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Evolutionary urban resilience as an incremental approach to sustainability: a multifunctional pluvial flood and wastewater risk reduction framework

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Abstract

After the increasing climate change and fast urbanization adverse effects on pluvial floods, in addition to the freshwater resources' shortage risk, transversal urban solutions need to be tackled. This paper focuses on how the evolutionary urban resilience practices (along with the nature-based solutions and climate change adaptation) work as an integrated approach to enhance multifunctionality levels of sustainable urban planning and design. This integration eventually leads to more pluvial flood-resilient cities and more sustainable urban water resources simultaneously. After thoroughly analyzing related literature and best practices using descriptional, comparative, and statistical approaches, a proposed risk reduction framework that facilitates the resilience operationalizing process was formulated. The proposed framework introduces a design equation that measures the relationship between sustainability and urban resilience sectors. In addition to that, prioritized strategies for enhancing flood resilience and urban wastewater management within the Egyptian local scale were ranked for future applications.

Keywords: Evolutionary urban resilience, Pluvial floods, Integrated wastewater management, Risk reduction, Nature-based solutions, Climate change adaptation, Integrated urban planning

Introduction

Today's cities' experience is a huge weight of risks, either resulting from yesterday's unsustainable urbanism practices, inevitable nature courses, or both. These urban risks can be unpredictable instant *shocks* (natural risks or pandemics for instance) or slowly pressing *stresses* (climate change or resources depletion for instance), and they dramatically threaten the sustainability potential.

Sufficient urban water management is an essential aspect of cities' sustainable development; however, global multi-factor reactions (Fig. 1) lead to the most stressing hydrometeorological and urban water-related risks nowadays, including floods.

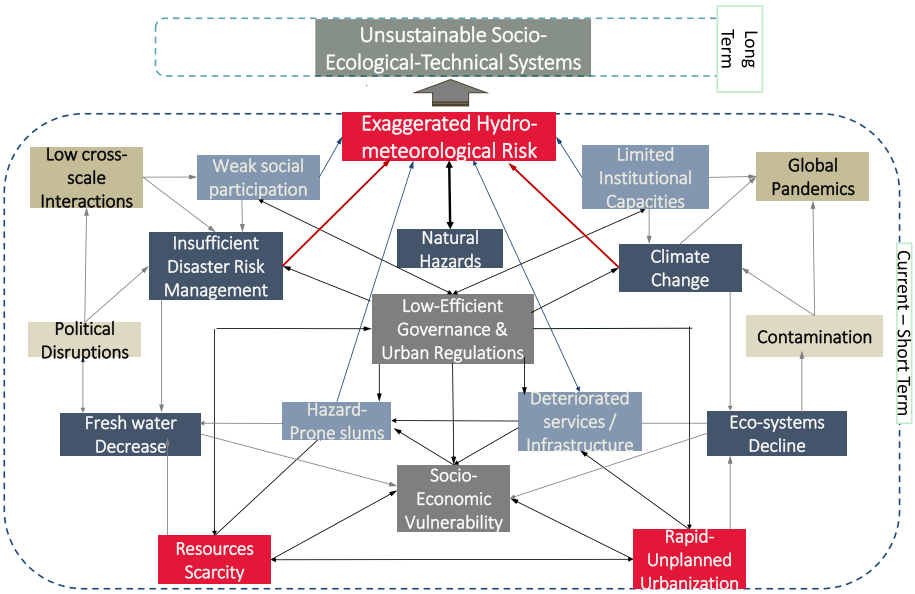

Fig. 1 Global and local risk cause-effect chain

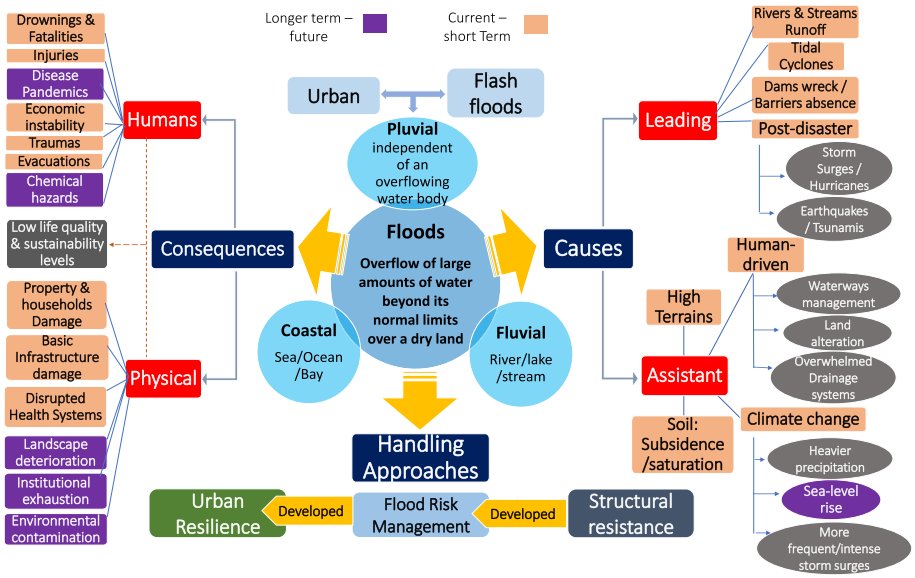

Fig. 2 Flood cause-effect chain

Among several flood triggers (Fig. 2), climate change is expected to increase their frequency and severity, affecting highly exposed cities, such as those in deltas and low-elevation coastal zones. Besides climate, the urbanism factors participate in urban water-related hazards and specifically trigger pluvial floods. Factors like "maladaptive drainage systems" and "insufficient stormwater discharge," along with "gray construction over-use," cause the removal of natural rainwater-retaining and recycling infrastructure [1].

During the last decades, the focus on reducing floods was manifested in risk management frames, but nowadays, several objectives need to be met for water quantity/quality

Fig. 3 Research conceptual framework

enhancement and rainwater recycling to approach sustainability. Since the current centralized urban drainage models became insufficient due to climate change, urbanization, and social circumstances constraints [1], other contemporary multifunctional strategies which consider nature and multi-discipline integrations are a must. An example of these integrations is a disaster risk reduction (DRR), climate change adaptation (CCA), and integrated urban water management (IUWM) within multi-scale planning and implementation framework (since hydro-meteorological risks and climate change negatively promote each other) [2]. Accordingly, the "resilience" term is gaining uprising significance even more than before as a contemporary integrated resolution for cities' vulnerability state. Resilience is a suitable approach to deal with "shocks" and "stresses" in cities since it's a function of "dynamic-complex" systems, which are presented the best within the city morphology. As of 2020, approximately 85 cities have national resilience policies. Due to its wide range of interrelations (physical, psychological, ecological, social, economic, individual, technical), resilience is a widely preferred approach in the various city development sectors for a while now, often interchangeably or inclusively with sustainability.

Rationale and scope

The study aims to explore the evolutionary resilience and nature-based solutions multifunctionality, to address Egypt's urban water stresses, within a sustainable and integrated urban development framework. This comes as a crucial adapting and preparation responding strategy to the current pluvial flood risks, and the upcoming freshwater shortage. For a conceptual scope, see Fig. 3.

Methods

A mixed approach of qualitative and quantitative methods was adopted throughout the study outline (Fig. 4). To develop the theoretical framework, qualitative processing included an inductive and analytical review of related literature on the background and traditional solutions of current urbanism, climate, and resource risks.

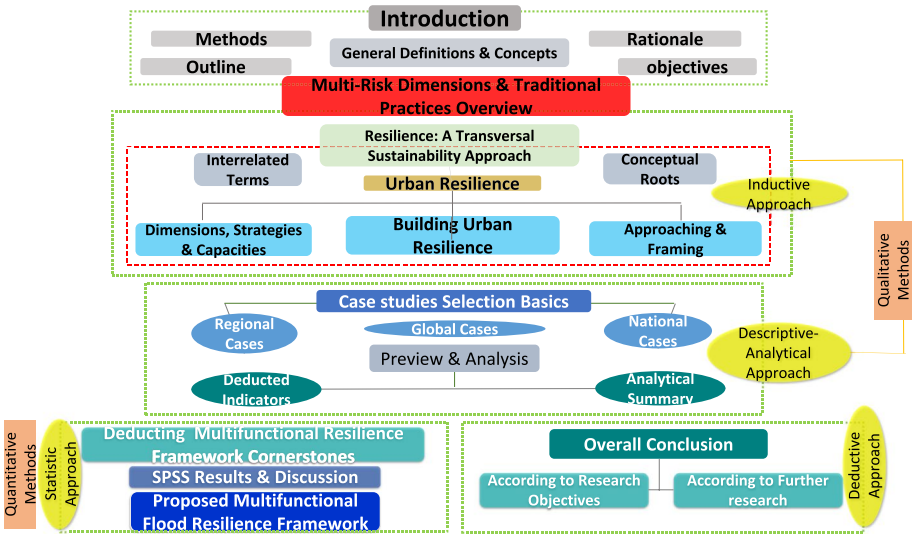

Fig. 4 The research outline

Then, the literature explored the role of resilience in sustainable urbanism, followed by studying the resilience concept and its interrelated disciplines. Combining the understanding of resilience capacities with the obtained knowledge on flood risk management led to a closer look at synergies between resilience and sustainability. These interactions led to thematic dimensions of resilience standards, which were focused on through the ten best practices of descriptive-analytical study. Case studies from different countries were chosen to reflect a wider range of urban resilience practices in both flood risk management and sustainable urban water management after or before severe damage of a crisis. The detailed descriptive study provided a clear vision of the resilience concept applicability and operationalizing within urban systems that seek sustainable practices. Conclusions on the relevance of multifunctional resilience for urban water and flood risk management through sustainable integrated urbanism were extracted for the specific case-study areas and in general. These indicators took the form of preliminary resilience framework pillars with proposed application strategies on the national scale. After that, quantitative processing of the proposed framework was conducted through field interviews and an online questionnaire. The results were statistically analyzed to deduct the finalized multifunctional urban resilience framework, based on the Egyptian urbanism variables. Primary data such as online questionnaires and interviews with experts were processed, besides secondary data (books, global organizations handbooks, national current profile statistics, international protocols, papers/articles, academic thesis, and websites).

Main literature indicators

Traditional risk management and alternative resolutions

In the 1960s, non-structural measures (warning systems, floodplain zoning, local floodproofing, and flood insurance programs) began to receive more attention while the appreciation of embankments degraded [3]. Using classic flood control measures

only became an inadequate response to the growing risks [4, 5]. Therefore, more efficiency was detected in alternative concepts that focused on the integration between structural and nonstructural measures and land/water management [6, 7]. Such holistic approaches are a shift from purely sectoral water management to more integrating urban planning wherewithal to separate vulnerable land uses from flood-prone areas. Hence, the resilience concept is a promising framework to merge the risks and uncertainties within planning [8], as Table 1 indicates. In 1994, resilience officially broke into the disaster field in the Guidelines for the World Conference on Natural Disaster reduction.

The resilience approach is mainly about handling undesired change, as it investigates the best management frameworks of interacting systems within cities. Urban resilience is "The capacity of all the city systems—individuals, communities, institutions, businesses—to survive, adapt, and grow, no matter what stresses and shocks they face" [10]. Table 2 summarizes urban resilience basic capacities, and Fig. 5 illustrates resilient and vulnerable cities' comparison.

Resilience and sustainability

Recently, the resilience term was used widely as an updated version of sustainability, which is controversial since the two concepts are different in many ways. Sustainability observes the global resources levels, which would be a failure without building resilient societies against natural hazards and making sure that future development does not reinforce the vulnerability [14]. Table 3 compares the basic properties of the two concepts.

In 2014, the Hyogo Framework for Action assured that "sustainable development demands future risks prevention and current risks reduction" [16], which is relative to the "Sendai Framework for DRR" recommendations, and the New Urban Agenda guidelines. Later, the sustainable development literature framed resilience as a fixed goal among the acknowledged 17 sustainable development goals SDGs and subtargets in many sectors (goals 9, 11, 13, 14).

Evolutionary urban resilience

Since resilience thinking is an interdisciplinary approach to city planning [17], planning for resilience, therefore, bridges the environmental, social, and economic resilience aspects in spatial planning [18]. Literature diverges into three main approaches

Table 1 Traditional vs resilient approaches. Ref: adopted from Zevenbergen et al. [9]

	Traditional approaches	Resilient approaches
System changes	Stable and predictable	Uncertain
Changes handling	Control and preserve	Sustain and adapt
Planning timeframe	30 year	Long-term (up to 100 years)
Planning process	Linear (sequential)	Circular (continuous process alignment)
Strategy making	Top-down	Bottom-up and top-down
Focus	Probability reduction	Less vulnerability
System nature	Aims with static standards	Strategic alternatives and whole solutions

Table 2 Resilience capacities

Classification		Focus domain	
		System-oriented	**Governance-oriented**
[11]			
Basic resilience Phases	Preparing	**Homeostasis**: constant self-balance maintaining via feedback. Ex: early/smart warnings, counter-expertise, flexible flood defenses, flood water removal	-System approach adoption -Beyond-design observing -Remain functioning-based building -Boost recovery capacities via socio/finance capital
	Absorbing	**Redundancy**: multiple backups/functional diversity. Ex: multiple roads/services connections/backup crisis centers/building access levels	
		Omnivory: multiple different ways of needs fulfilling. Ex: energy sources diversifying, multiple function buildings	
		Buffering: over-dimensioning system capacity for more disturbance absorbing. Ex: "water/public squares," arterial roads elevating to function in floods, risk-prone areas with rapidly changing functions	
	Recovery	**Flatness**: response rapidity and flexible participation empowering. Ex: locals' self-reliance/self-organization	
		High flux: resources fast mobilization. Ex: early warning system and recovery materials' rapid accessibility	
	Adapting	Including flexibility, and learning	
The "4Rs" [12]		**Robustness** (ability to withstand a shock), **Redundancy** (functional diversity), **Resourcefulness** (ability to mobilize when threatened), **Rapidity** (ability to contain losses and recover promptly)	
[13]		Flexibility: rearranging the ability of structure/functions when disturbed. Coordination: needed to make the best use of resources by decision-makers, citizens, and planners. Independence: needed self-reliance to survive adversities. Connectivity: interactions with other systems on a broader scale. Collaboration: inclusive and bottom-up urban management approach. Self-organization: establishing community-based activities via social institutions and networks. Efficiency: developing strategies to maximize benefits	

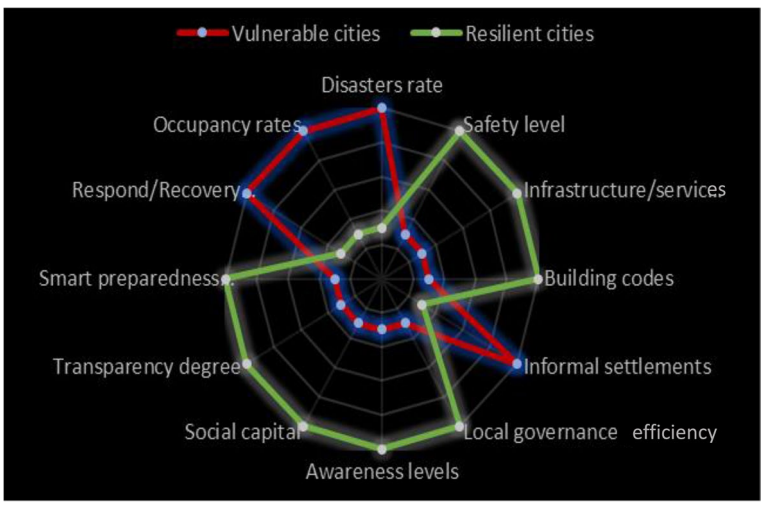

Fig. 5 Resilient and vulnerable cities characteristics

Table 3 Resilience and sustainability features

Factor	Resilience	Sustainability
Definition	The capacity of individuals, communities, institutions, businesses, and systems within a city to survive, adapt, and grow, no matter what kinds of stresses and shocks they experience	Development that meets present needs without compromising the ability of future generations to meet their needs
Activity years	Re-introduced in the 1960s	Developed since 1987
Direct objective	Self-sufficient and risks mitigating cities	Managing resources wisely
Criticism	Multi-vague definition/not easily measured and optimized	Highly politicized/expensive alternatives for developing countries
Related systems	Dynamic complex systems, nonlinear, unpredictable disruptions	Static, stable systems
Term	Current and coming term	Longer-term "future generations"
Basic challenges	Natural hazards—disease pandemics—man-made disasters—ecology/socio-economic retardation—vulnerability and exposure levels—insufficient institutional management—weak infrastructures—lack of resources	Raw materials scarcity—energy consumption rates—climate change and global warming—environment degradation—man-made practices—lack of resilience—natural disasters—injustice in resources distribution
Common interest	The global dimension of human activity environmental impacts and the possible responses [15]	

in terms of planning for resilience: new eco-towns, strategic navigation, and evolutionary approach. The evolutionary literature framework is concerned with interlinkages between preparedness, persistence, adaptability, and transformability over multi-scales/timeframes in which communities' role is central due to their learning, innovating, and changing capacity [19]. According to [18], the evolutionary perspective is the most comprehensive approach among these three resilience planning perspectives. The overall resilience aspects of this research are summarized in Fig. 6.

Nature-based solution approaches

Nature-based solutions are integrated urban water systems, summarized in Table 4, which target drainage landscapes and structures to achieve multifunctionality and ecosystem services provision. They also enhance drainage during design storm events (see Fig. 7).

Best practises' analytical summary

The descriptive approach of 10 best practices (Fig. 8) was a diagnostic tool of the past and current resilience applications, from which preliminary resilience framework pillars with proposed application strategies were deducted. The analysis included cities with varied spatial, institutional, and urban contexts, such as New Cairo, Amman, Casablanca, Hamburg, Sponge Cities, Santa Fe, Alba Iulia, Semarang, Dhaka, and Accra. Several practices of these cities were studied to spot general vulnerabilities that hinder the resilience implementation, make the best use of the relevant approaches as inspiration for our local resilience base to be, and reflect the role of integrated urban planning within the evolutionary resilience frames. Reviewed aspects included risk and vulnerability contexts, past management approaches, current resilience planning, and nature-based measures. On a global scale, resilience practices of Santa Fe city, for

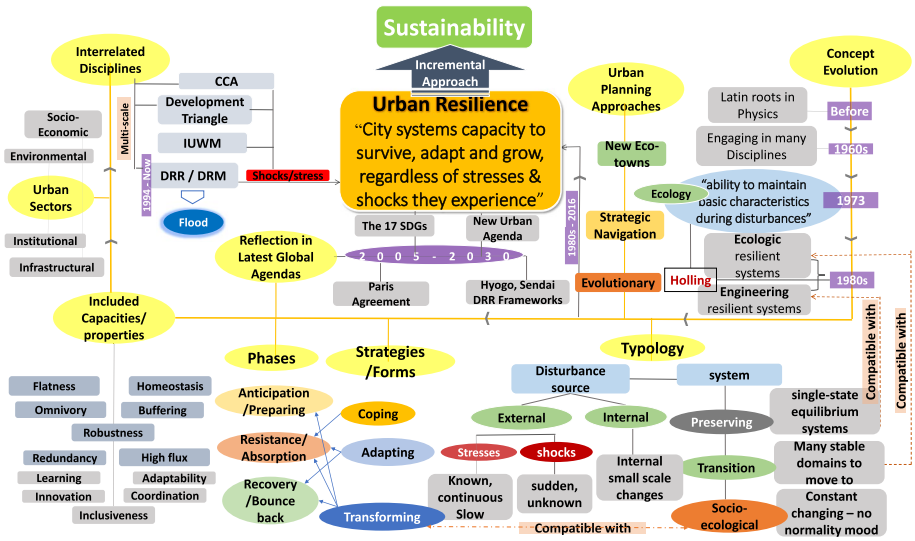

Fig. 6 Conceptualizing urban resilience

Table 4 Integrated urban water systems

System	Country, year	Tools	Objective—characteristics	Ref.
Best management practices BMP	USA, 1970s	Storage tanks Filtration/infiltration measures Constructed wetlands and retention ponds	Systems to limit water pollution caused by industry and stormwater.	[20]
Low-impact development LID	USA		Mimicking the natural hydrological response and absorbing urban stormwater	[21]
Water-sensitive urban design WSUD	Australia, 1990s		Addressing storm-water quantity/quality issues and environmental protection in sustainable and resilient cities	[1, 20]
Sustainable urban drainage systems SUDS	UK, 1990s		Handling the flood hazards and water pollution	[1, 22]
Sponge cities SC	China, 2014		Resolving urban water and climate risks problems and reinforcing urban resilience	[1]
Blue-green systems BGS	UK, 2000s		Restore the previous pre-urbanized hydrological function by using multifunctional green infrastructure	[22]
LIDUD	New Zealand, 1990s		Combined measures of the American LID and the Australian WSUD systems.	[23]

instance, were effective from a social-institutional approach, while in Hamburg, the physical-environmental approach had an outstanding impact. A summarized analytical matrix of best practices is attached in Additional file 1.

Fig. 7 Nature-based solution applications. Ref: Đurakovac et al. [24]

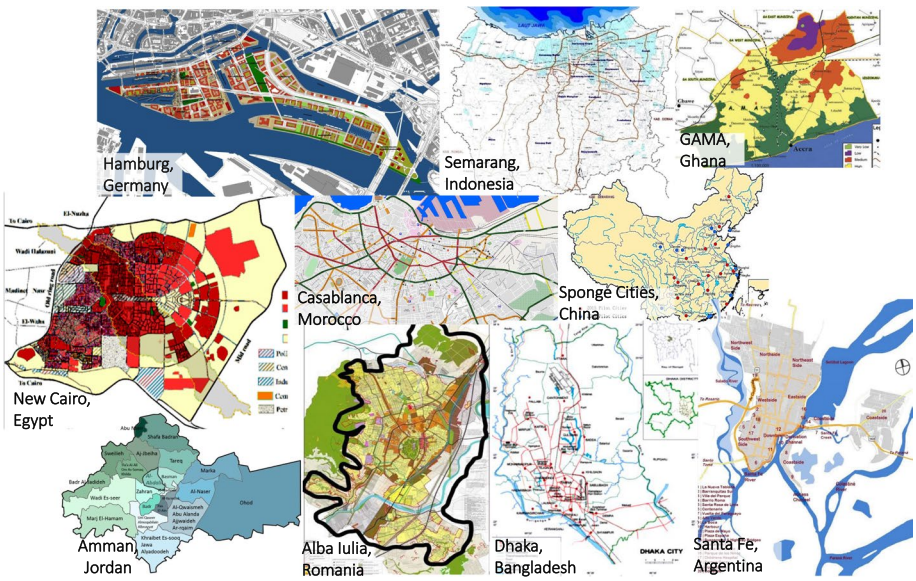

Fig. 8 Case-studies maps. Ref: literature reports

Egypt's national and local profile of water-related stresses reflected several risks and vulnerabilities that need to be addressed within integrated and resilient measures, such as the following:

1. "High-risk" flood classification due to increasing severity and frequency of current pluvial floods and future sea-level rise-based coastal floods [25, 26].
2. Water scarcity and droughts are a future risk due to Nile river political disruptions [27] and high evaporation rates with changing precipitation patterns according to IPCC literature.
3. Rapid urbanization with weak risk-informed land use planning and inadequate enforcement of sustainable design and green building codes.

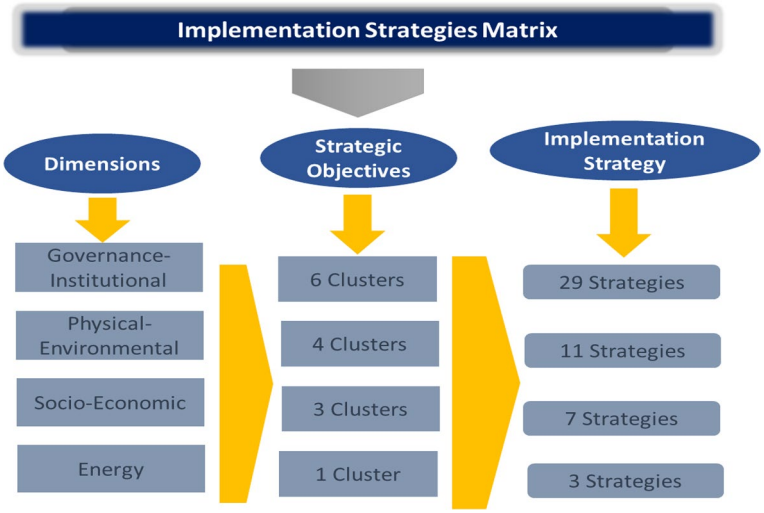

Fig. 9 Conceptualizing strategy matrix

4. Insufficient wastewater management (without a comprehensive rainfall drainage system) and a 105-year-old drainage network [28].

The following preliminary resilience framework pillars were deducted as prioritized pillars within the urban resilience enhancement process. These umbrella pillars and their initial branches have dramatically participated in the best practices' overall success and failure assessments:

1- Evolutionary resilience approach
2- Nature-based solutions and infrastructures
3- Governance and institutional capacities
4- Resources
5- Social capital and participation
6- Multi-risk-informed decision making
7- Critical infrastructure efficiency

Results and discussion

Developing resilience strategy matrix

The previously deducted indicators of case-study analysis included applied global and regional resilience strategies. Due to the wide previous literature spectrum, selecting key representative strategies to enhance urban resilience for pluvial floods and stormwater wasting is a complex process that depends on relativity to research objectives and applicability scale within the local climate. The following matrix in Fig. 9 indicates the selected strategies, formed through 4 complex urban resilience dimensions. These dimensions profile the urban system aspects and contain strategic target clusters. The detailed implementation strategies matrix is modified using excel to end

up with 50 indicators (after excluding the other 45 indicators for being either already applied in Egypt or irrelative).

Collecting and processing primary data

To address the research hypothesis, and adjust the proposed resilience strategies to the local and national application, two primary quantitative data sources were approached: pre-structured in-depth interviews and online questionnaires. They both targeted local officials, NGOs, private consultancy offices, and academics in urban planning and governance, infrastructural engineering, water resources, and environmental fields. The questionnaires and interviews also allowed respondents to assess the local and national performance on resilience. The questionnaire was structured into four sections: Section A, with 4 subsections representing the urban resilience sectors, had indicators with a 4-point Likert scale and aimed to measure the existing degree of urban resilience strategies, and nature-based solutions and CCA measures (successfully applied around the world) within the Egyptian flood risk management and reduction schemes. Section B, with a 3-point Likert scale, aimed to measure the awareness of pluvial floods and freshwater shortage in Egypt, including the insufficiency of sectoral traditional solutions and the need for new inclusive and multifunctional ones. Section C was designed to measure to what extent it is necessary to seek the integration and multifunctionality of resilience planning and other sustainability aspects within Egyptian cities. Section D is a 1–7 ranking scale that explores the hinders to establishing sufficient pluvial flood resilience and sustainable water management frameworks in Egyptian cities.

The questionnaire and interviews were conducted with 60 respondents to score the previous resilience strategy matrix. Google form technique was chosen to widen the responding experts' sample. The online questionnaire outputs were added to the interview responses and statistically analyzed using the SPSS to compare and rank them based on each weight and extract modified hierarchical multifunctional resilience strategies in addition to a resilience-sustainability regression equation. The questionnaire form is attached in Additional file 2.

SPSS result interpretation

Reliability

The reliability and validity of each dimension measured in the questionnaire and interviews were tested, and all of the Cronbach's alpha coefficient values were greater than 0.70, while the values ranged between 0.86 and 0.98 in the validity test. The overall high-reliability ratios have increased the researcher's confidence level with the upcoming results.

Factor analysis

Table 5 summarizes general component score coefficient matrix results within factor analysis of the 6 tested dimensions:

The above values indicate a significant relationship between each dimension's strategies, in addition to a strong expressing and measuring of the statements' latent variables, and suitable sampling adequacy.

Table 5 Component score coefficient matrix

Dimensions	GI	PE	SE	E	5th	6th
Kaiser-Meyer-Olkin measure of sampling adequacy	0.834	0.869	0.905	0.731	0.673	0.500
Approx. chi-square	1930.893***	399.844	206.730	93.469	37.083	22.341
Df	406	55	21	3	3	1
Sig.	0.000	0.000	0.000	0.000	0.000	0.000
AVE	52.088	62.907	66.951	83.623	67.788	80.627

*** Significant at .1%

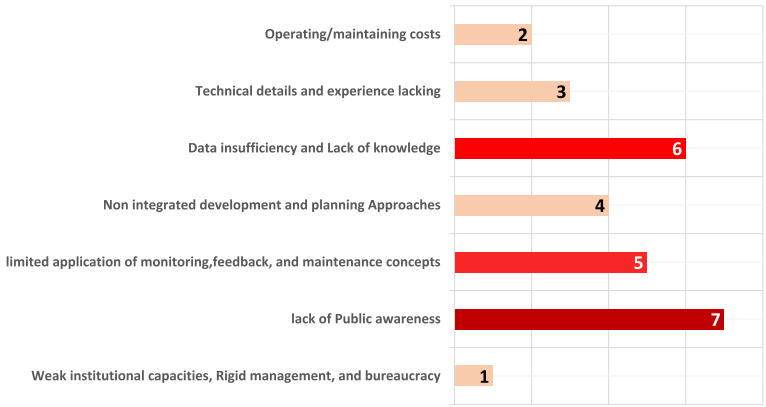

Fig. 10 Urban resilience sufficiency hinders

Ranking analysis

The respondents' answers frequency on the hinders of "establishing sufficient pluvial flood resilience and sustainable water management frameworks in Egyptian cities" have been statistically weighted and ranked (Fig. 10). The highest hinder according to the sample was ranked (7), while the least one was ranked (1).

According to this statistical ranking analysis, most respondents agreed on "lack of public awareness" as the biggest resilience sufficiency hinder, followed by "data insufficiency" and "limited application of monitoring, feedback, and maintenance concepts" respectively.

Descriptive analysis

Table 6 indicates some descriptive statistical measures for the main six dimensions of the questionnaire and interviews:

The above values refer to the following:

GI dimension The value of the arithmetic mean of responses with its standard deviation differs from the expected mean "3" of the 4-point Likert scale at a significant level of 1%, where the calculated *T* test value was greater than the tabulated value of 1.96. CV reflects a small degree of dispersion and a consensus and high tendency among respondents to the "uncertain" opinion, as a mean value, with (64.60%). Figure 11a shows the

Table 6 Descriptive analysis summarized results

Dimension	Mean	Std. deviation	CV	T Test
Governance-institutional	2.490	0.882	35.401	−4.088
Physical-environmental	2.142	0.955	44.567	−6.357
Socio-economic	2.314	1.039	44.913	−4.665
Energy	2.440	1.187	48.629	−3.337
General awareness of urban water-related hazards	2.493	0.647	25.940	1.786
Resilience approaches and multi-functional integrations	2.480	0.677	27.312	1.566

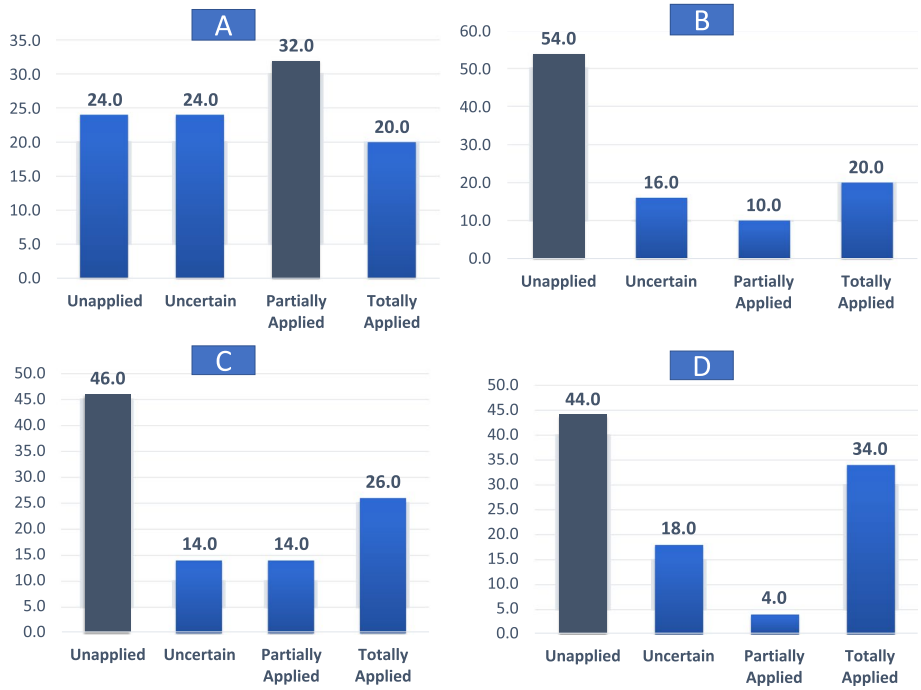

Fig. 11 Relative distribution for resilience dimensions

relative distribution of the sample responses to the (GI) strategies, where 32% of the sample went for "partially applied."

PE dimension Arithmetic mean of responses with its standard deviation differs from the expected mean "3" at a significant level of 1%, where the calculated T value was greater than the tabulated 2.58. The CV reflects a moderate degree of dispersion and a relatively high tendency to the "uncertain" opinion, as a mean value, with (55.44%). Figure 11b shows the relative distribution of the sample responses to the (PE) strategies, where 54% of the sample chose "unapplied."

SE dimension The arithmetic mean of responses with its standard deviation differs from the expected mean "3" of the 4-point Likert scale at a significant level of 1%, where the calculated T test value was greater than the tabulated value of 1.96. The CV reflects

a moderate degree of dispersion and a relatively high tendency to "uncertain" opinion, as a mean value, with (55.09%). Figure 11c shows the relative distribution of the sample responses to the (SE) strategies, where 46% of the sample went for "unapplied."

E dimension The arithmetic mean of responses with its standard deviation differs from the expected mean "3" of the 4-point Likert scale at a significant level of 1%, where the calculated *T* test value was greater than the tabulated value of 2.58. The CV reflects a moderate degree of dispersion and a high tendency among the respondents to "uncertain" opinion, as a mean value, with (51.37%). Figure 11d shows the relative distribution of the sample responses to the (E) strategies, where 44% of the sample went for "unapplied."

5th and 6th dimensions The values of arithmetic mean of responses differ from the expected mean "3" of the 3-point Likert scale at a significant level of 1%, where the calculated *T* test values were greater than the tabulated value of 2.33. The CV reflects a low degree of dispersion and indicates that there is a consensus and high tendency among the respondents to the "agree" opinion with +70%.

Prioritized implementation strategies Among 50 modified strategies of building and enhancing urban resilience towards pluvial floods and wastewater management, the statistical descriptive analysis indicated the prioritized strategies in each resilience dimension (based on the respondents' tendency mean values). These ranked strategies have the implementation priority to fulfill the indicated strategic objectives and resilience values in Table 7.

Resilience dimension correlation

A correlation test was conducted to measure the correlation degree between the main four adopted dimensions of resilience in the research, the following correlation matrix indicates the result (Table 8):

The table above shows that there is a significant correlation between the urban resilience sectors, where the highest correlation value of "0.851" was between the PE and SE dimensions, and the least correlation value of "0.727" between the PE and E dimensions.

The coefficient of the model

Table 9 indicates the R square analysis conducted to figure the relation between "sustainability," as a dependent variable, and the four resilience dimensions (GI, PE, SE, E), as independent variables:

From the above table, the coefficient of determination (R square) is equal to 1.000, and this indicates that the independent variables in the model (governance-institutional dimension, physical-environmental dimension, socio-economic dimension, energy dimension) explain 100.0% of any change in Sustainability. The model variables are statistically significant at a confidence level of 99%, so we accept the alternative hypothesis

Table 7 Prioritized urban resilience strategies

1. Governance-institutional dimension		**Strategic objectives**
GI.1	Reviewing flood hazard maps according to morphometric/topography analysis	Flood risk-informed decision making
GI.3	Increasing critical services accessibility throughout elevated roads	Modifying flood-resilience building and design codes
GI.4	Determining basements occupancy or clearance alternatives according to area risk level	
GI.5	Designing elevated parking lots in exposed areas	
GI.12	Spreading green street/parking networks design (permeable paving, urban canopies, bio-swales, planter box landscapes, rain gardens)	Including nature-based solutions within flood resilience planning
GI.13	Accommodating concrete inflow structures near GI with necessary slopes to direct stormwater to GI	
GI.15	Integrating CCA and DRR and sustainable urban water management solutions within city planning via medium-term development plans	Promoting comprehensive and integrated planning
GI.16	Considering local and national development plans in alignment with SDGs and Sendai frameworks	
GI.17	Preparing city green growth plan and launching green public procurement policy	
GI.18	Expanding slums re-planning projects scope and controlling urban sprawl directions via mandatory site selection and monitoring determinants	
GI.19	Encouraging diversified land-use patterns with avoiding compact/dense urban form developments	
2. Physical-environmental dimension		**Strategic objectives**
PE.4	Expand and maintain waste disposal network and landfills to avoid pipes blockages that limit flood drainage	Enhancing waste management performance
PE.5	Retrofitting vulnerable urban structures and founding regular urban structures monitoring techniques (e.g., on-site surveys)	Increasing structural mitigation
PE.6	Using temporary flood protection measures of buildings in exposed built areas (impervious materials, impact-resistant windows, and waterproof door frames) remotely installed through owners" mobiles applications	
PE.8	Increasing existing drainage pipes capacity and installing dry weather flow diversions in built-up areas with combined sewer	
PE.11	Preparing the infrastructure for transportation soft modes (cycling, pedestrians' paths, roller-skating, walking maps) along with an urban multi-modal mobility plan	Enhancing accessibility and mobility
3. Socio-economic dimension		**Strategic objectives**

Table 7 (continued)

SE.4	Enhancing information and practices sharing with the public pre and during floods (via published bulletins/public consultations/user-friendly mobile applications/media campaigns/workshops)	Enhancing social and stakeholders' participation and awareness
SE.6	Enabling public monitoring of institutional performance via monitoring and feedback program	Empowering civic capacity
4. Energy dimension		**Strategic objectives**
E.3	Enacting renewable energy law (allowing residents to set up solar PV rooftops and sell excess output back to the local grid	Improving redundancy characteristics

Table 8 Correlation matrix

Resilience dimension	Governance-institutional	Physical-environmental	Socio-economic	Energy
Governance-institutional	1	.790[a]	.781[a]	.759[a]
Physical-environmental	.790[a]	1	**.851**[a]	.727[a]
Socio-economic	.781[a]	.851[a]	1	.744[a]
Energy	.759[a]	**.727**[a]	.744[a]	1

[a] Correlation is significant at the 0.01 level (two-tailed)

Table 9 R square analysis

Resilience dimensions	Beta	Sig.	VIF
Governance-institutional dimension	0.238	0.000	3.457
Physical-environmental dimension	0.258	0.000	4.318
Socio-economic dimension	0.281	0.000	4.339
Energy dimension	0.321	0.000	2.783

that the independent variables have real value coefficients that are different from zero and they have a real impact on sustainability.

Regression equation

According to the previous R square test, a regression equation was formulated to describe the relationship between the four resilience dimensions and sustainable development, and figure out an index. It was found that: Sustainability "S" $= \sum (0.238*GI + 0.258*PE + 0.281*SE + 0.321*E)$.

Conclusions

❖ In this research, a detailed analysis of the worldwide applied resilience measures was conducted and compared to the national and local Egyptian scales. The output statistical figures also reflected the gaps and resilience hinders that need to be handled

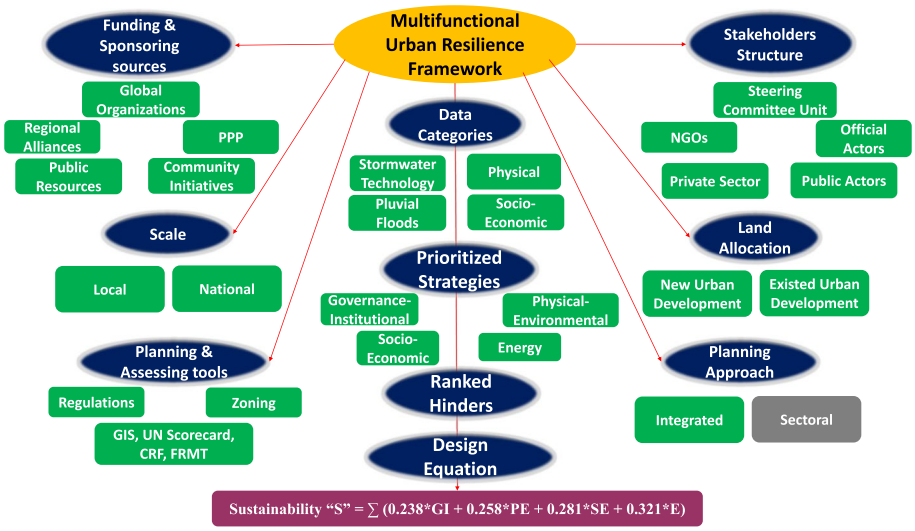

Fig. 12 Proposed multifunctional urban resilience framework

for enhanced pluvial flood resilience and wastewater management at the local level. The data collection process and strategies also indicated the proposed stakeholders' structure who can direct the resilience planning and management wheel to make the best use of multifunctional benefits of flood resilience and nature-based solutions.

❖ The previously mentioned "preliminary urban resilience building pillars" were developed after considering the statistical analysis results to frame a multifunctional framework of urban resilience. This concluded framework includes major 10 indicators of establishing and enhancing the local pluvial flood resilience and wastewater management. It was derived from a detailed analysis of statistical indicators, in addition to the previous literature review and best practices. This framework provides the local urban governance entities with an integrated vision to work on the current pluvial flood resilience and wastewater management system through the following pillars (Fig. 12).

❖ The authors agree with previous studies which suggested that a resilient city is adaptive to chronic stresses and acute shocks without neglecting its essential functions in the middle of risk, which in our case are the pluvial floods and unsustainable wastewater management. It was also proved (inductively and statistically) that urban resilience works toward achieving the long-term sustainability targets, but it needs its overall sector performance and capacity, not just its ability to cope with pluvial floods and water scarcity hazards or its partial climate change adapting within sectoral and non-coordinated development frames. Additionally, the authors agree on the necessity of investigating wider areas of the research process for higher operationalizing levels of resilience and nature-based solutions concepts in Egyptian cities. Eventually, these previous conclusions addressed the research's main problem by applying multifunctional flood resilience and nature-based solutions within an integrated management framework.

❖ In addition to the experts' sample analysis, future work will include the social participation of locals in the research interviews and questionnaires. Additionally, testing the framework through a specified application on a specific local case will be considered, if suitable resources are provided.

Abbreviations

CCA	Climate change adaptation
DRR	Disaster risk reduction
IUWM	Integrated Urban Water Management
SDGs	Sustainable development goals
GI	Green infrastructure

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s44147-022-00136-x.

Additional file 1. Analytical summary. Summarized descriptive analysis of best practices.

Additional file 2. Questionnaire. Google form sent to experts to develop a resilience framework.

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Authors' contributions
Each author has made substantial contributions to the conception and design of the work. HE has prepared the original draft, conceptualization, and methodology; performed the data analysis and interpretations; and attained the manuscript preparation. ME has directed the research's detailed specification, modified the procedure, and verified the general approaches. AE has modified the detailed descriptive and deductive approaches, contributed to the data resources, and revised the manuscript. The authors have read and approved the final manuscript to be personally accountable for the authors' contributions.

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Availability of data and materials
The datasets used and/or analyzed during the current study are available from the corresponding author upon reasonable request.

Declarations

Ethics approval and consent to participate
The consulted experts approved participating in interviews and online questionnaires.

Consent for publication
The consulted experts approved that their answers to the interviews and online questionnaire will be published.

Competing interests
The authors declare that they have no competing interests.

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References

1. Nguyen T, Ngo H, Guo W et al (2019) Implementation of a specific urban water management - Sponge City. Sci Total Environ 652:147–162. https://doi.org/10.1016/j.scitotenv.2018.10.168
2. Gupta AK, Nair SS, Wajih SA et al (2014) Mainstreaming climate change adaptation and disaster risk reduction into district level development plans. National Institute of Disaster Management, New Delhi
3. Rossi G et al (1994) Coping with floods. NATO Science, Kluwer Academic, Dordrecht, p 257
4. Hooijer A, Klijn F, Pedroli GBM, van Os AG (2004) Towards sustainable flood risk management in the Rhine and Meuse river basins: synopsis of the findings of IRMA-SPONGE. River Res Appl 20:343–357. https://doi.org/10.1002/RRA.781
5. Vis M, Klijn F, Bruijn KMD, van Buuren M (2010) Resilience strategies for flood risk management in the Netherlands. International Journal of River Basin Management, 1:33–40. https://doi.org/10.1080/15715124.2003.9635190
6. Schneidergruber M, Cierna M, Jones T (2004) Policy briefing living with floods: achieving ecologically sustainable flood management in Europe, World Wide Fund For Nature, Brussels
7. APFM (2010) World Meteorological Organization Associated Programme on Flood Management Annual Report Associated Programme on Flood Management 2
8. Restemeyer B, Woltjer J, van den Brink M (2015) A strategy-based framework for assessing the flood resilience of cities – a Hamburg case study. Plan Theory Pract 16:45–62. https://doi.org/10.1080/14649357.2014.1000950
9. Zevenbergen C, Veerbeek W, Gersonius B, van Herk S (2008) Challenges in urban flood management: travelling across spatial and temporal scales. J Flood Risk Manage 1:81–88. https://doi.org/10.1111/J.1753-318X.2008.00010.X
10. Carpenter S, Walker B, Anderies JM, Abel N (2001) From metaphor to measurement: resilience of what to what? Ecosystems 4(8):765–781. https://doi.org/10.1007/S10021-001-0045-9

11. Wardekker, A. (2018). Resilience principles as a tool for exploring options for urban resilience. Solutions, 9 (1).
12. MCEER (2008) Engineering resilience solutions: from earthquake engineering to extreme events, University at Buffalo, New York
13. Sharifi, A., Yamagata, Y. (2016). Urban Resilience Assessment: Multiple Dimensions, Criteria, and Indicators. In: Yamagata, Y., Maruyama, H. (eds) Urban Resilience. Advanced Sciences and Technologies for Security Applications. Springer, Cham. https://doi.org/10.1007/978-3-319-39812-9_13
14. United Nations (2002) Report of the world summit on sustainable development. In: World Summit on Sustainable Development. UN, Johannesburg
15. Chapin FS, Pickett STA, Power ME et al (2011) Earth stewardship: a strategy for social-ecological transformation to reverse planetary degradation. Journal of Environmental Studies and Sciences 1:44–53. https://doi.org/10.1007/S13412-011-0010-7
16. Saunders WSA, Becker JS (2015) A discussion of resilience and sustainability: land use planning recovery from the Canterbury earthquake sequence, New Zealand. Int J Disaster Risk Reduct 14:73–81. https://doi.org/10.1016/j.ijdrr.2015.01.013
17. Wilkinson C (2012) Social-ecological resilience: insights and issues for planning theory. Plan Theory 11:148–169. https://doi.org/10.1177/1473095211426274
18. Mehmood A (2016) Of resilient places: planning for urban resilience. Eur Plan Stud 24:407–419. https://doi.org/10.1080/09654313.2015.1082980
19. Davoudi S, Brooks E, Mehmood A (2013) Evolutionary resilience and strategies for climate adaptation. Plan Pract Res 28:307–322. https://doi.org/10.1080/02697459.2013.787695
20. Xiang C, Liu J, Shao W et al (2019) Sponge city construction in China: policy and implementation experiences. Water Policy 21:19–37. https://doi.org/10.2166/wp.2018.021
21. Chan F, Griffiths J, Higgitt D et al (2018) "Sponge City" in China—a breakthrough of planning and flood risk management in the urban context. Land Use Policy 76:772–778. https://doi.org/10.1016/j.landusepol.2018.03.005
22. Potter K, Vilcan T (2020) Managing urban flood resilience through the English planning system: insights from the 'SuDS-face'. Philos Trans A Math Phys Eng Sci 378:20190206. https://doi.org/10.1098/rsta.2019.0206
23. Nguyen T, Ngo H, Guo W, Wang X (2020) A new model framework for sponge city implementation: emerging challenges and future developments. J Environ Manag 253:109689. https://doi.org/10.1016/j.jenvman.2019.109689
24. Đurakovac A, Sekulić M (2017) 5th International Conference Contemporary achievements in civil engineering 21. https://doi.org/10.14415/konferencijaGFS2017.087
25. IPCC (2007) AR4 climate change 2007: synthesis report, IPCC, Geneva
26. NOAA (2011) Global climate report - annual 2011
27. USAID (2018) Climate risk profile Egypt
28. ACT Alliance (2020) Rapid response fund (RRF), ACT Alliance, Geneva

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