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CLIMATE CHANGE AND ITS IMPACTS ON COASTAL CITIES: A CASE STUDY FROM ALEXANDRIA

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Abstract: Throughout history, coastal cities have been influential and attracted a large population due to their rich resources, eco-social and cultural transfer. Today, such privilege is questionable as they are at high risk to be significantly damaged due to Sea Level Rise (SLR) and floods resulting from climate change. Sadly, the coastal Egyptian city; Alexandria, is listed among the 15 of the world's 20 coastal megacities that are at risk. However, such threats can be minimized through; 'mitigation' where causes can be controlled and 'adaptation' where cities can be protected. The objectives of this study are to; uncover and assess the negative impacts of climate change on Alexandria and its built environment. Also, the vulnerability of its residents and their level of awareness; identifying the gaps in Egypt National Climate Change Strategy (ENCCS) that triggers the city's sustainability. Additionally, explore design parameters that promote sustainable design for coastal buildings; assess the perception and knowledge of architects, engineers, and policymakers on issues related to climate change and building industry. In order to fulfill these objectives, an intensive literature study and hybrid methodology were undertaken. The findings of this study reveal and confirm the high vulnerability of the residents due to the inefficient practices, and poor communication with the government. Also, it pinpoints poor and limited knowledge for sustainable practices and designs that need to be adapted. Gaps in ENCCS were identified. Looking forward, a recommended design guideline based on mitigation and adaptation practices must be established.

Keywords: Climate Change, Coastal City, Alexandria, SLR, Mitigation, Adaptation

1. INTRODUCTION

Climate change has emerged as one of the crucial issues of the early 21st century. The impacts of climate change are mounting in intensity and frequency on a global scale, along with scientific consensus in which the increase of greenhouse gasses (GHG) and carbon dioxide (CO_2) in the atmosphere caused by several factors where anthropogenic activities are the largest contributor. Hundreds of millions of urban inhabitants in low and middle-income nations are at risk from direct and indirect impacts of climate change. Surprisingly, it may contribute to force migration, conflicts, hunger and destroy infrastructure across the world.

Coastal cities have always attracted humans because of their rich resources. Today, this natural geographic region is no longer an advantage as it increases the vulnerability of the cities to Sea Level Rise (SLR), floods, and wind storms in terms of frequency and severity. Around 360 million residents live in coastal

areas less than 10m above the sea level (World Bank 2010) are highly vulnerable to extreme events that threaten their life. For this reason, international organizations and institutions have been spending tremendous effort to scientifically explain the phenomenon, its impacts, and reasons behind to take more serious steps in recent times to limit and control its devastating effects on the environment and communities.

Sea Level Rise and Coastal Cities

Projections indicate that average sea level will rise between 7 and 36 cm by 2050, while in 2080 by 9 and 69 cm (Roaf, Crichton, and Nicol 2005). By the year 2100 and with the continued warming, sea levels are projected to be approximately 30-80 cm (Williams 2009) excluding uncertainties due to the collapse of the large ice sheets. There is also increasing concern about higher extreme sea levels due to the higher intensity of storms that may be superimposed on these mean rises which would worsen the impacts of global mean sea level rise leading to more damaging floods and storms (Nicholls and Cazenave 2010). On that account, populations in coastal area, especially low elevation coastal zones (less than 10m in altitude) are most vulnerable. These zones account 2% of the world's land but are home to 10% of the world's population and present 13% of the urban population (Gordon McGranahan, Deborah Balk, and Bridget Anderson 2007). Despite the vulnerability of these lands, the population is growing rapidly.

For these reasons, sustainability has become a global driver for development initiatives related to climate strategies and particularly providing sustainable building approaches that address climate change challenges have been undertaken seriously. Many studies explored the potential of having a sustainable design guideline that could be a foundation for designs. These studies agreed that any proposed sustainable design guideline should originate the Human Settlement section of Agenda 21. This guide will help the architects and engineers to meet the needs of nowadays without adversely affect the future generation. Based on previous research done by Lami E.A, this study is adopting the sustainable design parameters introduced in his research. These parameters include; Accessibility, Building material, Internal space layout, External space layout, Local climate, Energy Efficiency, Water Efficiency, and Air quality and pollution (Lami 2014).

Egypt National Climate Change Strategy

Despite its share of global GHG emissions are less than 1%, Egypt is the most impacted Arab country with at least 12 million persons displaced due to extreme scenarios (Abdel-Gelil 2014). The Egyptian coastal city; Alexandria is one of the top 10 vulnerable cities exposed to SLR and floods (Nicholls and Cazenave 2010). The Egyptian authorities have contributed in developing "Egypt National Strategy for Climate Change" in order to increase the resilience and flexibility of the Egyptian community while dealing with extreme climate events through mitigation and adaption (The Egyptian Cabinet Information & Decision Support Center 2011). Mitigation is defined as "the anthropogenic intervention to reduce the sources or enhance the sinks of greenhouse gases" (IPCC 2007). These interventions are; global strategies or measures that are taken to assist in preventing or minimize process leading to climate change. On the other hand, adaptation is defined as "adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploit beneficial opportunities" (Thornes 2002). Adaptation is needed as it tackles several impacts of climate change which is necessary to increase the resilience to future impacts for vulnerable communities, sectors, and cities (Mastrandrea et al. 2010). On this account, early mitigation efforts can reduce future harms and adaptation costs. However, some impacts in some parts of the world will not be avoidable and will require adaptation (Zari 2014). **Error! Reference source not found.** represents the measurements in the Egyptian strategy.

Table 1: Measurements in Egypt Climate Change Strategy that address SLR (The Egyptian Cabinet Information & Decision Support Center 2011)

Procedure	Include
Studies	Conducting detailed studies on the effectiveness of the proposed adaptation measures to assess destructive factors and meet the risks of torrential rains and floods.
Rules	Developing additional rules for coastal development that consider climate change Submitting EIA for projects taking place in coastal zones.
Structural and architectural interventions	Constructing and maintaining; maritime walls, barriers, shore coating, soil fixation, and prevention methods for seawater intrusion into land including the implementation of covered and uncovered sanitary drainage projects. Establishing solid protection measures such as stone heads or submersible barriers Building anti-flood protection structures to break flash floods
Rehabilitation of Installations	Strengthening the existing protection structures to act as wave breakers
Reinforcing natural protection	Maintaining natural protection Preserving natural defense lines against SLR

Although this strategy is specifically relevant to adaptation in different sectors, mitigation was also applied, as shown in Table 2

Table 2 Mitigation in Egypt National Strategy for Climate Change (The Egyptian Cabinet Information & Decision Support Center 2011)

Sector	Procedure	Approach		
		Mitigation	Adaptation	
			Hard	Soft
Water Resources & Irrigation	Launch a national campaign to raise water awareness among citizens			✓
	Recycling treated water		✓	
	Improving the distribution network to reduce water loss due to leakage		✓	
Agriculture	Capacity building for farmers to equip them with all information related to climate change and diseases, and methods of prevention			✓
	Encourage planting new varieties of crops with short growing seasons		✓	
Health	Developing weather and seasonal forecast and early warning systems		✓	
	Establishing an integrated database for diseases associated with climate change		✓	
	Raise awareness of citizens in health behavior to limit any harm resulting from extreme events			✓
Rural & Housing areas, & roads	Transfer the latest technology where renewable energies are used in the buildings	✓		
	Constructing dams to slow the flow of floods		✓	
	Renovate old houses in urban and rural areas		✓	
	Support the civil society to participate in applying strategic operational policies			✓

Tourism	Encourage the growth of tourism away from the high environmentally sensitive area	✓

Few years after establishing the strategy, The government mentioned in "Egyptian Intended Nationally Determined Contribution" report that the proposed actions were to promote resilience. It stated that "adaptation options for coastal zones are highly site-dependent" (Arab Republic of Egypt 2015), also some actions are to be undertaken such as;

- Changing in land use.
- Integrated coastal zone management.
- Providing job opportunities in safe areas to successfully absorb the affected population.

As for the adaptation action packages, the following actions were included;

- Reduce climate change associated risks and disasters.
- Capacity building of Egyptian society to adapt to climate change & associated risks.
- Enhance national & regional partnership in managing crisis and disasters related to climate change.

Mitigation policies were focused on reducing GHG emissions. These policies relied on;

- Reform energy subsidies.
- Use of advanced locally appropriate and more efficient fossil fuel technologies.
- Encourage the use of renewable energy as an alternative to non-renewables.
- More efficient use of energy, by the end user.

Despite these adaptation and mitigation plans, Egyptian coastal cities are still vulnerable and badly affected by sudden climatic changes. One of these cities is Alexandria. The objectives of this study are to; uncover and assess the negative impacts of climate change on Alexandria and its built environment. Also, the vulnerability of its residents and their level of awareness; identifying the gaps in Egypt National Climate Change Strategy (ENCCS). Additionally, explore design parameters that promote sustainable design for coastal buildings; assess the perception and knowledge of professionals in the building industry.

2. THE CASE STUDY OF ALEXANDRIA

Alexandria is the second populated city after Cairo. It hosts 40% of the Egyptian industrial and commercial activities as well as the largest harbor in the country (Agrawala et al. 2004; El Raey 2010). Early studies have evaluated the impacts of climate change on the city using two SLR scenarios (0.5m and 1.0m). A large percentage of the lands in the Mediterranean coast and Nile Delta are totally vulnerable to inundation and saltwater intrusion. If no action is taken, an area of about 51% of the city will be lost (Agrawala et al. 2004; Brooks, Grist, and Brown 2009; El Raey 2010; Steen 2007). Subsequently, in both scenarios, millions can be driven out from their homes. The optimistic scenario, in which SLR reaches 0.5m, will cause the displacement of almost 3.8 million people, and 1,800 km^2 of the cropland will be jeopardized. while when the SLR reaches 1.0m around 6 million people and 4,500 km^2 of the cropland will be endangered (El Raey 2010; Zakaria 2015).

Major evidence of climate change impact on Alexandria dates back to December 2010, when coastal flooding hit its coastline endorsing the severity of the progressive global phenomena (Zakaria 2015). Strong winds, and heavy precipitation, up to 60 km/hr with a 10 hours duration were enough to result from waves of more than 6.5 m height with a surge of over 1.0 m which forced the closure of Alexandria main harbor (Ismail, Iskander, and El Sayed 2012). It is worth to mention that one-third of Alexandria's total population is settled in informal areas, with deteriorating buildings and weak infrastructure in the old and dense part of the city. The population in these areas increased after 25th January Revolution when a huge number of buildings were constructed in unplanned and illegal areas together with the seismic risk as their foundation are particularly susceptible to land subsidence and earthquake (World Bank 2015). These human settlements potentially come under increased threats of flooding and inundation (Steen 2007). The last coastal floods have affected around 1,300 people and the number is expected to reach over 4 million by 2070 (Reuters 2010). Nevertheless, in the current days, Nawaat often drew city's streets, as the result of the huge and unexpected water volumes, which cannot be accommodated, hence some of the pump stations were disrupted.

In October 2015, Alexandria experienced unexpected severe rainfall event causing severe flooding, which has been described as, "the worst flooding of Alexandria City over the past decades in terms of the number of people affected and the amount of economic damage" (Egyptian Streets 2015). The unexpected event

destroyed the infrastructure causing the death of 7 people from electric shock as a power cable had fallen into the rainwater flooding the streets (FloodList 2015; Egyptian Streets 2015). In some districts, buildings showed severe structural damages and 100,000 people living in an informal area were threatened by the destruction of their homes (C. Zevenbergen et al. 2017). The flood losses were estimated at 9.7 million dollars with grave damages to private businesses and properties (FloodList 2015). The number of damages and losses could have been predicted at least one week in advance if an appropriate warning system was placed (Chris Zevenbergen 2015).

3. METHODOLOGY

The study focuses on highlighting the gaps in Egypt National Climate Change Strategy, assess the level of knowledge, awareness, and vulnerability of Alexandria's residents, as well as the knowledge of different stakeholders involved in the building industry in coastal zones. Besides the intensive literature review, practical work was undertaken which included; 2 questionnaires for different target groups; residents of Alexandria, and architects and engineers.

The residents' questionnaire included a number of multiple-choice questions to understand the channel of information they rely on and their role in addressing such threat. Moreover, the likability scale test was used in 2 sections. The first section was to explore the knowledge of the respondents on climate change and particularly, SLR. The second section is to measure the evidence of climate change happening in Alexandria.

As for the professional's questionnaire; likability scale test was used in 3 sections. The first section was to explore the knowledge of the respondents on climate change and particularly, SLR. The second section is to evaluate the current condition of the built environment in Alexandria, while the third section uncovers the professional's knowledge of how a new sustainable design guideline for builds in coastal cities should be.

Key Findings

Based on the data gathered, 112 residents were involved in this questionnaire yet only 100 were considered as reliable source as they were familiar by the topic of climate change and were living in Alexandria for the last 5 years. As for the professionals, 109 were involved from which only 100 respondents were closely involved in the design, building and operation phases, and were familiar with climate change.

Residents Questionnaire

Giving an insight into the respondents,100 reliable respondents participated, where 60% were males and 40% were females. Table 3 presents some of the statements provided in the 2 sections in which the analysis was built upon.

Table 3 Statements from Residents Questionnaire

Exploring Knowledge	1. I am aware of how climate change will affect coastal cities in Egypt 2. Sea-level rise has a negative impact on coastal cities in Egypt 3. I trust the information and data that the Egyptian government provides on the environment 4. Climate change is the main reason behind the SLR and Floods in Alexandria 5. I feel threatened where I live because of the implications of SLR 6. Egypt has a clear climate change strategy that protects its coastal zones 7. I am prepared to face any climatic threats like SLR and Floods.
Measuring Evidence of Climate Change happening in Alexandria	8. My coastal region has seen an increase in heavy rains & floods over the last 10 years 9. The current infrastructure is capable to save my city from SLR & floods 10. During floods and/or heavy rains, I can safely go outside 11. During flood &/or heavy rains, my house suffers from regular cutting off the electricity 12. During flood &/or heavy rains, my house suffers from a shortage of clean drinking water 13. There is local emergency-medical service rapidly accessible in the flood and heavy rains time

Professionals Questionnaire

100 reliable respondents participated, where 58% were males and 42% were females. 47% of the respondents hold a bachelor's degree, 45% with master's degree and only 8% completed their Ph.D. An interesting fact is 59% of the respondents worked for firms and companies that follow environmental standards and guidelines. Table 4 presents a sample of statements provided in the 3 sections in which the analysis was built upon.

Table 4 Statements from Professionals Questionnaire

Exploring Knowledge of the Respondents	1. Egypt is one of the countries that will be most affected by climate change 2. I am aware of how climate change will affect coastal cities in Egypt 3. Sea-level rise has a negative impact on coastal cities in Egypt 4. Climate change is the main reason behind the SLR and Floods in Alexandria 5. Egypt has a clear climate change strategy that protects its coastal zones
Measuring the Evidence of Climate Change happening in Alexandria	6. I am well informed about the Egyptian Building Codes 7. There is adequate information on climate change implications and its impact on buildings in Egypt 8. SLR has severe impacts on buildings and infrastructure in coastal regions like Alexandria 9. The current infrastructure in Alexandria needs to be upgraded to adapt the floods resulting from Sea Level Rise
Exploring New Design Guideline	10. A framework and design guideline are needed to assist architects and engineers in designing resilient buildings in coastal regions 11. The new design guideline; should include Building Accessibility 12. The new design guideline; should include Building Material that involves flood proofing techniques and considers Energy and Water Efficiency 13. The main design parameters for a new residential building in a coastal region like Alexandria should include Flooding Strategies Control 14. Retrofitting existing properties (buildings) should be given second priority

4. DISCUSSION AND ANALYSIS

Knowledge and Information

There are no available studies that comprehensively examine the practices that support in reducing the impact of SLR and floods on the built environment in the coastal cities. However, there are limited studies examining the impact of SLR on infrastructure. Also, other studies provide some data about the different scenarios of the rise in the sea level in coastal zones like Alexandria. However, very limited ones highlight the financial losses resulting.

The internet and social media play an important role in sharing the knowledge and information about climate change among both; residents of Alexandria, and engineers & architects. Still, these references are not accurate, well informed, and cannot support engineers, and architects in their design and building's decisions. Information and data provided by the Egypt government are not reliable and clearly delivered.

Egyptian Climate Change Strategy that protects the coastal zones is unclear and ineffective which may be the reason why both target groups; residents and professionals, do not know about it. There is a correlation between the knowledge of residents and the current preparation, the more the residents become aware of climate change, the more they understand that the current preparation is not sufficient to address the problem. This confirms the gaps in the strategy that needs to be tackled and the problem of missing a clear plan where responsibilities of related bodies are clearly addressed with actions, activities, timeline, and budget.

Educational institutes are not delivering updated knowledge in the matter of climate change. The results of the questionnaires reflect that education does not have any significant impact on the engineers and architects except for developing their perception. Despite the high percentage of engineers who obtained their master's degree, and being in their active years of practices, many are semi-informed about the Egyptian building code, and they are not considering environmental aspects in their design. Nonetheless, the study reveals that more than 90% are encouraging the design of framework and guideline that supports

engineers, and architects in coastal building's design. These confirm that Egypt already suffers from low technical capacity and low community resilience to cope with extreme events

Measuring Evidence

Over 75% of the residents confirmed that more intense than normal events over the last 10 years have been occurring. Moreover, such events had high negative impacts on the built environment such as; buildings, infrastructure, and other services that directly and indirectly affect the residents. As for the buildings, heavy rains and other climatic factors have increased the erosion and collapse of buildings. Apart from the occurrence of these extreme events, the existing urban hydraulic network of canals and drainage infrastructure in the city is poor, weak as they have not been designed to accommodate the large volume of water resulting from such events. Also, the inefficient flood barriers are no longer able to adapt the climatic change and SLR. These are the main reasons behind the water shortage and roads cut off.

Seasonal regular floods drastically interrupt transportation and hinder the accessibility of local emergency medical service. It is worth to mention that during such events, buildings suffer from regular cutting off electricity and clean water shortage. In addition, residents cannot safely go outside of their buildings. These confirm the data in the literature highlighting the death incidents during these events. Findings from the analysis validate the evidence and reflect the high vulnerability of Alexandria's community. Also, the conflict of information between studies witnessed evidence and the government. Literature and site visits also confirm Egypt is focusing only on the mitigation through establishing regulations and policies to reduce GHG emissions.

Design Considerations

Building Accessibility: Engineers did not consider building accessibility as a parameter that is needed in the design guide. This highlights the unawareness about accessibility and safety measurements which must be included in the design. Also, it reflects the exclusion of some people like; old and people with special needs in the design consideration.

Material Selection: Based on the analysis, it was confirmed that coastal buildings suffer from common problems; undermining and destruction of foundations which may lead to structure failure, and salt spray affecting most of the material's durability. Also, there is a correlation between material selection and energy efficiency. Selecting the right material isolates the climatic condition and provides internal comfort to the occupants. This will reduce the usage of air conditioning for heating and cooling in different seasons.

External & Internal Layout Space: External layout space acts as the first defender for rain run-off, flash floods, and SLR. Based on the site location, and the expected threat, adaptive designs can be proposed. Thus, there is a strong correlation between adaptation and external layout spaces. As for the internal space, it has been considered strongly related to air quality. This emphasizes the importance of considering natural ventilation and air circulation.

Water Efficiency: All the respondents and interviewees agreed that water efficiency is vital and should be considered in the design. This may be because of the recent fear related to water shortage and the crisis that Egypt is expecting after building the Ethiopian dam "Al Nahda". Also, respondents mentioned that they suffer from clean water shortage during extreme events.

Energy Efficiency: All of the respondents emphasized the importance of energy efficiency. Professionals suggested the following environmental and sustainable practices that reduce the usage of energy and electricity and shifting to renewables. There is a strong correlation between energy and water efficiency. This is due to the awareness in these two sectors and how it can affect national security.

Elevating Lowest Floor: The concept is quite unfamiliar among the professionals due to the lack of knowledge in global adaptation practices, hence it was not supported.

Site Selection and Analysis: Professionals confirmed that site selection is an important design parameter in the design guideline. This approves the literature that design, adaptation, and mitigation practices are all related to the site. Each site has its own challenge climatic condition, land character, and functionality.

5. RECOMMENDATIONS

Having a design guideline will offer the engineers and architects an opportunity to use sustainable principles for building designs that can face impacts of climate change and extreme events. Table 5 provides a primary design guideline for coastal cities, which needs to be examined in future research work.

Table 5 Primary Sustainable Design Guideline for Coastal Cities

Parameter	Recommended Actions
Site Selection & Analysis	- New project development should consider climate risk & improve selections strategies to minimize risks - Soil stabilization measures (buffer zones) to reduce risks and impacts - Considering set back line to be 300-400m instead of 200m - Avoid building in storm surges, and areas at high risk of SLR
Building Accessibility	- Providing accessible means that allow the building's occupants to safely move in and out of the building in normal and emergency situations
Material Selection	- Adopting well-designed insulation material for the roof to control conductive gains and losses - Using building materials that survive to get wet and dry without damage or mold growth
Water Efficiency	- Encourage rainwater harvesting (storage tanks, ponds, cisterns) - Design and develop wastewater management and greywater systems. - Install sewage backflow preventer to flow out wastewater in one direction and avoid reversing the flow.
Energy Efficiency	- Reduce energy consumption & emissions by using passive strategies - Moving to renewables other than non-renewables.
External and Internal Layout Space	External Layout - Retention ponds to be designed and considering future climate change to reduce runoff from the site. Indoor Environmental Quality - Use adaptive technologies (off-grid system) - Considering thermal comfort design and practices
Other Design Considerations & safety measurements	- Emergency management plan must be considered - During emergency & extreme events, area of refugee has to occupy those who cannot support themselves to reach to safe place till external help. - Apply power back up for energy generation during power outage - Elevator machinery has to be located above flood level & elevator tower has to be sealed.

In addition, different stakeholders have to have an effective role to control and limit the impact of climate change particularly; SLR on Alexandria and other coastal cities as follows;

Engineers & Architects

- Establish contextualized design guideline that considers climate change impacts on buildings in coastal cities.
- Develop new design practices & techniques for new buildings in coastal cities.
- Apply retrofitting practices for high-value buildings that may suffer from damages
- Strengthen the efficiency of dams and bridges

Policymakers

- Provide accurate, transparent and updated data about climatic threats
- Update the current national building codes and consider climatic changes
- Encourage the contracting companies and investors to invest in shifting the current infrastructure to greener one that can adapt to this change.
- Long term adaptive strategies for SLR must be considered, besides accessing the costs and benefits of intervention options.
- Encourage the integration between mitigation & adaptation practices
- Encourage the flood insurance for buildings in coastal zones.

Academic Society

- Update curriculum to be more relevant to today and tomorrow's challenges.
- Encourage the researchers to develop durable materials
- Establish proper observation systems, monitoring techniques and geographic databases of key indicators on SLR and floods to support decision makers
- Further research on new coastal cities like; New Alamein in terms of vulnerability financial losses due to the impacts of climate change on coastal buildings are needed

NGOs and International Development Entities

- Support the government in raising awareness among locals
- Capacity development of vulnerable communities at high risk, in order to participate in the development and implementation of national policies in the field of adaptation and risk reduction.
- International funds are needed to help in capacity building and technology transfer for adaption, protection, and measurements.

6. CONCLUSION

Alexandria is under real threat from SLR. The built environment, and mainly buildings and the infrastructure, limited resources have been put into maintenance and protection, and not enough has been directed to upgrade and adapt the existing ones to climatic changes. Egypt Climate Change Strategy is unclear and ineffective. The actions and practices that have been taken show very little attention from the government and other related bodies to climate change, as it only focused on mitigation but not the integration between mitigation and adaptation. Focusing only on mitigation, will not help to protect and save Alexandria.
Moreover, there is a lack of knowledge and reliable data that support residents and professionals in dealing with climate change. The existing reports and studies tackle the impact of climate change focuses only on coastal erosion resulting from different SLR scenarios. However, very limited studies examine the impact of SLR on infrastructure and buildings as well as the financial losses resulting. The educational institutes are delivering outdated curricula that do not address the current environmental challenges, a reason why most of the professionals do not consider climate change in their practice. For these reasons, updating the curricula, developing, approving, and enforcing new codes for infrastructure and buildings in coastal cities, encouraging the implementation of environmental practice, and considering innovative solutions while designing and constructing buildings are essential. In this study, primary design guideline parameters were proposed to support future research on developing specific design guideline for coastal cities built environment.

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