assessed the Reflectivity (*Rf*), Flexibility (*Fx*), Resourcefulness (*Rs*), and Rapidity (*Rp*) resilience qualities. The study entitled "Assessing the Built Environment's Reflectivity, Flexibility, Resourcefulness, and Rapidity Resilience Qualities against Climate Change Impacts from the Perspective of Different Stakeholders" utilized responses from the three respondent groups. The study is available for downlaod at this link: https://www.mdpi.com/2071-1050/15/6/5055. This research applied a similar methodology to assess the resilience qualities of Robustness (*Rb*), Redundancy (*Rd*), Inclusivity (*Ic*), and Integration (*It*). Both studies asses the built environment's resilience qualities from the prespective of different stakholders, aiming to establish a framework that outlines the phases, characteristics, boundaries, and relationships of all eight qualities.



The scope of the previous study published by authors includes four RQs: reflectivity (*Rf*), Flexibility (*Fx*), resourcefulness (*Rs*), and rapidity (*Rp*) (Al-Humaiqani and Al-Ghamdi, 2023e)

The scope of the current study includes four RQs: robustness (*Rb*), redundancy (*Rd*), inclusivity (*Ic*), and integration (*It*)